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The German approach to evaluate complaints about odour annoyance in indoor environments

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ABSTRACT

The perception of unusual or unexpected odours in indoor air can give rise to complaints about odour annoyance. These complaints are frequently accompanied by concerns for adverse health effects as a consequence of exposure to indoor air substances. The German Committee on Indoor Air Guide Values (AIR) developed a practical guidance on how to evaluate if the complaints about odour annoyance in indoor environments are reasonable and how to reduce odour exposure when a so-called odour guide value (OGV) is reached or exceeded. The AIR describes the procedure to derive odour guide values for relevant odorous substances in indoor air and recommends a graded approach of odour reduction measures.

1. Introduction

Odours are part of our natural environment. Our perception and response to odorants depend on numerous internal and external factors related to the exposed person (e.g., age, gender, previous experience with the odour), and to the context (e.g. housing or employment situation) [1–3]. The perception of unusual or unexpected odours in the air of a home, school, office, or other indoor spaces [4] can give rise to complaints about odour annoyance. Particularly odours that cannot be identified or attributed to a specific source often raise concerns for adverse health effects as a consequence of exposure to indoor air substances [5,6]. Although odour annoyance is not a toxicological endpoint, 'odour annoyance' is defined as a disturbance in the sense of well-being caused by the repeated perception of unwanted odours (see also below 'Model on the development and consequences of odour annoyance') [7,8]. The term 'nuisance' is often used in odour regulations to describe an extreme exposure situation that is defined as unacceptable for an exposed person. In general, odour annoyance can occur from substances above or below toxicological thresholds and should therefore be assessed separately.

In Germany, healthy indoor air is subject to the provisions of the building codes of the Federal States. These provisions require 'built structures to be designed, built, and maintained in such a way that' … 'chemical, physical, or biological influences do not result in any hazard or unacceptable nuisance' (Article 13 Model Building Code (Musterbauordnung (MBO), 2022)) [9]. In the area of tenancy law, a reduction in rent may be considered under Section 536 of the German Civil Code (BGB) [10] if a 'defect' is present. The smell of cigarettes repeatedly coming from the neighbouring apartment may be considered a 'defect' if it constitutes a 'permanent and significant impairment exceeding the normal level'. The challenge is to find out whether the odour exposure must be considered an 'unacceptable nuisance', or at what point the 'normal level of impairment' is exceeded.

Studies of exposure to environmental noise or odour have found that as exposure increases, factors such as age, gender or previous experience with the odour lose influence. At some point, almost all persons

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find the exposure annoying [8,11,12]. Within the framework of a survey, the degree of annoyance can be measured with the so-called '11-point thermometer scale' (0 = not annoyed at all; 10 = extremely annoyed). Two groups can be distinguished, the "not or less annoyed" (0 − 6) and the "highly annoyed" (7 − 10) persons [7].

In Germany, the Technical Instructions on Air Quality Control (TA Luft, 2021) [13] includes a nationwide regulation to protect residents from 'substantial impairment' due to odour immissions. Limit values were derived based on two exposure-response studies [8,12]. Odour exposure was classified as 'substantial impairment' if the percentage of "highly annoyed" residents exceeded 10 %. At this point, the percentage of "annoyed" residents with scores up to 6 on the thermometer scale was already 50 %. This means that if these limit values are observed, odours are already perceptible and can be perceived as annoying.

As mentioned above, many personal and contextual factors can attenuate or amplify the odour annoyance response. Consequences of (odour) annoyance express themselves through a) behavioural changes (i.e., interference with the normal use and enjoyment of property, such as not being able to use the bedroom), b) physical and emotional problems (e.g., headache, nausea, anger, fear), c) complaints about odour annoyance to the responsible person (e.g., the landlord, the building owner) according to the 'Model on the development and consequences of odour annoyance' [7]. Reported symptoms such as headache or nausea are more likely attributed to rather than induced by odours [14,15]. The model was developed based on the results and ideas of stress and attribution research, their application to the environmental stressors noise and odours, and the findings of odour impact research [7].

Based on these considerations, it can be assumed that complaints about odour annoyance are expressed when the odour annoyance has increased to such an extent that the intervention by a responsible person (e.g. home owner etc.) is deemed necessary. However, raising a complaint about odour annoyance not only depends on the intensity of the odour exposure, or the degree of annoyance, but also on the availability of a responsible person, or the confidence that the complaint will lead to an improvement in the situation.

In order to provide a practical guidance dealing with complaints about odour annoyance in indoor environments the German Committee on Indoor Air Guide Values (AIR) published a preliminary concept of odour guide values (OGV; in German "Geruchsleitwerte") in 2014 [16]. After a test period, the AIR published a revised concept [17] in 2023, which is now made available internationally.

The AIR is a working group of experts from federal states and federal authorities in Germany. Additional experts may be appointed as necessary. Main tasks of the AIR are to derive health-based guide values [18], risk-related guide values for selected carcinogens [19], and hygienic guide values [20].

The OGV concept does not aim to provide odour-free indoor air or prevent the occurrence of odour annoyance. It may be applied only when occupants express complaints about odour annoyance and can be applied in private, public and office environments. Based on the considerations outlined above, exposed persons who have already adressed complaints about odour annoyance to a responsible person are considered to be "highly annoyed". These assumptions are in accordance with the definition of 'Acceptable Indoor Air Quality (IAQ)' in the ANSI/ASHRAE Standard 62.1–2019. Acceptable IAQ is defined as 'air in which there are no known indoor contaminants at harmful concentrations as determined by competent authorities and with which a majority (80 % or more) of the people exposed do not express dissatisfaction' [21].

2. Methods

Odour guide values (OGV) are calculated based on the Weber-Fechner law (see Eq. 1), which can be used for all human senses. For the calculation experimentally determined and quality-assured odour detection thresholds (ODT_{50}) are needed and a classification at which odour intensity level complaints about odour annoyance are reasonable. The requirements for this are explained in the following chapters. A prerequisite for the application of the OGV concept is the existence of complaints about odour annoyance. The concept may not be applied if no occupant has adressed complaints about odour annoyance to a responsible person.

$$\textit{Weber-Fechner-law } I = k_w \text{ x } \log(C_i/ODT_{50}) + 0.5 \quad (1)$$

I Intensity level
k_w Weber-Fechner coefficient
C_i odorant concentration level
ODT_{50} odour detection threshold

2.1. Odour detection threshold (ODT)

An ODT can be defined as the concentration of a substance which is necessary to smell an odour ("there is something smelling"), whereas the odour recognition threshold can be defined as the concentration which is necessary to identify an odour ("it's banana"). The OGV values were derived with regard to healthy adults with a normal sense of smell. Therefore, ODT_{50} values were chosen. Usually, ODT values are determined with a group of trained panellists with an average sensitivity to odours. Within the scope of the OGV concept the ODT_{50} was defined as the concentration of a single substance that triggers a noticeable odour perception in 50 % of a group of panellists. Thus, the ODT_{50} values are not representative for the whole population, as in a group of normal, healthy individuals between 20 and 40 years of age, the ODT of the most sensitive 5 % is about 100 times lower compared to the least sensitive 5 % [3].

In general, an indispensable prerequisite for the derivation of an OGV is the availability of experimentally determined and quality assured ODT_{50}. Comprehensive compilations of odour threshold data, such as those of Devos et al. (1990) [22] or van Gemert (2011) [23], for example, were criticised as inadequate because the various ODT values for the same substance rarely exhibit accuracy better than ± 1000 % [24]. ODT have been determined for many decades. Standardised procedures for their quantitative determination have been described [24], who used an air dilution olfactometer called the 8-station vapour delivery device (VDD8). In Japan, the Triangle Odour Bag Method is used [25,26]. It has been shown that a sound methodology often yields ODT values, with low intra- and inter-individual variability of one or two orders of magnitude [27]. ODT determined according to the European Standard for Olfactometry (EN 13725:2022) [28], or a comparable high-quality methodology are considered to be objective, reliable, and reproducible [29]. Within a research project [30] on behalf of the German Environment Agency ODT_{50} for single substances were determined according to EN 13725:2022 [28] and used to derive nineteen OGV values (see Table A1).

ODT published without sufficient information on the test conditions are considered to be of low quality [31]. These include mainly older ODT published before 1990 [22,23,32–36]. No OGV are derived for substances with ODT considered of low quality. A general guide for assessing the reliability of ODT values for single substances, which lists the essential criteria of a well-conducted ODT determination, is available [37].

2.2. Odour intensity

Odour intensity (I) describes the strength of an odour exposure. Odour intensity can be assessed with selected and trained panellists according to VDI 3882 Sheet 1 (draft) [38]. According to the Weber-Fechner law (see Eq. 1), the relationship between odour intensity and odorant concentration is logarithmic [38].

Table 1
Odour intensity according to VDI 3882 Sheet 1 [38].

Intensity level	Odour intensity
0	No odour perception
1	Very weak odour perception
2	Weak odour perception
3	**Distinct odour perception**
4	Strong odour perception
5	Very strong odour perception
6	Extremely strong odour perception

A category scale can be used to assess odour intensity (Table 1). According to the Weber-Fechner law, verbal descriptors are assigned to the assessment categories in such a way that the entire intensity spectrum is covered at intervals which are referring to the perceived odour intensity as equal as possible. For a concentration Ci at an intensity level I, 50 % of the responses for a concentration Ci at an intensity level $I + 1$ are assigned to an intensity class $< I + 1$ and 50 % of the responses in an intensity class $\geq I + 1$. For this reason, assuming that the response distribution is symmetrical, and the mean intensity corresponds to the 50th percentile, the odour concentration C_i is assigned to the intensity level $I + 0.5$.

The Weber-Fechner coefficient k_w is substance-specific. Some substance-specific coefficients were determined in the research project [30] mentioned above and are compiled in Table A1. They ranged from 1.95 (benzothiazole and acetic acid) to 3.40 (nonanal). For substances without a known substance-specific coefficient k_w, the default value 2.6 is used within the OGV concept. The default value of 2.6 corresponds to the rounded median of the k_w values (mean: 2.62; median: 2.56) determined in the research project [30].

Based on an experimentally determined and quality assured ODT_{50} and using the default factor 2.6 as k_w value, the above formula results in the following odour intensity levels (Table 2).

It has been shown that repeated exposure to an odour intensity level three times above the ODT can result in complaints about odour annoyance [39]. Therefore, based on the six-point category scale (Table 1), an odour intensity level equal to 3 (distinct odour perception) was chosen.

This is supported by findings from a field study in the vicinity of a sewage treatment plant [40]. Based on the study results, the predicted probability of odour annoyance occurrence was 10 % if the odour was clearly perceptible (3 – distinct odour perception) on 75 % of the days of a year. It was already 80 % if the odour was clearly perceptible on only 25 % of the days of a year. Furthermore, when odour exposure occurred only rarely, the predicted probability of odour annoyance occurrence was high (nearly 50 %), even at a low odour intensity (2 – weak odour perception), and it was almost 100 % at a high odour intensity (4 – strong odour perception). Annoyance rates decreased with increasing frequency of odour exposure. The authors suggested that habituation to the odour exposure must have played a significant role in this.

The OGV refers to the odour intensity level $I = 3$ (Table 2) as a "distinct odour perception" that can be clearly perceived in indoor air. At the corresponding concentration level it is reasonable that occupants complain about odour annoyance. The odour intensity level $I = 3$ has also been used in other standardised procedures for the determination and evaluation of odours in indoor air [41]. After reviewing and weighing up the scientific literature, the AIR working group agreed on an intensity level of 3. The OGV resulting from the use of an intensity level of 3 also correspond to the practical experience of the working group members.

2.3. Hedonic tone

The hedonic tone describes the pleasant-unpleasant quality of an odour exposure and can be determined on a nine-point category scale [42] ranging from “extremely pleasant” to “extremely unpleasant” or with the polarity profile method [43]. Nevertheless, odours that are perceived as pleasant by most people can nevertheless lead to complaints about odour annoyance in some cases. However, there are no databases or reviews in which information on “pleasant” or “unpleasant” odorants has been systematically compiled [44]. In addition, hedonic tone is usually assessed by selected and trained panellists whose ratings may not adequately capture the perception of an exposed person [8].

Based on findings from an exposure-response study on industrial odours, it can be assumed that there is a relationship between the hedonic tone of an odour exposure and the odour annoyance response of the residents, i.e., that unpleasant odours are generally more annoying than “neutral” or “pleasant” odours [45]. However, the study revealed that the “neutral” textile odour with a mean value of 6 on the 11-point annoyance thermometer scale was more annoying than the unpleasant odour of fat with a mean value of 4.5 on the annoyance scale. As mentioned earlier, depending on personal experience or the context, even pleasant odours can give rise to complaints about odour annoyance.

If, as suggested by Both et al. [45] and Nicell [46], a pleasant odour does not lead to complaints about odour annoyance, then the OGV concept will not be applied, since a prerequisite for the application of the OGV concept is the existence of complaints about odour annoyance. Therefore, the consideration of hedonic tone in the derivation of OGV values is not relevant - or in other words - it is already implemented.

2.4. Deriving odour guide values (OGV)

Based on the previous explanations, the OGV refers to the odour intensity 3 (distinct odour perception) and depends on the substance-specific values ODT_{50} and k_w.

The generic equation (see Eq. 2) for deriving an OGV based on the Weber-Fechner law is:

$$OGV = ODT_{50} \times \left(10^{\left(\frac{(3-0.5)}{k_w}\right)}\right) \tag{2}$$

For substances without a substance-specific k_w value, the default value of 2.6 determined in the research project [30] should be used. In these cases, the OGV is equal to 9.2 times of the ODT_{50}.

Currently available OGV of the AIR are listed in Table A1 in the Appendix. This list will be regularly updated on the AIR website [47].

Table 2
Calculation of odour intensity levels based on ODT_{50} and default factor 2.6 as k_w value.

Category scale for odour intensity	Concentration with corresponding equation
$I = 1$	$C_{i=1}$ that equals to 1.6 x ODT_{50} (10^((1–0.5)/2.6))
$I = 2$	$C_{i=2}$ that equals to 3.8 x ODT_{50} (10^((2–0.5)/2.6))
$\boldsymbol{I = 3}$	**$C_{i=3}$ that equals to 9.2 x ODT_{50} (10^((3–0.5)/2.6))**
$I = 4$	$C_{i=4}$ that equals to 22.2 x ODT_{50} (10^((4–0.5)/2.6))

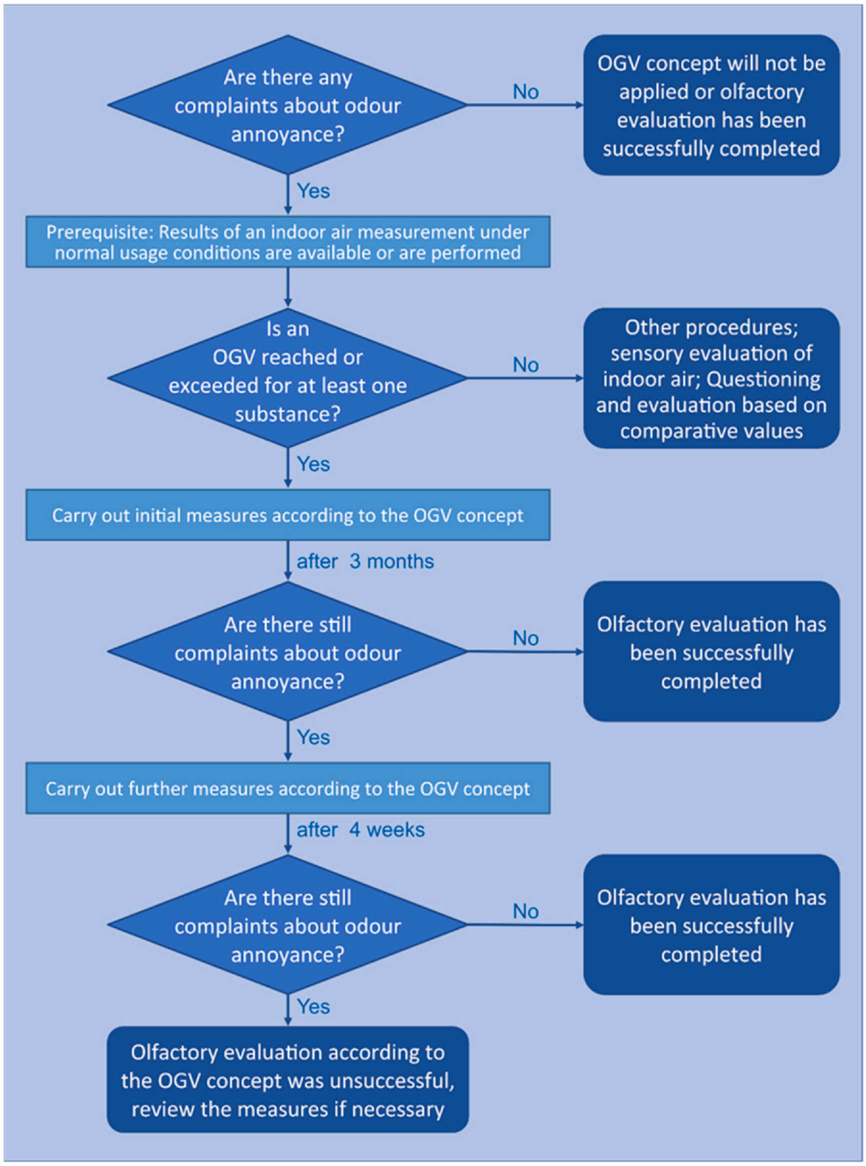

Fig. 1. Flowchart of the OGV concept [17].

3. Results

3.1. OGV concept

The OGV concept is a practical guidance dealing with complaints about odour annoyance in indoor environments and it provides a graded approach of odour reduction measures (see Fig. 1). As mentioned above, the OGV concept may only be applied when occupants express complaints about odour annoyance. Merely exceeding an OGV does not automatically indicate that the odour exposure can be classified as an ”unacceptable nuisance”. Therefore, an exceedance of an OGV without complaints about odour annoyance does not justify any measures according to the OGV concept. As odour annoyance from substances above or below toxicological effect thresholds can occur, a toxicological assessment should be carried out separately. Therefore health-related guide values for indoor air should be applied with priority.

If employees at indoor workplaces express complaints about odour annoyance in Germany, the report ‘Indoor workplaces: Procedure for investigation of the working environment’ assists occupational health and safety professionals by providing a stepwise approach to identify the causes and find practical solutions [48]. An internationally recommended approach to assess perceived indoor air quality in office-like environments was described by Carrer and Wolkoff (2018) [49]. The first step is the use of a questionnaire survey for comfort and health evaluation of the workers. The next step is an initial walk-in inspection of the location, e.g., by a health and safety expert, a measuring institute, or an occupational health service. The aim is to identify the odour source based on the experience with building and product’s emissions and their chemical stability, and possibly supported by using direct reading measurements. If the odour source can be identified, it should be eliminated immediately (see 3.2). If the odour source could not be found, and the initial inspection indicates that an influence from chemical factors may be present, then an appropriate measurement strategy has to be selected. This concept prioritises the identification of health problems via a questionnaire survey and their mitigation rather than the general adherence to regulatory guidelines. The aspects, like ventilation requirements to be considered when drawing up a measurement strategy for indoor air measurements for indoor workplaces have been described by Breuer et al. (2016) [4].

3.2. First steps in applying the concept

The first step is to check as part of a survey whether complaints about odour annoyance were the reason for the investigation. If this can be confirmed, in a next step indoor air measurements can be carried out. It is important to verify that the indoor air measurements were performed under so-called 'normal usage conditions' [4]. Only measurement results obtained under these conditions are suitable for comparison with the health-based guide values [20] or the OGV values of the AIR.

Measurements must be carried out after intensive ventilation and subsequent closure of windows and doors. Ventilation recommendations have to be considered. Special recommendations apply to schools [4,50] or indoor workplaces like offices [51]. In other indoor spaces, such as apartments, more general ventilation recommendations apply [50]. After closure of windows and doors for one hour, or one school hour respectively, indoor air measurements are carried out. During the measurement duration of up to one hour the space should remain closed. In the case of long-term measurements with a duration of more than one hour, measurements are carried out during normal usage while complying with the recommended room ventilation. In spaces under investigation that are equipped with mechanical ventilation, the system should be run under the usual operating conditions for at least three hours prior to sampling. There are internationally recognised standards for carrying out an indoor air measurement available [52–55].

Once the results of an indoor air measurement are available, the concentration of the odorous substance can be compared with the existing OGV in a next step. If the concentration of an odorous substance reveals that an **OGV is reached or exceeded**, it is assumed that the complaints about odour annoyance are reasonable. The odour exposure was probably caused by this single substance, either alone or in combination with other substances. In this case, a graded approach of odour reduction measures is recommended (see 3.3) similar to the measures recommended when a health-based guide value I (GV I) according to the AIR concept [56] is exceeded (in the range between GV I and GV II).

If the concentration of an odorous substance reveals that an **OGV is reached or exceeded and that also health-based guide values** (see requirements for exceeding GV I or GV II) **or risk-related (incl. preliminary) guide values for carcinogens are exceeded**, measures according to these concepts [18–20,56] must be applied with priority.

If the concentration of an odorous substance reveals that an **OGV is reached or exceeded and that also reference values** [57,58] **are exceeded**, measures based on the OGV concept must be applied with priority. Reference values are statistically determined descriptive values. They do not contain any information about the health effects on humans or the annoying effects of odours. Reference values refer to the 95th percentile of a data set. They indicate the concentration of an indoor air pollutant that was below or equal in 95 % of the reference group of indoor spaces measured.

If the concentration of an odorous substance reveals that **no OGV is reached or exceeded**, it cannot be assumed that the complaints about odour annoyance are *not reasonable*. One reason for this is that OGV are currently only available for a limited number of odorous indoor air pollutants. The odour could be related to a substance for which there is no analytical method and/or for which no OGV is available yet. Furthermore, there are numerous individual factors, such as experience and learning or a chronic disease, e.g., asthma or migraine, that can alter odour perception in such a way that occupants express complaints about odour annoyance far below a derived OGV. There is evidence from several studies that persons with a chronic disease such as respiratory allergy, asthma, or migraine respond more strongly to odorous substances than healthy persons. An intense odour can trigger an asthma or migraine attack [59–61]. According to a literature review, around 90 % of all migraine attacks are triggered by odours [62].

If no OGV is reached or exceeded, other methods for determining and evaluating indoor odour exposure may be used. In order to identify odour-relevant substances and possible odour sources, indoor air measurements could be carried out under so-called "equilibrium conditions" [4]. This means that the measurements are taken under reduced ventilation conditions. For this purpose, the room is thoroughly ventilated and subsequently kept closed for at least eight hours (overnight as a general rule). Sampling is then carried out in the unventilated room.

3.3. Measures according to the OGV concept

These following measures consider relevant odour emission sources, and the time interval from last conducted structural changes, e.g., renovation work or new furnishing. It has been shown that renovation work or bringing in new furniture into a room can be associated with exceeding individual OGV and lead to complaints about odour annoyance [63,64]. Some measures reported may only be useful for office work environments or public buildings and should be considered when selecting appropriate measures.

If an OGV is reached or exceeded, it is recommended to take initial measures (Table 3) and consider possible relevant odour sources (Table 4). As a first step, the room should be ventilated intensively and the ventilation routine should be documented with a ventilation protocol e.g., accompanied by measuring the carbon dioxide (CO_2) concentration in indoor air [65]. Ventilation recommendations for schools and indoor workplaces exist and can serve as a guideline [50,51].

The indoor climate conditions and the cleaning routine should be checked and optimised, if necessary, as these can have an influence on emission of odorous volatile organic compounds (VOC). Air fresheners or room fragrances should be removed, as these represent an additional source of VOC and can lead to complaints about odour annoyance. The results of the OFFICAIR project [66,67] show that aldehyde and VOC concentration in new or retrofitted office buildings depend on the building and furnishing materials (floor covering, ceiling, furnishings), indoor climate characteristics (room temperature, relative humidity), the use of consumer products (cleaning and personal care products,

Table 3
Initial measures according to the OGV concept. Review of the success of the measures after 3 months.

Initial measures	
Increased ventilation and examination of climate conditions and cleaning routines	▪ Record ventilation routine, if needed measure CO_2 ▪ Check room climate conditions and optimise if necessary (temperature, humidity) ▪ Check cleaning routines and adjust if necessary
Locating and eliminating the source of the odour	▪ Identify potential (and quickly eliminable) odour sources, see Table 4

Table 4
Examples for sources of odour in indoor environments that can be removed easily as part of initial measures of the OGV concept.

Source of odour	Examples
Furnishings	Furniture, technical devices, folders
Cleaning products	Pay attention to the inherent odour of the cleaning product, application errors
Plants	Pay attention to the inherent odour of the plant, odour of the potting soil or substrate
Air freshener/room fragrances	Fragrance lamps or sticks
Technical equipment	Ventilation, technical air purifiers
Other sources	"Forgotten garbage"

office equipment), and the presence of potential outdoor sources like traffic, and that ozone-initiated indoor air chemistry plays a key role particularly during summer.

If the odour source can be identified, it should be eliminated immediately. It should be mentioned and considered in the search for odour sources that secondary odour sources may arise that are not the origin of the odour annoyance. Examples of easy-to-remove odour sources that should be reviewed with priority as part of the initial measures are listed in Table 4. Moisture damage and mould growth are a hygienic deficiency and should be eliminated immediately as well [68]. Information from indoor environmental professionals about the effects of odours helps reduce perceived odour intensity and increase acceptance of indoor odours [69,70].

If the initial measures have been implemented consistently, the success of the measures should be checked after three months. Complaints about odour annoyance can be documented, e.g. with a survey [71]. If complaints about odour annoyance are no longer expressed by those previously exposed, these initial measures can be considered successful and the OGV concept has been successfully completed. If complaints about odour annoyance continue to exist, further individual or structural measures regarding the building products should be taken (Table 5).

As mentioned above, some occupants may be more responsive to odour exposure than others due to a chronic disease, like migraine, asthma or a respiratory allergy. Therefore, a possible individual measure for a responsive person in an office work environment could be to change the room with another person who works in a room without this specific odour. Another measure for an office work environment or a public environment might be the timely restriction or ban of the use of the room, if necessary.

When implementing further measures, structural measures (odours coming from construction products, floor coverings or contaminated sites) should also be considered. Removal of building products should only occur after the identification of odour-causing VOC. If the odour source could be identified but cannot be eliminated directly, temporary or alternative measures (sealing, isolation, painting) may be applied, depending on the local conditions. In this case, the odour source should be clearly described, and the structural measures should be documented in a comprehensible manner so that the changes can be tracked in the future.

After completion of these further measures, the success of the measures should be checked after an interval of four weeks by questioning the earlier exposed person. Again, complaints about odour annoyance can be documented, e.g. with a survey [71]. If complaints about odour annoyance are no longer expressed by those previously exposed, these further measures can be considered successful and the OGV concept has been successfully completed. If complaints about odour annoyance continue to exist, the olfactory evaluation according to the OGV concept was unsuccessful. A review of the measures taken is recommended.

Optionally and in addition to the documentation of the complaints about odour annoyance, a control air measurement and reassessment according to the OGV concept can be used to verify whether a reduction in the concentration of the critical single substance can be analytically demonstrated.

4. Discussion

The procedure presented here describes how the results of an indoor air measurement could be used to deal with complaints about odour annoyance. If an OGV is reached or exceeded it is assumed that the complaints about odour annoyance are reasonable. The odour exposure was probably caused by this single substance, either alone or in combination with other substances. A graded approach of measures is recommended to reduce the odour exposure. Conversely, however, in the case that an OGV is not reached or exceeded it cannot be assumed that the complaints about odour annoyance are *not reasonable*. When applying the OGV concept to evaluate complaints about odour annoyance, the following prerequisites must be observed:

First, an OGV value is available. OGV are only available for a few substances to date. Perhaps there is no OGV for the odour exposure causing substance yet. An indispensable prerequisite for the derivation of an OGV is the availability of quality assured ODT [40]. The AIR will release more OGV in the future.

Second, an analytically determined indoor air value for the odour causing substance is available. In some cases the analytical detection of a substance is not possible due to the lack of analytical methods or a high detection limit. This highlights the need to develop new measurement methods or methods with higher sensitivity. Only values from indoor air measurements that have been carried out under normal usage conditions as described in chapter 3.1 are suitable and may be considered.

Third, some occupants might have a better sense of smell than the average normal, healthy population. ODT_{50} values used to derive OGV values were determined with a group of trained panellists with average odour sensitivity. Therefore, these ODT values are not representative for the whole population. Additionally, OGV values were derived with regard to healthy adults with a normal sense of smell. As mentioned above, some occupants may be more responsive to odour exposure than others due to a chronic disease, for example.

Fourth, it should be noted that the OGV concept is based on the evaluation of single substances. To date, there is insufficient scientific knowledge to evaluate mixtures of substances in terms of odour effects [72]. Nowadays it is discussed if complex mixtures of odorants are either elemental or configurational processes. For example, a mixture of ethyl isobutyrate (strawberry) and ethyl maltol (caramel) is perceived configurational as pineapple at a 30/70 ratio or perceived elementally, and the components are identified at a 68/32 ratio [73]. In a recently published study [74] from Japan, the occurrence of building-related symptoms was correlated with odour intensity even though the TVOC level was below the Japanese provisional target value of 400 $\mu g/m^3$. Odour intensity was quantified based on the calculation of the sum of odour activity values (OAV) [75]. An OAV was determined by dividing the concentration of a single substance by its odour threshold. These results correspond to findings from a former study [76], which have shown that the overall perceived odour intensity of complex mixtures appears to be determined by

Table 5
Further measures according to the OGV concept. Check the success of the measures 4 weeks after completion of the measures.

Further measures	
Individual measures	▪ Changing rooms (e.g. in the case of chronic diseases such as respiratory allergy, asthma or migraine)
Further measures	▪ Timely restriction, change or ban of room use
Structural measures	▪ Removal of odour sources in the building fabric
	▪ Floor coverings (Surface material, glues, carpet, levelling compound)
	▪ Contaminated sites (Tar paper etc.)
	▪ Other building products
	▪ Sealing, isolation, painting if source cannot be removed
Optional measure	▪ Control measures

the odour intensity of the strongest VOC alone. However, it has also been found that below the threshold mixtures may sum their effects [77]. These considerations could be used as an approach for evaluating odorant mixtures but require further discussion.

In general, no data from exposure-response studies on odour exposure and odour annoyance are available to date. Therefore, it has not yet been possible to derive limit values that would provide preventive protection against 'unacceptable nuisance' caused by odours in indoor air.

However, the use of building products with low odour emission can help to avoid a significant odour exposure. Testing odour emissions of building products is part of several product labelling systems, such as DICL (Denmark), M1 (Finland), and Blue Angel and AgBB (Germany) certification [78]. The DIN ISO 16000–28:2021 [42] is the widely used standard to evaluate odour emissions from building products with sensory methods that mainly assess odour intensity, hedonic tone, and acceptability with a group of panellists [79].

Alternatively, or in addition to the OGV concept, indoor odours can be evaluated by trained or untrained panels regarding acceptability, intensity, and hedonic tone [41,80,81]. Furthermore, standardized questionnaires for indoor climate cases are available, which are based on the Örebro model [82] and additionally consider information on odour perception and annoyance [71]. Another future approach could be the development of a so-called Odour Wheel [83,84] for typical odorants in indoor air, possibly in combination with Sniffin' sticks [85] containing the corresponding odorants. A common language among indoor experts, panellists and occupants could facilitate the description of odour exposure and could be helpful both in planning an indoor measurement and in identifying potential odour sources [86].

5. Conclusions

Odours are ubiquitous in our outdoor and indoor environment and cannot be avoided. The perception of an unusual or unexpected odour in indoor air often give rise to complaints about odour annoyance. In the area of tenancy law or with regard to the building codes of the German Federal States, the challenge is to find out whether the odour exposure must be considered an 'unacceptable nuisance', or at what point the 'normal level of impairment' is exceeded. The OGV concept offers a practical guidance to evaluate if complaints about odour annoyance are reasonable based on indoor air measurements of single substances and it provides a graded approach of odour reduction measures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A.1
Odour guide values (OGV) from the German Committee on Indoor Air Guide Values (AIR), Status: August 2023.

Name	CAS No.	ODT_{50}	K_W	OGV	Unit	Annotations*
Acetone	67–64–1	24,69	2,51	**250**	mg/m^3	A, GV
Acetophenone	98–86–2	2,9	2,83	**22**	$\mu g/m^3$	A
Benzothiazole	95–16–9	3,4	1,95	**66**	$\mu g/m^3$	A, GV
2-Butanone oxime	96–29–7	0,27	3,27	**1,6**	mg/m^3	M, GV
Butyric acid	107–92–6	1,1	2,27	**14**	$\mu g/m^3$	M
Caprolactam	105–60–2	0,32	3,04	**2,0**	mg/m^3	A
Acetic acid	64–19–7	21	1,95	**400**	$\mu g/m^3$	M
2-Ethylhexanol (Racemate – 1:1 (R)- or (S)-2-Ethylhexanol)	104–76–7	0098	2,23	**1,3**	mg/m^3	A, GV
Hexanoic acid	142–61–1	0016	2,56	**0,15**	mg/m^3	M
Hexanal	66–25–1	3,2	2,74	**26**	$\mu g/m^3$	A, GV
m-cresol	108–39–4	0,3	2,28	**3,2**	$\mu g/m^3$	A, GV
p-cresol	106–44–5	0,4	2,10	**5,6**	$\mu g/m^3$	A, GV
Naphthalene	91–20–3	1,0	2,86	**7,3**	$\mu g/m^3$	A, GV
1-Methylnaphthalene	90–12–0	1,9	2,72	**15**	$\mu g/m^3$	A, GV
2-Methylnaphthalene	91–57–6	1,6	3,31	**8,9**	$\mu g/m^3$	A, GV
1,4-Dimethylnaphthalene	571–58–4	4,2	2,54	**41**	$\mu g/m^3$	A, GV
Nonanal	124–19–6	2,2	2,99	**15**	$\mu g/m^3$	A, GV
Phenol	108–95–2	14,2	3,40	**77**	$\mu g/m^3$	A, GV
2-Phenoxyethanol	122–99–6	4,2	2,42	**45**	mg/m^3	A, GV

The values in the regularly updated table on the AIR website are valid (see https://www.umweltbundesamt.de/en/topics/health/commissions-working-groups/german-committee-on-indoor-air-guide-values).

Values correspond to the AIR rounding rules for indoor air guide values, March 2020 [87].

*Annotations: **A** – The ODT_{50} was determined analytically, the values can be found in Table 128 in [30]. If no value is given in the column „optionale Geruchsschwelle (analytisch)", the analytical concentration in the primary bag was divided by the mean odorant concentration (can be found in the respective substance specific chapters in [30]). Example acetone: 13899/563 = 24,69. **M** – The ODT_{50} was determined mathematically, the values can be found in table 128 in [30]. **GV** – Health-based indoor air guide values derived from the AIR are also available for this substance.

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