ARBEITSGEMEINSCHAFT ÖKOLOGISCHER
FORSCHUNGSINSTITUTE e.V. –
Association of Ecological
Research Institutes e.V.

AGÖF Guidance Values for Volatile Organic Compounds in Indoor Air

10 October 2008 Edition

1. Introduction

In Germany, a joint federal and state commission[1] has issued indoor air guideline values since 1993. These are toxicologically based values for individual chemical compounds or compound groups. These guideline values can be used to assess indoor air testing results. However, up until 2007 hardly more than 10 such guideline values could be published. Thus, the assessment of the large majority of compounds measurable in indoor air remained uncertain. Based on their decade-long testing experience, the members of the Association of Ecological Research Institutes (AGÖF) developed a knowledge base about the presence of VOCs and health imbalances associated with them. Empirical observations were complemented with medical and toxicological references. To assist in the assessment of indoor air measurements, statistically derived attention values were determined for indoor air and house dust; and in 2004 they were, for the first time, presented to peers in Germany as the AGÖF Guidance Values. The guidance values allow classifying testing results according to their statistical probability; consequently, their relevance can also be weighted when searching for causes of health complaints. However, the guidance values cannot be used to evaluate the health impact of individual chemical compounds.

The publication attracted great interest and, among other venues, was hotly debated at the AGÖF seminar on “Indoor Air Standards” in Bremen in 2005. This debate spawned a joint research project between the AGÖF and the Federal Environment Agency (UBA) with the title “Bereitstellung einer Datenbank zum Vorkommen von flüchtigen organischen Verbindungen in der Innenraumluft [Provision of a Database for the Presence of Volatile Organic Compounds in Indoor Air]”. From the results of this research project, AGÖF presented a revised edition of its guidance values for over 150 volatile compounds in the fall of 2007.

In addition to the 50th and 90th percentile, the list also provides a guidance value. It is this guidance value that indicates the threshold, above which the indoor air concentration of a compound must be considered a problem based on statistical significance, or toxicological or olfactory knowledge.

Still in actualization are the “AGÖF-Orientierungswerte für mittel- und schwerflüchtige organische Verbindungen und Schwermetalle im Hausstaub [AGÖF Guidance Values for semivolatile organic compounds and heavy metals in household dust]”, the provisional German edition from the year 2004 can be found here: http://www.agoef.de/agoef/oewerte/orientierungswerte_staub.html.

[1] “Ad-hoc-Arbeitsgruppe [Ad Hoc Working Group]” with experts from the „Innenraumlufthygiene-Kommission (IRK) [Indoor Air Hygiene Commission]“ of the Federal Environment Agency and the Indoor Air Working Group of the Environmental Health Committee of the „Arbeitsgemeinschaft der Obersten Landesgesundheitsbehörden (AOLG) [Working Group of the State-Level Health Authorities]“

Energie- und Umweltzentrum 1 * 31832 Springe-Eldagsen
Tel.: 05044/ 97575 * Fax: 05044/ 97577
Email: info@agoef.de * Internet: www.agoef.de

2. Exposure Assessment of Indoor Air Pollutants

Within the framework of the above-mentioned research project, six important reasons for the investigation of indoor air were identified. Besides investigating ill-health symptoms, pure prevention, odor nuisance, and suspicion of exposure, there were also legal reasons and real estate transfers listed. Adverse health effects and odor pollution can be said to be the two dominating causes.

In practice, however, the reasons for indoor air investigations vary greatly, and sometimes individual situations are rather complex. Consequently, it is very important that the professional indoor air quality consultant—in cooperation with the client—first defines the objective of the investigation in order to select the required testing and assessment strategies accordingly.

For the assessment of volatile organic compounds (VOC)[2], there are mainly two types of assessment guidelines that have gained relevance:

- Toxicologically derived assessment concepts;
- Statistically derived assessment concepts.

Both assessment concepts are based on conventions.

Toxicologically derived assessments result in guideline values that are meant to answer health-related questions. In experiments, laboratory animals are exposed to different concentration levels of a compound in order to find the concentration level, at which observable effects are not triggered. An alternative approach to the development of guideline values is based on the observations from occupational studies, in which employees are exposed to relatively high concentrations. In order to evaluate the effects of low-emission indoor exposures in susceptible population groups (infants, sick people), so-called uncertainty factors are applied. A detailed discussion about how the guideline values of the so-called Ad-hoc-AG [Ad Hoc Working Group] were derived was published in 1996.[3]

With a toxicological approach, it remains open to what extent non-specific health symptoms such as headaches, concentration problems, etc. can be recognized in animal experiments, or investigations of laboratory workplaces. The health problems that are most frequently mentioned in the context of indoor air problems are non-specific symptoms. Furthermore, indoor air usually contains compound mixtures that cannot be evaluated by toxicological reasoning alone. The definition of uncertainty factors, e.g. a factor of one hundred, cannot be justified anymore by toxicological reasoning and is based on conventions. The rather high cost of generating toxicological data is an important reason why there is only such a small number of guideline values available. This approach is not adequate for establishing verified assessments for the myriad of chemical compounds occurring in indoor air. However, it is an important tool for answering questions regarding threats to public health.

In the statistically derived assessment concept, reference values are developed. From a large number of representative investigations, a “usual, average” level of indoor air pollutants is established and defined as “normal”. In many cases, the so-called 90^{th} or 95^{th} percentile is chosen as the concentration threshold whereby any value exceeding the latter indicates an unusual exposure. It is impossible to use these reference values for health assessments. With regard to new chemical compounds or compound groups released into indoor air, no reference values will be available at first. In the event of an increased application of known compound groups due to a change in production (e.g. when solvents in paints were replaced), established reference values can consistently be exceeded. Updating the reference values on a regular basis can counteract both occurrences.

Both concepts need to respond to a changing environment. New medical and toxicological knowledge helps keep the toxicological approach up-to-date. In case of the statistically derived values, changes in VOC concentrations in indoor air, which are associated with new product formulas and consumer habits, need to be tested.

A complete and user-specific assessment of indoor air problems needs to rely on both concepts. Only by considering statistical relationships as well as toxicological data, health risks can be weighted and

[2] In this document, the AGÖF uses a somewhat extended definition of VOC; all chemical compounds that can be identified with the analytical procedures listed in chapter 3 are in first approximation defined as volatile, regardless whether according to WHO conventions they would more likely be regarded as “very volatile”, “volatile”, or “semivolatile”.

[3] http://www.umweltbundesamt.de/gesundheit/innenraumhygiene/irk.htm#4

the sources of indoor air problems identified. Odor problems, however, are not satisfactorily addressed by either one of the two concepts.

From testing experiences, it is known that, depending on the problem and situation, both assessment guidelines are important and need to be utilized by the professional indoor air consultant with different weighting strategies. Additional guidelines or assessment tools such as the TVOC concept, information on odors and the consultant's personal experience complement both. It is the consultant's responsibility how to apply and weight the various assessment guidelines, presenting his or her reasoning in a clear and comprehensible manner in a report. The published AGÖF Guidance Values below support consultants in their work. On the one hand, they represent an up-to-date compendium of statistical reference values, and beyond that, they also show toxicologically relevant guideline values of other authors, experiences by AGÖF members, and odor threshold values known so far. With their help, it is possible to achieve preventive health care through minimizing VOC problems in indoor spaces as recommended by the AGÖF.

3. Data Collection and the Procedure How AGÖF Guidance Values Are Established

The new guidance values are based on an updated database from the years 2002 through 2006, which was generated as part of the research project "Bereitstellung einer Datenbank zum Vorkommen von flüchtigen organischen Verbindungen in der Innenraumluft [Provision of a Database for the Presence of Volatile Organic Compounds in Indoor Air]". Sample taking procedures and methods will only be summarized here. For more detailed information see the project report of the German Federal Environment Agency. [4]

For sample taking, the procedures set out in the VDI Guideline 4300 sheet 1 and sheet 6 were followed, most of which were adopted into DIN EN ISO 16000. In general, samples were taken after a space had not been ventilated for a minimum of eight hours. Active sampling techniques were used to collect air samples. In addition to thermal desorption techniques, methods based on solvent desorption (activated carbon or Anasorb) with the corresponding set of two samples for analyzing compounds with different polarity were also permitted for identification. In the analysis of the desorbent compounds, mostly gas chromatography with a mass-selective detector was used, but in some cases flame ionization and electron capture detectors were also used.

In addition, data on aldehyde and ketone concentrations were also collected, samples were taken with impingers (formaldehyde) and DNPH-based methods and analyses were performed (desorption with acetonitrile, analysis based on high-pressure liquid chromatography with UV detector).

To ensure quality of the various analytical methods, the participants of the research project conducted comparative laboratory measurements[5] over the past years.

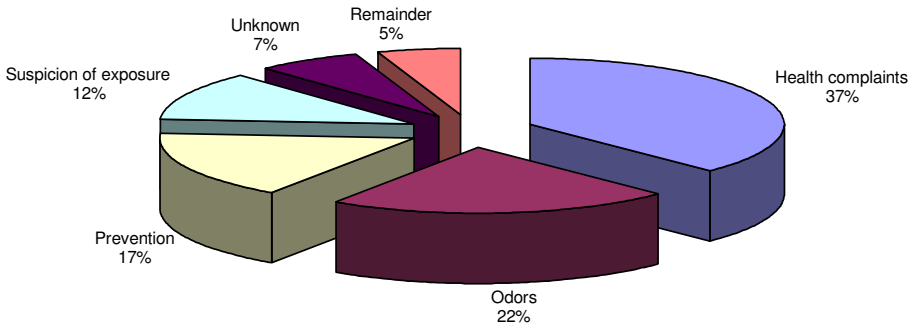
Guidance values are only given for those compound concentrations, for which, on the one hand, a sufficient number of indoor air measurements is available and, on the other hand, whose measurement data come from four or more different laboratories.

The measurement data available are derived from testing situations, for which there was a reason and, therefore, elevated values for one or more parameters were to be expected. Consequently, the measurement results cannot directly reflect the real concentration levels in problem-free indoor spaces. It would be more likely to expect that some values of those measurements are to be elevated. Within the framework of the research project, it was possible to show that, in fact, the collected data do not follow a normal distribution. For this reason, AGÖF maintains its approach to choosing the 90th percentile as the threshold limit for potential problem areas. When the measurement of a compound's concentration value was below the limit of quantitation, it was not equated to zero, but the imputed one-half of the limit of quantitation was taken into consideration for deriving the statistical values (percentiles).

[4] http://www.umweltdaten.de/publikationen/fpdf-l/3633.pdf
[5] http://www.agoef.de/agoef/oewerte/agoef_laborvergleichsmessung2006_07.html

4. Guidance Values for Odorous Compounds

After health complaints, odors are the second most frequent reason for indoor air investigations. The reason for ca. 22% of the indoor air investigations conducted by AGÖF institutes is noticeable or unpleasant odors (see graph 1).



Graph 1: Reasons for Indoor Air Investigations

This high percentage of odor-related investigations shows that the measurement and assessment of odors in indoor spaces has great priority.

In contrast to volatile organic compounds, however, there are—as of yet—no proven testing methods and also no established assessment procedures for odors in indoor spaces.

Sensory methods, in which the human nose functions as the testing probe, are sufficiently sensitive to detect odors. Even though different people perceive the same compound at an identical concentration differently. Furthermore, odor perceptions are interpreted in the brain and, based on an individual's stored memory values, are evaluated differently. For an objective measurement, therefore, it is essential that the range of odor perceptions among the inspectors corresponds with the existing distribution in the total population. Naturally, a single inspector would be unable to accomplish this goal. This is why sensory odor measurements are usually conducted with a minimum of eight to ten inspectors. For indoor spaces, this testing method can be used in exceptional cases only.

Even though it is possible to chemically analyze some odors in indoor air with sufficient detection sensitivity, common odors are often caused by a complex mixture of several—sometimes hundreds of—individual compounds. Many of these compounds can already be perceived at concentrations of only a few nanograms per cubic meter air, but analytically they are hardly detectable. When assessments are based on odor thresholds, it is important to consider that aromatic compounds interact with each other in mixtures. Interactions such as synergisms can have a substantial impact on the odor characteristics of compound mixtures. Often the chemical analysis of odorous compounds in indoor air is not sufficient to completely measure odor problems and evaluate them accordingly.

For many indoor air pollutants, we lack the data of their odor thresholds. The pollutant exposure profile of indoor air is subject to constant changes, and for many volatile organic compounds that have only been recently detected in indoor air very little information is available. The AGÖF is convinced that it is essential to establish odor threshold values for additional compounds. The List of AGÖF Guidance Values reflects the currently available exposure profile of indoor air conditions, which, therefore, makes it a suitable priority list for identifying odor thresholds.

The quality of existing odor threshold values varies. Alongside up-to-date odor thresholds established by well-documented procedures, we also find quotes of rather old odor thresholds in the literature that were established by incompatible methods.

Despite all these limitations, guidance values for individual compounds that are derived from odor thresholds can, in many cases, be an important tool for the assessment of indoor odor problems. Thus, when the chemical analysis shows that the odor threshold value for one or several individual compounds is exceeded in a given indoor air, this would be proof of a non-normal odor. However,

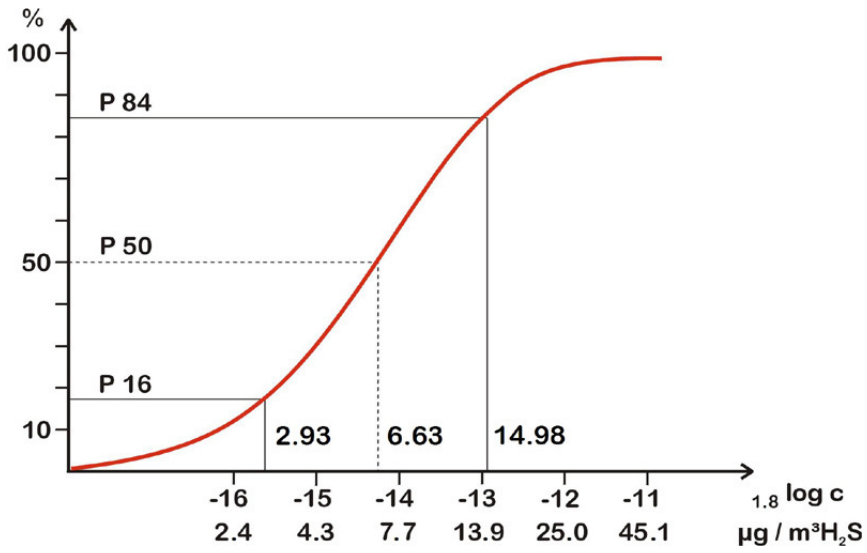
when all individual compounds analyzed meet the respective odor threshold values, for the reasons cited above, this would not constitute proof of a normal or problem-free odor in the indoor air.

The AGÖF, therefore, has decided to include more guidance values based on odor thresholds in its current list. The standardized odor thresholds published by Devos et al. serve as knowledge base.[6]

Odor threshold values usually correspond with the 50th percentile of the perception distribution. This means that even below the odor threshold of a given substance 50% of the population can still perceive its odor.

The odor threshold of hydrogen sulfide, for example, is 6.6 µg/m³. 16% of the population can still detect the odor of hydrogen sulfide at a concentration of only ca. 3 µg/m³, which is even less than half of the odor threshold (see graph 2).

Through establishing guidance values on the basis of odor thresholds, the AGÖF pursues the goal of including the odor perception of at least 90% of the population as a guideline for assessing odors in indoor spaces. Basing a guidance value on odor thresholds is done in order to ensure that at least 90% of the population will not detect this compound.



Graph 2: Odor Threshold Curve of a 42-person Group for Hydrogen Sulfide[7]

The guidance value derived from odor thresholds is based on the following convention: The AGÖF guidance value is derived by taking the odor threshold value according to DIN EN 13725 or a similar procedure and by applying a safety factor of 3. This approach is based on the assumption that the odor threshold distribution in the population for a given compound matches a distribution similar to the odor threshold curve for hydrogen sulfide. When a value, which was calculated from odor thresholds and had a safety factor of 3 applied, falls below the statistically derived attention value (90th percentile) of a given compound, according to the understanding of the AGÖF, this would represent a non-normal situation that should be considered separately when assessing indoor air measurements. At concentrations above the guidance value, this compound could actually contribute to the olfactory impairment of respective sensitive individuals even though the compound may neither be detectable by the majority of occupants nor the inspector.

[6] Devos et al.: Standardized Human Olfactory Thresholds. Oxford University Press 1990
[7] Huber, G., Hangartner, M. Gierer, R.: Sensorische Geruchsmessung, Sozial- und Präventivmedizin 26, 179 – 182 (1981)

5. Explanatory Notes for the List of Guidance Values

Column 1: Name of chemical compound

Column 2: Corresponding CAS number for accurate identification

Column 3: Number N

It provides the number of data values the statistical analysis is based on.

Column 4: Normal value

The normal value represents the "average" exposure situation in a given group. It is equivalent to the 50th percentile. Even indoor air concentrations within the normal-value range are usually the result of one or several emission sources, but in general, it is not considered sufficient evidence for an urgent call to action to minimize the exposure.

Column 5: Attention value

The attention value refers to the 90th percentile value. It shows that common indoor air concentrations are exceeded, and thus, indicates that a respective emission source must exist.

Column 6: AGÖF guidance value

In addition to the attention value, the column of the guidance value may also list toxicologically derived values or odor threshold values provided that those fall below the 90th percentile value.

It is the opinion of the AGÖF that whenever a guidance value is reached or exceeded, it should be checked whether additional preventive actions are called for to minimize VOC exposures even further. Its relevance to health and the necessity for remediation should also be reviewed. The extent and procedure of the testing must—as far as possible—be left to the expert's judgment. In addition to the local conditions during testing, there should also be attention paid to the fact that:

a) Procedural uncertainties exist for VOC measurements. Additional information on this topic can be learnt from the round robin tests and comparative measurements conducted by the AGÖF;

b) Fluctuations in indoor VOC concentrations are to be expected as a function of climatic conditions and users' habits;

c) Depending on the emission source, a reduction of the exposure may follow an attenuation pattern.

Column 7: Notes

In this column, relevant notes on additional assessment guidelines for individual compounds are offered, for example, the toxicological guideline values of the so-called Ad-hoc-AG. They are listed as guideline value pair (GV II and GV I).

Within the region of the State of Hamburg, various levels of government issued guideline values for indoor air assessments, using the same terminology as the Ad-hoc-AG, which are also listed in the table below and, following the notation of the original authors, provisional guideline values are indicated with a "p".

Only recently, both institutions also issued guideline values for compound mixtures whose analytical definition and identification is not conclusive (C1-C4 alkylbenzene, aliphatics C9 to C14, aldehydes C3 to C6, bicyclic and monocyclic terpenes). In the table below, the AGÖF always adds a note for each compound, which can be assigned to any of these sum total values. Also, in the last column of any such compound the sum total values are listed, which result from the addition of the respective compounds.

Likewise the effect-based indoor guideline values (WIR) of the Indoor Air Working Group from the Austrian Federal Ministry of Agriculture and Forestry, Environment and Water Management as well as toxicological guideline values or concepts from additional single authors were also listed.

Furthermore, a few notes on compound characteristics particularly relevant to assessment issues or commentaries by other organizations were also included.

The AGÖF is dedicated to up-to-date information; when in doubt, however, the up-to-dateness of a given guideline value should be checked at the link listed or the original paper, respectively.

6. List of Guidance Values

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Aliphatic Hydrocarbons						
n-Hexane	110-54-3	2288	2.0	11.0	10	
n-Heptane	142-82-5	2358	3.0	13.0	14	
n-Octane	111-65-9	2343	1.0	7.1	7	
n-Nonane	111-84-2	2344	1.0	7.6	8	Ad-hoc-AG: Sum total of aliphatics C9-C14 GV I = 200µg/m³ ; GV II = 2,000µg/m³
n-Decane	124-18-5	2349	2.0	20.1	20	
n-Undecane	1120-21-4	2362	3.0	29.0	30	
n-Dodecane	112-40-3	2363	2.0	16.0	16	
n-Tridecane	629-50-5	2364	1.0	5.0	5	
n-Tetradecane	629-59-4	2358	1.1	5.0	5	
n-Pentadecane	629-62-9	2352	1.0	3.4	3	
n-Hexadecane	544-76-3	1991	1.0	3.0	3	
n-Heptadecane	629-78-7	926	1.0	2.0	2	
n-Octadecane	593-45-3	838	0.5	2.0	2	
n-Nonadecane	629-92-5	831	0.5	1.0	1	
n-Eicosane	112-95-8	831	0.5	0.5	1	
2-Methylpentane	107-83-5	863	1.7	6.1	6	
3-Methylpentane	96-14-0	869	0.7	5.0	5	
3-Methylhexane	589-34-4	662	1.0	8.9	9	
2,2,4-Trimethylpentane (Isooctane)	540-84-1	1993	0.5	1.0	1	
2,2,4,6,6-Pentamethylheptane	13475-82-6	1560	0.7	6.4	6	
2,2,4,4,6,8,8-Heptamethylnonane	4390-04-9	1281	0.5	2.0	2	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Cycloalkanes						
Cyclohexane	110-82-7	2365	2.0	13.0	13	BWG: pGV I = 400µg/m³ ; pGV II = 4,000µg/m³
Methylcyclopentane	96-37-7	2356	0.9	4.1	4	
Methylcyclohexane	108-87-2	2330	1.0	9.0	9	
Alkenes						
1-Octene	111-66-0	1403	0.7	1.0	2	
1-Nonene	124-11-8	1110	0.7	1.0	2	
1-Decene	872-05-9	1105	0.9	1.0	2	
1-Undecene	821-95-4	1101	0.7	1.0	2	
1-Propene, 2-methyl-, trimer (Triisobutylene)	7756-94-7	2077	0.5	1.0	1	
4-Vinylcyclohexene	100-40-3	2032	0.5	0.5	1	
4-Phenylcyclohexene	4994-16-5	2323	0.5	0.5	1	
Aromatic Hydrocarbons						
Benzene	71-43-2	2361	1.7	4.0	4	• Carcinogen • 22. BImSchV: limit values for ambient air: 5µg/m³ (equivalent to regulation 2000/69/EG) • WHO: “no safe level”
Toluene	108-88-3	2402	12.0	49.0	50	• Ad-hoc-AG: GV I = 300µg/m³ ; GV II = 3,000µg/m³ • BWG: Sum total of C1-C4 alkylbenzenes pGV I = 300µg/m³ ; pGV II = 3,000µg/m³ • BMLFUW: WIR = 75µg/m³ • WHO: GV = 260µg/m³ (toxicity), GV = 1,000 µg/m³ (odor)
Ethylbenzene	100-41-4	2395	2.0	13.0	4 [NB 7]	BWG: Sum total of C1-C4 alkylbenzenes pGV I = 300µg/m³ ; pGV II = 3,000µg/m³
3,4-Xylene	108-38-3/ 106-42-3	2396	5.0	38.4	40	
2-Xylene	95-47-6	2375	2.0	14.0	14	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
n-Propylbenzene	103-65-1	2362	0.5	3.0	3	
1-Methylethylbenzene (Cumene)	98-82-8	2112	0.5	2.0	2	
Benzene, 1-ethyl-2-methyl- (2-Ethyltoluene)	611-14-3	1944	0.5	4.0	4	
Benzene, 1-ethyl-3-methyl- (3-Ethyltoluene)	620-14-4	1144	1.4	10.0	10	BWG: Sum total of C1-C4 alkylbenzenes pGV I = 300µg/m³ ; pGV II = 3,000µg/m³
Benzene, 1-ethyl-4-methyl- (4-Ethyltoluene)	622-96-8	1124	0.9	5.7	6	
1,2,3-Trimethylbenzene (Hemimellitene)	526-73-8	2153	0.5	4.2	4	
1,2,4-Trimethylbenzene (Pseudocumene)	95-63-6	2375	2.0	16.0	16	
1,3,5-Trimethylbenzene (Mesitylene)	108-67-8	2359	1.0	5.0	5	
1,2,4,5-Tetramethylbenzene (Durene)	95-93-2	1371	0.5	1.1	1	
n-Butylbenzene	104-51-8	1114	0.5	2.0	2	
Benzene-1-methyl-4-(1-methylethyl) (4-Cymene)	99-87-6	1661	0.5	3.6	4 [NB 7]	
1,3-Diisopropylbenzene	99-62-7	917	0.7	0.9	1	
1,4-Diisopropylbenzene	100-18-5	784	0.7	0.9	1	
Naphthalene	91-20-3	1615	1.0	2.0	2 [NB 1]	• Carcinogen • Ad-hoc-AG: GV I = 2µg/m³ ; GV II = 20µg/m³ BUI: Sum total of PAHs including toxicity factors
Styrene	100-42-5	2374	2.0	12.1	12	• Ad-hoc-AG: GV I = 30µg/m³ ; GV II = 300µg/m³ • BMLFUW: WIR = 40µg/m³ • WHO: GV = 260µg/m³ (toxicity), GV = 30µg/m³ (odors)
Phenol	108-95-2	1507	0.5	3.0	3	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
2,6-Di-tert.-butyl-4-methylphenol (Butylated hydroxytoluene BHT)	128-37-0	834	0.5	0.5	1	
Benzothiazole	95-16-9	601	0.5	1.0	2	
Indan	496-11-7	542	0.5	2.0	2	
Halocarbons						
Carbon tetrachloride	56-23-5	999	0.5	1.0	1	
1,1,1-Trichloroethane (Methylchloroform)	71-55-6	2325	0.5	2.0	2	
Trichloroethylene	79-01-6	1618	0.5	1.0	1	• Carcinogen • WHO: „no safe level“
Tetrachloroethylene	127-18-4	2330	0.5	1.0	1	• 2. BImSchV: 100µg/m³ • WHO: GV = 250µg/m³ • BMLFUW: WIR = 250µg/m³
1,2-Dichlorobenzene	95-50-1	1121	0.9	0.9	1	
1,4-Dichlorobenzene	106-46-7	2283	0.5	0.9	1	
Alcohols						
2-Propanol (Isopropyl alcohol)	67-63-0	869	15.0	74.2	75	
1-Butanol	71-36-3	2284	11.0	45.7	45	
Isobutyl alcohol (2-Methyl-1-propanol)	78-83-1	1277	3.0	21.7	20	
Isoamyl alcohol (3-Methylbutan-1-ol)	123-51-3	729	0.3	0.7	1	
n-Pentanol (1-Pentyl alcohol)	71-41-0	462	1.8	6.6	7	
1-Hexanol	111-27-3	445	0.4	2.1	2	
2-Ethylhexanol (2-Ethyl-1-hexanol)	104-76-7	2283	2.4	12.8	12	
1-Octen-3-ol	3391-86-4	746	0.2	0.3	1	
Benzyl alcohol	100-51-6	746	0.5	4.2	4	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Terpenes						
alpha-Pinene	80-56-8	2395	8.0	93.0	95	Ad-hoc-AG: Sum total of bicyclic terpenes GV I = 200µg/m³ ; GV II = 2,000µg/m³
beta-Pinene	127-91-3	2362	1.0	12.0	12	
3-Carene ((+-)-delta3-Carene)	13466-78-9	2379	2.5	34.0	35	
Limonene	138-86-3	2394	6.0	33.3	35	BWG: Sum total of monocyclic terpenes pGV I = 200µg/m³ ; pGV II = 2,000µg/m³
Linalool (beta-Linalool)	78-70-6	748	0.5	1.0	1	
Camphor	76-22-2	1321	0.9	1.3	2	Ad-hoc-AG: Sum total of bicyclic terpenes GV I = 200µg/m³ ; GV II = 2,000µg/m³
Camphene	79-92-5	1455	0.7	3.0	3	
Eucalyptol	470-82-6	1334	1.0	2.3	2	
Racementhol (Menthol)	89-78-1	796	0.5	1.0	1	
alpha-Terpinene	99-86-5	999	0.5	0.5	1	
gamma-Terpinene	99-85-4	718	0.7	0.9	1	
Borneol	507-70-0	615	0.5	2.0	2	Ad-hoc-AG: Sum total of bicyclic terpenes GV I = 200µg/m³ ; GV II = 2,000µg/m³
2H-2,4a-Methanonaphthalene, 1,3,4,5,6,7-hexahydro-1,1,5,5-tetramethyl- (Isolongifolene)	1135-66-6	1227	0.9	0.9	2	
(1(1alpha,3Abeta,4alpha,8abeta))-decahydro-4,8,8-trimethyl-9-methylene-1,4-methanoazulene (Longifolene)	475-20-7	2047	0.9	2.0	2	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Bicyclo(3.1.1)hept-3-en-2-one, 4,6,6-trimethyl-, (1S,5S)- (Verbenone)	1196-01-6	539	0.5	1.0	1	Ad-hoc-AG: Sum total of bicyclic terpenes GV I = 200µg/m³ ; GV II = 2,000µg/m³
Caryophyllene (beta-Caryophyllen)	87-44-5	1190	0.9	1.1	2	
Citronellol	106-22-9	731	0.5	0.5	1	
Aldehydes						
Formaldehyde	50-00-0	446	32.5	84.5	30 [NB 6]	• Carcinogen [NB 4] • BGA: 0.1 ppm (≡ 120µg/m³) • BWG: pGV I = 30µg/m³; pGV II = 100µg/m³ • WHO: GV = 100µg/m³
Acetaldehyde	75-07-0	297	23.0	72.2	70	B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
Propionaldehyde (Propanal)	123-38-6	274	4.0	17.7	18	• BWG: pGV I = 20µg/m³ • BWG: Sum total of alkanals C3-C6: pGV I = 100µg/m³; pGV II = 1,000µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
Butyraldehyde (Butanal)	123-72-8	1742	3.0	11.0	9 [NB 7]	• BWG: pGV I = 10µg/m³ • BWG: Sum total of alkanals C3-C6: pGV I = 100µg/m³; pGV II = 1,000µg/m³ • B.A.U.CH. (b): GV = 44µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
Pentanal (Valeraldehyde)	110-62-3	2297	5.0	24.2	7 [NB 7]	• BWG: Sum total of alkanals C3-C6: pGV I = 100µg/m³; pGV II = 1,000µg/m³ • B.A.U.CH. (b): GV =53µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
n-Hexanal (Capronaldehyde)	66-25-1	2318	14.0	67.0	19 [NB 7]	• BWG: pGV I = 20µg/m³ • BWG: Sum total of alkanals C3-C6: pGV I = 100µg/m³; pGV II = 1,000µg/m³ • B.A.U.CH. (b): GV = 61µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
n-Heptanal (Heptanal)	111-71-7	2109	2.0	7.8	8 [NB 7]	• B.A.U.CH. (b): GV =70µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
n-Octanal (Caprylic aldehyde)	124-13-0	2100	3.0	9.0	2 [NB 7]	• B.A.U.CH. (b): GV =79µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
n-Nonanal (Pelargonic aldehyde)	124-19-6	2309	7.0	21.0	4 [NB 7]	• B.A.U.CH. (b): GV =87µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
n-Decanal (Caprinic aldehyde)	112-31-2	2051	2.0	7.5	2 [NB 7]	• B.A.U.CH. (b): GV =96µg/m³ • B.A.U.CH. (b): Sum total of C2-C10 n-aldehydes GV = 60ppb
Benzaldehyde	100-52-7	1564	3.5	10.0	10	
2-Furaldehyde (Furfural)	98-01-1	358	1.0	2.0	2	
Ketones						
2-Butanone (Methylethyl ketone MEK)	78-93-3	2285	5.0	42.2	40	
2-Hexanone (Methyl butyl ketone MBK)	591-78-6	830	0.2	1.4	1	
4-Methyl-2-pentanone (Methyl isobutyl ketone MIBK)	108-10-1	2433	1.0	7.7	8	
2-Heptanone (Methyl pentyl ketone)	110-43-0	771	0.5	1.9	2	
3-Heptanone (Ethyl-n-butyl ketone)	106-35-4	862	0.4	1.5	2	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
3-Octanone (Ethyl pentyl ketone	106-68-3	763	0.2	0.2	1	
Acetophenone (Methyl phenyl ketone)	98-86-2	1252	1.6	4.0	4	
Cyclohexanone	108-94-1	2412	1.0	4.0	4	
1-Methyl-2-pyrrolidinone (N-Methylpyrrolidone)	872-50-4	2003	1.0	5.0	5	BWG: pGV I = 40µg/m³; pGV II = 400µg/m³
Esters of monohydric and dihydric Alcohols						
Ethyl acetate	141-78-6	2371	4.0	38.0	40	
n-Propyl acetate	109-60-4	1250	1.0	1.3	2	
Isopropyl acetate	108-21-4	1501	0.9	1.3	2	
n-Butyl acetate	123-86-4	2371	3.1	49.8	10 [NB 7]	
Isobutyl acetate	110-19-0	2143	0.5	4.0	4	
1-Butanol, 3-methoxy-, 1-acetate (3-Methoxybutyl acetate *or* Butoxyl)	4435-53-4	865	0.5	0.9	1	
Formic acid, butyl ester (n-Butyl formate)	592-84-7	818	0.5	2.0	2	
Benzoic acid, methyl ester (Methyl benzoate)	93-58-3	606	0.5	2.5	3	
Acrylic acid, methyl ester (Methyl acrylate)	96-33-3	862	0.5	0.5	1 [NB 7]	
Acrylic acid, ethyl ester (Ethyl acrylate)	140-88-5	819	0.5	0.5	1	
Acrylic acid, butyl ester (n-Butyl acrylate)	141-32-2	896	0.5	0.5	1	
Methacrylic acid, methyl ester (Methyl methacrylate)	80-62-6	1828	0.5	2.0	2	BWG: pGV I = 100µg/m³; pGV II = 1,000µg/m³
Ethylenglykole mono methyl ether acetate (EGMEA, 2-Methoxyethanol acetate)	110-49-6	1958	0.5	0.9	1	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Ethylene glycol monoethyl ether acetate (EGEEA, 2-Ethoxyethyl acetate)	111-15-9	2228	0.7	1.0	2	
Ethylene glycol monobutyl ether acetate (EGBEA, 2-Butoxyethyl acetate)	112-07-2	2022	0.5	0.7	1	
Propylene glycol mono methyl ether acetate (PGMEA, 1-Methoxy-2-propanol acetate)	108-65-6	2035	1.0	12.0	12	
Propanol, (2-methoxymethylethoxy)-, acetate (Propanol, 1(or 2)-(2-methoxymethylethoxy)-, acetate)	88917-22-0	735	0.5	0.5	1	
Diethyleneglycol monobutyl ether acetate (Butyl carbitol acetate)	124-17-4	1948	0.5	2.0	2	
2,2,4-trimethyl-1,3-pentanediol diisobutyrate (TXIB)	6846-50-0	2165	0.9	4.0	4	BWG: pGV II = 1,000µg/m³
Texanol	25265-77-4	2176	0.7	4.0	4	
Dimethyl succinate	106-65-0	763	0.5	1.8	2	
Dimethyl glutarate	1119-40-0	766	0.5	1.1	2	
Dimethyl adipate (Hexanedioic acid, dimethyl ester)	627-93-0	793	0.5	1.8	2	
Dibutyl maleate	105-76-0	1392	0.5	1.0	1	
Dimethyl phthalate	131-11-3	1277	0.5	2.0	2	
Diethyl Phthalate	84-66-2	821	1.0	3.0	3	
Dibutyl phthalate	84-74-2	738	0.5	3.0	3	
Diisobutyl phthalate	84-69-5	727	1.0	4.0	4	B.A.U.CH. (c): 2.8µg/m³
Bornyl acetate	76-49-3	621	0.7	1.0	2	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Polyhydric Alcohols and Their Ethers (Glycols and Glycol Ethers)						
Propylene glycol (1,2-Propylene glycol)	57-55-6	1965	2.5	17.0	18	
Ethylene glycol monomethyl ether (2-Methoxyethanol, Methyl cellosolve)	109-86-4	2190	2.5	3.0	4	• B.A.U.CH. (a): GV = 30µg/m³ • B.A.U.CH. (a): Summary assessment of different glycol derivatives
Ethylene glycol monoethyl ether (2-Ethoxyethanol)	110-80-5	2238	0.5	2.5	3	• B.A.U.CH. (a): GV = 90µg/m³ • B.A.U.CH. (a): Summary assessment of different glycol derivatives
Ethylene glycol monobutyl ether (n-Butoxyethanol)	111-76-2	2096	2.3	18.1	18	• B.A.U.CH. (a): GV = 120µg/m³ • B.A.U.CH. (a): Summary assessment of different glycol derivatives
Ethylene glycol monophenyl ether (2-Phenoxyethanol)	122-99-6	2240	1.0	9.2	9	B.A.U.CH. (d): GV = 300µg/m³ (toxicity), GV = 100µg/m³ (odors)
Diethylene glycol monomethyl ether (2-(2-Methoxyethoxy)ethanol, Methoxydiglycol)	111-77-3	1842	3.0	8.5	8	
Diethylene glycol monoethyl ether (2-(2-Ethoxyethoxy)ethanol, Ethoxydiglycol)	111-90-0	1888	2.5	8.5	9	
Diethylene glycol mono-n-butyl ether (2-(2-Butoxyethoxy)ethanol, Butyl diglycol)	112-34-5	2194	1.5	13.9	14	
1-Methoxy-2-hydroxypropane (PGME, 1-Methoxy-2-propanol)	107-98-2	2239	3.0	23.0	25	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
1-Butoxy-2-propanol (1,2-Propylene glycol monobutyl ether)	5131-66-8	1531	1.3	3.0	3	
1-Phenoxypropan-2-ol (Propylene phenoxetol)	770-35-4	1152	0.6	2.0	2	
Dipropylene glycol monomethyl ether	34590-94-8	1278	0.5	7.0	7	
Dipropylene glycol monobutyl ether (2-Propanol, 1-(2-butoxy-1-methylethoxy)-)	29911-28-2	1932	1.0	4.7	5	
Tripropylene glycol n-butyl ether (Propanol, (2-(2-butoxymethylethoxy) methylethoxy)-)	55934-93-5	1911	1.0	6.0	6	
Siloxanes						
Hexamethylcyclotrisiloxane	541-05-9	1659	1.0	9.0	9	
Octamethylcyclotetrasiloxane	556-67-2	1728	1.5	9.8	10	
Decamethylcyclopentasiloxane	541-02-6	1646	4.3	30.4	30	BWG: pGV I = 300µg/m³; pGV II = 3,000µg/m³
Others						
Methyl tert-butyl ether (MTBE)	1634-04-4	890	1.7	2.5	3	
Tetrahydrofuran (THF)	109-99-9	1414	0.5	2.5	3	
2-pentyl Furan	3777-69-3	954	0.5	2.0	2	
1,4-Dioxane	123-91-1	893	1.0	5.0	5	

Chemical Compound (Synonym)	**CAS**	**N**	**Normal Value P 50** [in µg/m³]	**Attention Value P 90** [in µg/m³]	**Guidance Value** [in µg/m³]	**Notes (see chapter 6.1)**
Sum Total Values						
TVOC (total volatile organic compounds)		382	380	1,636	1,000 [NB 8]	Seifert: TVOC assessment concept [NB 8] Ad-Hoc-AG: Handout [NB 5]
∑ C1 – C4 Alkyl aromatic hydrocarbons		1929	30	168	170	Ad-hoc-AG: Sum total of C1-C4 alkyl aromatic hydrocarbons GV I = 300µg/m³ ; GV II = 3,000µg/m³
∑ Bicyclic terpenes		2351	12	150	150	Ad-hoc-AG: Sum total of bicyclic terpenes GV I = 200µg/m³ ; GV II = 2,000µg/m³
∑ Monocyclic terpenes		2381	6	34	35	BWG: Sum total of monocyclic terpenes pGV I = 200µg/m³ ; pGV II = 2,000µg/m³
∑ C3 – C6 Alkanals		1737	21	96	95	BWG: Sum total of alkanals C3-C6: pGV I = 100µg/m³; pGV II = 1,000µg/m³

6.1. Abbreviations

Ad-hoc-AG: Ad-hoc Arbeitsgruppe Innenraumrichtwerte der Innenraumlufthygiene-Kommission (UBA) and AG der Obersten Landesbehörden (AOLG) [Ad Hoc Working Group for Indoor Guideline Values from the Indoor Air Hygiene Commission of the Federal Environment Agency and the Indoor Air Working Group of the State-Level Health Authorities in Germany]

In particular: Ad-hoc-Arbeitsgruppe der Innenraumlufthygiene-Kommission des Umweltbundesamtes und der AGLMB [Ad Hoc Working Group of the Indoor Air Hygiene Commission of the Federal Environment Agency and the AGLMB] (1996): Richtwerte für die Innenraumluft: Basisschema [Indoor air guideline values: basic scheme]. Bundesgesundheitsblatt 39: 422-426. German

B.A.U.CH.: Beratung und Analyse – Verein für Umweltchemie [Consulting and Analysis – Association for Environmental Chemistry]

a) Sachbericht: Vorkommen von Estern und Ethern mehrwertiger Alkohole in der Raumluft [Technical report: presence of polyvalent esters and ethers in indoor air] (1994) German

b) Sachbericht: Analyse und Bewertung der in Innenräumen vorkommenden Konzentrationen an längerkettigen Aldehyden [Technical report: analysis and assessment of longer-chain aldehyde concentrations in indoor air] (1993) German

c) Sachbericht: Analyse und Bewertung der in Raumluft und Hausstaub vorhandenen Konzentrationen der Weichmacherbestandteile Diethylhexylphthalat (DEHP) und Dibutylphthalat (DBP) [Technical report: analysis and assessment of concentrations of the plasticizer components diethylhexyl phthalate (DEHP) and dibutyl phthalate (DBP) in indoor air and house dust] (1991) German

d) Marchl, D. (1998): Raumluftbelastungen durch Glykolverbindungen [Indoor air pollution due to glycol compounds]. In Diel, Feist, Krieg und Linden: Ökologisches Bauen und Sanieren [Ecological building and remediation]. C.F. Müller Verlag. ISBN 3-7880-9901-1. p. 71-77. German

BGA: Bundesgesundheitsamt [Federal Health Office in Germany];
(in the meantime part of it merged into the Federal Institute for Risk Assessment)

In particular: „Zur Gültigkeit des 0,1-ppm-Wertes für Formaldehyd [On the validity of the 0.1 ppm value for formaldehyde]“. Bundesgesundheitsblatt 35 (1992) p. 482-483. German

BImSchV: Bundesimmissionsschutzverordnung [Ordinances to the Federal Immission Control Act in Germany]

In particular: 2. BImSchV (1990): Verordnung zur Emissionsbegrenzung von leichtflüchtigen halogenierten organischen Verbindungen [Ordinance limiting emissions of volatile halogenated organic compounds] German

In particular: 22. BImSchV (2002): Verordnung über Immissionswerte für Schadstoffe in der Luft [Ordinance on limit values for ambient air] German

BMLFUW: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft [Federal Ministry for Agriculture, Forestry, Environment and Water Management in Austria]
In particular: Indoor Air Working Group at the BMLFUW and the Austrian Academy of Sciences
Refer to the link: http://www.innenraumanalytik.at/

BUI: Bremer Umweltinstitut [Bremen Environmental Institute]

In particular: ZORN, C.; KÖHLER, M.; WEIS; N.; SCHARENBERG, W (2005): Proposal for assessment of indoor air polycyclic aromatic hydrocarbon (PAH). 10th International Conference on Indoor Air Quality and Climate. Beijing, China

See also www.bremer-umweltinstitut.de

BWG = Hamburger Behörde für Wissenschaft und Gesundheit (BWG) [Hamburg Office for Science and Health],
previously Hamburg Office for Environment and Health or Health and Social Affairs, respectively

In particular: VOC-Tabelle 1: http://www.hamburg.de/servlet/contentblob/122306/voc-tab1/data.pdf and VOC-Tabelle 2: http://www.hamburg.de/servlet/contentblob/122308/voc-tab2/data.pdf or for the guideline value of formaldehyde (methanal) see the publication "Richtwerte für die Innneraumluft in Mecklenburg-Vorpommern [Indoor air guideline values for Mecklenburg-Western Pomerania]"/ page 8:
http://www.lagus.mv-regierung.de/land-mv/LAGuS_prod/LAGuS/Gesundheit/Umwelthygiene__Umweltmedizin/Services__Formulare/Lufthygiene/509RW_MV.pdf

GV = guidelines value [in German documents: RW = Richtwert]

pGV = provisional guideline value [in German documents: vRW = vorläufiger Richtwert]

WHO: World Health Organization

In particular: WHO air quality guidelines for Europe, second edition, 2000

http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

WIR = Wirkungsbezogene Innenraumrichtwerte [effect-based indoor guideline values]

6.2. Annotations:

[NB 1]: An exposure to naphthalene can indicate the presence of a more complex exposure to polycyclic aromatic hydrocarbons. It is recommended to check for the latter and to adjust the assessment accordingly.

[NB 2]: To a great degree, formaldehyde concentrations are dependent on the climatic conditions of a given space or emission source, respectively. When formaldehyde concentrations of 60 µg/m³ are exceeded at climatic conditions that are associated with a low rate of emissions from materials, we know from experience that, when the emission sources stay the same but the climatic conditions change, this can result in exposures within the range of WHO or BGA guideline values (e.g. winter/summer effects). This fact can be accounted for by a test value that is meant to encourage retesting formaldehyde exposures at other climatic conditions where applicable.

[NB 3]: Precautionary value based on odor nuisance according to Marchl, D. (1998): Raumluftbelastungen durch Glykolverbindungen [Indoor air pollution due to glycol compounds]. In Diel, Feist, Krieg und Linden: Ökologisches Bauen und Sanieren [Ecological building and remediation]. C.F. Müller Verlag. ISBN 3-7880-9901-1. p. 71-77. German

[NB 4] In a recent statement, the German Federal Institute for Risk Assessment confirmed that formaldehyde is considered carcinogenic when inhaled. However, the effect is said to be dependent on the concentration and in this assessment the currently valid guideline value of 0.1 ppm (124 µg/m³) is reconfirmed, at which virtually no carcinogenic effect is to be expected.

[NB 5]: Ad-hoc-AG: Beurteilung von Innenraumluftkontaminationen mittels Referenz- und Richtwerten [Ad-hoc-AG: Assessment of indoor air contaminations through reference and guideline values]. Bundesgesundheitsblatt 7 (2007) German

[NB 6]: See notes; BWG

[NB 7]: Attention value due to low odor threshold see chapter 4

[NB 8]: The Indoor Air Hygiene Commission of the Federal Environment Agency in Germany (IRK) suggests that in indoor spaces, where humans are intended to spend longer periods of time, the TVOC value between one and three milligrams per cubic meter should not be exceeded in the long term; also see: Seifert, Bernd (1999): Richtwerte für die Innenraumluft. Die Beurteilung der Innenraumluftqualität mit Hilfe der Summe der flüchtigen organischen Verbindungen (TVOC-Wert) [Indoor air guideline values: indoor air quality assessment by means of the sum total of volatile organic compounds (TVOC value)]. In: Bundesgesundheitsblatt - Gesundheitsforschung- Gesundheitsschutz, vol. 42, p. 270–278. German