12 Chemical exposure

Health complaints arising in indoor workplaces are often felt to be directly linked to the presence of harmful substances in the air. Typical examples of this are formaldehyde and wood preservatives.

Odour (see Chapter 4), acute complaints, results of medical examinations and press reports, for example, can point to the presence of hazardous substances or cause their presence to be suspected. However, they do not constitute actual evidence of their presence.

In such cases, appropriate investigations (Section 12.1) must be carried out to determine whether there are any grounds to suspect exposure to hazardous substances before conducting hazardous substance measurements, which usually entail significant technical and staffing effort. Frequently, the findings of such investigations enable decisions to be made as to the necessary measures (e.g. redevelopment) without hazardous substance measurements having to be performed.

The action to be taken must be decided on the basis of the findings. If the suspected exposure to hazardous substances cannot be confirmed, other causes for the complaints must be sought. However, if the initial suspicion (i.e. the suspected presence of hazardous substances in the workplace air) is confirmed, specific hazardous substance measurements can take place, as described in Section 12.2, based on the findings of the investigation.

Section 12.3 provides general advice on how to assess measurement results. Information on specific substances and categories of substance is given in Section 12.4.

12.1 General guidance on investigating chemical exposures

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The potential sources of indoor air pollution are manifold. Table 24 shows possible sources and the most important substances they emit. Further information can also be found in Section 6.4, “Materials”, among other places. The questionnaires on building design and decoration of rooms (S5) and procedures for cleaning of buildings (S6), which deal with the matters covered in Section 6.4, are available on the internet (www.dguv.de, webcode 650356), and are also useful tools for this investigation.

Section 12.4 provides substance-specific information. A table showing frequently detected substances and their possible sources is presented in Annex 5.

Table 24:
Sources of indoor air pollution and the most important substances they emit, based on DIN EN ISO 16000, Part 1 [1]

Source/cause	Process/activity	Products used, more precise definition of source	Substances emitted
Biological sources			
E.g. humans, animals, insects, mites	Breathing		Carbon dioxide, water vapour, naturally occurring odorant substances , odorant substances from foodstuffs
	Perspiration		Water vapour, odorant substances
	Digestion, excretion		E.g. bowel gases, odorant substances, excrements, decomposition products
	Hair loss, shedding of skin		E.g. bowel gases, odorant substances, excrements, decomposition products
Indoor plants	Transpiration, mould infestation	Substrate	Terpenes and other odorant substances, water vapour, microbial VOCs
Building sources			
Building structure and materials	Product processing, outgassing, ageing, abrasion, decomposition, mould infestation	Construction materials, building protection and anti-corrosion products, insulating materials, sealant materials, paints, concrete admixtures	Gaseous and particulate substances, e.g. solvents, plasticisers, wood preservatives, flame retardants, fibres (asbestos, mineral wool), radon (e.g. from granite), amines, ammonia, microbial VOCs
Ventilation and air conditioning systems	Operation and maintenance	Washers, filters, insulation and sealant materials, deposits, heat exchangers	Dust, fibres, biocides, odorant substances

Source/cause	Process/activity	Products used, more precise definition of source	Substances emitted
Building sources			
Furniture and furnishings	Product processing, decoration, outgassing	Furniture, floor coverings, home textiles, varnishes and paints, wallpaper	Monomers and oligomers from plastics, resins, surface coatings, adhesives (e.g. formaldehyde); fibres, solvents, plasticisers, stabilisers, biocides (e.g. pyrethroids)
Indoor activities			
Use as office	Office work	Office items, IT equipment, copiers	Organic solvents, semi-volatile organic substances (plasticisers, flame retardants), toner ingredients, ozone
Hygiene and personal care products	Personal care, cosmetic treatments	Personal care products and articles of daily use	Solvents, propellants, perfumes, inorganic and organic aerosols (colouring agents, pigments, varnishes, resins), haloforms
Room cleaning	Cleaning and furniture care; pest control	Washing and cleaning agents, polishes, disinfectants, pest control products	Water, ammonia, chlorine, organic solvents (e.g. ethanol), bactericides (formaldehyde), insecticides (organophospates, pyrethroids, carbamates) and chlorine compounds; house dust
Cooling and heating	Combustion processes (heating, cooking), use of open fire (e.g. including candles)	Coal, heating oil, gas, wood, foodstuffs	Gas (town gas, bottled gas, natural gas), heating oil vapour, carbon dioxide, carbon monoxide, water vapour, suspended particulate matter, hydrocarbons and many other organic substances (combustion products and char)
Outdoor air			
Emissions from human activity	Ventilation, infiltration and diffusion through the building envelope	Industrial enterprises, transport, domestic heating, agriculture, outdoor fires, landfills, contaminated waste	Inorganic and organic gases and aerosols (e.g. solvents, ammonia, odorant substances, polycyclic aromatic hydrocarbons)
Biogenic and geogenic emissions	Ventilation, soil air penetration, dust raising	Plants in bloom, uranium deposits in the earth, sea spray, soil resuspension, natural rotting	Pollen, radon, methane and other volatile organic compounds (hydrocarbons, organohalogen compounds), odorant substances, dusts, sea salt
Living organisms	Excretion	Bowel gases, odorant substances, excrements, decomposition products	Ammonia and sulphur compounds

Reference

[1] DIN EN ISO 16000-1: Innenraumluftverunreinigungen – Teil 1: Allgemeine Aspekte der Probenahmestrategie (06.06). Beuth, Berlin 2006

12.2 Measurement of chemical exposures

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Continuous pollutant monitoring, as practised in industrial workplaces, is usually not possible in indoor workplaces. On-site measurements should be conducted using easy-to-handle devices that cause little disruption to the workflow. Indoor pollutants have numerous sources (cf. Section 12.1), whose emission characteristics differ significantly. There are

- continuous sources, which can emit pollutants over a long period (e.g. building materials or furnishings), and
- intermittent sources, which can cause short-term peak exposure to pollutants (e.g. cleaning agents and, in the past, tobacco smoke).

Figure 25 shows examples of emission characteristics for specific sources.

When selecting a measuring strategy, it is important to know the emission characteristics of the pollutant source. For pollutants from continuous sources, passive samplers are particularly useful whilst active sampling systems make more sense for pollutants emitted from discontinuous sources.

A key problem in indoor pollutant measurement is the variety of possible pollutants and source characteristics. Information about the nature and location of sources and about potential pollutants should therefore be gathered, if possible, when carrying out hazardous substance investigations, in addition to information about emission characteristics. These findings can then be used to determine where measurements should be taken, for how long, how frequently and how many.

If the investigations do not yield any concrete evidence concerning the hazardous substances, indicative measurements can be performed based on the MGU measuring system for indoor measurements (see Section 12.2.2). This system covers volatile organic compounds, aldehydes and carbon dioxide.

At any stage of the measurements, the result can be that

- the source is identified and eliminated or
- no heightened pollution levels are identified.

If no heightened chemical exposure levels are identified, no further measurements should be conducted. If increased chemical exposure is detected, it must be assessed and, where appropriate, action taken. Such action must be in keeping with the case in question and further steps must be defined. Where necessary, additional measurements can be performed in accordance with the VDI 4300 series of guidelines [2] and parts of the BS (EN) ISO 16000 series of “indoor air” standards [3].

Figure 26 illustrates the procedure that can be followed when measuring pollutants. In many cases, indoor measurements can be carried out as shown in this flowchart.

Figure 25:
Emission characteristics for specific sources of indoor air pollution [1]

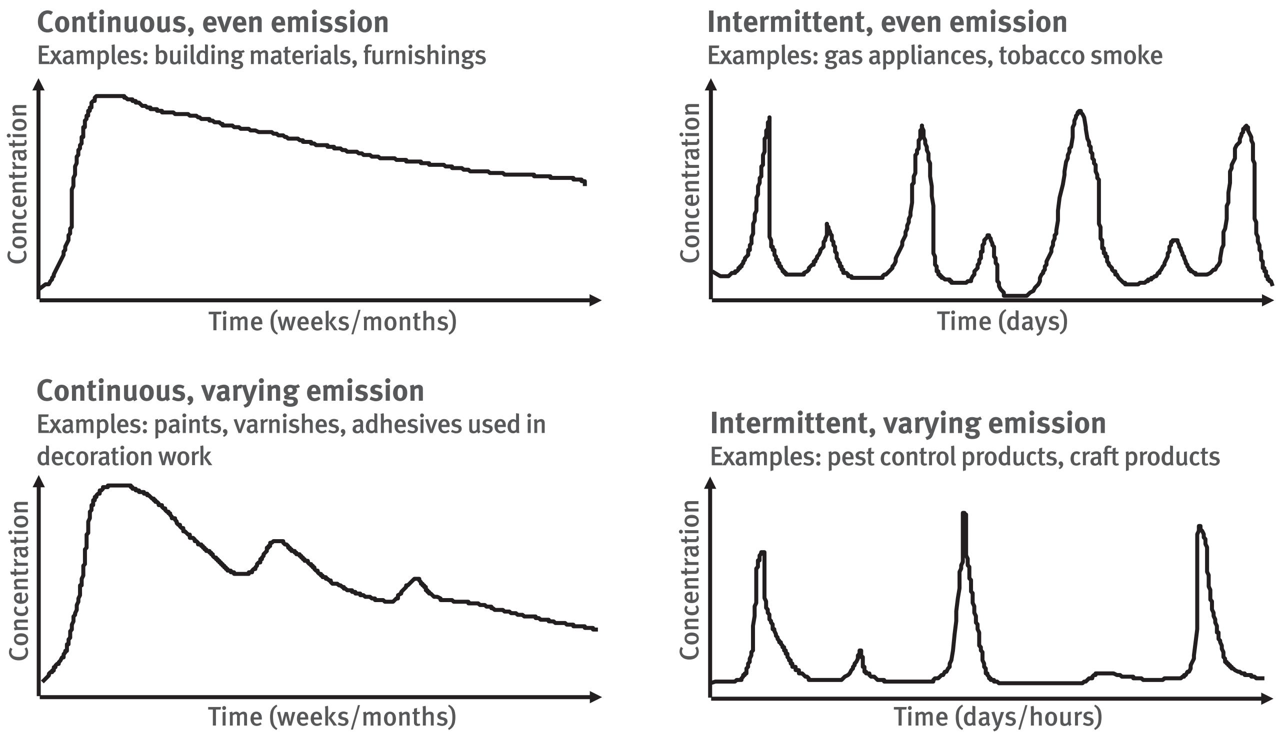
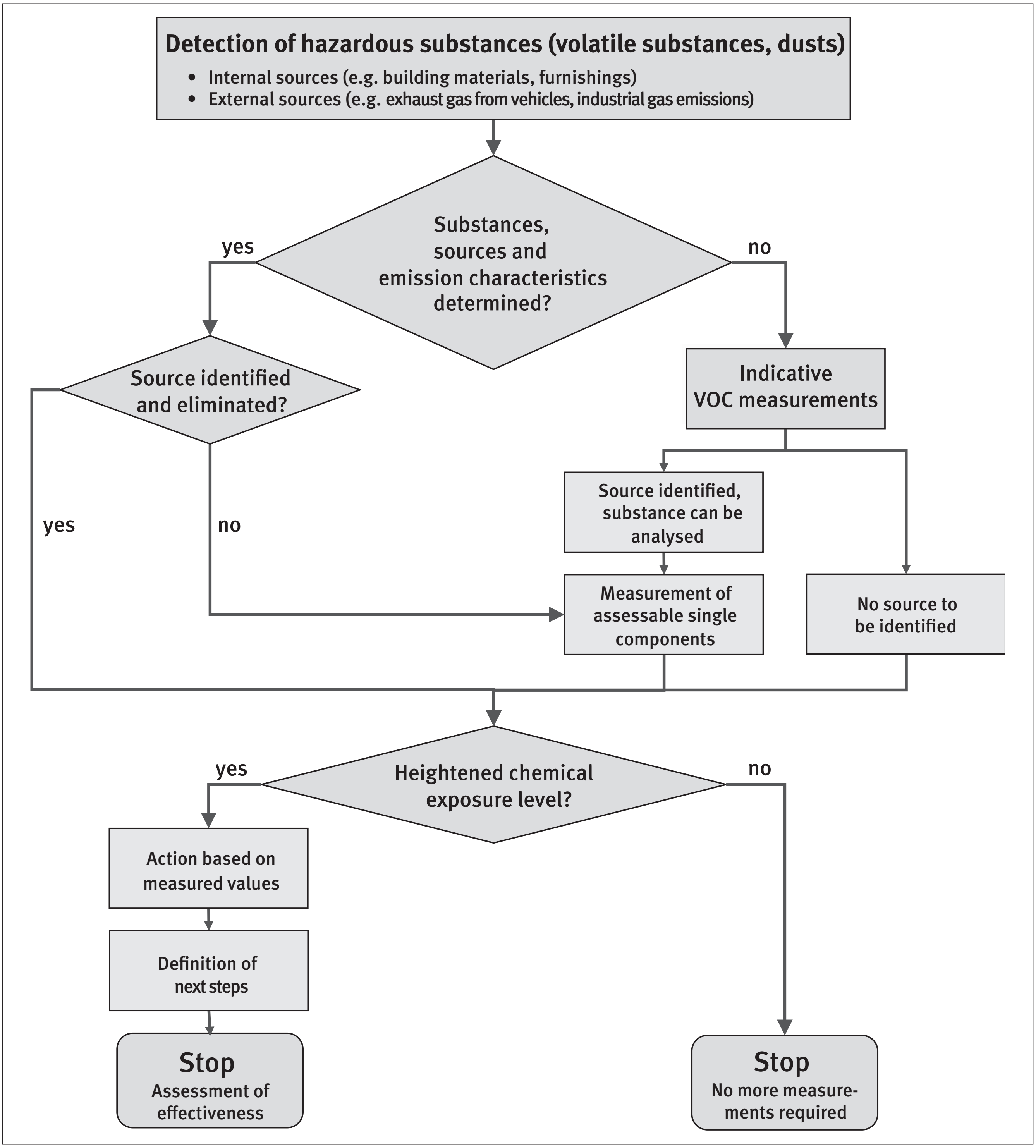


Figure 26:
Detection of hazardous substances (flowchart)



12.2.1 Measuring strategy

The sampling periods must be long enough to enable the substance in question to be identified and quantified. In addition to the time factor, the features of the measuring site must also be taken into account. All ambient conditions (temperature, humidity, air movement, measurement site, etc.) must be documented as part of the measuring procedure.

In buildings with ventilation and air conditioning systems, any information available regarding the supply and extract air must always be taken into account. In such buildings, it is often possible for pollutant sources to be located somewhere else than in the room in which the measurement is being performed.

The type of room involved is also an important factor. The measuring conditions that are suitable in large rooms (e.g. open plan offices) are different to those in smaller office rooms.

Choosing a suitable sampling site is particularly important. The middle of the room is generally felt to be a good place for measurements. Sampling should be carried out at breathing height, i.e. 1 to 1.5 m above floor level for a seated activity. In the case of open plan offices, it can be beneficial to measure at various locations. This is also true if concentration gradients are possible within one room.

In the case of short-term measurements, it must be ensured that the parameters do not change significantly during sampling (e.g. due to windows being opened). Long-term measurements should be carried out under typical working conditions where possible. If passive samplers are used for long-term measurements, the air movement and positioning in the room must always be checked in order to prevent, for example, the results recorded in corners of rooms being lower than the true values.

The basic conditions of the measurement must always correspond to the measurement site. The sampling strategy can only be decided on once the site has been inspected. A working group at the Deutsche Forschungsgemeinschaft (German Research Foundation) is currently drafting a workplace sampling policy.

12.2.2 MGU system for indoor measurements

The German Social Accident Insurance Institutions' MGU measuring system for exposure assessment has been recording hazardous substance measurements from indoor tests for more than 10 years. The measurement procedures that MGU uses for this purpose [4; 5] were developed and introduced on the basis of DIN EN ISO 16017-1 [6]. These procedures are used to measure concentrations of

- volatile organic compounds, as described in [4],
- aldehydes, especially formaldehyde, as described in [5] and
- carbon dioxide.

The system analyses both the total volatile organic compound (TVOC) concentration and, as far as possible, concentrations of certain individual substance. Over the years, the list has grown from the 25 individual substances originally examined to 40 today. These additions were necessary for two reasons. Firstly, sample assessments using the "indoor measurement" system repeatedly detected certain substances. And secondly, substances such as naphthalene and hydrocarbon mixtures with low aromatic contents (chain length C_9 to C_{14}) were added, for which the Ausschuss für Innenraumrichtwerte (Committee on Indoor Guide Values, formerly: Ad Hoc Working Group on indoor guide values) of the Umweltbundesamt (Federal Environmental Agency) and the supreme federal state health authorities had drawn up guide values in the meantime.

Sampling

Before concentrations of volatile organic compounds and aldehydes can be measured, indoor rooms that are naturally ventilated must be thoroughly ventilated (15 minutes) and then have their doors and windows closed for a period of at least eight hours. It is simplest to do this overnight.

The sampling is then carried out with the doors and windows still closed. There must be no smoking in the rooms after ventilation and up until the end of the measurement process. Work can continue in the rooms during measurement.

When carrying out investigations in rooms with forced ventilation or air conditioning system, said system should run for three hours in operating conditions typical for the room in question prior to sampling.

In line with DIN EN ISO 16000-1, the procedure is the same for rooms for which ventilation instructions are defined (for example, schools and nurseries). The standard states that a complete and typical usage cycle must pass prior to measurement in such rooms. During school time, this would usually be no more than the duration of one lesson. This type of ventilation would significantly reduce the indoor concentration levels, making it extremely difficult to identify the causes of poor air quality resulting from sources in the building or in the furniture and furnishings as would otherwise be necessary in naturally ventilated rooms. This would mean that any problem in schools and nurseries could be "remedied by ventilation and measurement" [7]. However, this should not be standard practice, especially in places where children and young people are present. It is therefore recommended that these rooms are also kept closed for at least eight hours prior to sampling so that the sources can be detected.

If the indoor measurements are being carried out due to complaints concerning indoor air quality, it is useful to conduct a parallel measurement in a reference room for which no complaints have been made. This enables room-specific differences to be identified as well as potential sources. As far as possible, the reference room should be located close to the room with air quality issues and be similar in size and use.

A further reference measurement that can be taken is the concentration of volatile organic compounds and aldehydes in the outdoor air. If measurements are to be taken in several polluted rooms and if the measurements are carried out on different days, it is advisable to perform an outdoor air reference measurement for each of the days. The outdoor air measurement should be performed near to the building being investigated, at the same height if possible. The measurements should be taken at a sufficient distance from the building (› 2 m).

The VOC concentration is determined by sampling air using a TENAX TA thermal desorption tube at a flow rate of 4 l/h (66.6 ml/min) for a period of 30 minutes. This is followed by aldehyde sampling for a period of one hour at a flow rate of 80 l/h (1.333 l/min) using a Waters Sep-Pak XpoSure sampler. The aldehyde sampling must not take place at the same time as the VOC sampling because the Waters Sep-Pak XpoSure samplers contain acetonitrile, which could find its way into the ambient air and thus onto the TENAX TA sampler during the measurement process.

The carbon dioxide concentrations can be determined using either detector tubes and a hand pump recommended by the tube manufacturer or with direct-reading devices. The detector tubes mainly serve the purpose of obtaining an initial idea of the usual situation in the room. To verify whether the carbon dioxide concentration in a room provides optimum hygiene conditions, measurements must be carried out continuously over a long period using a direct-reading device under normal conditions of use and with the usual number of room inhabitants. Before measurement starts, the room must be thoroughly ventilated once. The initial carbon dioxide concentration is then that of the outdoor air. The room parameters, e.g. number of windows open and number of persons present, must be documented.

The measurement is carried out at the employees' breathing height, around 1 to 1.5 m above floor level and at a distance of at least 1 to 2 m from the walls. Measures must be taken to prevent the air inhaled and exhaled by persons nearby influencing the measurement (this also includes the person carrying out the sampling). As a rule, one sampling site is sufficient for relatively small rooms up to 50 m². An outdoor air measurement is taken on the same day to provide a reference value.

If the measurements are carried out indoors without any people present in the room, there is no need to measure the CO_2 levels unless there is evidence that there are CO_2 sources in the room.

Analysis

To analyse the VOCs, the TENAX-TA tubes are heated, causing the substances collected to desorb. A gas chromatography analysis is then performed. A flame ionisation detector (FID) is used for quantification. As a rule, the substances shown in Table 25 are quantified and the detector is calibrated based on a single substance calibration. Calibration curves are used for the quantitative assessment. Toluene calibration is used to quantify any additional individual substances, which are then identified using a mass spectrometer. The list of substances to be analysed is continuously adapted in line with the list of substances for which the Umweltbundesamt (German Environmental Protection Agency) has drawn up indoor air guide values. In addition, substances frequently determined by means of toluene calibration are also added to the list.

The total volatile organic compounds (TVOCs) include all substances that appear in the gas chromatogram between the signals for n-hexane and n-hexadecane following separation using a non-polar capillary column. The butanone and ethyl acetate concentrations are also included.

The Waters Sep Pack cartridges are first eluted with acetonitrile before the aldehyde levels are determined. The quality and quantity are established by means of high performance liquid chromatography (HPLC). The quantitative evaluation is done using calibration curves. Currently, the aldehydes listed in Table 25 are given as individual components. See Section 12.3 for an explanation of how the measurement results are assessed.

Table 25:
VOCs and aldehydes included in the analysis

Substance category	Individual substances
Alkanes	n-Heptane, n-octane, n-nonane, n-decane, n-undecane, n-dodecane, n-tridecane, n-tetradecane, n-pentadecane, n-hexadecane
Aromatic compounds	Benzene, toluene, ethylbenzene, xylene (all isomers), 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene (mesitylene), styrene, naphthalene, phenol
Alcohols	n-Butanol, 2-ethylhexanol
Ketones	Butanone, acetophenone[1]
Esters	Ethyl acetate, n-butyl acetate, 2-butoxyethyl acetate, 2-(2-butoxyethoxy)ethyl acetate
Glycols/glycol ethers	2-Butoxyethanol, 2-(2-butoxyethoxy)ethanol, 2-phenoxyethanol
Terpenes/sesquiterpenes	α-Pinene, 3-carene, limonene, (+)-longifolene
Aldehydes	Formaldehyde, acetaldehyde, propionaldehyde[1], acrylaldehyde (acrolein), butyraldehyde, furfural, glyoxal, glutaraldehyde, hexanal[2]
Siloxanes	Hexamethylcyclotrisiloxane, octamethylcyclotetrasiloxane, decamethylcyclopentasiloxane, dodecamethylcyclohexasiloxane[1]

[1] Method in preparation
[2] Unlike other aldehydes, hexanal are determined using the VOC method

12.2.3 Determining the air exchange rate

The air exchange rate is an important parameter in indoor air quality assessment. It measures the air replaced as the volume of supply air in relation to room volume. Adequate air replacement ensures that sufficient fresh air is supplied to indoor rooms, pollutants and odorant substances are removed and damage due to excessive humidity is prevented. In rooms that only have natural ventilation, air is replaced via windows, doors and leaks in the building envelope.

Method

One way of determining the air exchange rate is the concentration-decay method described in VDI 4300, Part 7 [8] and BS EN ISO 12569 [9].This method calculates the exchange rate on the basis of the decay in the concentration of an indicator gas (e.g. sulphur hexafluoride) over time. It can only be applied if it can be assumed that the air in the room is thoroughly mixed. To determine the air exchange rate, a certain quantity of sulphur hexafluoride is introduced into the room to be measured. The gas must be distributed evenly throughout the room. The concentration of the indicator gas is then determined at various points in time. The degree to which the concentration decreases over time can be used to calculate the air exchange rate.

Application

Indoor pollutant concentrations depend on various factors, including the source strength, the air exchange rate and the volume of the room. If the pollutant concentration in a room and the air exchange rate are determined in identical ventilation conditions, the source strength can be calculated using the following formula:

$$q = (\beta - \beta_0) \cdot n \cdot V_R$$

Where

q: Source strength in mg/h

β: Pollutant concentration in room in mg/m^3

β_0: Pollutant concentration in outdoor air in mg/m^3

n: Air exchange rate in 1/h

V_R: Room volume in m^3

Knowing the source strength and the air exchange rate makes it possible, for example, to better compare the substance concentrations measured in polluted rooms with those of unpolluted reference rooms.

The sampling of the indicator gas sulphur hexafluouride to determine the air exchange rate can be done at the same time as the sampling required to determine VOC and aldehyde levels, described in Section 12.2.2.

12.2.4 Methods for measuring other substances

As a rule, the measurement methods developed by the IFA are not indoor measurement methods. The majority of them are intended to monitor compliance with the occupational exposure limits set out in TRGS 402 [10]. These measurement methods are designed for a measuring period of up to eight hours. It is usually not possible to monitor compliance with the guide values recommended for indoor rooms using these methods. In particular, long-term measurements are not possible because, for example, of a lack of experience with passive samplers. Please also refer to Section 12.4 for information on how to measure individual substances or categories of substance.

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Tei 2: Probenahmestrategie für Formaldehyd (06.06). Beuth, Berlin 2006
Teil 3: Messen von Formaldehyd und anderen Carbonylverbindungen – Probenahmen mit einer Pumpe (01.13). Beuth, Berlin 2013
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12.3 Assessment of chemical exposures

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The values to be used for assessing air quality in indoor workplaces such as offices are frequently the subject of some debate.

The potential health risks to humans as a result of hazardous substances in the air they inhale are generally assessed on the basis of limit values defined for specific areas. The TRGS 900 [2] sets out occupational exposure limits (OELs) for the workplace substances that the Gefahrstoffverordnung (GefStoffV; Ordinance on Hazardous Substances) [1] describes as hazardous. However, these OELs only apply to workplaces at which the hazardous substances concerned are either used in or are produced during the activities performed there, according to the definition given in the Gefahrstoffverordnung. There are no specified occupational exposure limits for indoor workplaces that do not fall within the scope of the ordinance.

Instead, such workplaces are subject to the general guidance on ventilation given in Annex 3.6 of the Arbeitsstättenverordnung (Ordinance on Workplaces) [3], according to which there must be sufficient healthy air in work rooms. As per ASR A3.6 Ventilation [4], this requirement is met if the quality of the air is essentially the same as that of the outdoor air. However, the immission values and other assessment values specified for outdoor air cannot automatically be applied to indoor air since they may have been drawn up with the aim, for example, of protecting vulnerable plant or animal life, not human beings. Furthermore, using the quality of the outdoor air as a standard against which to compare the quality of the indoor air causes problems in practice if the outdoor air is polluted.

As a result, the values currently used in Germany to assess exposure in indoor workplaces vary considerably in terms of their nature and origin. Unlike occupational exposure limits, these values are not presented in one, binding rule and, in particular, they do not have consistent legal relevance. Almost all values for indoor rooms are merely recommendations. The most important values used for assessing indoor air are described in the following. In addition, the main assessment values for outdoor air can be found in the latest list of limit values published by the IFA [5]. Values for assessing individual substances and categories of substance are presented in Section 12.4.

12.3.1 Indoor air guide values set by the Federal Environmental Agency (UBA)

The Committee for Indoor Guide Values, set up by the UBA’s Indoor Air Hygiene Commission and the highest state health authorities, has drawn up guide values for indoor rooms in general, including rooms in dwellings, based on toxicological evidence. These values best meet the criteria for a valid assessment of air quality in indoor workplaces. A distinction is drawn between guide value II and guide value I, as follows:

“Guide value II (RW II) is an effect-related value based on current toxicological and epidemiological knowledge of a substance‘s effect threshold that takes uncertainty factors into account. It represents the concentration of a substance which, if reached or exceeded, requires immediate action as this concentration could pose a health hazard, especially for sensitive people who reside in these spaces over long periods of time. Depending on how the substance concerned works, guide value II may be defined either as a short-term value (RW II K) or a long-term value (RW II L).

Guide value I (RW I) represents the concentration of a substance in indoor air for which, when considered individually, there is no evidence at present that even life-long exposure is expected to bear any adverse health impacts. Values exceeding this are associated with exposure that is undesirable for health reasons. For the sake of precaution, there is also need for action in the concentration range between RW I and RW II. RW I can act as a target value during clean-up efforts, which should be undercut rather than merely complied with. Guide value I is derived from guide value II through the introduction of an additional factor based on convention.”

Whilst the occupational exposure limits relate to eight-hour periods, the guide values usually refer to long-term periods (24 hours a day, seven days a week) and also apply to children and people with an illness. They are not used extensively because they are currently only available for a very limited number of individual substances (see Table 26).

12.3.2 WHO Air Quality Guidelines

In 2009, the World Health Organization (WHO) published its first guidelines for indoor air quality, intended to protect public health against the risks posed by damp and associated microorganism growth [7]. Additional guidelines were added in 2010 for a number of chemicals commonly found in indoor air (Table 27 on page 82) [8].

Table 26:
Guide values established for indoor air up to May 2013 [6]

Compound	Guide value II [1] in mg/m³	Guide value I [1] in mg/m³	Year established
2-Furaldehyde	0.1	0.01	2011
Aldehydes, C_4 to C_{11} (saturated, acyclic, aliphatic)	2	0.1	2009
Alkyl benzene, C_9 to C_{15}	1	0.1	2012
Benzaldehyde	0.2	0.02	2010
Benzyl alcohol	4	0.4	2010
Dearomatized hydrocarbon solvents (C_9 to C_{14})	2	0.2	2005
Dichloromethane	2 (24 h)	0.2	1997
Diethylene glycol butyl ether (DEGBE)	1	0.4	2013
Diethylene glycol dimethyl ether (DEGDME)	0.3	0.03	2013
Diethylene glycol methyl ether (DEGME)	6	2	2013
Diethylene glycol monoethyl ether (DEGEE)	2	0.7	2013
Diisocyanates	See notes [2]		2000
Dipropylene glycol 1-methyl ether (D-PGME)	7	2	2013
Ethylbenzene	2	0.2	2012
Ethylene glycol butyl ether (EGBE)	1	0.1	2013
Ethylene glycol butyl ether acetate (EGBEA)	2	0.2	2013
Ethylene glycol hexyl ether (EGHE)	1	0.1	2013
Ethylene glycol monoethyl ether (EGEE)	1	0.1	2013
Ethylene glycol monoethyl ether acetate (EGEEA)	2	0.2	2013
Ethylene glycol monomethyl ether (EGME)	0.2	0.02	2013
2-Ethylhexanol	1	0.1	2013
Carbon monoxide	60 (0.5 h) 15 (8 h)	6 (0.5 h) 1.5 (8 h)	1997
Cresols	0.05	0.005	2012
Methyl isobutyl ketone	1	0.1	2013
Monocyclic monoterpenes (guiding substance: d-limonene)	10	1	2010
Naphthalene	0.020	0.002	2004
Pentachlorophenol (PCP)	0.001	0.0001	1997
Phenol	0.2	0.02	2011
2-Propylene glycol 1-ethyl ether (2PG1EE)	3	0.3	2013
2-Propylene glycol 1-methyl ether (2PG1ME)	10	1	2013
2-Propylene glycol 1-tert-butyl ether (2PG1tBE)	3	0.3	2013
Mercury (as metallic vapour)	0.00035	0.000035	1999
Nitrogen dioxide (NO_2)	0.35 (30-minute value) 0.06 (7-day value)	-	1998
Styrene	0.3	0.030	1998
Bicyclic terpenes (guiding substance: α-pinenes)	2	0.2	2003
Toluene	3	0.3	1996
Tris(2-chloroethyl) phosphate (TCEP)	0.05	0.005	2002
Cyclic dimethylsiloxanes D3-D6 (total guide value)	4	0.4	2011

[1] These are usually long-term values. Where this is not the case, the averaging period is indicated in parentheses, e.g. 24 hours (h).

[2] The working group felt that it did not make sense to specify a guide value II for diisocyanates (DIs) (see explanation in the publication). Where varnishes and adhesives containing diisocyanates are used, the concentration in the indoor air is initially relatively high (concentration approximately equal to the MAK value) but it drops sharply and long-term pollution is unlikely once the hardening process has finished. As a rule, however, rooms in which products containing diisocyanates are processed should be well ventilated.

Table 27:
Summary of the WHO guidelines for selected pollutants in indoor air [9]

Pollutant	Guidelines
Benzene	- No safe level of exposure can be recommended - Unit risk[1] of leukaemia per 1 µg/m^3 air concentration is $6 \cdot 10^{-6}$ - The concentrations of airborne benzene associated with an excess lifetime risk[2] of 1/10,000, 1/100,000 and 1/1,000,000 are 17, 1.7 and 0.17 µg/m^3, respectively
Formaldehyde	0.1 mg/m^3 (30-minute average)
Carbon monoxide	- 15 minutes – 100 mg/m^3 - 1 hour – 35 mg/m^3 - 8 hours – 10 mg/m^3 - 24 hours – 7 mg/m^3
Naphthalene	0.01 mg/m^3 (annual average)
Polycyclic aromatic hydrocarbons	- No threshold can be determined and all indoor exposures are considered relevant to health - Unit risk for lung cancer for PAH mixtures is estimated to be $8.7 \cdot 10^{-5}$ per ng/m^3 of B[a]P - The corresponding concentrations for lifetime exposure to B[a]P producing excess lifetime cancer risks of 1/10,000, 1/100,000 and 1/1,000,000 are approximately 1.2, 0.12 and 0.012 ng/m^3, respectively
Radon	- The excess lifetime risk of death from radon-induced lung cancer (by the age of 75 years) is estimated to be $0.67 \cdot 10^{-5}$ per Bq/m^3 for lifelong non-smokers and $15 \cdot 10^{-5}$ per Bq/m^3 for current smokers (15 to 24 cigarettes per day); among ex-smokers, the risk is intermediate, depending on time since smoking cessation - The radon concentrations associated with an excess lifetime risk of 1/100 and 1/1,000 are 67 and 6.7 Bq/m^3 for current smokers and 1670 and 167 Bq/m^3 for lifelong non-smokers, respectively
Nitrogen dioxide	- 200 µg/m^3 (1-hour average) - 40 µg/m^3 (annual average)
Trichloroethylene	- Unit risk estimate of $4.37 \cdot 10^{-7}$ per µg/m^3 - The concentrations of airborne trichloroethylene associated with an excess lifetime cancer risk of 1 : 10,000, 1 : 100,000 and 1 : 1,000,000 are 230, 23 and 2.3 µg/m^3, respectively
Tetrachloroethylene	- 0.25 mg/m^3 (annual average)

[1] Unit risk: Risk of developing cancer as a result of lifelong exposure to a concentration of 1 µg/m^3

[2] Lifetime risk: Probability of developing, for example, cancer during an average lifetime

12.3.3 Derivation of reference values for individual substances

Statistically derived reference values can be used to assess those substances for which there are no guide values yet. In accordance with an international convention, the 95 percentile value of a sufficiently large set of data can be used as a reference value. This assumes (without a toxicological assessment being carried out) that the “normal conditions” that are present in the rooms investigated and do not give rise to illness or health complaints can be deemed generally acceptable. Unlike guide values, reference values cannot be used to assess health risks. As such, if the actual values are lower than the reference values this does not necessarily mean that there is no risk to health. By the same token, if the values are higher it does not automatically mean that there is a risk [10].

Having said that, a value that is significantly higher than the reference value may be an indication that the room contains emission sources that might impair health. For reference values to be usable, it must be possible to compare the reference room and the indoor room being investigated. The main parameters that determine whether this is the case are the fittings and furnishings, the way in which the rooms are used, the measuring method and the measuring strategy.

Reference values for assessing indoor workplaces (e.g. offices)

Reference values for assessing indoor workplaces, based on measurement data compiled by the statutory accident insurance institutions, were published for the first time in 2004 [11]. They were reviewed in 2010 and updated in line with the findings of a statistical evaluation of all of the measurement data documented in the IFA’s MEGA exposure database up to September 2010 [12].

This statistical evaluation only considered data from stationary measurements gathered in offices without mechanical ventilation and where the sampling duration was as specified in the measuring procedures [13; 14]. The results can be considered statistically reliable since, in most cases, more than 700 measurements were evaluated per compound. The German statutory accident insurance institutions apply the lower 90 percentile value instead of the 95 percentile value when deriving reference values, in contrast with international convention, for prevention purposes. The values have been rounded strictly to 2 decimal places. The indoor workplace reference values derived in 2011 are listed in Table 28. They are only applicable in conjunction with the MGU measurement programme for indoor measurements (including the associated measurement strategy) described in Section 12.2.2.

Reference values for assessing classrooms

A study conducted between 2004 and 2009 monitored concentrations of aldehydes and VOCs in 421 unpolluted classrooms in 119 schools in the German state of North Rhine-Westphalia [15]. The measuring and analysis methods used were similar to those in the MGU measuring programme for indoor measurements. The data was used to derive classroom reference values as was done for indoor workplaces [16]. The classroom reference values are shown in Table 29.

Table 28:
Indoor workplace reference values set by the German statutory accident insurance institutions

Compound	**Indoor workplace reference value in mg/m^3**
TVOCs	1
Hydrocarbon mixtures, aliphatic (C_9 to C_{14})	0.07
Alkanes	
n-Heptane	0.02
n-Octane	0.01
n-Nonane	0.01
n-Decane	0.01
n-Undecane	0.02
n-Dodecane	0.01
n-Tridecane	0.01
n-Tetradecane	0.01
n-Pentadecane	0.01
Aromatic compounds	
Toluene	0.04
Ethylbenzene	0.01
o-Xylene	0.01
m-Xylene	0.02
p-Xylene	0.01
1,2,4-Trimethylbenzene	0.01
Styrene	0.01
Alcohols	
n-Butanol	0.04
2-Ethylhexanol	0.02
Ketones	
Butanone	0.01
Esters	
Ethyl acetate	0.02
n-Butyl acetate	0.02
Ethers	
2-Butoxyethanol	0.01
2-Phenoxyethanol	0.01
Terpenes	
α-Pinene	0.02
Limonene	0.03
3-Carene	0.01
Aldehydes	
Formaldehyde	0.06
Acetaldehyde	0.05
Hexanal	0.03
Siloxanes	
Hexamethylcyclotrisiloxane (D3)	0.03
Octamethylcyclotetrasiloxane (D4)	0.02
Decamethylcyclopentasiloxane (D5)	0.06

Table 29:
Classroom reference values set by the German statutory accident insurance institutions [16]

Compound	**Classroom reference value in mg/m^3**
TVOCs	0.68
Hydrocarbon mixtures, aliphatic (C_9 to C_{14})	0.03
Alkanes	
n-Heptane	0.01
n-Undecane	0.01
n-Dodecane	0.01
n-Tridecane	0.01
Aromatic compounds	
Toluene	0.03
Ethylbenzene	0.01
Xylene (all isomers)	0.02
m-Xylene	0.01
1,2,4-Trimethylbenzene	0.01
Styrene	0.01
Phenol	0.01
Alcohols	
n-Butanol	0.03
2-Ethylhexanol	0.02
Ketones	
Butanone	0.01
Esters	
Ethyl acetate	0.01
n-Butyl acetate	0.01
Ethers	
2-Butoxyethanol	0.02
2-(2-Butoxyethoxy)ethanol	0.03
2-Phenoxyethanol	0.02
Terpenes	
α-Pinene	0.02
Limonene	0.02
3-Carene	0.01
Aldehydes	
Formaldehyde	0.06
Acetaldehyde	0.05
Hexanal	0.02
Siloxanes	
Hexamethylcyclotrisiloxane (D3)	0.03
Octamethylcyclotetrasiloxane (D4)	0.02
Decamethylcyclopentasiloxane (D5)	0.02

Reference values set by other institutions

As well as the statutory accident insurance institutions, other bodies have drawn up reference values for assessing indoor air [17 to 19]. The measurements were conducted in a variety of indoor rooms, including in dwellings, and are decades old in some cases. Irrespective of whether this data can be applied to office workplaces, it should be borne in mind that there have been major changes in indoor furnishings, fittings and equipment and the way in which rooms are used. Those changes, of which new interior decoration materials and different cleaning methods are just a few examples, have affected air pollution levels too. Another problematic aspect is that different measuring methods and strategies were used in the studies. As such, they offer limited comparability, which is a key prerequisite for reference values to be used. They can therefore only be applied to indoor workplaces subject to certain provisos.

12.3.4 References

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12.4 Specific information regarding individual substances and categories of substance

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12.4.1 Carbon dioxide

Humans and their breathing are the main source of indoor carbon dioxide (CO_2) emissions. However, they do not result in toxically relevant levels CO_2 concentrations even in unfavourable conditions, e.g. where the air exchange rate is low. As odorant substance emissions are usually proportional to humans' CO_2 emissions, CO_2 concentration levels are a suitable indicator of indoor air quality provided there are no other sources of CO_2 emissions or odours. They also indicate how effective the room ventilation is.

As described in Section 12.2.2, indoor CO_2 concentrations can be measured using detector tubes or direct-reading measuring devices. However, they can also be calculated on the basis of the human CO_2 emissions and the number of people present, their activities and the air exchange rate (ventilation efficiency) [1]. When engaged in non-strenuous activities, a human emits around 20,000 ml/h of CO_2. This value can be used to calculate the maximum CO_2 concentration level that will be reached in accordance with equation (1).

$$x_{CO_2} = \frac{n \cdot m_{CO_2}}{\lambda \cdot V_R} + x_{CO_2,\,\mathrm{outdoor}} = \frac{n \cdot 20\,000\,{}^{\mathrm{ml}}\!/_{\mathrm{h}}}{\lambda \cdot V_R} + x_{CO_2,\,\mathrm{outdoor}} \qquad (1)$$

x_{CO_2} : CO_2 concentration in ml/m³

m_{CO_2} : CO_2 emission rate per person in ml/h

λ : Air exchange rate in h^{-1}

V_R : Room volume in m^3

$x_{CO_2\mathrm{outdoor}}$: Outdoor air CO_2 concentration in ml/m³

n : number of people

For example, if the volume of an office used by two people is 100 m³ and if a natural air exchange rate λ of 0.5 h^{-1} is assumed for the office, the maximum possible CO_2 concentration – taking into account a mean CO_2 concentration of 400 ml/m³ in the outdoor air [2] – is 1,200 ml/m³ (see equation 2).

$$x_{CO_2} = \frac{2 \cdot 20{,}000\,{}^{\mathrm{ml}}\!/_{\mathrm{h}}}{0{,}5\ \mathrm{h}^{-1} \cdot 100\ \mathrm{m}^3} + x_{CO_2\,\mathrm{outdoor}} \qquad (2)$$

$$= 800\,{}^{\mathrm{ml}}\!/_{\mathrm{m^3}} + 400\,{}^{\mathrm{ml}}\!/_{\mathrm{m^3}} = 1{,}200\,{}^{\mathrm{ml}}\!/_{\mathrm{m^3}}$$

For assessment purposes, the general rule is that the concentration level should not exceed

0.1 vol.-%CO_2 (1,000 ppm or 1,800 mg/m³)

(*Pettenkofer* value, see e.g. [3; 4]). In 2008, the Ad Hoc Working Group on Indoor Guide Values derived the following guide values for momentary concentrations of CO_2, based on health and hygiene aspects and the findings of intervention studies. These values have since been incorporated into ASR A3.6 "Ventilation" [2]:

- Carbon dioxide concentration lower than 1,000 ppm = Safe hygiene standard
- Carbon dioxide concentration between 1,000 and 2,000 ppm = Critical hygiene standard
- Carbon dioxide concentration higher than 2,000 ppm = Unacceptable hygiene standard

In accordance with these guide values, ventilation is recommended where the momentary CO_2 concentration level exceeds 1,000 ppm. If the concentration level is over 2,000 ppm, ventilation is compulsory. If ventilation is not sufficient to bring the concentration down to below the guide value of 2,000 ppm (a ventilation plan may have to be introduced), further organisational, ventilation-system or structural measures are necessary. These include, for example, reducing the number of people present in the room or installing a ventilation system.

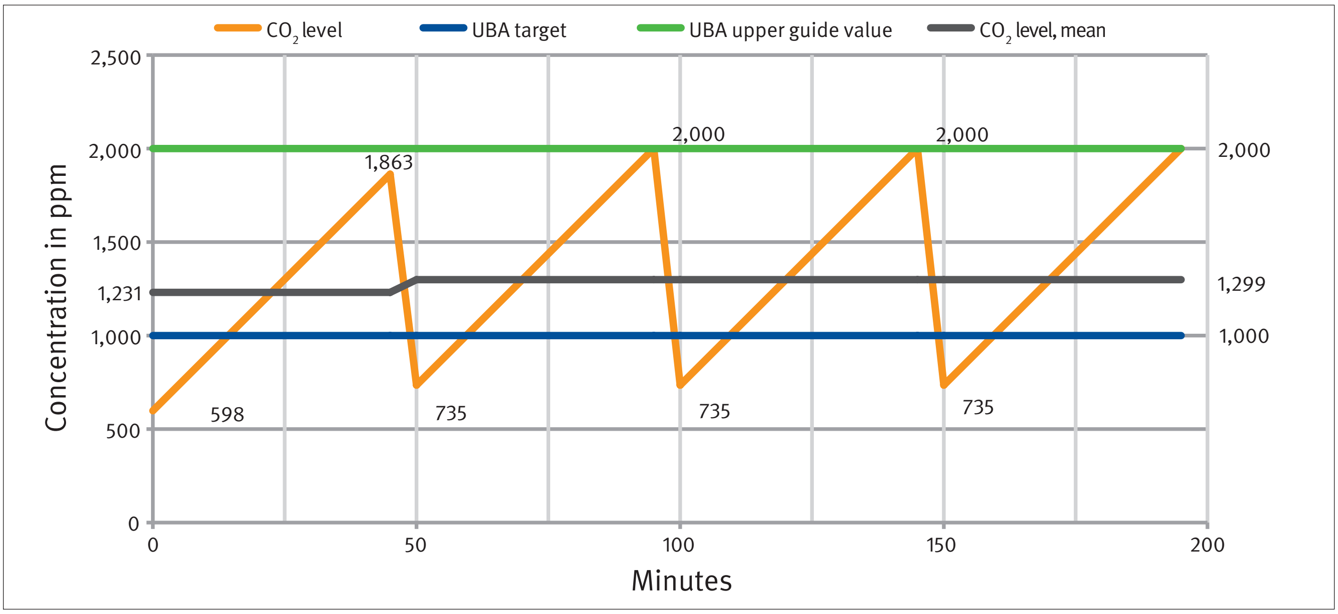
Carbon dioxide pollution in classrooms

A study conducted by the North Rhine-Westphalian Social Accident Insurance Institution for the public sector in 379 classrooms in 111 schools [5] confirmed that CO_2 is usually the most significant air pollutant in classrooms too. According to the findings, the CO_2 concentration in the classroom during lessons increases substantially if the room is not ventilated (Figure 27, page 86). Airing the room thoroughly during breaks can briefly reduce the CO_2 concentration to below the guide value of 1,000 ppm but it is exceeded again just a few minutes after closing the windows.

The guide value can only be constantly maintained by airing the room again briefly halfway through the lesson or by keeping the windows tilted open for the duration of the lesson. The latter option does not necessarily require the window area to be large. In the winter months, approximately 1 m² of open window is sufficient on average to ensure hygienically safe air. In the summer, an average of 1.8 m² of open window ensures that the CO_2 concentration only rises slightly during lessons.

CO_2 concentrations of 1,000 ppm can also be permanently achieved with the help of mechanical ventilation, be it in the form of a central ventilation or air conditioning system for the building or a room-specific solution.

Figure 27:
Mean CO_2 pollution in classrooms aired briefly and thoroughly after each lesson; UBA = Umweltbundesamt (Federal Environmental Agency)



12.4.2 Ozone

The main source of indoor ozone pollution is contamination through outdoor air as a result of ventilation (e.g. open windows). Ozone formation caused by operating laser printers and copiers is no longer a problem today (see Section 7.2.3).

Ozone is produced in the outdoor air by means of solar irradiation and photochemical smog reactions. Ventilation, especially in the form of open windows and doors, enables it to make its way from the outdoor air into the indoor air. Ventilation systems, on the other hand, break down part of the ozone as it travels through the filter and the pipes towards the work area. Indoors, ozone decomposes with a half-life of approximately 30 minutes, partly by reacting with other volatile substances.

Directive 2008/50/EC of the European Parliament and the Council on ambient air quality and cleaner air for Europe [6] stipulates an ozone value of 120 µg/m³ as the maximum eight-hour average for one day in order to protect human health. This value may be exceeded on no more than 25 days per year. For the one-hour value, the directive also lays down an information threshold of 180 µg/m³ (the public must be informed when this value is exceeded) and an alert threshold of 240 µg/m³.

High concentrations, resulting in the assessment values being exceeded, are particularly likely during sunny weather at the height of summer. On such days, it is advisable to keep windows and doors closed as far as possible to prevent too much ozone entering indoor rooms. The preferred option should always be to air rooms briefly and thoroughly and then close the doors and windows again.

12.4.3 Formaldehyde

Formaldehyde is a basic chemical that serves as an inexpensive precursor for a variety of chemical products. For instance, it is used in the production of phenol formaldehyde resins and aminoplasts, which in turn are used, for example, to glue chipboard, plywood and edge-glued panels (see Section 6.4.3).

Other formaldehyde sources of relevance in indoor spaces include in situ foams made from urea formaldehyde resin, varnishes (mainly acid-catalysed coatings for wooden floors and furniture), veneers, textiles, carpets and fibre mats containing binders. Aqueous solutions used as disinfectants and preservatives also contain formaldehyde and it can also be detected in personal care and cleaning products.

In 2004, a working group at the International Agency for Research on Cancer (IARC) classified formaldehyde as category 1, carcinogenic to humans [7; 8]. Germany's Bundesinstitut für Risikobewertung (BfR; Federal Institute for Risk Assessment) responded in the spring of 2006 by suggesting an air concentration level of 0.1 ppm (0.12 mg/m³) as a safe level in view of the carcinogenic effect of formaldehyde on human beings [9]. The Ad Hoc Working Group on Indoor Guide Values followed step in the autumn of 2006 [10].

The WHO proposes a 30-minute average of 0.1 mg/m³ (0.08 ppm) as a precaution against sensory irritation in the general public [11]. Where exposure is prolonged, the recommendation is not to exceed a concentration of 0.06 mg/m³ (0.05 ppm) [12].

12.4.4 Volatile organic compounds

Volatile organic compounds (VOCs) can be classified as shown in Table 30. The very volatile and volatile organic compounds are almost exclusively found in the ambient air. The semi-volatile organic compounds, such as biocides and phthalates, and the organic compounds associated with particulate organic matter (POM) are mostly found in sedimented house dust and attached to airborne dust. These cases can only be assessed adequately by examining the dust deposits.

Table 30:
VOC classification based on the World Health Organization method [13]

Classification	Abbreviation	Boiling range in °C
Very volatile organic compounds	VVOC	< 0 to 50-100
Volatile organic compounds	VOC	50-100 to 240-260
Semi-volatile organic compounds	SVOC	240-260 to 380-400
Organic compounds associated with particulate (organic) matter	POM	> 380

The airborne VOCs consist of a huge range of substances, which can be classified as follows:

- aliphatic hydrocarbons,
- aromatic hydrocarbons,
- alcohols,
- ketones,
- esters, primarily acetates and acrylates,
- glycol compounds, both glycol esters and glycol ethers,
- terpenes and
- siloxanes (D3 to D6 siloxane).

Although aldehydes are also VOCs, the methods used to analyse them are different and they are therefore often considered separately.

There are a number of potential sources of volatile organic compounds in indoor spaces. They can be divided into the following three categories:

- building-related sources,
- sources related to human activity and
- sources related to the outdoor air.

Almost any of the materials used in modern buildings can constitute a building-related VOC source. The range of substances reflects the changes in the composition of the materials used. For instance, more dibasic esters (DBEs) – a substance category that is used as a substitute for conventional solvents – will be detected in the future. In addition, materials such as bricks, mortar and other elements of buildings, which used to be low in emissions, now contain aggregates that have plastics and solvents in them. Other potential sources are wall panelling, floor coverings, insulation materials, sealants, furniture, paints, varnishes and solvents used in interiors (see Section 6.4).

Human activities cause VOCs to enter rooms in the form of cleaning and furniture care products, cosmetics, disinfectants, plant protection products and tobacco. VOC contamination is also possible through the outdoor air (e.g. from road traffic).

Investigation

When identifying potential VOC sources, the first step should be to ascertain whether redecoration work has been carried out or new furniture, equipment, etc. installed recently (see questionnaire G2 in Annex 3). In such cases, the VOC concentrations can often be reduced by ventilating the room for a prolonged period whilst simultaneously heating it. The investigation should also check whether any specific cleaning agents or air fresheners used could be sources. Questionnaire G2 also includes aspects such as the location of the building, thus covering contamination from outside too.

A key parameter in any assessment of indoor air quality is the total of the VOCs in the 50 to 260 °C boiling range (see Table 30), referred to as TVOCs (total volatile organic compounds). This boiling range includes the majority of substances that can be detected analytically on a non-polar column in the elution range between n-hexane and n-hexadecane [14].

Although there are no substantiated dose-effect relationships and TVOC concentrations should not be used as the sole criterion when assessing the healthiness of indoor air quality, the TVOC concentration levels can be used to assess VOC-related adverse effects on the indoor air. For instance, the probability of irritation and perception of odours increases as the TVOC concentration rises. The Committee on Indoor Guide Values recommends Seifert's five-level approach from 1999 for assessing TVOC concentration levels (see Table 31, page 88) [14]. Generally speaking, the VOC assessment must provide answers to the following:

- Have guide values been exceeded? (See Section 12.3.1)

- Are there any abnormal instances of the reference values being exceeded? (See Section 12.3.3)

- Does the thermal environment (air exchange, temperature, humidity) comply with the requirements (see Chapter 9)?

Annex 5 contains a table listing possible sources of individual substances.

Table 31:
Hygiene ratings for TVOC values and resulting recommendations for action to be taken [14]

Level	Concentration in mg/m^3	Hygiene rating	Recommendations
1	≤ 0.3	Hygienically safe Usually no complaints	No further action
2	> 0.3 to 1	Still hygienically safe provided no guide values for individual substances or categories of substance have been exceeded. Complaints or perception of odours in individual cases, e.g. following small-scale redecoration work or installation of new furniture in the weeks preceding	Sufficient ventilation, especially after redecoration work Identify VOC sources (e.g. by inspecting the room), check use of cleaning agents, follow-up measurements to monitor compliance with guide values under conditions of use
3	> 1 to 3	Critical in terms of hygiene Use of regularly used rooms only acceptable for limited periods (< 12 months) Within approx. 6 months, the TVOC concentration should be decreased to considerably lower than the value initially measured. Cases of complaints or perception of odours, e.g. following large-scale redecoration work	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health In all cases: search for source and review ventilation patterns: ventilate thoroughly and, where appropriate, specify conditions of use and ventilation Control/follow-up measurement recommended after approx. one month (under conditions of use)
4	> 3 to 10	Hygienically unsafe Use of regularly used rooms only acceptable for limited periods (< 1 month) The TVOC concentration should be decreased to below 3 mg/m^3 within one month. Multiple cases of complaints or perception of odours, e.g. following large-scale redecoration work	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health. Toxicological assessment of individual substances or categories of substance necessary In all cases: search for source, ventilate thoroughly and, where appropriate, specify conditions of use and ventilation and take appropriate steps to minimise concentration levels. Where people are required to spend time in the room concerned, the in-room time per day must be limited over a maximum period set by the Gesundheitsamt (public health department) (hours per day/time limit). Control/follow-up measurement recommended after approx. one month (under conditions of use) If, after one month, the TVOC concentration remains higher than 3 mg/m^3 despite the recommended action, appropriate remediation measures must be planned.
5	> 10	Hygienically unacceptable. Room should not be used as far as possible. People should only spend time in the room if it is limited to a certain number of hours per day/a certain amount of time. The room must not be used at all if the values are higher than 25 mg/m^3. The TVOC concentration should be decreased to below 3 mg/m^3 within one month. Usually complaints and noise annoyance, e.g. following incorrect use or accidents.	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health. Toxicological assessment of individual substances or categories of substance necessary. In all cases: search for source, ventilate thoroughly, specify conditions of use and ventilation and take appropriate steps to minimise concentration levels. Where people are required to spend time in the room concerned, the in-room time per day must be limited over a maximum period set by the public health department (Gesundheitsamt) (hours per day/time limit). Control/follow-up measurement recommended after approx. one month (under conditions of use) If minimisation efforts reduce the concentration level to below 10 mg/m^3 during the period considered but it is still higher than 3 mg/m^3, the action recommended in Level 4 should be taken. If, after one month, the TVOC concentration remains higher than 10 mg/m^3 despite the recommended action, the room should not be used and appropriate remediation measures must be taken.

12.4.5 Mercury in compact fluorescent lamps (energy-saving light bulbs) and fluorescent tubes

Compact fluorescent lamps (energy-saving lamps) and fluorescent tubes contain small amounts of mercury, which is required for the illumination process in these lighting products. Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment [15] restricts the quantity of mercury that can be used in lamps in the European Union and requires manufacturers to reduce the levels further. Since January 2012, manufacturers have had to mark the mercury content on the packaging of the lamps.

No mercury is emitted from lamps when they are used as intended. However, when energy-saving lamps or fluorescent tubes are replaced or otherwise handled (when being collected for recycling, for example), there is a risk that they might be damaged. If they break, mercury vapours can be released [16].

Measurements conducted by the UBA on new energy-saving lamps on the market have shown that there are no significant concentrations of mercury following lamp breakages when the broken lamp is disposed of completely and the room immediately aired [17]. It can therefore be assumed that mercury does not pose any health risks.

To minimise the risk of mercury exposure, any new lamps purchased should contain as little mercury as possible. Faulty lamps should not be replaced while still hot because hot lamps give off more mercury vapours when broken than cold ones do. Spent lamps must be disposed of at appropriate collection centres (e.g. recycling centres or retailers), not along with household waste, and breakage should be kept to a minimum.

12.4.6 Dust

Up to 50% of the dust that occurs indoors originates in the outdoor air. Other sources of dust in the rooms used include dust attached to room users' shoes and clothes, sedimented particles being raised or disturbed mechanically (e.g. when vacuum cleaners are used or paper is handled) and work equipment. The concentration and composition of indoor dust varies significantly depending on how the room in question is used [18]. For instance, large deposits of dust in rooms that are otherwise cleaned normally or situations in which large quantities of paper are handled, e.g. archives and during copy processes are an indication that the dust levels in the ambient air will be high.

Bar a few exceptions, dusts do not have harmful or unwanted effects provided the concentration in the indoor air is roughly equivalent to that in the outdoor air. It should, however, be borne in mind that semi-volatile organic compounds (SVOCs), biocides, polycyclic aromatic hydrocarbons, and plasticisers, among other things, may accumulate on the dust particles thereby potentially causing unwanted, irritating or harmful effects [19].

The potential health hazards posed by exposure to dust are assessed on the basis of dust fractions, which depend on the particle size. The fractions commonly used in the field of occupational safety and health are "respirable dust" and "alveolar dust". These are not identical to the fractions commonly used in the area of environmental protection, PM_{10} (particular matter) and $PM_{2.5}$, which provide a first approximation of the total of all airborne dust particles with a diameter of up to 10 and up to 2.5 µm respectively [20].

The recommended practice for assessing dust exposure in indoor workplaces is to use the $PM_{2.5}$ and PM_{10} fractions defined for environmental protection purposes since the indoor concentration levels are mainly influenced by the outdoor air, for which assessment values are available. The Committee on Indoor Guide Values suggests that, where there are no combustion processes (e.g. tobacco smoke), the 25 µg/m³ daily value defined by the WHO be used as the assessment value for the $PM_{2.5}$ fraction [18].

The working group does not propose an assessment value for the PM_{10} fraction, however, citing the fact that the concentration levels for this fraction are considerably higher indoors than they are outdoors. This means that the main sources of this particle fraction are to be found indoors. A conclusive assessment is not possible because there are no further details available on the composition of this fraction [18].

In general, it should be ensured that the PM_{10} fraction concentration does not exceed the EU dust limit for tropospheric air of 50 µg/m³ [6].

The Committee on Indoor Guide Values recommends that rooms be sufficiently ventilated in order to reduce indoor dust exposure. In addition, every effort should be made to find and minimise known sources of particular matter [18].

Fibrous dust

The effects of fibrous dust are such that it requires a separate assessment. The main indoor sources are textile fibres, e.g. interior textiles or clothing, and natural and man-made mineral fibres, e.g. in thermal insulating materials. Asbestos fibres are no longer of relevance indoors, provided the Asbestos Directive's [21] requirements concerning assessment of the urgency of clean-up measures are complied with as well as the criteria set out in TRGS 519 "Hazardous Substances" [22] regarding the protection of employees and third parties in connection with clean-up measures.

Fibrous dust is considered harmful to health if it can be inhaled and is "bio-persistent". According to a WHO definition, fibres can be inhaled if they have a length of > 5 µm, a diameter of < 3 µm and a length-to-diameter ratio of > 3 : 1 (these are known as "WHO fibres"). The level of bio-persistence depends on the fibre material. Since 1998, man-made mineral fibres (MMMFs), as used in mineral-wool insulating materials, have only been allowed to be sold if their bio-solubility half-life (breakdown by endogenous substances) is less than 40 days.

Mineral-wool insulating materials can cause fibrous dust exposure if they come into direct contact with the ambient air (as in open applications such as sound-absorbing panels in louvre systems) and, in particular, if they are subjected to vibrations or accelerated air velocity. Only in these cases are measurements potentially useful.

The irritant effect of MMMFs, which is occasionally the subject of debate, is linked to fibres larger than the WHO variety and only occurs if mineral-wool insulating materials have not been installed properly or the cladding has become damaged over time and there are visible fibrous dust deposits. According to *Walker* et al. [23], there are no health-related grounds for removing old MMMF insulating materials that have been properly installed.

Asbestos fibre dust poses much more of a hazard. If it is suspected that asbestos fibres have been released in the building in question, further investigation must be carried out using the customary procedures, as described at length in [24] for example. If necessary, a refurbishment plan must be drawn up in line with the requirements of the Asbestos Directive [21].

Tobacco smoke in indoor workplaces

Tobacco smoke in indoor air is classified as carcinogenic for humans. By law, employees are entitled to a smoke-free workplace. Section 5 (1) of the Arbeitsstättenverordnung (Ordinance on Workplaces) [25] states:

“Employers must take the measures necessary to ensure effective workplace protection for non-smoking employees against the health hazards of tobacco smoke.”

There are various ways of complying with the legal requirement to protect non-smokers. The most effective is to impose a universal ban on smoking throughout the building concerned. Once such a ban is in place, there is no longer any need to include tobacco smoke when investigating sources of air pollution.

The German statutory accident insurance institutions published a report in 2011 on the topic of tobacco smoke pollution in workplaces, including an in-depth review of exposure situations in indoor workplaces [26].

12.4.7 Phthalates

Phthalates continue to be manufactured on a large scale. Around 1 million tonnes are currently produced every year in Western Europe, roughly 90% of which is used for plasticising in polyvinyl chloride (PVC) production [27]. Indoor applications include plastic floor coverings, additives including additives in building materials such as concrete, coatings or sealants and in condensers, wallpapers and textiles. As phthalates can be used as solubilising agents, they can also be found in paints, varnishes, adhesives, cosmetics and personal care products.

Unusually high levels of butanol and/or 2-ethylhexanol detected in the VOC analysis can be an indication of increased phthalate concentrations since they can be released from dibutyl phthalate (DBP) and di(2-ethylhexyl)phthalate (DEHP) plasticisers by means of hydrolysis.

Usually DEHP dominates indoors and has been found at concentrations around the low µg/m³ mark in the air in homes examined in a number of studies [27]. The total phthalate content usually detected in house dust can be up to 1,000 mg/kg though this increasingly includes longer-chain phthalate substitutes, e.g. diisononyl phthalate, in addition to the main component, DEHP [28].

Due to their hormonal properties and toxicity to reproduction, phthalate plasticisers in dust in nurseries can be a particular problem. The average phthalate level in such dust is more than three times higher than that of dust in homes [29]. The main sources are furnishings made of soft PVC – for instance, PVC floors, vinyl wallpaper, gym mats, plastic tablecloths or imitation leather upholstery. By contrast, there has long been a ban, for example, on the use of phthalates in children’s toys, which used to be common.

The UBA has recommended nurseries not to buy soft PVC products so as to reduce phthalate levels. Instead, nurseries and parents should opt for products that do not contain any of the plasticisers listed as being “of high concern” [30]. Retailers and distributors must provide consumers with the relevant information on request. Parents and nurseries should take advantage of this right. The UBA has drawn up a template letter for contacting retailers to find out more [31].

12.4.8 Insecticides

Although insecticides, i.e. products for insect pest control, are primarily used in agriculture and forestry, they are also used extensively indoors for the following purposes:

- to preserve wood and protect fabric (e.g. permethrin in wool carpets);
- to provide mosquito protection (electric vaporisers and sprays);
- to protect plants against pests;
- to treat parasitic skin diseases in humans and animals; and
- to eliminate pests (e.g. cockroaches, silverfish) by means of decontamination.

The following categories of substance currently play a role in indoor applications:

- Pyrethroids

  Pyrethroids serve as active ingredients in more than half of the insecticides used indoors. They go by various names, including permethrin, cypermethrin, cyfluthrin, deltamethrin, allethrin and tetramethrin. Recently, there has been much debate about their effect on human beings. The target organ for pyrethroids is the nervous system – both in insects and in warm-blooded animals. Incorrect handling can cause acute poisoning in humans but there is also some debate as to the possibility of the substances penetrating the skin. The chronic neurotoxic potential is deemed to be low. Unlike the natural product pyrethrum, pyrethroids are extremely persistent by virtue of their absorption capacity, low vapour pressure and high photostability. As a result, rooms that have been subject to pyrethroid exposure may have to be decontaminated [32].

- Phosphoric esters

  Another class of insecticides frequently found are phosphoric esters, also known as organophosphates. The main types found indoors are dichlorvos, chlorpyrifos and diazinon. They appear in various products, including many insecticides found in the home, most of which are sprayed or applied in powder form. Dichlorvos is commonly found in insect strips because its relatively high vapour pressure means that it is distributed evenly throughout the room. As a result of recent findings concerning the properties of this substance, it has been removed from the list of active ingredients permitted in plant protection products. All phosphoric esters have a high acute toxicity for warm-blooded animals. As with the pyrethroids, they attack the nervous system but their method of attack is to inhibit important enzymes that are involved in muscle control processes. They also inhibit the breakdown of a pyrethroid-cleaving enzyme, thus reinforcing the effect when phosphoric esters are used in combination with pyrethroids.

- Carbamates

  Carbamates are not very widespread in insecticide products, apart from those used in agriculture. They work in much the same way as organophosphates though their effect is not quite as strong. The main type is propoxur, which is mostly used in combination with active ingredients from the other two categories mentioned.

All insecticides can be emitted into the indoor air even quite some time after they are applied. This is due to a variety of processes such as vaporisation, desorption or attachment to dust. In practice, they can pollute the air for anything from a few days (as in the case of pyrethrum) to several weeks (dichlorvos) and months or longer (deltamethrin, permethrin).

Since many insecticides accumulate in dust, analysing dust deposits can deliver important information about the substances that have been applied indoors and the doses used. For instance, samples are taken from the air, airborne dust, house dust and surfaces (swipe samples) in order to analyse indoor pyrethroid levels.

Special polyurethane foam filter heads are suitable for air sampling. The airborne dust is separated off onto a fibreglass filter. Household dust is collected using conventional vacuum cleaners; selected sieve fractions with an upper grain size of 2 mm or 63 µm are then examined. Swipe sampling involves a defined surface being wiped with a swipe material (usually cotton) containing a solvent.

12.4.9 Pentachlorophenol (PCP) and lindane wood preservatives

With their biocidal agents, chemical wood preservatives prevent damage to wood. A distinction is made between fungicides, which prevent wood being destroyed or discoloured by fungi, and insecticides for preventing wood damage caused by insects. In terms of indoor air quality, the wood preservatives pentachlorophenol (PCP) and lindane play a particularly significant role especially due to their widespread use, toxic effects and emission patterns.

Pentachlorophenol (PCP)

Due to its wide spectrum of activity, PCP was used to combat bacteria, fungi, dry rot, algae, snails and insects. It was primarily used as a fungicide in wood preservatives but it was also used in the textile and leather industry, e.g. for marquees and tents. It was approved for large-scale indoor coating between the end of the 1960s and 1978. The substance used was almost always technical-grade PCP, contaminated with dioxins and furans. The contamination levels reached up to 0.3%.

Following a ban on indoor PCP use in 1986, production of PCPs was banned in former West Germany in 1989 [33].

Lindane

PCP's significance as a fungicide was matched by lindane's as an insecticide wood preservative. Since 1983, at least 99% of the content of lindane has been γ-hexachlorocyclohexane – an effective insecticide. Lindane used to be the most commonly used insecticide in chemical wood protection, but substitutes such as pyrethroids (see Section 12.4.8) have largely taken its place.

Lindane was usually combined with PCP (see above) or dichlorodiphenyltrichloroethane (DDT). In the German Democratic Republic, the lindane/DDT mixture was used under the name "hylotox 59" up until 1988, especially in attics and sometimes in indoor rooms. Remaining supplies of hylotox products were allowed to be used until the end of June 1991. Since September 2006, there has been an EU-wide ban on the use of lindane indoors [35].

The active ingredients in the wood preservatives are emitted from the treated materials over a period of several years. Consequently, like many of the insecticides described in Section 12.4.8, they can be detected in many indoor rooms. An effective approach is to examine the treated materials and the house dust as well as taking air samples.

Investigation

To determine the level of pollution from wood preservatives, it is first necessary to establish when and how the wood preservative in question was used and in what quantity. Based on the PCP Directive [35], the following steps are then taken:

- If the investigation reveals that no PCP wood preservatives have been used, no further action is necessary.

- If there are grounds to suspect that PCP wood preservatives have been used, the first step, notwithstanding the PCP Directive, is to calculate the quotient of the treated wood surface and the room volume. Further action is only required if the quotient is › 0.2 m^2/m^3.

- If the quotient is exceeded, an analysis of “fresh dust” or “old dust” is required. The fresh dust, which is approximately one week old, is collected using vacuum cleaners. Old dust, i.e. dust deposits that have accumulated over a long period, as can be found behind panelling, for example, is merely collected passively, e.g. with the aid of a brush and spatula.

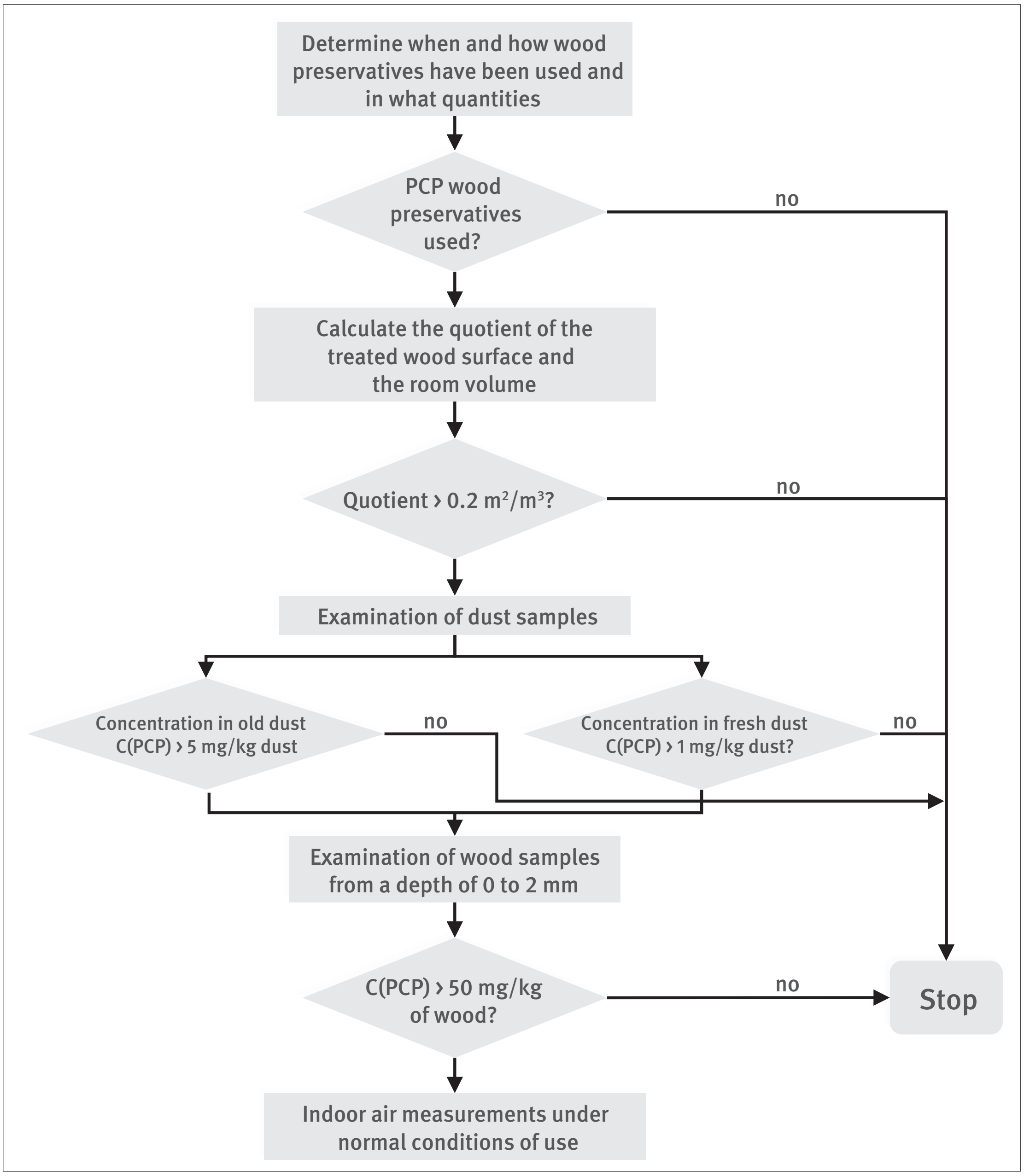
- If the concentrations are higher than 1 mg PCP/kg of fresh dust or more than 5 mg PCP/kg of old dust, the next step is to take samples from a depth of 0 to 2 mm in the wood concerned. Past wood preservation practice meant that PCPs were mainly only found at the edges of the wood.

- If the resulting value is higher than 50 mg PCP/kg of wood, the annual mean indoor air pollution level must be determined. The PCP Directive stipulates that remediation is necessary if the annual mean concentration is above 1 µg PCP/m³ of air.

The individual steps are shown in Figure 28. The same procedure can be used for lindane.

There are special cases in which people regularly spend more than eight hours a day over a prolonged period in indoor rooms whose purpose is such that exposure to dust, foodstuffs, etc. is likely (e.g. in nurseries or care homes). Where this is the case, the anticipated annual mean air pollution must be checked to determine whether it is higher than the target refurbishment value of 0.1 µg PCP/m³ of air [36]. If it is not, it is unlikely that there is any hazard to health. If the indoor air pollution levels are between 0.1 and 1.0 µg PCP/m³ of air, blood and urine tests must be conducted before making a decision [36]. The remaining procedure is described in the PCP Directive [35].

Figure 28:
Flowchart for investigation of PCP pollution from wood preservatives in indoor rooms (based on the PCP Directive [35])



12.4.10 Polychlorinated biphenyls (PCBs)

From around 1950, PCBs were often to be found as plasticisers in a number of open applications as well as in fluorescent lamp capacitors and other closed applications. Open applications using PCBs are particularly likely in buildings erected before the end of the 1970s. Based on current knowledge, open PCB applications are unlikely in buildings constructed after 1980.

In particular, open PCB applications can be contained in permanent elastic sealants in the form of

- building joints,
- expansion joints between precast concrete products,
- connecting joints (windows, door frames),
- connecting joints between glass and window frames and
- joints in sanitary facilities (rare).

In addition, PCBs can be contained in

- paints,
- adhesives,
- ceiling panels (as plasticisers or flame retardants),
- plastics and
- cable sheaths.

One of the most common applications in this area was PCB used as a plasticiser in polysulphide resin-based sealants. The products used for this purpose contained 30 to 60% chlorine by weight. They were marketed under names such as Clophen, Arodor, Kanechlor and Fenchlor.

The PCB products used in open applications up until around 1975 can still pollute indoor air today. The extent of that pollution depends on the type of PCB, the PCB content in the product concerned, the type of material contaminated, the quantity and nature of the PCP products in the room, the thermal environment in the room, the building's surface temperatures and the weather conditions. In such rooms, it is also possible for components and items that do not contain PCBs to be contaminated over time by substances that do contain PCBs and thus contribute to pollution in the indoor air themselves. A distinction must therefore be drawn between primary and secondary sources.

"Primary sources are products to which PCBs have specifically been added in order to change the product's characteristics. These products, e.g. sealants or coatings, usually contain more than 0.1% PCB by weight, and experience to date indicates that they can cause a significant increase in PCB indoor air pollution. Besides the PCB content, the ratio of contaminated surface to room volume and the type of PCB mixture have a major influence on the resultin pollution of the indoor air" [37].

According to VDI 4300, Part 2 [38], the following are possible primary sources of PCBs in indoor air:

- faulty capacitors, e.g. in lights,
- faulty transformers,
- paints and varnishes containing flame retardants,
- plasticisers used in plastics, e.g. sealants for expansion joints in precast concrete buildings,
- form oil used in concrete construction and
- dust ingress from emission sources and contaminated sites.

"Secondary sources are components (e.g. walls or ceilings) or items (e.g. furniture or furnishings such as carpets or curtains) that have usually absorbed PCBs from the polluted indoor air over a prolonged period. They can gradually release the PCBs that have accumulated on their surfaces back into the indoor air. Large-scale secondary contamination can cause indoor air PCB concentrations to remain high even after the primary sources have been completely removed" [37].

Primary sources that have not been removed to a sufficient depth and secondary sources that have not been sufficiently removed can cause heightened indoor air pollution levels years after remediation measures have been taken.

Investigation

When identifying potential PCB sources, the first step is to verify the age of the building product or electronic component suspected of containing PCBs (see Questionnaire G2 in Annex 3). It is usually possible to assume that the following points hold true:

- no open applications since 1978 (when the PCP Directive came into force),
- no PCBs in lamp capacitors or other capacitors since 1981,
- production stopped in 1983 and
- complete ban as of 1989 (PCB-Verbotsverordnung/Ordinance Banning PCBs [39]).

If this first step does not eliminate the possibility of PCB pollution in buildings, the following method should be employed:

- an inspection of the workplace should be carried out by people with relevant expertise, representative samples should be taken and any suspicious materials analysed (precise records should also be kept);
- representative indoor air samples should be taken (the sampling strategy should also be justified and documented); and
- a pollutant register should be drawn up (material samples, layer profiles, air samples) as a basis for a refurbishment

plan and for determining the pollution situation for the whole building.

The findings thus obtained must then be assessed.

Assessing PCB pollution and urgency of refurbishment measures

The health risk for users of PCB-polluted rooms rises as the PCB concentration in the indoor air increases and is influenced by the room's use and the duration of exposure.

The toxicological assessment of PCBs in the air in permanently used rooms carried out by the former Bundesgesundheitsamt (Federal Health Office) and the Arbeitsgemeinschaft der Leitenden Medizinalbeamten der Länder (hospital commission study group of governing medical officials) [37], is used to assess how urgently remediation is required:

- *"Indoor air concentrations below 300 ng PCB/m³ of air are deemed tolerable in the long term (precautionary value).*
- *Where indoor air concentrations lie between 300 and 3,000 ng PCB/m³ of air, the source of the indoor air contamination must be identified and eliminated in the medium term by means proportionate to the risk. In the interim, the rooms should be ventilated regularly, cleaned thoroughly and dust removed in an effort to reduce the PCB concentration level. The target is a value below 300 ng PCB/m³ of air (refurbishment guide value).*
- *Where the indoor air concentration level is higher than 3,000 ng PCB/m³ of air (intervention value for immediate action), acute health hazards cannot be ruled out. If such values are detected, control analyses should be carried out immediately. If they confirm the initial result, immediate action must be taken – in line with the pollution level – to reduce the PCB concentration levels in the indoor air in order to prevent health risks in the rooms concerned. Here too, the target is a value lower than 300 ng PCB/m³ of air."*

To date, it has not been possible to confirm any clear link between the PCB content of sealant materials and the PCB concentration in the indoor air. Nonetheless, approximate estimations of the PCB concentrations in indoor air are possible on the basis of data given in the literature (see Table 32) [40].

Table 32:
Guide values for indoor air PCB concentrations as a function of PCB content in sealant materials [40]

Clophen type[1]	Maximum PCB concentration in sealant (%)	Indoor air PCB concentration in µg/m³
A 40	21 maximum	Approx. 0.2 to 6.0
A 50	35 maximum	Approx. 0.2 to 2.5
A 60	47 maximum	0.55 maximum

[1] Technical-grade PCB mixture produced by Bayer

Where there are large-scale primary sources, e.g. (fire retardant) paints or ceiling panels, which often contain a highly chlorinated PCB mixture (Chlopen A 50/60), the possibility of direct cutaneous or oral absorption of contaminated particles resulting from abrasion must also be taken into account. A material's dioxin and furan content also usually increases as the PCB content increases [37].

Recommendations for building refurbishment

The aim of refurbishment measures for PCB-polluted buildings is to achieve a permanent reduction in the indoor air pollution caused by products containing PCBs. This can be done, for example, by removing, stripping or coating PCB products. However, coating primary sources has not proved successful so far.

Refurbishment of primary sources

Generally speaking, the only way to ensure permanent refurbishment of PCB-polluted rooms is to remove the primary sources, e.g. sealants, paints or ceiling panels. The methods described below have proved successful in practice but this does not mean that other procedures that yield equivalent results are not possible. However, heat-treating PCB materials, e.g. flame-cleaning, and methods that entail PCB materials being heated to › 100 °C are not suitable.

Permanent elastic sealants must only be removed using tools that generate little dust or by hand. They are then collected in containers suitable for disposal. Any backfill material should be removed. Dust should be collected where it occurs, using a suitable vacuum cleaner, e.g. of dust category H. The edges of seals should be removed, if possible, taking into account structural requirements and the depth of the PCB penetration. As with the sealants, they must be removed by hand or with the help of low-dust-emission tools and techniques with constant suction removal or in a self-contained system. If it is not possible to remove the edges, they must be completely freed of any remaining sealant and coated with a suitable diffusion-inhibiting material. Once the joint has been coated and new backfill material installed, the joint can be resealed.

Large-scale primary sources, such as paints or coatings, must be removed in a dust-free process with constant suction removal or in a self-contained system. If there is any residual contaminant, the approach to be taken is the same as that for handling secondary sources.

Removable primary sources, such as ceiling panels, must be cleaned and then removed without allowing any dust to escape, using suction if necessary.

Refurbishment of secondary sources

If the measures aimed at refurbishing primary sources do not reduce the indoor air PCB concentration to below the refurbishment guide value of 300 ng PCB/m³ of air, refurbishment of the secondary sources is also necessary.

As with primary sources, refurbishment of secondary sources should take the form of removal. If this method is not chosen, indoor air PCB pollution arising from contaminated components can also be adequately reduced by means of low-dust processes to remove the surfaces of these components, with constant suction removal or in self-contained systems, e.g. by stripping off paint layers and surface coatings. Based on current knowledge, products such as diffusion-inhibiting insulating wallpapers, emulsion paints with a high binding agent content, particularly those based on acrylate, and two-part epoxy resin and polyurethane coatings are suitable for this purpose.

Another option is to separate secondary sources from the indoor air using airtight methods, e.g. permanently sealed panelling. However, they must then be labelled and documented so that they can be disposed of separately later. This type of approach requires permanently sealed joints, including joints with ancillary building components, and must be carefully examined to determine the impact on the physics of the building and the thermal environment.

Contaminated items, such as furniture, carpets or curtains, should be cleaned thoroughly and checked for any residual contamination before being used again.

The long-term success of these measures must be documented by means of measurements.

Cleaning

Once refurbishment has been completed, the entire area that has been refurbished must be cleaned thoroughly, starting with all building component and furnishing surfaces, which must be cleaned using a suitable vacuum cleaner. This is followed by a wet clean of all surfaces that can be cleaned in this manner and any furniture that is to be reused. The cleaning must be done manually using conventional cleaning products. High pressure cleaners are not suitable as the cleaning fluid cannot be fully collected.

Monitoring

The PCB concentration in the indoor air must be measured using a strategy set out in the PCB Directive so as to document the success of the remediation process.

12.4.11 References

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