Determination and evaluation of chemical contamination of indoor workplace atmospheres (excluding activities involving hazardous substances)

Contents

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1
Introduction

The health, wellbeing and performance of employees at workplaces inside buildings depend on a number of influencing factors. In addition to chemical, physical and biological influences, work-related physiological and psychological factors also play a role. Chemical factors include gases, volatile and semi-volatile organic compounds, particles, dusts and components therein, such as metals and fibres. Odours are also classified as chemical influences. Physical factors include e.g. the room and ambient surface temperatures, the relative humidity, the air flow rate, the lighting, a glare-free environment, sounds (e.g. in open-plan offices) or noises (e.g. from office equipment), electromagnetic fields, radon and ions. Viruses, bacteria, fungi, domestic animal allergens and pollen represent the principal biological factors. Furthermore, provision of ergonomic facilities, a disturbance-free work atmosphere and the social aspects of the work environment should also be taken into account in the overall evaluation. However, this chapter deals only with the assessment of possible chemical factors in indoor spaces.

The procedures described below should provide guidance for the evaluation of indoor air at workplaces, where no work involving hazardous substances is carried out. These workplaces are referred to as indoor workplaces. Therefore the Occupational Exposure Limits in accordance with the German Hazardous Substance Ordinance (*Gefahrstoffverordnung*) [1], such as OEL or MAK values, do not apply [2, 3]; instead another set of rules for assessment is utilised (see Section 6 Assessment Criteria).

The basic requirement for good indoor air quality is a commonly accepted standard of hygiene and cleanliness, such as the regular cleaning of work spaces, including work surfaces, as well as regular emptying of paper and waste bins. Ventilation of indoor spaces is considered an essential part of internal space utilisation. Users of indoor spaces can be reasonably expected to ensure that the work space is adequately ventilated. A more precise definition of what can be considered reasonable with regard to ventilation of workplaces is provided in Germany by the ASR A3.6 technical rule "*Lüftung*" ('Ventilation') [4], which has been effective since January 2012. According to its provisions, enclosed work rooms must have breathable air that is conducive to health. Where natural ventilation is relied upon, shock ventilation should be carried out at such regular intervals as is required. It is advisable to schedule shock ventilation of three to ten minutes duration (winter/summer) once every 60 minutes (office spaces) or 20 minutes (meeting rooms). Regular servicing and maintenance is a prerequisite when an air-conditioning system (HVAC) is operated.

Smoking is generally assumed to be prohibited at workplaces inside buildings or it is presumed that special smoking rooms with specific requirements are provided.

2 Definitions

2.1 Indoor spaces

According to ISO 16000-1 [5] indoor spaces include:

– private living and recreation rooms,
– spaces in public buildings (e.g. crèches, schools, youth centres, hospitals, sport halls, libraries, restaurants and function rooms),
– work spaces and workplaces in buildings that are not subject to the rules governing hazardous substances as well as
– the interior of motor vehicles and public transport.

2.2 Indoor workplaces

According to the German Workplace Ordinance [6] work rooms are defined as environments in which workplaces within buildings are permanently established. They are considered indoor workplaces as long as activities involving hazardous substances are not carried out within them. In addition to offices, internal workplaces also include sales rooms as well as workplaces in public buildings (e.g. schools, crèches, hospitals, sport halls, libraries, restaurants, theatres and cinemas) [7]. The German Hazardous Substance Ordinance (*Gefahrstoffverordnung*) [1] applies, if activities involving hazardous substances are carried out. In such cases the procedures described in the relevant sections of this collection of methods (see http://onlinelibrary.wiley.com/book/10.1002/3527600418/topics) become effective for the determination and evaluation of the exposure to hazardous substances.

There is no clear distinction between indoor private spaces and indoor workplaces. A room in a private residence can very well be considered an indoor workplace in the context of working from home or teleworking. This includes the large group of off-site employees, amongst others, who generally require a work room in their own living space.

The phases of usage of an internal space (space utilisation excluding activities involving hazardous substances) have to be differentiated between the commercial set-up, renovation and cleaning phases, in which activities involving hazardous substances are carried out. In such cases these activities are subject to the German Hazardous Substance Ordinance. These include, for example, the performance of maintenance and repair activities such as painting and floor-laying work or sanitary installation.

3
Substances in indoor air

Air pollutants in indoor spaces can be emitted from a number of sources. Table 1 provides an overview of the possible sources and the most significant substances emitted by them.

Table 1 Sources of air pollutants at indoor workplaces and the most significant substances emitted by them, based on ISO 16000, Part 1 [5]

Source/cause	Process/activity	Products used, potential sources	Emitted substances
Biological sources			
People, animals, insects, mites	Respiration		Carbon dioxide, water vapour, body odorants, food odorants
	Transpiration		Water vapour, odorants
	Digestion, excretion process Hair loss, skin peeling		e.g. Odorants, excretions, decomposition products, allergens, endotoxins
House plants	Transpiration, mould infestation		Terpenes and other odorants, water vapour, microbial volatile organic compounds
Building structure/equipment			
Structural shell and building materials	Product processing, degassing, ageing, abrasion, decomposition, mould infestation	Construction materials, building protection and anti-corrosion materials, insulation materials, sealants, paints, concrete additives	Various substances in gaseous and particulate form such as solvents, plasticisers, monomers, oligomers, timber preservatives and flame retardants, fibres (asbestos, mineral wool), radon (e.g. from granite), amines and ammonia, microbial volatile organic compounds
Air-conditioning systems	Operation and maintenance	Scrubbers, filters, insulation material, sealants, sediments, heat exchangers	Biocides, fibres, odorants
Interior fixtures, furnishings	Product processing, renovations, degassing	Furniture, floor coverings, home textiles, varnishes and coating materials, wallpaper	Monomers and oligomers from synthetic materials, resins, surface coatings, adhesives (e.g. formaldehyde), fibres, solvents, plasticisers, stabilisers, biocides (e.g. pyrethroids)

Table 1 (Continued)

Source/cause	Process/activity	Products used, potential sources	Emitted substances
Activities in indoor spaces			
Use as an office	Office operation	Office supplies, IT equipment, copiers	Organic solvents, semi-volatile organic substances (plasticisers, flame retardants), emissions from printers
Cleaning	Cleaning and care activities, pest control	Detergents and cleaning agents, polishes, disinfectants, pesticides	Water, ammonia, chlorine, organic solvents (e.g. ethanol), bactericides, insecticides and dust
Hygiene and body care products	Body care, cosmetic treatment	Cosmetics and cosmetic articles	Solvents, propellants, perfumes, inorganic and organic aerosols (colorants, pigments, lacquers, resins)
Cooking and heating processes	Combustion processes (heating, cooking), open fires (including candles)	Coal, heating oil, gas, wood, food	Gas (e.g. town gas, bottled gas, natural gas), heating oil vapour, carbon dioxide, carbon monoxide, water vapour, airborne dust, hydrocarbons and many other organic substances (products of combustion/ smouldering)
Outdoor air			
Emissions through human activities	Ventilation, infiltration and diffusion through the building's structural shell	Commercial/ industrial businesses, traffic, house fire, agriculture, outdoor fires	Inorganic and organic gases and aerosols, solvents, ammonia, odorants, PAHs
Biogenic and geogenic emissions	Ventilation, penetration of soil gas, dust dispersal	Flowering plants, soils, landfills, contaminated sites, soil re-suspensions, natural decomposition	Pollen, radon, methane etc., volatile organic compounds (e.g. hydrocarbons, organohalogen compounds), odorants, dusts
Living organisms	Excretions	Intestinal gases, odorants as well as excretion and decomposition products	Methane, ammonia and sulphur compounds and biological agents

4 Measurement strategy

Employees working in indoor spaces sometimes complain of feeling unwell, without the cause of the symptoms being clearly evident. In view of the influencing factors mentioned in the introduction, a thorough preliminary study should be carried out to establish whether chemical influences may be responsible for the apparent symptoms. Besides chemical and physical influencing factors, psychological or other factors can equally be the cause. It should be noted, that psychological factors are not addressed in this publication. Comprehensive guidance for the determination and evaluation of chemical contaminants in the air of indoor workplaces is provided by e.g. accident insurance companies [7].

Comprehensive preliminary information is required to ensure that representative results are obtained for indoor air measurements. The measurement strategy is subsequently derived from this information. Guidance on acquiring the preliminary information for work areas is provided by TRGS 402 [8]. Specific framework conditions that are relevant to the planning of measurements in indoor spaces must also be considered when measuring in indoor spaces. These are described in the ISO 16000 [9] and VDI 4300 [10] series of standards.

Ambient conditions (temperature, air pressure and relative humidity) must be recorded and documented during measurements in indoor spaces. Correcting the results to standard conditions (20 °C, 1013 hPa) is generally not necessary in Germany, as the conditions prevalent in indoor work spaces deviate only slightly from the standard conditions.

4.1 Preliminary study

An inspection of the workplace must be carried out by e.g. a health and safety expert, a measuring institute or an occupational health service as part of the preliminary study. Information can also be obtained from the appropriate authorities and from accident insurance companies. Should the preliminary study indicate that an influence from chemical factors may be present, then a suitable measurement strategy has to be selected. The aspects to be considered when drawing up a measurement strategy for indoor workplaces are described in the following sections.

In addition to a description of the work space, information gathering includes such items as the fixtures and construction materials, the environment of the object to be examined as well as the identification of possible sources of contamination. It is also important to consider contaminated sites or substances used in adjacent areas in this context. Room temperature, relative humidity and air movement are also of significance to wellbeing. Preliminary tests with continuously recording measurement devices such as flame ionisation detectors (FID) or photoionisation detectors (PID) can provide valuable indications of the presence of a source. In particular, answers to the following questions should be sought:

– Is there a suspicion of the presence of airborne pollutants in the work space or in adjacent areas?
  These include individual substances, mixtures of substances and formulations.
– Are there rooms and areas in the building in which health complaints have not arisen? Are these rooms/areas equipped in a comparative manner to the work space in question?
– Are there emission sources present in the work space?
  These include e.g. fixtures/furniture and office equipment/materials.
  Sources from the building itself: Emissions from building products (for information on which substances can be released from building materials see [11]).
  Exposed as well as hidden emission sources within the building structure must be considered.
– Which emission characteristics does the source exhibit? (For examples see Figure 1).
  Continuous sources: e.g. building materials or fixtures/furniture that release substances over a longer period
  Intermittent sources: e.g. the use of cleaning and care products or pesticides
– Has renovation and/or maintenance work been carried out recently?
  Typical continuous sources can arise from external work such as water-repellent treatment of the building as well as from internal construction such as varnishes, paints, adhesives etc. that have been introduced into the space.
– Have energy-saving measures been carried out?
  These include, in particular, thermal insulation or replacement of windows. These measures influence the air change rate and therefore the indoor climate

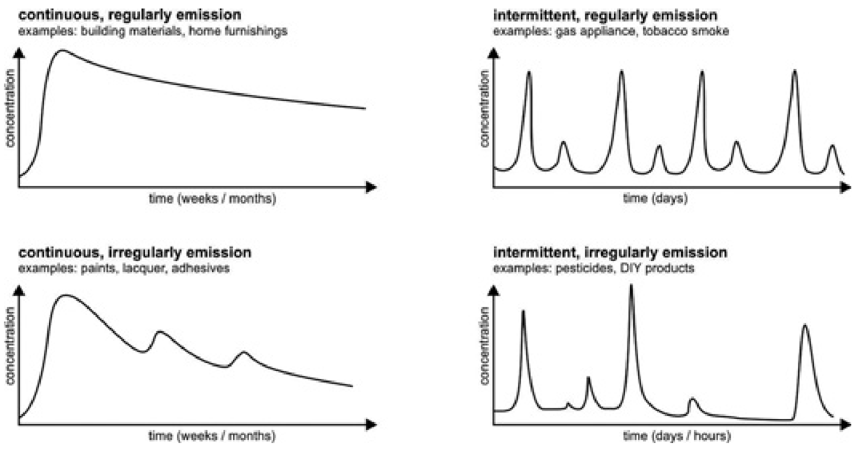

Fig. 1 Emission characteristics for several sources of air pollutants in indoor spaces [12].

– What is the history of the building and the room?
  Information on the age and usage of the building as well as any damage (e.g. fire damage) must be compiled. Knowledge on the plot of land (if there is any suspicion that the ground may be contaminated) should also be taken into consideration.
– Are there potential sources present in the immediate vicinity, particularly from commercial uses in the same building?
  These include e.g. manufacturing plants, storage areas or service providers (e.g. dry cleaning, restaurants) in the same building.
– Do emissions in the outdoor air play a role in the indoor air quality?
  This includes traffic emissions such as CO, NO_x, CO_2 and particles (soot) as well as other emitters such as industrial facilities, waste disposal plants or agricultural activities.
– How is ventilation carried out?
  Natural ventilation and technical ventilation systems must be assessed separately. In the case of air-conditioning units, for example, the air change rate or other set parameters such as relative humidity should be considered.
– What is the temporal profile of the health complaints expressed by the employees?
  For instance, do the symptoms appear daily, after work, only on specific working days, in the morning or on entering the space? Problems for measurement planning may arise, if the onset of the effect occurs a considerable length of time after exposure has taken place.

The checklist provided in the Appendix facilitates documentation of the preliminary information obtained.

4.2 Planning of the measurement

The measurement plan is drawn up on the basis of the results of the preliminary study and coordinated with the client. The measurement plan covers the following questions:

– Why should measurements be carried out (reason)?
– What should be measured (substance/substance group)?
– When should measurements be carried out (point of time)?
– Where should measurements be carried out (measurement locations)?
– How shall the measurements be carried out (measurement procedure)?

Why should the measurements be carried out?

If suspicion of airborne pollution has arisen from the previously posed questions, then it is advisable to carry out measurements. The measurements aim to determine the type, level and scope of the exposure, on the basis of which decisions can be taken on the necessity of corrective measures. If measures (e.g. renovation) are to be implemented based on the measurements, their effectiveness should be checked by subsequent testing.

What should be measured?

Answers to questions on which substances or substance groups should be analysed is derived from the research carried out in the preliminary study. If no or only insufficient information is available on the substances to be analysed, then it is advisable to carry out an overview analysis on a limited spectrum of substances, such as volatile organic compounds (VOCs) and aldehydes. Furthermore, carbon dioxide (CO_2) should also be determined in order to assess the air quality in spaces with high numbers of occupants.

When should measurements be carried out?

The timing of the measurements is dependent upon the characteristics of the source, ventilation, the activities of the employees as well as the room temperature and the relative humidity. In the case of intermittent, temporarily emitting sources, measurements to determine concentration peaks are only feasible when the source is active. The ventilation guidelines and how ventilation is carried out by the employees must also be considered when choosing the measurement time.

Where should measurements be carried out?

It is advisable to plan for one measurement point per 50 m^2 of area, and spatial conditions (e.g. window facade, doors, irregularities of the work space) must be taken into consideration. Stationary measurement should be carried out. However, the measurement sites should be selected to ensure that personal exposure can be assessed. The sampling system should be set up at a distance of at least one meter from the walls and at a height of at least one meter above floor level.

Comparative measurements in an unaffected space are recommended.

If an influence from outdoor air cannot be excluded, then the outdoor air should also be analysed.

How shall the measurements be carried out?

The analytical procedure must be suitable for the substance to be analysed and its anticipated concentrations. In the case of measurements over the course of an hour up to several hours, predominantly active sampling systems consisting of a sampling pump and an enriching sample carrier (normally a sorbent tube) are used.

In the case of longer sampling times, other sampling systems can also be suitable in some cases, e.g. diffusive samplers.

4.3
Measurement during normal usage conditions

The ASR A3.6 [4], which came into force in January 2012, provides guidelines on ventilation of indoor workplaces and indirectly contains instructions for the measurement strategy. Measurements that take the ventilation recommendations in ASR A3.6 into account are carried out after intensive ventilation (3 minutes (winter) to 10 minutes (summer)) and subsequent closure of windows and doors. Measurement is carried out after one hour. During a measurement duration of up to 1 hour the space should remain closed. In the case of long-term measurements ($t > 1$ h), measurement is carried out during normal usage while complying with the recommended room ventilation as stipulated in ASR A3.6. The measurement results obtained under these conditions are suitable for comparison with guide values [13].

Note:
If, due to the pattern of use, e.g. in schools, shorter usage cycles are the norm, then the measurement strategy should be adapted accordingly.

In spaces under investigation that are ventilated with a technical air-conditioning system (HVAC system), the AC system should be run under the usual operating conditions for at least three hours prior to sampling.

4.4
Measurement under equilibrium conditions

If it is necessary to obtain additional information on sources in the work space, then measurement should be carried out under equilibrium conditions according to the measurement strategy [9, 10]. For this purpose the space is thoroughly ventilated and subsequently kept closed for at least 8 hours (overnight as a general rule). Sampling is then carried out in the unventilated room. This measurement strategy was used to derive the DGUV reference values for indoor workplaces [14].

4.5
Measurement strategies for workplaces

It is advisable to carry out both measurements (Sections 4.3 and 4.4), one immediately after the other, at workplaces. Measurement under equilibrium conditions is carried out first, followed by measurement during normal usage. Long-term measurements must not exceed the relevant shift length for the workplaces being assessed.

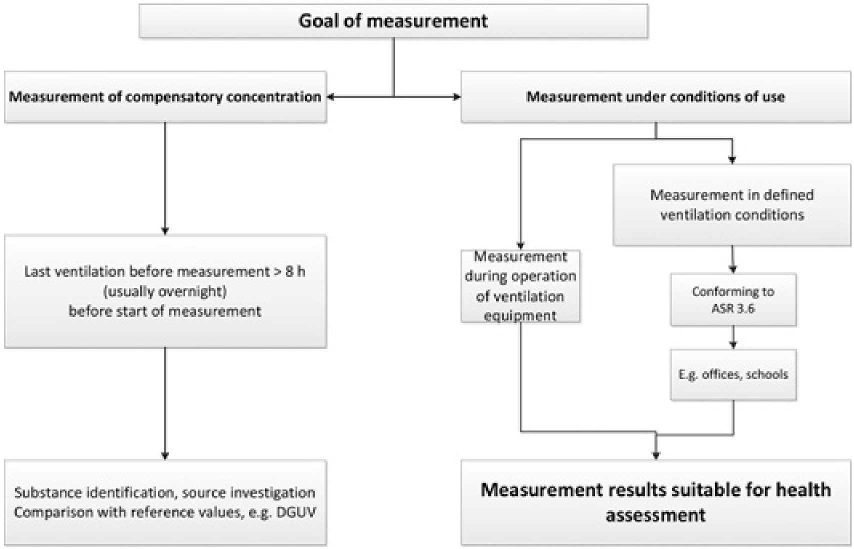

Fig. 2 Overview of the different measurement conditions.

Examples

Elimination of a source arising from the building

A building that was conventionally constructed without a cellar and built in the 1950s was extensively thermally insulated in the 1990s. Thereafter, moisture damage was discovered on the walls of the ground floor. In order to remedy the damage, damp-proofing was implemented in the foundations of the building. This involved injecting a synthetic material dissolved in hydrocarbons into the masonry. According to the information provided by the product data sheet, the solvent was supposed to evaporate within a few weeks. Nonetheless, some of the employees complained of irritation of the respiratory tract 10 weeks after the damp-proofing measures had been carried out. An overview measurement conducted in one space with a diffusion sampler gave a TVOC concentration of 55 000 µg/m³, which primarily consisted of aliphatic hydrocarbons. This result was confirmed by measurements carried out by an independent measurement institute. In order to lower the hazardous substance exposure more rapidly, an increase in the room temperature and regular shock ventilation was recommended. A control measurement carried out after 12 weeks under comparable conditions confirmed the success of the measures; a TVOC concentration of less than 1 000 µg/m³ was found.

Renovation of an office complex after improper flooring installation

Nearly all the employees working on the first floor of a new administration building complained of headaches, irritation of the eyes, mucous membranes and respiratory tract on entering the rooms. Whereas, few complaints were expressed on the ground floor. After intensive research it became apparent that two factors were significant for the planned measurement programme. On the one hand, the flooring in the rooms of the first floor was installed without recording the residual moisture in the screed due, to time constraints, in contrast to the ground floor. On the other, an adhesive was used on the first floor that tends to release volatile components in an alkaline environment.

The investigation of the air in six rooms that were representative in terms of their facilities and position in the building complex, as well as two identically equipped reference rooms on the ground floor, confirmed the initial suspicion. In the "rooms under suspicion" an average of 15 000 µg/m^3 of 2-ethyl-1-hexanol, as well as other VOCs, were measured under normal usage conditions. The concentration of VOCs was 350 µg/m^3 in the uncontaminated reference rooms. Subsequent investigation of the flooring material layers (carpet-adhesive-screed-insulation) identified these as the source of the air contamination. Based on the investigation results, the flooring, along with the adhesive and screed was removed and replaced. Control measurements on completion of the remedial work confirmed the success of the corrective measure.

5 Measurement methods

5.1 Basic findings on measurement strategies

When measuring indoor air pollution, many, in part very different, substances and substance groups must be taken into consideration. These can be in gaseous/vaporous as well as particulate form. It must be ensured when choosing a measurement method that it is suitable for indoor measurement.

When measurement methods are carried out in indoor spaces that are used as workplaces, then the requirements based on TRGS 402 [8], EN 482 [15] and the additional standards EN 838 [16], EN 1076 [17], EN 13890 [18] and EN 13936 [19] must be taken into consideration.

At workplaces where activities involving hazardous substances are carried out, a measurement method, according to EN 482, must cover at least a minimum measurement range of a tenth up to twice the limit value. This requirement should also be met by measurement methods used for indoor workplaces. In order to be able to evaluate individual substances in indoor spaces there is a preventive value (Guide Value I) and a hazard value (Guide Value II) (see Section 6). The measurement method should cover the entire range of values to be evaluated. The requirements according to EN 482 must then be adapted accordingly. The maximum permissible uncertainty of the measurement method of 30% is valid for the range of 0.5 of Guide Value I up to twice Guide Value II. A maximum permissible uncertainty of 50% applies to the concentration range of 0.1 up to 0.5 of Guide Value I. This applies to other evaluation criteria in an analogous manner.

The requirements outlined above generally do not have to be fulfilled in the case of total volatile organic compounds (TVOCs), due to the large number of individual substances that must be taken into account. The uncertainty has to be determined for the sum of all the individual substances.

The presentation of the measurement results should be adjusted to reflect the uncertainty of the method (see Table 2). The requirements set out by the German Committee on Indoor Guide Values must be taken into consideration for this purpose [20].

Table 2 Examples for the presentation of measurement results

Measured value	Result
1.22 mg/m^3	1.2 mg/m^3
0.116 mg/m^3	0.12 mg/m^3 or 120 µg/m^3
0.0122 mg/m^3	0.012 mg/m^3 or 12 µg/m^3

5.2 Gases

Carbon dioxide (CO_2)

The concentration of carbon dioxide in the air is regarded as a good indicator for the hygienic conditions of indoor air [21]. Humans are a significant source of CO_2 in indoor spaces.

In order to check whether acceptable hygienic air conditions prevail in a room with regard to the carbon dioxide concentration, continuous monitoring must be carried out with a direct-reading measurement device under normal usage conditions for a time period equal to regular working day usage (cf. Section 4.3) and with the usual occupancy of the room. According to ASR A3.6 [4] measurement is carried out at a height of 1.5 m above floor level and at a distance of at least 1 to 2 m from the walls. Generally, one sampling site is sufficient for smaller rooms (up to 50 m^2).

The boundary conditions (e.g. window openings, number of people) must be recorded in the data collection. Care should be taken during measurement to ensure that the measurement results are not influenced by the respiratory air from an adjacent person (this also applies to the person carrying out the sampling).

Suitable infrared spectrometric measurement devices or electrochemical sensors are available for measurement of CO_2. Detector tubes can also be used for screening measurements.

Nitrogen dioxide (NO_2)

As a general rule, nitrogen dioxide is not determined in indoor workplaces. If the preliminary investigation has shown that the NO_2 concentration must be determined, then this should be carried out as stipulated in ISO 16000-15 [22].

Ozone (O_3)

The introduction of ozone from the outdoor air through ventilation (e.g. open windows) is the most significant source of exposure to ozone in indoor spaces. The formation of ozone from the operation of laser printers and copiers no longer poses a problem these days.

If the preliminary investigation has shown that the ozone concentration must be determined, then direct-reading measurement methods are available (e.g. chemical sensors and UV detectors).

Radon

The majority of the dose from natural radiation sources is caused by the radioactive noble gas radon and its decomposition products; building materials can also contribute to the contamination [23]. An overview map showing the radon concentrations in soil gas is published by the Federal Office for Radiation Protection (*Bundesamt für Strahlenschutz*) [24].

A legal requirement, according to European Council Directive 2013/59/EURATOM, to determine the radiation exposure from radon and to comply with the limit values for workplaces in offices and office-like rooms will come into force in 2018 at the latest [25]. The measurement of radon is to be carried out according to ISO 11665-8 [26].

5.3 Volatile organic compounds

There are several well-described measurement methods for the determination of VOCs [27, 28, 29, 30, 31], that are suitable for measuring volatile organic compounds in indoor workplaces, when correctly implemented. The methods are based on adsorption of the volatile compounds onto an adsorbent. The compounds are subsequently desorbed thermally or with the help of a solvent. In general, gas chromatographic methods with mass spectrometric or flame ionisation detection are used for the analytical determination.

It is advisable to calibrate at least those VOCs as individual components for which indoor air guide values have been set. When the methods are used, they yield results for these calibrated individual components.

In the case of substances, for which the concentration is calculated with respect to toluene, the so-called toluene equivalent is obtained. The measure of total volatile organic compounds (TVOCs) is arrived at by addition of all these individual values.

Measurement of VOCs

Stationary sampling is carried out at a height of 1 to 1.5 m above floor level at the respiratory level of the employees and at a distance of at least 1 to 2 m from the walls. It may be necessary to take several samples at various locations in the room, depending on the size of the room. If the indoor measurement is carried out as a result of complaints about the air quality in the room, it is recommended to perform a parallel measurement in an uncontaminated reference room (e.g. a room in which no complaints have arisen) in order to find differences specific to different rooms and identify possible VOC sources. The reference room should preferably be situated close to and have a size and use comparable to the contaminated room.

In individual cases measurement of the concentration of volatile organic compounds in the outdoor air can be useful. If measurement is planned for several contaminated rooms and these measurements are to take place on different days, then conducting a reference measurement as described above is recommended for each measurement day. The outdoor air measurement is to be carried out in the vicinity of the building under investigation and if possible at the same height. A sufficient distance from the building (> 2 m) is advisable. In buildings with air-conditioning units it can be useful to carry out the outdoor air measurement as close as possible to the air inlet.

Calculation of the TVOC value

Only the signals that lie above the limit of quantification should be used for calculation of the TVOC concentration. First, the concentrations of all calibrated individual components are to be calculated (see Equation (1)). Each calibrated individual component should have a limit of quantification of less than 5 µg/m³.

$$\rho_K = \frac{m_K}{V_{air}} \tag{1}$$

where:

ρ_K is the mass concentration of calibrated individual components in the sample in µg/m³
m_K is the mass of calibrated individual components in the collected sample in ng
V_{air} is the air sample volume in litres

The second step consists of calculating all concentrations of the individual components that have not been calibrated with respect to toluene (see Equation (2)). These substances should be included in the calculations if the toluene equivalent is equal to or greater than 1 µg/m³.

$$\rho_{NK} = \frac{m_{NK}}{V_{air}} \tag{2}$$

where:

ρ_{NK} is the mass concentration of individual components that have not been calibrated in the sample in µg/m^3
m_{NK} is the mass of individual components that have not been calibrated in the collected sample in ng with respect to toluene
V_{air} is the air sample volume in litres

The TVOC value consists of the sum of the concentrations of calibrated and non-calibrated individual components in the retention range of n-hexane to n-hexadecane (see Equation (3)).

$$\rho_{TVOC} = \sum_{N}^{i}(\rho_K > LQ) + \sum_{N}^{i}(\rho_{NK} > LQ) \quad (3)$$

where:

ρ_{TVOC} is the mass concentration of TVOC in the sample in µg/m^3
LQ is the limit of quantification

The aim of the investigation of indoor air at workplaces is the evaluation of workplace situations in the context of a risk assessment. Various guide and guideline values that have to be quantified individually are available for the evaluation of indoor spaces. This can only be ensured with substance-specific calibration. It should be further noted that the TVOC guideline values are arrived at on the basis of the calculation procedure described by Equation (3).

The procedure described here for calculating the TVOC concentration differs from the procedure according to ISO 16000-6, as the simplified TVOC calculation using the toluene equivalent for all VOC, as stipulated in Note 2 of the standard, is only semi-quantitative [27].

Aldehydes

Aldehydes represent an important substance group in indoor spaces. There are also suitable and well-described measurement methods for aldehydes [32, 33, 34]. The measurement methods are based on collection and derivatisation of aldehydes, with subsequent determination by liquid chromatography. The longer-chain aldehydes (> C_6) are determined using the method described above for VOCs.

If aldehydes and VOCs are to be determined at the same workplace, it should be noted that the measurements can, under certain circumstances, influence one another. Acetonitrile is used as a solvent in the preparation of the sample carriers for aldehydes, which can result in residues remaining on the sample carrier after preparation. Under unfavourable conditions the excess acetonitrile can evaporate during collection of the aldehydes. It is important to prevent detection of this acetonitrile when sampling VOCs.

5.4
Semi-volatile organic compounds

The following substance groups should only be included in the measurement programme if there is justified suspicion of their presence:

Polycyclic aromatic hydrocarbons (PAHs)
It is advisable to use the measurement strategy and method outlined in ISO 16000-12 [35] for the determination of PAHs.

Pentachlorophenols (PCPs)/lindane
The measurement strategy and method described in VDI 4300-4 [36] and VDI 4301-2 and 3 [37, 38] are recommended for the determination of PCPs and lindane.

Polychlorinated biphenyls (PCBs)
The measurement strategy and method outlined in ISO 16000-12, -13 and -14 [36, 40, 4] are recommended for the determination of PCBs [35, 39, 40].

Plasticisers/Flame retardants
A number of substances and substance groups are employed as plasticisers and flame retardants. Measurement methods for individual substances and substance groups are available, such as flame retardants based on organophosphorus compounds (VDI 4301-5 [41]) and phthalates (VDI 4301-6 [42].

5.5
Dusts and fibres

Dusts
Sources of dust in indoor spaces include outdoor air, deposits on shoes and clothing of the space users, mechanical disturbance of settled particles (e.g. by vacuum cleaning, handling of paper), combustion processes as well as use of work equipment. The dust concentration and composition varies greatly depending on the use of the indoor spaces [43].

Particle size-dependent dust fractions are used for the evaluation of possible health risks from exposure to dust. The dust fractions “inhalable dust” (**I** fraction) and “respirable dust” (alveolar fraction, **R** fraction) commonly used in health and safety at work, do not exactly tally with those used in the area of environmental protection: PM_{10} (thoracic fine dust) and $PM_{2.5}$ fractions (fine dust) [44].

VDI 4300 Part 11[45] should be taken into consideration for the measurement of indoor dust.

Fibres

Dusts consisting of fibres should be considered separately. In indoor spaces these are predominantly textile fibres e.g. from furnishing textiles or clothing as well as natural or synthetic mineral fibres (SMF), e.g. from thermal insulation.

Furthermore, asbestos fibres may also be present in indoor spaces e.g. in building materials (asbestos cement), flooring as well as sound and thermal insulation. Release of asbestos fibres is possible, in particular during building work and renovations. In this case the specifications laid out in the asbestos guidelines [46] for evaluation of the urgency of the renovation work and TRGS 519 [47] for the protection of the employees as well as third parties, in relation to renovation work, must be considered. A measurement is required for indoor spaces after completion of the relevant measures.

The specifications according to ISO 16000-7 must be taken into account [48] for measurement planning and measurement of fibres.

5.6 Air change rate

The air change rate describes the air exchange in a room and is calculated from the volume of air entering the room with respect to the room volume. A sufficient air change rate ensures an adequate supply of fresh air in indoor spaces, removal of contaminants and protection from damage due to excessive or insufficient relative humidity. Air exchange in a room that relies only on natural ventilation occurs via windows, doors and unsealed areas in the building's structural shell. Requirements for natural as well as technical ventilation can be found in ASR A3.6 [4]. Generally, determination of the air change rate is not necessary if these requirements are fulfilled. VDI 4300 Part 7 [49] and ISO 12569 [50] can be useful in determining the air change rate if the ventilation is thought to be ineffective, e.g. in open-plan offices.

6 Assessment criteria

Reviews provide information on the procedures for assessing chemical contamination of indoor air [20, 51]. As a rule, the assessment is carried out on the basis of limit values, guide values, guideline values as well as reference values. These values differ with respect to their legal obligation and their significance to health. While limit values are legally binding, this does not apply to guide, guideline and reference values.

Limit, guide and guideline values are justified for toxicological or health reasons, whereas reference values reflect a statistical status and have no justification on health grounds. The individual evaluation criteria are described below.

6.1 Limit values

According to VDI 6022 Part 3 [52], a limit value is described as a "*legally specified assessment value to be observed; any value must be sufficiently less than the limit value*". Limit values can be classified as legislative and administrative limit values:

Legislative limit values represent the result of a parliamentary process, in which health-related and economic aspects, feasibility and effort (e.g. with respect to the limit of quantification) are weighed against one another [51]. To date, only the limit value for tetrachloroethene exists for indoor air according to the 2nd German Federal Emission Control Act (2. BImSchV)) [53].

Administrative limit values, on the one hand, oblige the authorities to adopt certain procedures, but also describe obligations of so-called affected groups such as landlords or businesses [51]. These include the technical building regulations for asbestos, PCPs or PCBs and the technical rules for hazardous substances.

6.2 Guide values

According to VDI 6022 Part 3 [52] a guide value is a "*toxicology-based value derived from suitable findings about the toxic effects and the dose-effect relationship of the substance in question*". In Germany national guide values for air in indoor spaces, in which no activities involving hazardous substances are carried out, are established on behalf of the German Committee on Indoor Guide Values (former name: Ad-hoc Working Group for Indoor Air Guide Values) [54].

In each case a Guide Value II (risk value), which states "*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*" and a Guide Value I (preventive value), up to which "*in the context of an individual substance based on current knowledge no health issues can be expected in susceptible people even after life-long exposure*" [20], are set.

The German Committee on Indoor Guide Values publishes a detailed justification on all established guide values for indoor air in the Federal Health Gazette (*Bundesgesundheitsblatt*). These can be found on the webpage of the German Committee on Indoor Guide Values at the Federal Environment Agency (*Umweltbundesamt*).

6.3 Guideline values

According to VDI 6022 Part 3 [52], a guideline value is an "*assessment value for a substance justified on health and hygiene grounds, for which the level of knowledge is not sufficient to stipulate a toxicologically justified guide value.*" To date, the Ad-hoc Working Group for Indoor Air Guide Values has derived guideline values for TVOC, carbon dioxide, fine dust ($PM_{2.5}$) and selected odorants found in indoor air [20, 43, 55, 56]. These can be found on the webpage of the German Committee on Indoor Guide Values at the Federal Environment Agency (*Umweltbundesamt*).

Furthermore, assessment values stipulated by other international committees are also included in the guideline values, e.g. the recommendations of the World Health Organisation (WHO). The WHO explicitly states that its recommendations are strictly non-binding and must be adapted according to the legal frameworks of the respective countries. In 2010, the WHO published indoor air quality guideline values for six substances or substance groups as well as unit risks values for three further substances or substance groups for the first time [57].

6.4 Reference values

A reference value is "*a value that is derived from a series of measurement values from one random sample of a sample population according to a predefined procedure*". It is a purely statistically defined value that describes the distribution of the substance in the relevant environmental medium for a defined sample population at the time of carrying out the investigation. Reference values represent the current commonly existing exposure to a substance ("*background exposure")* and offer no conclusions on health risks [20].

A reference value should "*be stated as a numerical value that is defined unambiguously by the applied statistical procedure and the sample population tested at a certain point in time"*. The (upper) reference value is the 95th percentile of the substance concentration in the investigated environmental medium for the reference population. The definition of the 95th percentile is an internationally accepted convention. It is imperative to also state the size of the random sample, from which the reference value has been derived, as additional important information. The reliability of the statistically calculated 95th percentile can be described, by way of example, by providing the 0.95 confidence interval of the 95th percentile [20].

Reference values are available amongst others for offices [14] and classrooms [58, 59]. Further information on indoor spaces used privately, publicly and commercially can be found in [60].

6.5 Evaluation of measurement results

The following applies to the evaluation of indoor air: There must be strict compliance with the limit, guide and guideline values. In the case of guide values, the preventive value (Guide Value I) should be consulted. Should these values be exceeded, then measures according to the recommendations [20] issued by the German Committee on Indoor Guide Values must be taken. The effectiveness of these measures must be checked.

If no limit, guide or guideline values are available for substances or substance groups, then existing reference values can be used if necessary. When such reference values are exceeded, the cause must be investigated. This can be achieved, for example, by comparison with concentration in the outdoor air (traffic, adjacent industry, weather conditions). Equally, recent building or maintenance work must be taken into consideration. On the basis of this information investigations must be carried out to check whether the reference values will be exceeded on a long-term basis or if a reduction of the concentration can be expected. If it is anticipated that a reference value will be exceeded for a prolonged time, then further expert advice should be sought e.g. from the competent authority or accident insurance companies.

Appendix

Example of a checklist for the preliminary study of a measurement in indoor workplaces

Company (Name, Address):	
Company section:	
Workplace:	
Operator:	
Date:	
1	**Measuring task:**
1.1	What are the reasons for carrying out the indoor measurement?
	☐ Checking of limit, guide and guideline values as part of a risk assessment
	☐ Investigation due to complaints of odours and irritation
	☐ Investigation to establish whether remedial work is necessary
	☐ Indicative measurements (screenings)

2 Details of possible complaints by the employees

2.1 How many employees have complained of health issues? Percentage %

2.2 What is the nature of the complaints?

2.3 When did the complaints first arise?

2.4 When do the symptoms occur?

2.5 Can the complaints be traced back to one of the following causes?

- ☐ high workload of the employees
- ☐ unsatisfactory working atmosphere
- ☐ changes to the organisation structure
- ☐ insufficient lighting
- ☐ disturbing noises
- ☐ unsatisfactory climatic conditions
- ☐ unpleasant odours from outdoors
- ☐ unpleasant indoor odours
- ☐ renovation work
- ☐ other, please provide details:

3 General building data

3.1 When was the building constructed?

4 Details of the building location

4.1 Where is the building situated?

- ☐ in the city centre
- ☐ in an industrial area or business park
- ☐ in a mixed use area
- ☐ in a residential area
- ☐ adjacent to a busy street/motorway/railway line
- ☐ other location, please provide details:

Please add a context map or a sketch, if possible!

4.2 Is there industrial plant in the immediate vicinity of the building?

☐ No ☐ Yes, please provide details:

4.3 Are there known vent stacks/outdoor sources of contamination in the area surrounding the building?

☐ No ☐ Yes, please provide details:

5 Details of the work areas or parts of the building, in which employee complaints have been received

5.1 How are the work areas/parts of the building used?

Work area/part of the building	Size of the rooms	Type of use (e.g. monitor workstation)	Remarks

5.2 Did the work areas/surrounding parts of the building have different uses in the past?

☐ No ☐ Yes

Please list type and time period of the former usage in the following table.

Work area/part of the building	Type of usage	Time period	Remarks

5.3 Did building renovations, extensions or alterations take place?

☐ No ☐ Yes

Please list the type and extent of the changes in the following table.

Time period	Type and extent of the changes to the building (e.g. painting, laying flooring, additional windows, thermal insulation, sealing, asbestos removal)

6	**Details of the building ventilation**
6.1	Are the rooms ventilated naturally (e.g. via windows)?
	☐ No ☐ Yes
	Remarks:
6.2	State the type of window.
	☐ Timber
	☐ Metal
	☐ Synthetic material
	☐ other, please provide details:
6.3	Are the rooms ventilated by technical means?
	☐ No ☐ Only technical air intake and exhaust
	☐ Air-conditioning system
	☐ With humidity regulation
	Remarks:
6.4	If applicable: Is the ventilation/air-conditioning system checked regularly?
	☐ No ☐ Yes, by
	☐ Documentation attached
7	**What type of heating system is there?**
	☐ Gas
	☐ Oil
	☐ other, please provide details:

8	**Construction type and building materials of the ceilings in the affected work rooms**
8.1	Construction
	☐ Concrete
	☐ Screed
	☐ Timber
	☐ Fibreboard
	☐ other, please provide details
8.2	State the type of lower ceiling construction.
	☐ Suspended ceiling
	☐ Acoustic ceiling
	☐ Ventilated ceiling
	☐ Plastered ceiling
	☐ Other construction, please provide details:
8.3	Please describe the ceiling finish in the affected work rooms.
	☐ Wallpaper made out of paper
	☐ Wallpaper made out of synthetic material
	☐ Painted plaster
	☐ Coated ceiling tiles
	☐ Timber cladding
	☐ Other finish, please provide details:
8.4	State the type of ceiling surface treatment.
	☐ No surface treatment
	☐ Painted
	☐ Other treatment, please provide details:

9 Construction and building materials of the walls in the affected work rooms

In the case of different construction types and materials, the following is to be completed for each work room.

9.1 Construction

☐ Prefabricated construction (e.g. timber frame construction)

☐ Pre-cast concrete slabs with permanently elastic jointing material

☐ Masonry construction using

- ☐ Lime-sand bricks
- ☐ Bricks
- ☐ Breeze blocks
- ☐ Aerated concrete blocks
- ☐ other, please provide details:

☐ Timber construction

☐ Pre-fabricated units

☐ other construction, please provide details:

9.2 Are the external walls thermally insulated?

☐ No ☐ Yes, please provide details e.g. inner wall or cavity wall insulation; insulation material

9.3 State the type of interior and partition walls.

☐ Brick wall

☐ Stud wall

☐ other, please provide details:

9.4 Please describe the wall finish in the affected work rooms.

☐ Wallpaper made out of paper

☐ Wallpaper made out of synthetic material

☐ Painted plaster

☐ Coated wall panels

☐ Timber cladding

☐ Other finish, please provide details:

9.5 State the type of wall surface treatment.

☐ No surface treatment

☐ Painted

☐ Other treatment, please provide details:

10 Floors

10.1 Please describe the flooring in the affected work rooms.

☐ Parquet floor, please provide details of the type of parquet floor:

Primer coat: trade name

Adhesive: trade name

Sealant: trade name

☐ Floorboards, please provide details:

Primer coat: trade name

Adhesive: trade name

Sealant: trade name

☐ Carpet, please provide details of material:

glued down: ☐ No ☐ Yes, with adhesive

Age: Years

☐ Synthetic flooring, please provide details of material:

glued down: ☐ No ☐ Yes, with adhesive

Age: Years

☐ Floor tiles, please provide details of material:

glued down: ☐ No ☐ Yes, with adhesive

Age: Years

☐ Other flooring, please provide details:

10.2 Has the flooring been certified for quality?

☐ No ☐ Yes, please provide details:

10.3 Provide the GISCODE (classification system of the German Builders' Trade Associations) of the flooring material.

10.4 Safety data sheets of the flooring material.

☐ See attached

☐ To be provided

☐ Not available

11 Are sealing joints visible in the affected work rooms?

☐ No ☐ Yes

12 Furniture

12.1 How old is the furniture in the affected work rooms on average?

Years

12.2 Has new furniture been installed in the affected work rooms within the last year?

☐ No ☐ Yes, please provide details: installed months ago

12.3 What material is the furniture made of?

☐ Solid wood

☐ Wood-based materials

- ☐ Chipboard
- ☐ Blockboard
- ☐ Veneer board
- ☐ Fibreboard

☐ Metal

☐ Plastic

☐ Combination of materials, please provide details:

☐ Other, please provide details:

12.4 Does the furniture have any quality labeling?

☐ Furniture quality passport (contains manufacturing details, care and maintenance instructions)

☐ "Blue Angel" eco-label

☐ RAL quality mark

☐ Other quality labelling, please provide details:

☐ No quality labelling

13 Soft furnishings

13.1 Is there upholstered furniture present in the affected work rooms?

☐ No ☐ Yes, please provide details of number and type:

13.2 Are there curtains or net curtains present in the affected work rooms?

☐ No ☐ Yes, please provide details of number and type:

13.3 Are there any objects with extensive textile surfaces present in the affected work rooms?

☐ No ☐ Yes, please provide details of number and type:

14 **Details of the technical facilities of the work areas**

14.1 Are there devices, machines or other equipment (e.g. printers, copiers) in the work area, which produce disruptive emissions (e.g. noise, odours)?

☐ No ☐ Yes, please provide details of number and type:

14.2 Is this office equipment regularly maintained and checked?

☐ No ☐ Yes, by

☐ Documentation attached

15 **Are there plants in the work room?**

☐ No ☐ Yes, please provide details of the plant species:

Number: Cultivation: e.g. soil, hydroculture

16 **Cleaning and care of the affected rooms**

16.1 How frequently are the rooms cleaned?

☐ Daily

☐ Weekly

☐ Monthly

☐ Yearly

☐ Other time interval, please provide details:

16.2 What products are used to clean the rooms?

16.3 Were or are any other products used in the rooms?

☐ No ☐ Yes

☐ Disinfectants

☐ Air freshener

☐ Insecticides, fungicides, pesticides

☐ other, please provide details:

17 **Are any previous air measurement results from the rooms available?**

☐ No ☐ Yes, please provide details:

☐ Formaldehyde: µg/m^3

☐ VOCs: µg/m^3

☐ Other hazardous substances, please provide details of any hazardous substances and the measurement results:

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Authors: *Dietmar Breuer, Helmut Sagunski, Michael Ball, Ralph Hebisch, Nadja von Hahn, Thomas Lahrz, Gerda Nitz, Karl-Heinz Pannwitz, Wolfgang Rosenberger*