

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, wall-paper	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 (organophosphates, 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, food-stuffs	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]

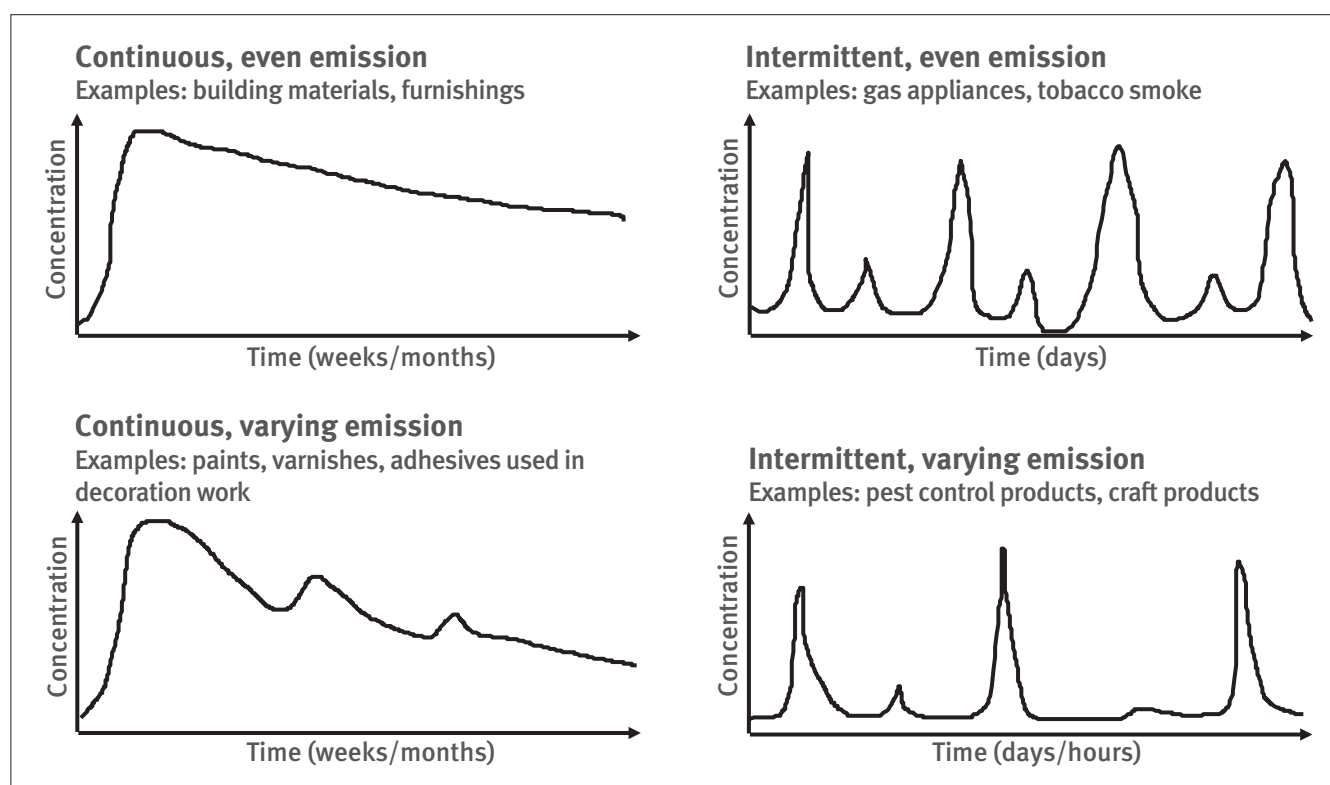
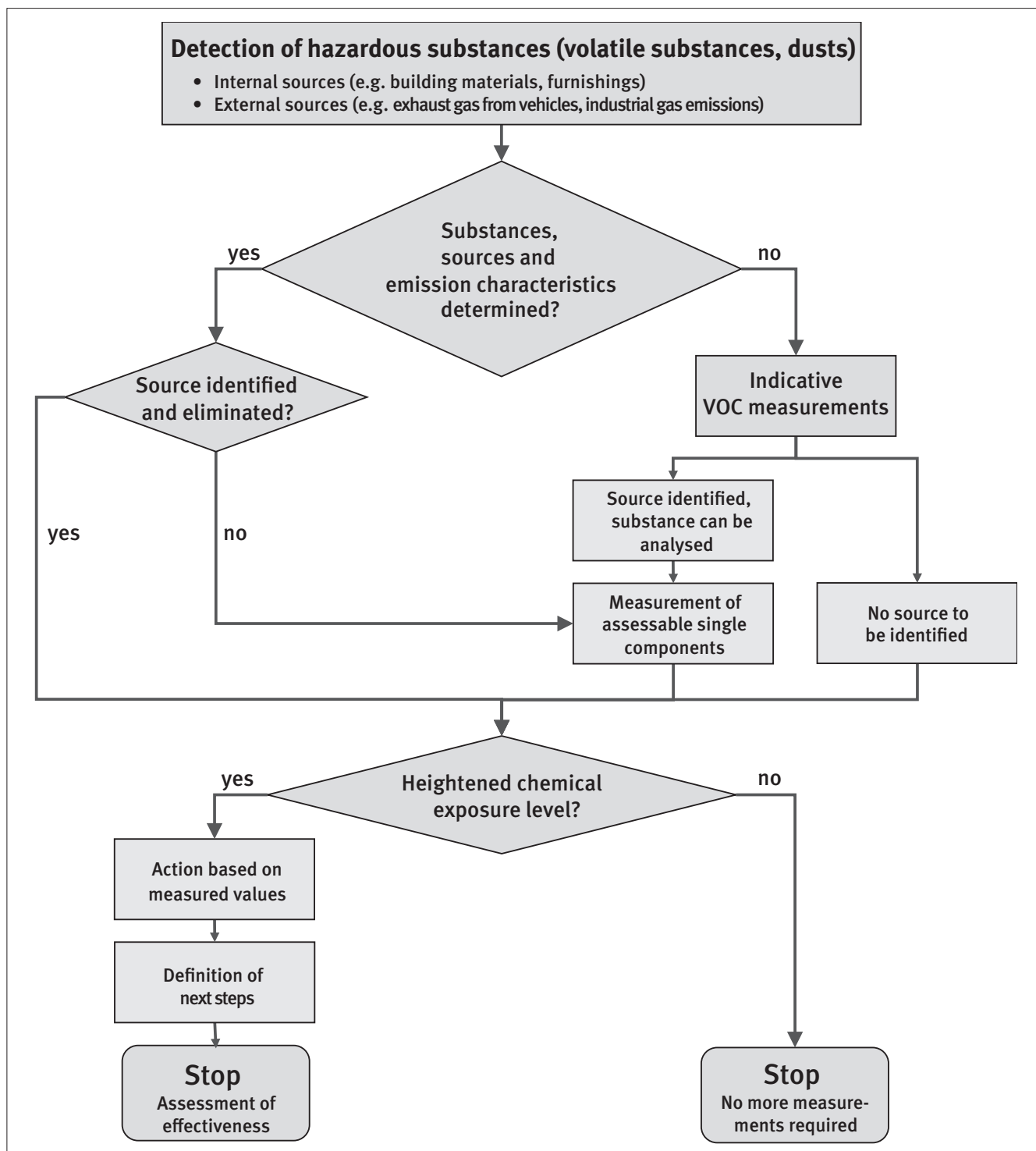


Figure 26:
Detection of hazardous substances (flowchart)



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 CO₂ levels unless there is evidence that there are CO₂ 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.

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

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.

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 hexafluoride 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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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).