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The German approach to regulate indoor air contaminants

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ABSTRACT

Indoor air quality (IAQ) and exposure to indoor chemicals are widely discussed in terms of personal discomfort and health risks. In contrast to ambient air and working environments, legally binding regulations are only partially established for indoor contaminants, and other available European guidelines are limited. To correct these deficits, the German Committee on Indoor Guide Values (AIR), formerly known as the Ad hoc Working Group (Ad hoc AG), performed health assessments of indoor air contaminants. The main tasks were to develop toxicologically based indoor air guide values, health-based guideline values, and reference values largely based on the 95th percentile of the concentrations found in a reference population.

Here, we provide a comprehensive overview of the indoor air values set in Germany and discuss the basis of their derivation. This overview includes a description of legally binding standards, indoor air guide values for 38 substances or groups, and guidelines for TVOC (total volatile organic compounds), particulate matter, and carbon dioxide as well as risk-related guidelines for carcinogenic substances.

1. Introduction

Indoor air quality (IAQ) is one of the major sources of concern in environmental health protection and toxicology. Exposure to indoor chemicals is often discussed in terms of personal discomfort and health risks to the occupants. Overall, it must be guaranteed that indoor air does not contain contaminants at harmful concentrations and will be of a satisfactory quality. A lack of an EU-wide legally binding framework that regulates IAQ in non-working environments is likely to blame for this problem. Nevertheless, for certain substances residential regulations are available in some EU member states (summarized in Kunkel et al., 2015) as well as in Canada (GC, 2018). For example, Health Canada has developed for 8 chemical substances Residential Indoor Air Quality Guidelines (acetaldehyde, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, ozone, radon, and toluene) associated with acceptable levels of risk after short-term or long-term exposure (GC, 2018). For benzene and particulate matter ($PM_{2.5}$) the indoor concentrations should be as low as possible. Again, Indoor Air Quality Guideline levels were developed for 11 indoor contaminants (formaldehyde, carbon monoxide, benzene, naphthalene, trichloroethylene, tetrachloroethylene, nitrogen dioxide, acrolein, acetaldehyde, ethylbenzene, and toluene) in France (ANSES, 2018). Moreover, different organizations derived toxicologically based values (WHO, 2010; OEHHA 2016; US-EPA, 2017; ATSDR, 2017). Additionally, legal requirements for indoor contaminants in occupational environments were established e.g. in Germany on the basis of the Safety and Health at Work Act. Overall, this situation is somewhat surprising and unacceptable because people spend significantly more time in indoor environments and can also be partially exposed to substances at higher concentrations than when outdoors. Notably, vulnerable subsets of the population, such as infants, children, and persons suffering from respiratory or cardiovascular diseases have to be considered (SCHER, 2007). To the best of our knowledge, a law that regulates all aspects of indoor air quality, including the acceptable limits of a wide range of contaminants, is not currently available in Europe.

To address this unsatisfactory situation, the German Conference of the Health Ministers of the Federal States and the Indoor Air Hygiene Committee by the German Environment Agency established a joint working group of experts from health authorities and scientific institutions in 1994. The major assignment of the working group was to

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develop a harmonized procedure for the risk assessment of indoor air contaminants and create toxicologically based indoor air guide values and exposure limits. Initially, this working group was considered temporary and thus called the Ad hoc Working Group. An overview of the previous work was published in 2009 (Heinzow and Sagunski, 2009). After more than twenty years of successful work, the tasks of the working group were proven to be permanently necessary. Therefore, the Ad hoc Working Group was renamed as the German Committee on Indoor Guide Values (Ausschuss für Innenraumrichtwerte, AIR) in 2015.

Initially a definition for the term "indoor environment" was established in accordance to the Council of Environmental Advisors (SRU, 1987; Ad hoc AG, 2007a). Indoor environments have been defined as follows:

- private living rooms, bedrooms, bathrooms, kitchens, hobby and sport rooms and adjoining rooms,
- public buildings (e.g., daycare centers, schools, youth centers, hospitals, sports clubs, libraries, restaurants, lounges, and public event venues),
- workplaces in buildings where no hazardous substances are used and occupational exposure limits for hazardous substances do not apply,
- passenger compartments in motor vehicles and all forms of public transportation.

Next, a legal basis for health assessments was investigated. As an essential skeleton law, the Building Ordinance of the federal states emerged as a suitable foundation for the establishment of acceptable indoor air guide values. According to § 3 of the Building Ordinance, a building must be constructed and maintained without posing a potential health hazard to the inhabitants. From a toxicological point of view, the concentration of an indoor air substance that can potentially injure people can be referred to as the adverse effect concentration for that substance.

The Working Group derived, when possible, concentration limits for substances in indoor air based on specific risk assessments. The procedures for deriving these values are described in detail in a subsequent chapter. Additionally, the legal requirements in Germany and reference values for contaminants are discussed in this manuscript. According to VDI 6022 (VDI, 2011), the Committee used the following definitions:

- Limit values are legally binding values that are mandatory.
- Guide values (GV) are toxicology-based values that consider the toxic effects and dose-effect relationship of a chemical that may be applied in the context of a legal frame like e. g. the Building Ordinance.
- Guidelines (GL) are health-based values used when the available toxicological information is not sufficient to derive a GV.
- Reference values are statistically derived values based on the concentrations observed in a reference population (i.e., the 95th percentile).

2. Assessment approaches for indoor air contaminants

2.1. Legally binding standards

Legally, mandatory limits on the concentrations of substances in indoor air are still lacking in Europe with the exception of radon. According to the EU regulation given in 2014 (EC, 2014) the member states of the European Union shall ensure that reference levels are established for emergency and existing exposure situations and are required till 2018 to adopt national reference levels for radon concentrations in indoor air. The annual average activity concentration for radon shall not be higher than 300 Bq/m^3. Unfortunately, the German parliament decided in June 2017 to allow higher levels of radon in indoor air if measures have been examined to be inappropriate (StrSchG, 2017).

In Germany, only 4 indoor contaminants, such as PCBs, PCP, asbestos fibers and tetrachloroethene are legally regulated. In general, building regulations are under the authority of individual German federal states; thus, technical building regulations, which may differ from state to state, are provided by the Supreme Building Authorities and are a legal aspect of Building Codes (DiBT, 2015). PCB, PCP, and asbestos fibers are regulated by this system:

- A guide values-like approach was introduced for polychlorinated biphenyls (PCB) (BMHBT, 2018). Here, PCB refer to the sum of the indicator PCB congeners 28, 52, 101, 138, 153, and 180 (according to Ballschmiter and Zell, 1980) multiplied by a factor of 5. Indoor air levels below 300 ng PCB/m^3 are tolerable over a long-time period (precautionary value). Sources of indoor air concentration between 300 and 3000 ng/m^3 PCBs should be detected and eliminated. In this case a concentration level < 300 ng/m^3 is recommended to be aimed at. An indoor air concentration above 3000 ng/m^3 that is verified in a control measurement following regular ventilation requires immediate measures to reduce exposure and prevent health effects using appropriate redevelopment measures. This response aims to restore PCB levels to < 300 ng/m^3 if achievable.

For the assessment of dioxin-like PCB (dl-PCB), the Working Group used a toxicity equivalence factor approach resulting to a criterion of 5 pg dl-PCB-TEQ/m^3 indoor air (Ad hoc AG, 2007b; DiBT, 2015). Regarding sealants as the main source of lower chlorinated PCB, a PCB concentration below 3000 ng/m^3 corresponds to a PCB-TEQ concentration of less than 5 pg/m^3. For higher chlorinated PCB, which usually originate from wall or suspended ceiling boards was shown, that a PCB-TEQ of 5 pg is not exceeded by a total PCB concentration below 1000 ng/m^3. Because dl-PCB measurements are expensive and laborious the committee concluded that the determination of congener PCB 118 is sufficient in addition to the indicator congeners. A PCB 118 concentration below 10 ng/m^3 corresponds to a dl-PCBs concentration well below the 5 pg TEQ/m^3 limit, independent of the PCB source. Therefore, PCB 118 in indoor air can be used as a reliable substitute for the PCB-TEQ assessment.

- If the use of wood preservatives is likely and dust or material samples show a pentachlorophenol (PCP) contamination, indoor air samples must be collected (BMHBT, 2018). A guide value of 1 µg PCP/m^3 was established based on the liver effects observed in workers (Ad hoc AG, 1997). In residences and public buildings such as kindergarten or schools, a value of 0.1 µg PCP/m^3 is mandatory if PCP levels were detected in the serum at > 70 µg/l or in the urine at > 40 µg/l.
- Buildings containing friable asbestos with a bulk density < 1000 kg/m^3 must be assessed for the urgency of redevelopment measures using a standardized questionnaire (BMHBT, 2018). The asbestos fibers (length L > 5 µm, diameter D < 3 µm, and aspect ratio L/D > 3/1) may not exceed 500 fibers/m^3 and an upper boundary of a 1000 fibers/m^3 confidence interval.

Additionally, a legal limit was set for tetrachloroethene by the Second Ordinance for the Implementation of the Federal Immission Control Act (BImSchV, 1990). For indoor environments near extraction facilities, surface treatment facilities, dry cleaning facilities or textile finishing plants, the mean concentration of tetrachloroethene over 7 consecutive days cannot exceed 0.1 mg/m^3.

2.2. Values recommended by the German Committee on Indoor Guide Values (AIR)

2.2.1. Toxicologically based indoor air guide values

Indoor air guide values (GV) for a selected substance are based on its toxic effects and dose-response relationships of relevant endpoints. Moreover, specific extrapolation (unsafety) factors are implemented in the evaluation process. The individual steps in the derivation of guide

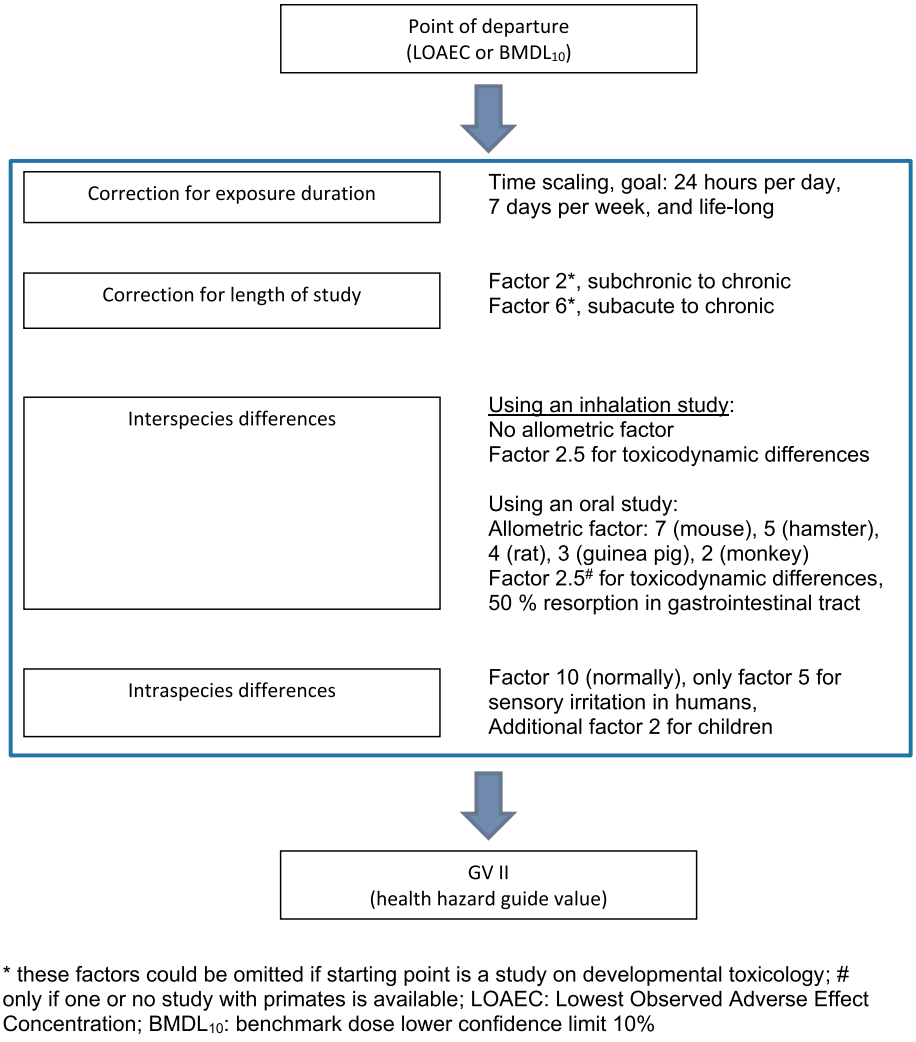

Fig. 1. Assessment of guide values II (GV II) (Ad hoc AG, 2012a.) * these factors could be omitted if starting point is a study on developmental toxicology; # only if one or no study with primates is available; LOAEC: Lowest Observed Adverse Effect Concentration; $BMDL_{10}$: benchmark dose lower confidence limit 10%.

values II (GV II) are provided in Fig. 1. As a rule, the lowest-observed-adverse- effect-concentration (LOAEC) or a benchmark dose lower confidence limit 10% (BMDL10) for the most sensitive toxicological endpoint are used as a point of departure (POD). The key concepts of the benchmark dose approach are published by EFSA in 2017 (EFSA, 2017). Next, various assessment and extrapolation factors are applied based on the recommendations of World Health Organization and the European Chemical Agency (WHO, 2010; ECHA, 2012). In addition to the commonly applied assessment factors, the AIR uses a factor of 2 to protect the especially sensitive groups of children and newborns. This factor is necessary because the breathing rates per kg of body weight of children and newborns are about twice as high in children and up to three times as high in newborns compared to adults. Finally, GV I is derived from the no-observed-adverse-effect-concentration (NOAEC). If a reliable NOAEC was not available an additional factor (usually 3–10) on the GV II is used.

According to the aforementioned requirements, two indoor air guide values are typically defined if valid data are available:

- the so-called precautionary guide value (GV I) is the maximum concentration level of a single substance in indoor air that shows no adverse health effects even in sensitive subjects or after life-long exposure. Sensibilization and allergic reactions are in general not considered.
- the so-called health hazard guide value (GV II) is the minimum concentration of a substance in indoor air that will likely cause adverse health effects based on available toxicological or epidemiological data. Concentrations exceeding the GV II are likely to threaten an individual's health, especially of sensitive people. Thus, there is an urgent need for action (for more details see chapter 3).
- Indoor air concentrations between GV I and GV II represent an undesired contamination of indoor air that requires precautionary action based on the specific concentration present.

Table 1 provides an overview of all indoor air guide values issued.

2.2.2. *Non-toxicologically based guidelines (GL)*

If the toxicological database is not sufficient to derive a guide value, the committee derives guidelines that might be used as indicators for indoor air quality.

2.2.2.1. TVOC guidelines. Total volatile organic compounds (TVOC) include the sum of the concentrations of all identified and non-identified VOC using the response factor of toluene and eluted between n-hexane and n-hexadecane (ISO, 2011; JRC, 1997). The analytical procedure for the determination of TVOC values consist normally on the use of a sorbent like Tenax TA for sampling and thermal elution to transfer the collected VOCs from the sorbent to a non-polar GC column for analysis (Molhave et al., 1997). The main use for this calculated TVOC value is to help estimate the complex

Table 1
Guide values (GV I and GV II) for indoor air quality.

Substances	GV II (mg/m³)	GV I (mg/m³)	Reference
Nitrogen dioxide (NO_2)	0.25 (1 h)	0.08 (1 h)	submitted
Acetophenone	2.0	0.2	submitted
2-Phenoxyethanol	0.1	0.03	AIR (2018)
Tetrachloroethylene	1.0	0.1	AIR (2017b)
1,2-Propanediol (propylene glycol)	0.6	0.06	AIR (2017a)
Formaldehyde	–	0.1	AIR (2016b)
Toluene	3.0	0.3	AIR (2016a)
Xylenes (sum) (dimethylbenzene)	0.8	0.1	AIR (2015b)
Butanone oxime	0.06	0.02	Ad hoc AG (2015b)
2-Chloropropane	8.0	0.8	2015[c]
Ethyl acetate	6.0	0.6	Ad hoc AG (2014e)
1-Methyl-2-pyrrolidone	1.0	0.1	Ad hoc AG (2014d)
n-Butanol	2.0	0.7	Ad hoc AG (2014c)
2-Ethyl-1-hexanol	1.0[a]	0.1[a]	Ad hoc AG (2013e)
Glycol ether and their acetates*			Ad hoc AG (2013d)
Ethylene glycol monomethyl ether (EGME)	0.2	0.02	
Diethylene glycol monomethyl ether (DEGME)	6.0[a]	2.0	
Diethylene glycol dimethyl ether (DEGDME)	0.3	0.03	
Ethylene glycol monoethyl ether (EGEE)	1.0	0.1	
Ethylene glycol monoethyl ether acetate(EGEEA)	2.0	0.2	
Diethylene glycol monoethyl ether (DEGEE)	2.0[a]	0.7[a]	
Ethylene glycol monobutyl ether (EGBE)	1.0	0.1	
Ethylene glycol monobutyl ether acetate (EGBEA)	2.0[a]	0.2[a]	
Diethylene glycol monobutyl ether (DEGBE)	1.0[a]	0.4[a]	
Ethylene glycol monohexyl ether (EGHE)	1.0	0.1	
Propylene glycol monomethyl ether (2PG1ME)	10	1.0	
Dipropylene glycol monomethyl ether (DPG1ME)	7.0[a]	2.0[a]	
Propylene glycol monoethyl ether (2PG1EE)	3.0	0.3	
Propylene glycol mono-tertiary-butyl ether (2PG1tertBE)	3.0	0.3	
Naphthalene	0.03[b]	0.01[b]	Ad hoc AG (2013c)
Acetaldehyde	1.0	0.1	Ad hoc AG (2013b)
Methyl isobutyl ketone (MTBE)	1.0	0.1	Ad hoc AG (2013a)
Ethylbenzene	2.0	0.2	Ad hoc AG (2012d)
Alkylbenzenes, C_9-C_{15} (trimethylbenzenes)	1.0	0.1	Ad hoc AG (2012c)
Alkylbenzenes, C_9-C_{15} (isopropylbenzenes)	1.0	0.1	Ad hoc AG (2012c)
Cresols	0.05	0.005	Ad hoc AG (2012b)
Phenol	0.2	0.02	Ad hoc AG (2011c)
2-Furaldehyde	0.1	0.01	Ad hoc AG (2011b)
Cyclic volatile methyl siloxanes (D3-D6) (Sum)	4.0	0.4	Ad hoc AG (2011a)
Benzaldehyde	0.2	0.02	Ad hoc AG (2010c)
Benzyl alcohol	4.0	0.4	Ad hoc AG (2010b)
Monocyclic monoterpenes (lead structure: limonene)	10	1.0	Ad hoc AG (2010a)
Aldehydes, C_4 - C_{11} (saturated acyclic, aliphatic)	2.0	0.1	Ad hoc AG (2009)
Dioxin-like PCB	[c]	[c]	Ad hoc AG 2007b
Alkanes/Isoalkanes, C_9-C_{14} (limited aromatic constituents)	2.0	0.2	Sagunski and Mangelsdorf (2005)
Bicyclic terpenes (α-pinene)	2.0	0.2	Sagunski and Heinzow (2003)
Tris(2-chloroethyl) phosphate (TCEP)	0.05	0.005	Sagunski and Rosskamp (2002)
Diisocyanates	[d]	[d]	Wolf and Stirn (2000)
Mercury (Hg-vapor)	0.00035	0.000035	Link (1999)
Styrene	0.3	0.03	Sagunski (1998)
Dichloromethane	2.0 (24 h)	0.2	Witten et al. (1997)
Pentachlorophenol	0.001	0.0001	Ad hoc AG (1997)

* If the toxicological data were limited, GV was assessed for a glycol ether and the measured concentrations were compared with the "default" guide value. Based on statistical evaluations, a "default" GV II of 0.05 ml/m³ and a "default" GV I of 0.005 ml/m³ were established. If different glycol ethers were detected, then dose additivity was assumed. Therefore, for a single substance, I, the ratio, R, was calculated using the equation $R_I = C_I/GV\ II$, where C_I is the concentration in air and GW II is the guide value. For glycol ethers without a GV, the aforementioned "default" values were used.

[a] Temporary guide value.

[b] These values should be temporarily used for the sums of bi- and tricyclic aromatic hydrocarbons.

[c] See the description in the text.

[d] The GV II for diisocyanate (DI) was not suggested because indoor air levels are only high immediately after the processing of DI-containing lacquer and glue and rapidly decline after the termination of product hardening. An exposure for longer time periods is not probable. Nevertheless, ventilation is essential during application.

[e] Only a data sheet available.

composition of chemicals that determine indoor air quality (JRC, 1997). Therefore, TVOC may be used as an indicator for the chemical load in the indoor environment, in the search for specific contamination sources, and in cases of insufficient ventilation. Nevertheless, some limitations must be considered. In terms of low level VOC exposure, only a few controlled chamber studies using single substances or defined mixtures have been published. These studies found a higher probability of sensory effects, odour perceptions and comfort problems (summarized by JRC, 1997; Andersson et al., 1997; Salthammer, 2011). On the other hand, summing only the mass of different volatile substances may not always result in an accurate description of the overall biological effects. Therefore, if specific substances are found in unexpectedly high concentrations, a further risk assessment of these chemicals is essential. Moreover, an additional assessment is required

for substances with a low odour perception threshold.

Based on the aforementioned information, 5 concentration levels with specific recommendations were defined by the committee (Ad hoc AG, 2007a):

- Level 1, TVOC < 0.3 mg/m^3: No hygienic consequences if no other guide values were exceeded. The value defines the concentration after the erection or renovation of a building (target value).
- Level 2, TVOC 0.3–1 mg/m^3: No relevant consequences required; however, increased ventilation is recommended.
- Level 3, TVOC > 1–3 mg/m^3: Concerning hygienic aspects, some objections due to elevated concentration level. Values are acceptable at maximum for 12 months. A search for specific contamination sources and increased ventilation are recommended.
- Level 4, TVOC > 3–10 mg/m^3: Major consequences. Such rooms should not be used. If no alternative rooms are available, they should not be used for longer than 1 month; on condition that intensified ventilation is established. A specific toxicological risk assessment is mandatory.
- Level 5, TVOC > 10–25 mg/m^3: This concentration is not acceptable. Such rooms should be used only if unavoidable, but only for short periods (hours) with intensified ventilation. Rooms with levels above 25 mg/m^3 should never be used.

These recommendations should not be used if a toxicologically based guide value for a single substance was exceeded. Furthermore, higher levels are tolerable for up to 12 months in newly constructed buildings or freshly renovated residences; however, the value should not exceed 3 mg/m^3.

2.2.2.2. Carbon dioxide guideline. If there is no concern of specific health complaints or single pollutants, sufficient indoor air quality is mainly based on indirect approaches, such as ventilation rates. Different standards, including ASHRAE Standard 62 (ASHRAE, 2016) and CEN EN 15251 (CEN EN, 2012), provide minimum ventilation rates for different building types with the goals of improving indoor air quality via fresh air and preventing adverse health effects. Overall, there is an agreement that guidelines should consider occupant-generated contaminants, odors and emissions from buildings and furnishings. The required ventilation rates can also be calculated based on a mass balance equation using carbon dioxide (CO_2) as an indicator (CEN EN, 2007). Apart from the early guideline value of 1000 ppm for CO_2 recommended by Max von Pettenkofer in 1858 (von Pettenkofer, 1858), other standards propose four different guideline values of indoor CO_2 concentrations for non-residential buildings (CEN EN, 2007) and all rooms intended for long-lasting human occupancy (VDI, 2011).

Generally, CO_2 levels above 1000 ppm are considered as an indicator of unacceptable ventilation and can negatively affect people perceptions and performance (Daisey et al., 2003; Satish et al., 2012; Allen et al., 2016; Zhang et al., 2017).

The following CO_2 guidelines were set by the committee based on health and hygiene considerations (Ad hoc AG, 2008a):

- Concentrations below 1000 ppm are regarded as harmless and no measures are necessary.
- Concentrations between 1000 and 2000 ppm are suspicious and ventilation must be improved.
- Concentrations above 2000 ppm are unacceptable. If improved ventilation is not sufficient, other organizational or constructional measures and/or mechanical ventilation are recommended.

2.2.2.3. Particulate matter guideline. Particulate matter (PM) in indoor environments consists of distinct particles that vary in terms of size, form and chemical composition; furthermore, indoor PM is not always comparable to ambient particles. Particles in the fine fraction such as $PM_{2.5}$ develop primarily from the transformation process of gases or combustion processes. In contrast, particles in the coarse fraction such as PM_{10} mainly develop mechanically from the disintegration of larger solid particles and typically consist of whirled up dust and biological material, such as pollen and bacteria fragments. Short- or long-term exposure to $PM_{2.5}$ and PM_{10} are associated with health effects, especially those related to the respiratory or cardiovascular systems (WHO, 2006).

Generally, since $PM_{2.5}$ indoor air concentration of non-smoking environments is largely influenced by its outdoor concentration, the committee recommends the WHO 24-h mean guideline level of 25 µg $PM_{2.5}$/m^3 (WHO, 2006) as a guideline for the indoor air of living spaces in residences (Ad hoc AG, 2008b). In contrast to $PM_{2.5}$, especially PM_{10} shows a much higher indoor air concentration in schools, kindergartens, and partly residences when compared with the outdoor values (Fromme et al., 2008; Cattaneo et al., 2011). The health effects of PM_{10} in indoor air cannot be evaluated up to now because of the different composition of PM indoors versus outdoors and the lack of dose-response relationships for coarse particles generated in indoor air. Nevertheless, sufficient and consistent ventilation is an indispensable method to reduce PM concentrations in indoor spaces. Furthermore, it is recommended that known sources of indoor PM are detected and minimized.

2.2.3. Risk-related guidelines for carcinogenic substances

The risk assessment of indoor air pollutants is based on studies with the most sensitive endpoint or the most critical effect on human health. If substances are identified as carcinogenic, specific characteristics must be considered during the risk assessment process. Carcinogens can be divided into two groups: substances with a known threshold level and those without. For substances with a known threshold of a different toxicological endpoint, and if carcinogenicity may be not the most sensitive endpoint for human health, the standard procedure to derive guide values can be used. An example of such an approach is the derivation of a guide value for formaldehyde, which is classified as carcinogenic to humans (EU-COM, 2014; IARC, 2006). Nevertheless, in this case carcinogenicity does not represent the most sensitive endpoint (AIR, 2016b).

For carcinogenic substances without an identified threshold but a genotoxic potential, leading to DNA damage, an increased cancer risk is assumed even at low doses (SCHER, SCCP, SCENHIR, 2009). On the other hand, there is evidence that exposure to low levels of genotoxic carcinogens is not associated with an increased cancer incidence because of the use of several cellular defense mechanisms, such as metabolic inactivation of the reactive compounds, repair of DNA lesions, or elimination of heavily damaged cells by apoptosis or necrosis (SCHER, SCCP, SCENHIR, 2009; Greim and Albertini, 2012). However, data of a biological threshold for the effects of genotoxic carcinogens in indoor air are usually not available.

For some substances with carcinogenic potential, sufficient data on exposure-risk relationships has been published. If valid data is available, a theoretical cancer risk may be derived even to common concentrations in indoor air. For a few carcinogens without a known threshold, the WHO derived indoor air levels based on an excess lifetime risk of 1/10,000 (10^{-4}), 1/100,000 (10^{-5}), and 1/1,000,000 (10^{-6}) (WHO, 2010). The calculated theoretical risk estimates suggest that 1 additional case of cancer may statistically occurs in a population of 10,000–1,000,000 individuals exposed life-long to these indoor air levels. WHO does not provide any advice which type of risk ratio should be used to protect exposed individuals. Nevertheless, the ECHA recommends to restrict lifetime cancer risk to risk levels of 10^{-5} for workers and 10^{-6} for the general population (ECHA, 2012). Since this exposure limit is not achievable for many indoor air carcinogens without identifiable threshold levels, the following procedure is recommended (AIR, 2015a):

First, valid data on the typical occurrence of the substance in indoor

air must be identified. The 95th percentile of the concentration from a preferably representative dataset is a commonly used criterion. Next, data on exposure-risk relationships are needed. These data are mandatory to evaluate potential cancer risks. If sufficient data for exposure-risk relationships is available, a theoretical cancer risk of 1/1,000,000 (10^{-6}) following lifetime exposure should be calculated. If the concentration obtained from the exposure-risk relationship exceeds the reference value (95th percentile), it should be used as a risk-related guideline. The first example of an established risk-related guideline value is trichloroethene (Ad hoc AG, 2015a). On the basis of an ECHA-RAC estimation a life-long risk of 10^{-6} corresponding to 0.02 mg trichloroethylene/m^3 in indoor air (ECHA-RAC, 2014). This concentration is well above the reference concentration of trichloroethylene observed in indoor air in Germany. Consequently the AIR recommends 0.02 mg trichloroethylene/m^3 as a risk-related guideline for indoor air.

If the concentration of the reference value is associated with a cancer risk above 10^{-6}, the current reference value should be used as preliminary guideline. These reference values should be checked periodically, and the relevant guidelines should be adopted accordingly.

2.3. Reference values

As a convention, the reference value is determined as the 95th percentile of the distribution of the contamination levels in a reference population (Poulsen et al., 1997). An assessment based on reference values only provides information on the exposure relative to a reference group. Exceeding a reference value does not automatically imply a health risk to the user. Generally, reference values represent the recent exposure in a population, preferably obtained from a representative basis. Therefore, reference values must be regularly updated. In Germany, reference values for residences are only available from a representative study (the Children Environmental Survey) that investigated 555 rooms, mainly sleeping rooms of children, in 2003–2006 (UBA, 2008). The ungoing German Environmental Survey (GerES), carried out in 2014–2017, shall establish new reference values of VOS in indoor air. If a reference value is exceeded, the plausibility of the dataset should be checked. This verification step should include analytical conditions and method validation, building characteristics, and the sampling procedure.

2.4. Other recommendations

If no established guide values exist, the health relevance of the concentrations should be assessed on the basis of the available toxicological data. If the contamination concentration poses a health risk, the reason and source of the contamination must be found. The strength and cause of the emission source must also be determined. The necessity and magnitude of the recommended response should be assessed based on the collected information.

The results of indoor air measurements are strongly influenced by sampling strategy, ventilation and climatic factors; thus, specific recommendations for the standardization of sampling procedures and analytical conditions are essential (see Ad hoc AG, 2014b).

3. Risk management of indoor air contaminants using guide values

If an indoor air guide value is exceeded, the reliability of the first measurement must be confirmed due to possible legal consequences. The reliability of data may be assumed if odour and irritation or other health symptoms were reported by the user. In some cases, the collection of additional data, e. g., the internal exposure to a contaminant or documentation of the reported health effects, may be useful.

Assuming that the measured data reliably indicates a value exceeding the health hazard guide value (GV II), the immediate (which legally means without delay) reduction of exposure is recommended to avoid possible health risks. A reduction of exposure can be achieved by removing the identified source of contamination. If the source is a building product or located within the building, e. g., in the wall, and cannot be easily removed, the restriction or prohibition of using the affected room(s) or the complete dwelling should be issued, usually after consultation with the local health authority. With respect to possible lawsuits, all of the relevant data concerning the contamination source and recommended actions must be properly documented. In any case, a concentration under the GV I is the target value of all actions.

If the measured indoor air concentration of a contaminant exceeds its precautionary guide value (GV I), immediate endangerment to the health of the user of the room is not expected. However, some users may report an odour perception or other health impairments. Based on our current scientific knowledge, these health impairments are not considered to be adverse effects. Although, continuous exposure (e. g., more than 12 months) to such indoor air concentrations may be unacceptable.

The ventilation rate should be raised when a precautionary guide value is exceeded. In some cases, e. g., if a precautionary guide value of a SVOC is exceeded, a more intensive regular dust-bonding cleaning is recommended. All actions should be documented. Typically, additional measurement should be obtained after one month to determine if the recommended action reduced exposure. If no improvement of the indoor air quality is detectable and the guide value I is still exceeded despite intensified ventilation and dust cleaning, further action, including removal of contaminated building products, must be taken.

By definition, health hazard guide values apply to a continuous, long-term exposure of a sensitive individual to an indoor air contaminant. This typically holds true for indoor environments used as residences. If rooms are used for shorter time periods it may be appropriate to factor in the duration of exposure when completing a risk assessment. This procedure is allowed if e. g. the mechanism of the health effects of the substance in question is known. In contrary, particular indoor environments, e. g., sports halls, must be carefully considered due to the elevated breathing rates of users. The duration of exposure should not be taken into account if an indoor air guide value is based on health effects, such as odour perception or irritation. These endpoints are assumed to be more dependent on concentration rather than dose.

4. Outlook

To address the question of how odour occurrence in indoor air can be evaluated and how sufficient protection against odour-based health effects can be guaranteed, the AIR committee developed a preliminary concept of odour guideline values to differentiate between a lower acceptable and a higher unacceptable odour annoyance (Ad hoc AG, 2014a). So far, there are no internationally established methods to assess discomfort of single-odour indoor substances. The German draft of odour guideline values was based on the Dutch concept of ‘levels of distinct odour awareness’ for outdoor air (Ruijten et al., 2009) and was two years open for public comments. Currently, the AIR committee is reevaluating this approach having received several suggestions from external experts. Furthermore, the concept will be extended by including new data on odour detection thresholds, odour intensity and hedonic evaluation of several odour-intensive volatile organic compounds provided by the German Environment Agency.

The German basic scheme for the derivation of guide values for indoor air mainly refers to the ECHA guidance document R8 (ECHA, 2012). Regarding sensory irritation assessment factors for this toxicological endpoint are missing in the ECHA document. Especially the question whether a time scaling of the Point of Departure (PoD) is needed has to be regarded. Further, assessment factors when using human short time exposure data (i. e. 1–4 h exposure) are needed. Therefore, the German Environment Agency has initiated two research projects to cover these aspects.

Other main topics for the next period are the development of indoor risk-related guidelines for different carcinogens like benzo(a)pyrene, benzene, and vinyl chloride. Moreover, the very volatile organic compounds (VVOC) are a major focus for the future work of the committee.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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