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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)<br>15 (8 h) | 6 (0.5 h)<br>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)<br>0.06 (7-day value) | - | 1998 |
| Styrene | 0.3 | 0.030 | 1998 |
| Bicyclic terpenes (guiding substance: $\alpha$-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<br>• Unit risk[1)] of leukaemia per 1 µg/m³ air concentration is $6 \cdot 10^{-6}$<br>• 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/m³, respectively |
| Formaldehyde | 0.1 mg/m³ (30-minute average) |
| Carbon monoxide | • 15 minutes – 100 mg/m³<br>• 1 hour – 35 mg/m³<br>• 8 hours – 10 mg/m³<br>• 24 hours – 7 mg/m³ |
| Naphthalene | 0.01 mg/m³ (annual average) |
| Polycyclic aromatic hydrocarbons | • No threshold can be determined and all indoor exposures are considered relevant to health<br>• Unit risk for lung cancer for PAH mixtures is estimated to be $8.7 \cdot 10^{-5}$ per ng/m³ of B[a]P<br>• 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/m³, 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/m³ for lifelong non-smokers and $15 \cdot 10^{-5}$ per Bq/m³ for current smokers (15 to 24 cigarettes per day); among ex-smokers, the risk is intermediate, depending on time since smoking cessation<br>• The radon concentrations associated with an excess lifetime risk of 1/100 and 1/1,000 are 67 and 6.7 Bq/m³ for current smokers and 1670 and 167 Bq/m³ for lifelong non-smokers, respectively |
| Nitrogen dioxide | • 200 µg/m³ (1-hour average)<br>• 40 µg/m³ (annual average) |
| Trichloroethylene | • Unit risk estimate of $4.37 \cdot 10^{-7}$ per µg/m³<br>• 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/m³, respectively |
| Tetrachloroethylene | • 0.25 mg/m³ (annual average) |

1) Unit risk: Risk of developing cancer as a result of lifelong exposure to a concentration of 1 µg/m³
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/m³ |
|---|---|
| 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/m³ |
|---|---|
| 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.

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