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Report

Indoor workplaces – Recommended procedure for the investigation of working environment

Report by the German Social Accident Insurance, Institutions for Trade and Industry and the public sector, in collaboration with the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)

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Abstract

Indoor workplaces: Recommended procedure for investigation of the working environment

Indoor workplaces are found in a wide variety of working environments such as offices, sales areas, hospitals, schools and preschool childcare facilities, and libraries. By definition, tasks involving hazardous substances (such as those encountered in a chemical laboratory) are not performed at such workplaces, nor do they include high-noise areas, such as workshops.

The complaints of employees at such workplaces are frequently described as sick-building syndrome. Symptoms include burning of the eyes, a scratchy throat, blocked nose, and headaches. These problems often cannot be attributed to a single cause, and require comprehensive analysis. Factors such as the room climate, disturbing sounds, lighting, workplace organization, and mental factors such as stress must also be considered, besides the quality of the breathable air.

The present report, "Indoor workplaces: Recommended procedure for investigation of the working environment", now in a third and completely revised edition, is intended to assist in the systematic investigation of health problems and subjective disorders arising at indoor workplaces, and in the identification of practical solutions. It describes a concept, geared to use in the field, for step-by-step identification of the causes, giving consideration to all essential factors which according to present knowledge must be considered possible causes of problems in indoor areas. Topics covered include health complaints, buildings, facilities, workplace organization, physical, chemical and biological hazards, and mental factors. The individual elements contain a wealth of information for the user which extends beyond investigation in response to complaints. This information is required for a greater understanding of the issues and serves at the same time as a basis for the redesign of workplaces in indoor areas such that they enhance performance and do not give rise to complaints.

Kurzfassung

Innenraumarbeitsplätze – Vorgehensempfehlung für die Ermittlungen im Arbeitsumfeld

Innenraumarbeitsplätze finden sich in ganz unterschiedlichen Arbeitsumgebungen wie Büros, Verkaufsräumen, Krankenhäusern, Schulen, Kindergärten oder Bibliotheken. An solchen Arbeitsplätzen gibt es laut Definition keine Tätigkeiten mit Gefahrstoffen (wie z. B. in einem chemischen Labor) und es handelt sich auch nicht um Lärmbereiche (wie z. B. in einer Werkstatt).

Beschwerden von Beschäftigten an solchen Arbeitsplätzen werden häufig als Sick-Building-Syndrom bezeichnet: Augenbrennen, Kratzen im Hals, verstopfte Nase oder Kopfschmerzen sind die Symptome. Oft lassen sich die Probleme nicht auf eine einzige Ursache zurückführen, sondern bedürfen einer umfassenden Analyse. Neben der Qualität der Atemluft sind u. a. das Raumklima, störende Geräusche, die Beleuchtung, die Arbeitsplatzgestaltung und psychische Faktoren wie z. B. Stress zu berücksichtigen.

Die Vorgehensempfehlung „Innenraumarbeitsplätze – Ermittlungen zum Arbeitsumfeld“ soll in ihrer dritten komplett überarbeiteten Auflage helfen, gesundheitlichen Problemen und Befindlichkeitsstörungen an Innenraumarbeitsplätzen systematisch auf den Grund zu gehen und praxistaugliche Lösungen zu finden. Sie beschreibt ein auf die Praxis zugeschnittenes Konzept zur stufenweisen Ursachenermittlung, das alle wesentlichen Faktoren berücksichtigt, die nach heutigem Kenntnisstand als Ursache für Innenraumprobleme in Erwägung zu ziehen sind. Dabei werden Themenbereiche wie gesundheitliche Beschwerden, Gebäude, Einrichtungen, Arbeitsplatzgestaltung, physikalische, chemische und biologische Einwirkungen sowie psychische Faktoren abgedeckt. Die einzelnen Bausteine enthalten eine Fülle von Informationen für den Anwender, die über den Rahmen der Ermittlung in Beschwerdefällen hinausgehen, aber für das tiefere Verständnis notwendig sind. Zugleich können sie als Grundlage für die Neugestaltung von beschwerdefreien und leistungsfördernden Arbeitsbedingungen in Innenräumen dienen.

Résumé

Procédure pour les inverstigations relatives à l'environment des postes de travail d'intérieur

Il existe des postes de travail d'intérieur de natures très diverses dans des bureaux, des points de vente, des hôpitaux, des écoles, des jardins d'enfants, des bibliothèques, etc. Par définition, les personnes occupant de tels postes de travail ne manipulent pas de substances dangereuses (comme dans un laboratoire chimique par ex.) et ne sont soumises à aucune nuisance sonore importante (comme dans un atelier par ex.).

Les troubles dont elles souffrent sont souvent désignés par le terme « sick building syndrome », qui se manifeste par les symptômes suivants : yeux qui piquent, gorge qui gratte, nez bouché ou maux de tête. Il arrive fréquemment que ces problèmes ne soient pas imputables à une cause unique mais nécessitent une analyse approfondie. Outre la qualité de l'air, il faut également tenir compte, entre autres, du climat ambiant, des nuisances sonores, de l'éclairage, de l'aménagement du poste de travail et de facteurs psychiques tels que le stress, par exemple.

La troisième édition, entièrement remaniée, de la recommandation « Procédure pour les investigations relatives à l'environnement des postes de travail d'intérieur » doit faciliter la recherche systématique des causes des problèmes de santé et des indispositions rencontrés à des postes de travail d'intérieur et aider à trouver des solutions pouvant être mises en pratique. Dans cette recommandation est décrit un concept pour la détermination par étapes des causes de ces problèmes de santé et indispositions qui est axé sur la pratique et prend en considération tous les facteurs importants pouvant entrer en ligne de compte d'après les connaissances actuelles. Des thèmes tels que problèmes de santé, bâtiment, mobilier, aménagement du poste de travail, environnement physique, chimique et biologique ainsi que facteurs psychiques sont pris en compte. Les différents modules offrent à l'utilisateur une multitude d'informations qui sortent du cadre des investigations faisant suite à des problèmes de santé mais qui sont nécessaires pour une parfaite compréhension, et qui peuvent également servir de base pour l'aménagement de postes de travail d'intérieur n'entraînant pas de problèmes de santé et augmentant le rendement des travailleurs.

Resumen

Puestos de trabajo en espacios interiores; modo de proceder en las investigaciones sobre el entorno laboral

Los puestos de trabajo en espacios interiores se dan en entornos laborales muy distintos, como por ejemplo oficinas, tiendas, hospitales, escuelas, guarderías o bibliotecas. De acuerdo con la definición, en estos puestos de trabajo no se llevan a cabo actividades relacionadas con materias peligrosas (como, por ejemplo, en un laboratorio químico) ni tampoco se encuentran en zonas ruidosas (como, por ejemplo, en una fábrica).

En tales puestos de trabajo, las molestias de los empleados se suelen considerar a menudo un «síndrome del edificio enfermo» (SBS, por sus siglas en inglés): los síntomas suelen ser picor en los ojos, irritación de garganta, congestión nasal o dolor de cabeza. Por lo general, no es posible atribuir estos problemas a una única causa, sino que es necesario llevar a cabo un amplio análisis. Además de la calidad del aire, también se han de tener en cuenta, entre otras cosas, el clima ambiental, los ruidos molestos, la iluminación, la organización del lugar de trabajo y los factores psíquicos, como por ejemplo el estrés.

El modo de proceder recomendado en la tercera edición totalmente revisada de «Puestos de trabajo en espacios interiores; modo de proceder en las investigaciones sobre el entorno laboral» debe ayudar a detectar sistemáticamente los problemas de salud y los trastornos en el estado anímico originados en los puestos de trabajo en espacios interiores y a encontrar soluciones que se puedan llevar a la práctica. Este modo de proceder describe un concepto adaptado a la práctica para la investigación gradual de las causas que tiene en cuenta todos aquellos factores importantes que se deben barajar como causa de los problemas en los espacios interiores conforme al nivel de conocimientos actual. Para ello, se abarcan temas como problemas de salud, edificios, instalaciones, diseño del lugar de trabajo, impacto físico, químico y biológico, así como los factores psíquicos. Cada uno de los módulos contiene una gran cantidad de información para los usuarios que va más allá del marco de investigación en caso de molestias, pero que es necesaria para poder comprenderlo más en profundidad y que, al mismo tiempo, puede servir como base para la remodelación de las condiciones laborales y para crear espacios interiores libre de molestias y que ofrezcan un mayor rendimiento.

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1 Introduction

H. Kleine, Sankt Augustin
N. von Hahn, Sankt Augustin

These recommendations for "Investigations of indoor working environments" provide a graded and modular organised strategy for investigating and assessing problems in indoor workplaces. They are the result of interdisciplinary collaboration and cover all the key factors currently known to be potential causes of health complaints in indoor workplaces. Apart from air quality, these factors include (amongst others) indoor climate, noise, lighting, electromagnetic fields and ionising radiation. But psychological and ergonomic aspects – often the "unseen" cause of health issues – should also be taken into consideration.

The Sachverständigenrat für Umweltfragen (SRU, German Advisory Council on the Environment) defines "indoor spaces" as including the following [1]:

Dwellings with living spaces, sleeping, indoor workshop, fitness and basement areas, kitchens and bathrooms; workspaces/ workplaces in buildings whose air pollution levels are not subject to health and safety monitoring requirements (e.g. offices or salesrooms); public buildings (hospitals, schools, nurseries, sports halls, libraries, pubs, restaurants, theatres, cinemas and other event venues) plus the occupant areas of motor vehicles and of all types of public transport.

For the purposes of these recommendations, indoor workplaces are deemed to include all of the spaces cited by the SRU – with the exception of homes, motor vehicle interiors and all public transport – provided they are not used for activities involving hazardous substances (as would be the case in a chemistry laboratory, for instance) and are not high-noise areas (as in a factory workshop, for example). The recommendations can also be applied to activities that are defined as "low-risk" in the Gefahrstoffverordnung (GefStoffV; Ordinance on Hazardous Substances) [2]. The compliance with the conditions must be established in the risk assessment. Since the usual models for assessing indoor air quality are not suitable for workplaces in pubs and restaurants, they are not given further consideration in these recommendations.

The health complaints suffered by employees at indoor workplaces are often referred to as "sick building syndrome". Symptoms include eye and throat irritation, a blocked nose and headaches. The causes are diverse and investigating them tends to be a difficult task. Affected employees make subjective assumptions about what has triggered the problem, often leading any investigation of the matter in the wrong direction. For instance, employers can end up commissioning expensive air pollution measurements when, actually, it is inadequate lighting that has caused the health complaints.

As the resources and options available for identifying the causes of indoor workplace health problems are limited, investigation methods need to be made more systematic and objective. The first step in these recommendations is to determine the nature and incidence of the health complaints. An initial investigation of the work environment is necessary at this stage too in order to narrow down the probable causes. Finally, this is also a good time to conduct a workplace inspection and interviews with the employees affected (Figure 1, page 12). The inspection and interview team should include the organisation's occupational physician and OSH[1] professional.

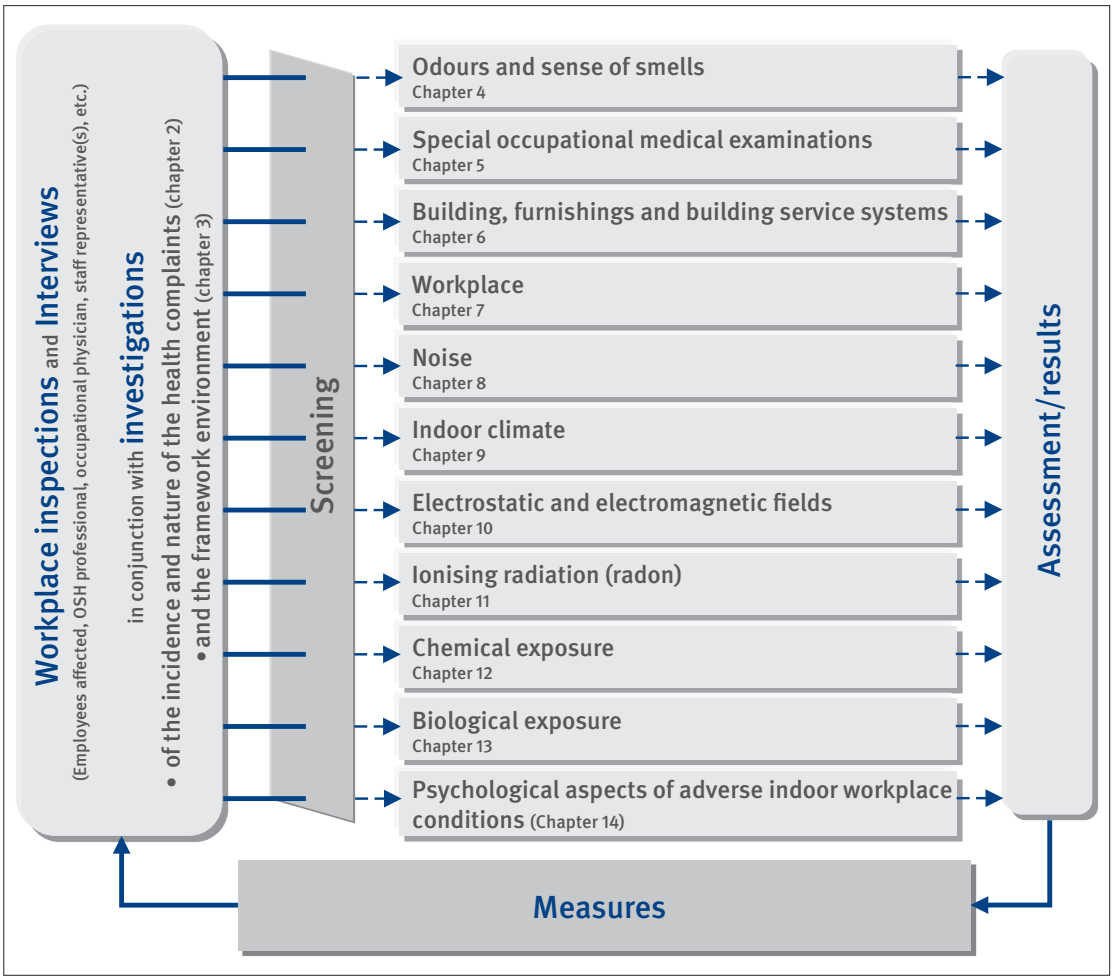
Based on the results specific investigations on the different issue(s) can then be carried out independently. Figure 1 shows the possible options, each of which is dealt with in its own chapter in the following. These dedicated chapters provide background information, guidance, measurement strategies and assessment criteria for a variety of parameters that can potentially cause health complaints in indoor workplaces. Any links between the various issues are indicated in the respective chapters.

Where necessary, experts should be consulted additionally as the topics can be very complex. The questionnaires mentioned in the different chapters can be downloaded from the website of the Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA; Institute for Occupational Safety and Health of the German Social Accident Insurance) at www.dguv.de/ifa (webcode e650356).

Occasionally, problems that become apparent at the workplace are actually caused by factors in employees' private lives. Whilst these recommendations endeavour to include these aspects, they do not describe how to handle them because the German statutory accident insurance institutions are not responsible for such health complaints. It is, of course, also possible that the investigations might not provide a remedy at all. In such cases, the only option is to explore other possible solutions.

1 OSH: occupational safety and health

Figure 1:
Graded modular organised investigation strategy



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[1] Luftverunreinigungen in Innenräumen. Sondergutachten des Rates von Sachverständigen für Umweltfragen vom Mai 1987. Deutscher Bundestag (1987), Drucksache 11/613

[2] Verordnung zum Schutz vor Gefahrstoffen (Gefahrstoffverordnung – GefStoffV) vom 26. November 2010. BGBl. I (2010) No. 59, p. 1643-1692; last revision BGBl. (2013), p. 2514-2534

2 Investigating the incidence and nature of health complaints

J. Petersen, Hamburg
K. Sucker, Bochum

2.1 General aspects

Health complaints usually prompt the question of whether they have been brought on by adverse workplace conditions. However, it is practically impossible to identify one single event as the cause except in the case of an accident. For the most part, several factors are involved and the way people experience health complaints differs significantly. Consequently, documenting the symptoms the affected employees describe is not as simple as determining, for example, when a house was built.

The preliminary workplace inspection as part of a health complaint investigation can be used to interview those involved and thus gain an initial impression of the nature of the health complaints, the number of employees affected and the suspected causes.

Table 1 lists some examples of possible health complaints in different parts of the body. In addition, experience has shown it to be helpful to involve the organisation's occupational physician from the outset.

The **questionnaire** shown in Section 2.2 can be used to prepare for the interviews. Its questions are intended to help document health complaints in a way that takes into account workplace specifics as far as possible. Interviewers should be careful not to influence employees' responses by asking them about particular symptoms. Interviews offer an opportunity to "read between the lines" and thus obtain information that often turns out to be relevant in any further action that needs to be taken.

Questionnaire G1 (see Annex 1), which covers health conditions in the workplace, permits a more comprehensive investigation of health complaints. An evaluation table and an evaluation example are presented in Annex 2 of this recommendation.

Based on the results specific investigations on the different issue(s) can then be carried out independently. If required, special occupational medical investigations and further diagnostic measures can also be initiated on the basis of the findings.

Table 1:
Parts of the body and associated health complaints that affected employees might report

Part of the body	Possible health complaints
Eyes	Stinging, itching, pain, watery or dry eyes, redness, irritation, inflammation, sensitivity to light, blurred vision, spots before the eyes, etc.
Throat, nose, ears	Aches, pain, itching, irritation, inflammation, dryness, saliva, blocked nose, nose bleeds, etc.
Other parts of the head	Loss of sensation, tingling, numbness, headache (stabbing, piercing, throbbing, pulsating), etc.
Respiratory tract/bronchi	Shortness of breath, coughing, mucus formation, increased incidence of infection, etc.
Cardiovascular system	Palpitations, rapid heartbeat, chest pain, low/high blood pressure, poor circulation, etc.
Skin	Lesions, pigmentation, reddening, inflammation, flakiness, rashes, wheals, itchiness, etc.
Digestion	Loss of appetite, nausea, vomiting, etc.
Musculoskeletal system	Tension, pain, impaired mobility, paralysis, etc.
Nervous system	Loss of sensation, numbness, tingling, paralysis, dizziness, feebleness, exhaustion, fatigue, poor concentration, irritability, etc.

2.2 Questionnaire for interviews conducted as part of health complaint investigations

Dear employee,

As you may know, some of your fellow workers have informed us that they have health complaints that they feel are linked to their workplace. We are investigating this issue to determine whether and where health is adversely affected within our organisation. We are also seeking to establish whether the building itself, the rooms in it or the furnishings and building service systems play a role.

Consequently, this questionnaire is obviously only concerned with illnesses or other health complaints that arise or have previously arisen in connection with your work. It does not address health problems caused by accidents, inherited diseases or any other illnesses developed elsewhere.

Completion of the questionnaire is voluntary and your answers will be recorded anonymously. If you do choose to give information, we would be very grateful if you could supply as much detail as possible.

1. Do you have any health complaints that you feel are linked to your workplace? If so, what are they?
2. Which health complaints are the worst in your opinion?
3. Have you been examined by a doctor in connection with these complaints?
4. Are you being treated for these complaints?
5. Have you ever been written off sick due to these complaints?
6. When did the health complaints start? (Month, year)
7. When exactly do they occur? (E.g. season, day of the week, time of day)
8. Do the complaints subside when you are not at your workplace? (E.g. when you have finished work, at the weekend, on holiday)
9. What do you think causes your health complaints?
10. Have there been any changes at your workplace recently? (E.g. redecoration, restructuring of the organisation/department, staff changes, changes in responsibilities, etc.)
11. Do you have any allergies?
12. Do you smoke?
13. How old are you?

2.3 Assessment

The workplace inspection and interview(s) reveal the number of employees affected and the ratio of room users affected to those not affected. As such, they contribute important input for the remainder of the investigation.

The nature of the health complaints, particularly those considered worst, and the information about whether the complaints subside when the employee is not at the workplace indicate whether the complaints can be attributed to the employee's work. If one specific factor is repeatedly cited as a suspected cause, it can point the investigation towards factors that might have played a role.

Figure 2 shows how the investigation can then proceed.

Sometimes it will not be possible to establish beyond doubt whether the health complaints are related to the workplace or not, or the problem might prove to be extremely complex. In such cases, it is advisable to convene a round-table forum with representatives of management, the employees affected, the organisation's OSH professional and occupational physician, and the staff representatives. External specialists, e.g.

an inspector and an occupational physician from the relevant Social Accident Insurance Institution, should also participate.

The purpose of the round table is to engage in an open dialogue concerning the problems, the possible causes, the various stakeholders' interests and the course of action to be taken. All measures agreed on should be communicated to the employees in a transparent process. Past experience has shown that secrecy and conspiracy are counterproductive approaches to these problems and must be rejected.

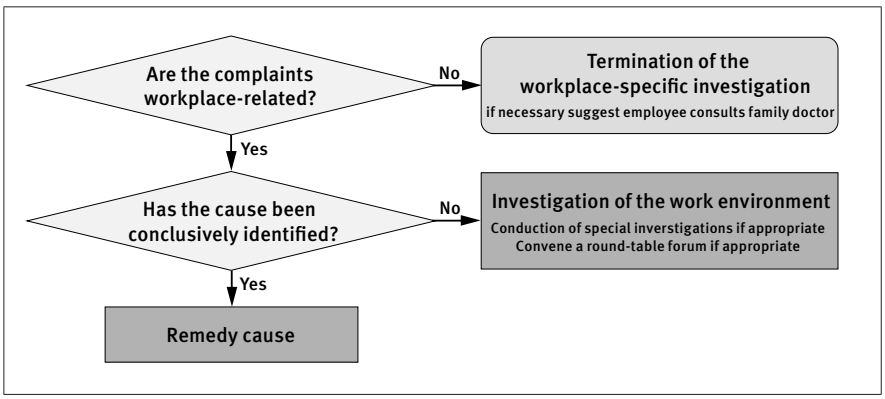

Figure 2:
Subsequent action based on the results of the investigation

3 Investigations of the work environment

P. Michels, Cologne
H.-D. Neumann, Düsseldorf

If the results of the workplace inspection, the interviews and the investigation of the incidence and nature of the health complaints indicate that they are workplace-related or at least potentially workplace-related, the next step is to investigate the main features of the working environment. In particular, these investigations concentrate on the building itself and the furnishings, building service systems and technical equipment.

If the health complaints began to be noticed at one specific point in time, they may well be linked to redecoration or conversion work. This possibility should also be taken into consideration.

Questionnaire G2 (see Annex 3) can be used to perform a detailed investigation of the work environment. Based on the findings derived from it, the potential causes of the health complaints can be divided into “less probable” and “more probable”. This makes it easier to decide on further action and which topics, if any, are to be the subject of a special investigation.

4 Odour and sense of smell

K. Sucker, Bochum
H.-D. Neumann, Düsseldorf

Many of the complaints presented by indoor workers are due to odour. With this in mind, this chapter provides background information as an aid in interpreting complaints about odours correctly and identifying the options available for remedial action.

4.1 The nose's olfactory sensory system

The olfactory sense is a sensory system that allows odorant substances to be perceived/sensed for the purpose of assessing the environment around us, food and potential mates [1].

Odour perception [2] begins in the olfactory mucosa – an area measuring approximately two by five centimetres and home to the olfactory receptor cells, which number between 10 and 30 million. Unlike all other nerve cells, these cells are reproduced approximately every four weeks and are in direct contact with the outside world. Each cell only has one type of odorant receptor. Human beings have around 350 different odorant receptors, capable of molecular recognition. As such, they react not only to the form of odorant molecules (size and shape) but also to their chemical properties (chain length, number and arrangement of functional groups, etc.). They are particularly sensitive to certain molecular characteristics but also have a high tolerance for other chemical properties. As a result, a receptor responds to several odorant substances and a single odorant substance is registered by several receptors.

Once an odorant molecule reaches the receptor, it triggers an electrical signal in the cell, which is then relayed to the olfactory bulb in the brain. This contains spherical control centres, known as the glomeruli. The information from around 1,000 olfactory cells of the same type is bundled in one such glomerulus. The advantage of this huge concentration is that the olfactory system can continue to perceive odours even if large parts of the olfactory mucosa are damaged, e.g. as in the case of an infection. In total, there are some 350 different types of glomerulus though each type has a large number of redundant glomeruli.

The olfactory system appears to use a combination of receptors of differing levels of activity, much like the combination of notes and sounds used in music. In this way, it is able to identify and distinguish between the multitude of different odours (the "sounds"), around 10,000 in number, using just the "few" 350 different types of receptor ("notes") at its disposal.

Odours in turn are each comprised of various chemical substances, making it virtually impossible to determine precisely how many substances are capable of being smelled. The scent of a rose alone consists of around 500 individual components. However, it is usually possible to recognise an odour based on just a few key substances that determine it. The scent of a rose, for example, is determined by geraniol. When we smell geraniol, we are immediately reminded of roses but we also notice there is something lacking that would make the smell that of a real rose.

The neuronal activity pattern produced in the olfactory bulb is relayed to the "smell brain", where the neural impulses are processed, bundled and forwarded. One of the routes the information takes leads directly from the smell brain to the centre of our emotions, the limbic system. The odour information that arrives there immediately generates an emotion. Depending on the odour, that emotion can range from happiness to fear or even disgust. If the smell is strong enough, the smell brain sends neural impulses to the olfactory cortex via the thalamus. This is where the conscious olfactory impression is created and the scent is recognised as being (in our example) that of a rose.

The human nose is extremely sensitive to certain substances. For instance, it detects isobutyl-methoxypyrazine, an odour compound found in the bell pepper, at concentrations as low as 0.002 µg/m³ [3]. Difficulties arise if an odorant substance is present in a concentration so low that measuring devices cannot register it but the human nose can. It is therefore often impossible to register and assess odours using conventional chemical and physical measurement methods as would normally be used to measure air pollution (see Section 12.2).

4.2 Odour detection thresholds in the literature

Evaluating odour detection thresholds (ODTs) cited in the literature can be problematic. In particular, where a substance has been the subject of extensive research and one would expect a certain level of consistency in the values in the literature, the opposite is often the case. In fact, the more ODTs one finds in the literature for one specific substance, the more they differ from each other – often by several orders of magnitude. For instance, the literature cites ODTs for aniline ranging from 0.2 to 350,000 µg/m³. Though partly the result of different measurement strategies, this divergence is also due to the differences in humans' sensitivity to smell. Inevitably, this large variation in the published values means that any assertions concerning the concentration required for a substance to be perceptible to the olfactory system will be extremely unreliable. By the same token, if the literature only states one single ODT for a given substance, there is no certainty that this value is correct.

4.3 Perception of smell

Like or dislike of a particular odour is not something we are born with – it depends on our experience of the odour. Dried fish provides a good illustration. The way we perceive the smell of dried fish differs according to our cultural background: whilst Japanese noses find it pleasant, the average German nose does not.

Our sense of smell can also not be depended on to distinguish "good" from "bad". It perceives many aromatic hydrocarbon compounds as having a pleasant odour although they are often toxic even at low concentrations. Conversely, it sometimes protests strongly when faced with the completely harmless odour of some pungent types of cheese.

When we smell something, we take in a variety of aromatic substances (e.g. vanilla), add them to information supplied by our other senses ("The oven is still warm", "Grandma wanted to do some baking today", etc.) and then perceive and store the information as "cake smell". Yet the same olfactory impression, if mixed with different information or perceived by a different person, might be stored as "overly sweet perfume" and "unpleasant".

In this way, smells are linked to memories and can make us feel good or bad without us realising at that particular moment that we are associating them with past events.

Whether an odour is perceived as unpleasant and undesirable depends on various factors. As well as the substance's concentration, type of odour and the individual's experiences and memories, these factors include the duration and frequency of perception (habituation effect) and the individual's sensitivity to smell.

4.4 The nocebo effect

The nocebo effect is the opposite of the placebo effect, which is best known as a medical concept [4].

Medical drugs always transmit two "messages". Firstly, the active ingredients convey chemical information, reacting with particular parts of the organism and triggering events that lead to desired or undesired effects. Secondly, drugs send a signal to the patient to tell them that something is happening to them. As a result, the mere expectation of a positive effect can lead the patient's symptoms to improve even if there is no chemical information. This is referred to as the placebo phenomenon (Latin for "I shall please").

A nocebo is the negative counterpart of a placebo. It means "I shall cause harm" and is essentially the manifestation of what a person fears. He or she displays physical symptoms and endeavours to identify factors in their environment that they consider to be likely causes. As with a placebo, this phenomenon can occur irrespective of whether the substance has any chemical effect. For instance, it has been reported that people who hear that the ozone levels have increased and that certain courses of action are recommended feel that this must affect them and can begin to worry that they are at risk. These people cite symptoms that the media have described as being typical of ozone exposure, e.g. irritated eyes, difficulty swallowing, difficulty breathing, pain when inhaling deeply, headaches, flaccidity and circulatory problems. Strikingly, these health complaints are cited where the ozone concentration is actually probably not high enough to cause such symptoms.

Conclusion

It is not possible to draw any health-related conclusions about an odour merely by perceiving it. Even if a human perceives a smell as being very strong it can still be lower than the analytical detection limit for that specific substance. Conversely, it is not always possible to detect all potentially hazardous substances by their smell. It is therefore important to take seriously any reports of unusual odours. They may be an indication that the air quality or other ambient conditions at the workplace are not as they should be.

The pertinent legal requirement can be found in Section 3.6, "Ventilation", of the Annex to the Arbeitsstättenverordnung (Ordinance on Workplaces) [5]. It states that the amount of healthy, breathable air in enclosed workrooms must be sufficient for the work processes, the level of physical strain and the number of employees and other persons present. Odour annoyance must therefore be avoided as far as the nature of the organisation's operations permits. As a rule, this means there must not be any unwanted odour emissions from products (e.g. construction chemicals), equipment (e.g. laser printers/copiers) or systems (e.g. ventilation and air conditioning systems).

4.5 References

[1] Roche Lexikon Medizin. 5th ed. Urban & Fischer, München 2003

[2] *Hatt, H.*: Geschmack und Geruch. In: *Schmidt, R. F.; Lang, F.* (ed.) Physiologie des Menschen – Mit Pathophysiologie. 30th ed. Sprinre, Berlin 2007, p. 422-438

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[4] *Habermann, E.*: Vergiftet ohne Gift – Glauben und Angst in der Toxikologie. Skeptiker (1995) No. 3, p. 92-100

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5 Special occupational medical investigations

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K. Sucker, Bochum

The procedure for special occupational medical investigations cannot be adequately described in the form of questionnaires and flowcharts. People's health is generally influenced not only by their workplace but also, to a significant degree, by factors such as individual constitution, medical history, home/family life, lifestyle and consumption habits. Consequently, the procedure and diagnosis usually need to be tailored to each specific case.

Since confidential matters and personal data are involved, the organisation's occupational physician should be responsible for coordinating these investigations. He or she will know the employee in question and be familiar with the adverse health effects of their workplace and their general state of health. The occupational physician is in a position to judge whether further investigations are necessary and to explain the occupational medical grounds for them. Ideally, he or she should work closely with the employee's family doctor who can disclose information on any health complaints the employee might have that are not related to the workplace. The latter, like the former, is bound by medical confidentiality. More often than not, the occupational physician can quickly determine whether the complaints presented were caused by a factor outside the workplace by sharing information and diagnoses with the family doctors and specialists treating the employee (release from medical confidentiality must be at hand). If there are grounds to believe that an employee's health has been impaired by their working environment, special investigations should be carried out in consultation with the occupational physician and based on the results of any other investigations.

It should be noted that it is not possible to list all of the competing and potential causes of the complex conditions that manifest themselves in individual health complaints. Questionnaire S1 (available at www.dguv.de/ifa, webcode e650356), which is intended to document employees' health situation outside the workplace, can therefore only point to possible and common causes.

6 Building, furnishings and building service systems

Building design, furnishings and building service systems are key potential contributors to health problems in indoor workplaces. In addition to construction and layout, the building materials and the technical equipment installed are of particular relevance.

6.1 Building parameters

N. Kluger, Frankfurt

Questionnaire S2 (which can be found at www.dguv.de/ifa, webcode e650356) deals with the building situation and is intended to help ascertain whether employees' health complaints might be linked to the building in which they work. S2 must be completed based on the information gathered in the investigation of the work environment using questionnaire G2 (see Annex 3, page 115) which must always be carried out beforehand. To gain full benefit, both investigations should be carried out in collaboration with the people responsible for managing the building.

If a building has serious defects (e.g. water damage), experts must be brought in to provide advice on the necessary repair work. Questionnaire S2 can be backed up by investigations specifically dealing with:

- ventilation and air conditioning systems (see Section 6.2),
- lighting (see Section 6.3),
- building materials and their condition (see Section 6.4),
- furniture, soft furnishings and carpets (see Section 6.4) and
- cleaning procedures (see Section 6.4).

6.2 Ventilation and air conditioning systems

B. Küter, Wiesbaden
G. Franke, Leipzig
T. von der Heyden, Sankt Augustin

Ventilation and air conditioning systems (VAC systems) include equipment for heating, cooling, humidifying and dehumidifying the supply air in rooms. Unlike heating systems, whose sole purpose is to heat indoor air during the winter months, ventilation and air conditioning systems are designed to keep purity, temperature, humidity, etc. of the air constant within certain ranges. Systems used for direct room heating (e.g. radiators or convection heaters) do not fall within the accepted definition of VAC systems. Nonetheless, just like VACs, they do have a certain impact on indoor air condition and quality.

Well-planned and regularly serviced VACs have a positive effect on indoor climate and the concentration levels of indoor air pollutants. By contrast, VACs that are poorly serviced or not serviced at all can generate complaints about the indoor climate as well as resulting in unwanted indoor odours. When filters, heaters, coolers or humidifiers are not serviced or designed in line with hygiene standards, biopollution can occur.

6.2.1 VAC classification

VAC systems form a subset of air handling technology [1] which can be divided into three categories:

- Natural ventilation:
  whereby the air is distributed by means of differences in pressure and temperature within and around the building
- Mechanical or forced ventilation:
  whereby the air is distributed via ventilators
- Hybrid ventilation:
  whereby natural ventilation is temporarily supported or replaced by mechanical ventilation.

There are various types of natural ventilation (see Figure 3). In all of them, the flow at which air is moved through a building can depend on the weather or the difference between the inside and outside temperature. As a result, these systems are unpredictable and unreliable.

Mechanical ventilation, on the other hand, allows the indoor air conditions to be defined irrespective of the weather and the conditions within the building. These systems are called ventilation, partial air conditioning or air conditioning systems, depending on the air handling method (see Table 2).

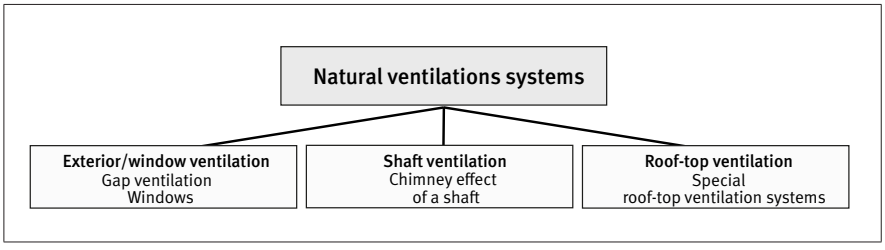


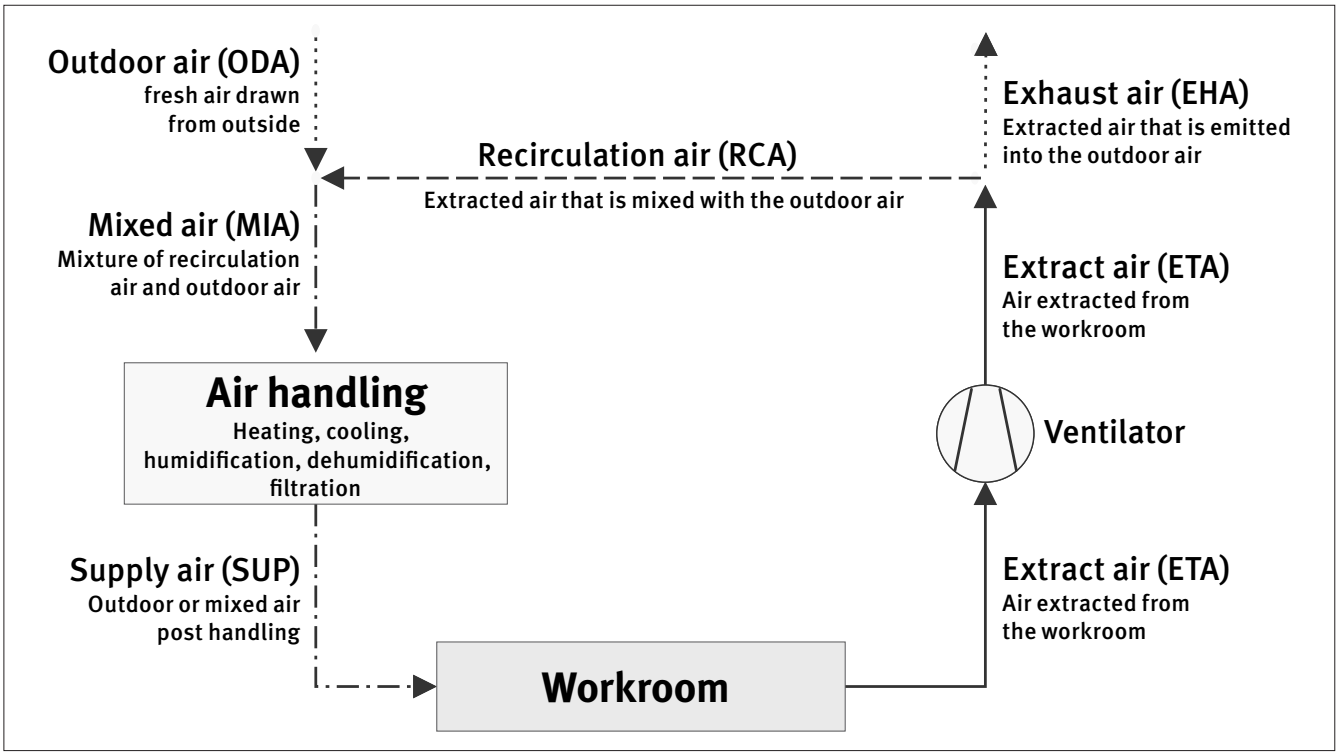
Figure 3:
Natural ventilation system types

Table 2:
VAC system types

Type of VAC system	Air handling method
Exhaust system	None
Ventilation system	Heating Cooling Humidification Dehumidification
Partial air conditioning system	Heating and cooling Heating and humidification Heating and dehumidification Cooling and humidification Cooling and dehumidification Humidification and dehumidification Heating, cooling and humidification Heating, cooling and dehumidification Cooling, humidification and dehumidification Heating, humidification and dehumidification
Air conditioning system	Heating, cooling humidification and dehumidification

Ventilation, partial air conditioning and air conditioning systems work using either outdoor air (ODA) or mixed air (MIA) – a combination of outdoor air and recirculation air (RCA) (Figure 4). There are certain exceptions, for example the warm-up phase outside of working hours, where these systems can also be operated using recirculation air only. They are then referred to as air recirculation systems.

Figure 4:
Airflows in VAC systems (mechanical ventilation)



6.2.2 Conducting the investigation

The question of whether there is a VAC system in the workplace is initially answered during the investigation of the work environment using questionnaire G2 (see Chapter 3). A special questionnaire (S3, which can be found on the internet at www.dguv.de/ifa, webcode e650356) is also available assessing heating and VAC systems in as much detail as possible. This information can then be used to assess the systems' impact on the quality of the indoor air and to detect fault sources. The questionnaire is divided into the following sections:

- Section A:
  Data pertaining specifically to the VAC system

- Section B:
  Data pertaining specifically to humidifiers (if present)

- Section C:
  Data pertaining specifically to the heating system

It is customary for the organisation to complete the questionnaire itself. Later, when the workplace is inspected, the answers on the questionnaire should be checked and, where necessary, corrected and information added. Figures 3 and 4, Tables 2 and 3 and the references listed at the end of this section provide guidance on key technical details.

Table 3:
Classification of air filters in accordance with DIN EN 779 [2] and DIN EN 1822 [3; 4]

Designation	Filter class
Coarse filter	G1 G2 G3 G4
Medium filter	M5 M6
Fine filter	F7 F8 F9
Highly efficient particulate air (HEPA) filter	E10 E11 E12 H13 H14 U15 U16 U17

The requirements concerning how the planning, design, customer approval, operation and servicing of VAC systems should ensure maximum hygiene are laid down in, amongst other documents, the standards DIN EN 13779 [5] and DIN EN 12599 [6] as well as in the Guideline VDI 6022, Part 1 [7].

To comply with the hygiene requirements and to ensure the VAC systems are properly maintained, trained employees (from the organisation) must check the systems at regular intervals. The intervals are also set out in Guideline VDI 6022, Part 1. They include the disinfection unit, which must be checked every six months to ensure it is in good working order, and the air filters, which need to be checked every three months for soiling, damage (leakage) and odours. The entire VAC system must undergo periodic hygiene inspections – carried out and documented by trained employees – every two years if the system has a humidification component and every three years if it does not.

Guidance on best practice in the maintenance and servicing of VAC systems, and specifically humidifiers, is available from a variety of sources. Examples are the servicing information drawn up by the Arbeitsgemeinschaft Instandhaltung Gebäudetechnik (AIG; Association for the Servicing of Building Service Systems) [8 to 10] and the humidification information pack produced by the Berufsgenossenschaft Energie Textil Elektro Medienerzeugnisse (BG ETEM; German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors) [11], which also deals with humidification in VAC systems.

6.2.3 Carrying out the evaluation

Experience has shown that specialist knowledge is generally required in order to appraise and assess VAC systems. Experts should therefore be commissioned to perform this work. Nonetheless, it is still useful to keep a record of one's initial visual impression during the investigation.

It is possible to determine beforehand whether the hygiene-related design and operating requirements for VAC systems specified in Guideline VDI 6022, Part 1 [7] have been complied with. This assessment concerns, inter alia, the air filters, humidifiers and the servicing (maintenance, inspection and repairs). Prior evaluation is possible because hygiene checks, cleaning and disinfection are usually documented, e.g. in a maintenance record or operating log. Experience shows that there are often records concerning air flow rate and indoor climate measurements. If these documents are already several years old, the information is usually no longer relevant. Another crucial aspect of the hygiene inspection is that the employees involved must have the necessary qualification (hygiene training category A, B, C or RLQ).

The Guideline VDI 6022 specifies that filters for central VAC systems must be at least class F7 (cf. Table 3). If the outdoor air is polluted, the filter requirements are higher. In special circumstances, the recommendation is to use two-stage filters with filter classes F7 + F9 (see VDI 6022, Part 3 [12]).

Where VAC systems cause noise pollution, the noise level must be between 35 and 45 dB(A) depending on the nature of the room (see Guideline VDI 2081 [13]).

Information concerning compliance with indoor climate parameters (including mean air velocity at the workplace ‹ 0.15 m/s, see also ASR A3.6 "Ventilation" [14]) is given in Chapter 9, "Indoor climate".

The water used in humidifiers must be of drinking quality. The total viable count (TVC) in the humidifier water should be no higher than 1,000 CFU/ml (CFU = colony forming unit). The total colony count for legionellae must not exceed 100 CFU/100 ml [7].

6.2.4 References

[1] DIN EN 12792: Lüftung von Gebäuden – Symbole, Terminologie und graphische Symbole (01.04). Beuth, Berlin 2004

[2] DIN EN 779: Partikel-Luftfilter für die allgemeine Raumlufttechnik – Bestimmung der Filterleistung (10.12). Beuth, Berlin 2012

[3] DIN EN 1822 Blatt 1: Schwebstofffilter (EPA, HEPA und ULPA) – Teil 1: Klassifikation, Leistungsprüfung, Kennzeichnung (01.11). Beuth, Berlin 2011

[4] Schwebstofffilter neu genormt – DIN EN 1822. VDMA Luftfilterinformation 06/2011. Published by: Verband Deutscher Maschinen- und Anlagenbau (VDMA), Frankfurt am Main 2011

[5] DIN EN 13779: Lüftung von Nichtwohngebäuden – Allgemeine Grundlagen und Anforderungen für Lüftungs- und Klimaanlagen und Raumkühlsysteme (09.07). Beuth, Berlin 2007

[6] DIN EN 12599: Lüftung von Gebäuden – Prüf- und Messverfahren für die Übergabe raumlufttechnischer Anlagen (01.13). Beuth, Berlin 2013

[7] VDI 6022 Blatt 1: Raumlufttechnik, Raumluftqualität – Hygieneanforderungen an Raumlufttechnische Anlagen und Geräte (VDI Lüftungsregeln) (07.11). Beuth, Berlin 2011

[8] AIG-Information Nr. 4: Luftbefeuchter in raumlufttechnischen Anlagen. Published by: Arbeitsgemeinschaft Instandhaltung Gebäudetechnik (AIG) der Fachgemeinschaft Allgemeine Lufttechnik im Verband Deutscher Maschinen- und Anlagenbau (VDMA), Frankfurt am Main 2004

[9] AIG-Information Nr. 6: Wartungsschwerpunkte bei Lüftungs- und Klimaanlagen. Published by: Arbeitsgemeinschaft Instandhaltung Gebäudetechnik (AIG) der Fachgemeinschaft Allgemeine Lufttechnik im Verband Deutscher Maschinen- und Anlagenbau (VDMA), Frankfurt 2001

[10] AIG-Information Nr. 7: Hygieneanforderungen in der Raumlufttechnik. Published by: Arbeitsgemeinschaft Instandhaltung Gebäudetechnik (AIG) der Fachgemeinschaft Allgemeine Lufttechnik im Verband Deutscher Maschinen- und Anlagenbau (VDMA), Frankfurt am Main 2001

[11] Informationen zur Luftbefeuchtung (03.12). Published by: Berufsgenossenschaft Energie Textil Elektro Medienerzeugnisse (BG ETEM), Köln 2012

[12] VDI 6022 Blatt 3: Raumlufttechnik, Raumluftqualität – Beurteilung der Raumluftqualität (07.11). Beuth, Berlin 2011

[13] VDI 2081 Blatt 1: Geräuscherzeugung und Lärmminderung in Raumlufttechnischen Anlagen (07.01). Beuth, Berlin 2001

[14] Technische Regeln für Arbeitsstätten: Lüftung (ASR A3.6). GMBl. (2012) No. 6, p. 92-97; last revision GMBl. (2013) No. 16, p. 359

6.3 Office lighting

S. Neumann, Hamburg

6.3.1 General aspects

Lighting requirements for workplaces are set out in the Arbeitsstättenverordnung (Ordinance on Workplaces) [1] and the Technical Rule for Workplaces ASR A3.4, "Lighting" [2]. DGUV Information 215-442, formerly BGI 856, "Office lighting" [3], adds more specific detail and recommendations.

This section outlines the salient requirements of ASR A3.4 and the DGUV Information 215-442 as well as providing guidance on how to assess lighting systems (see Section 6.3.5). The S4 questionnaire can also be downloaded from the internet (www.dguv.de/ifa, webcode e650356) as an aid.

6.3.2 Daylight

Daylight plays an important role in indoor lighting. An adequate supply of daylight, combined with as little obstruction of the outside view (undistorted and unaltered) as possible, has a positive impact on employees' sense of wellbeing and thus on morale and productivity.

Consequently, it is important that office rooms have adequately sized windows. This can be said to be the case if

- the area of the transparent window surfaces is equal to at least one tenth of the room's floor area or
- the daylight factor[2] at the workstations is at least 2%.

In addition, the proportions and balustrade heights must be such that, as far as possible, they do not obstruct employees' view of the outside environment. Where circumstances allow, the workstations should therefore be positioned near the windows, not in the middle of the room.

At the same time, the windows must be fitted with suitable, adjustable solar protection solutions (see DGUV Information 215-444, formerly BGI 827, "Sun protection in offices" [4]) so as to minimise glare and illuminance[3] caused by daylight shining on display screens.

Daylight alone is not enough to ensure good quality lighting (particularly adequate illumination) throughout the entire working day, whatever the season. This is true even if the workstations are positioned directly next to the window and make optimum use of the daylight. As a result, artificial lighting has to be used. The quality parameters described below refer to artificial lighting but the aims they serve in terms of protection can also be applied to daylight. It should be pointed out, however, that employees appreciate the positive effects of daylight and the

[2] The daylight factor is the ratio of the illuminance at a given point inside to the illuminance outside without any obstruction. The sky must be overcast [2].

[3] Illuminance is a unit of measurement for the light that hits a given surface. It is measured in lux (lx) [2].

fact that they can see outside. So they are willing to accept more extreme levels of glare, light colour, luminance variance, etc. caused by natural light and actually find them agreeable.

6.3.3 Lighting quality parameters

Lighting quality affects humans in two ways. Firstly, it influences vision, determining how quickly and precisely a person can discern detail, colour and shape. And secondly, it can boost or reduce activity and performance levels. Poor lighting can cause visual strain, leading to headaches, watery or stinging eyes or spots before the eyes.

The following lighting (or "photometric") quality parameters are particularly important when endeavouring to achieve an adequate standard of lighting for visual tasks at display screens:

- Level of illumination
- Luminance distribution
- Direct glare limitation
- Reflected glare limitation for display screens and other equipment
- Daylight glare limitation
- Light direction and shadiness
- Light colour and colour rendering
- Flicker-free lighting

Strain on employees can largely be avoided by ensuring these quality parameters are applied. The employees' eyesight must also be taken into account.

Level of illumination

Artificial lighting must provide an adequate level of illumination. For display screen and office workplaces, this requires a horizontal illuminance[4] of at least 500 lx. The same level is required for the work area "meetings". Surrounding areas must have a horizontal illuminance of at least 300 lx.

The illumination level is determined not only by the horizontal illuminances but also by the vertical illuminances[5] and the evenness of the illuminance distribution across the surface being assessed.

Since the illuminance values are minimum requirements, lighting systems must be serviced as soon as the specified minimum value is reached (see also Section 6.3.4, "Maintenance").

Luminance distribution

Luminance is the photometric parameter that quantifies brightness. To achieve unhindered vision, the luminance ratio in the field of vision must be balanced. This is the case if the ratio between the luminance

- in the work area (e.g. a sheet of paper) and the immediate surroundings (e.g. desk) is 3 : 1 ("task-to-surround ratio") and
- on large surfaces in the working environment (e.g. walls) and the work area (e.g. a display screen) is 10 : 1.

The differences in luminance should not be too slight as this gives rooms a monotonous look.

A room's boundary surfaces can be deemed to be adequately bright if the colour scheme is such that the reflectance is between

- 0.7 and 0.9 on the ceiling,
- 0.5 and 0.8 on the walls and
- 0.2 and 0.4 on the floor.

The recommended reflectance range for work planes, furnishings and equipment is 0.2 to 0.7. The recommended gloss level is matt to satin matt (60 ° reflectometer reading ≤ 20).

Direct glare limitation

Unwanted direct glare can occur in a room or in employees' field of vision due to bright surfaces (e.g. luminaires, windows or illuminated surfaces) and steps must be taken to limit it. The discomfort glare from luminaires is evaluated using the UGR (Unified Glare Rating) method [5]. The lower the UGR, the less the glare. In rooms with display screens and office workstations, the UGR must not be higher than 19, irrespective of the level of illumination.

Reflected glare limitation

Reflected glare, caused by high luminances being reflected on glossy surfaces, also has to be limited. It is therefore important to ensure that only LCD screens with good anti-glare properties are used at display screen workstations. Reflected glare on other work equipment can be avoided by complying with the recommended gloss levels (see "Luminance distribution"). It is also important to use matt paper and document wallets. Other factors that can help prevent reflected glare are the type of lighting (see "Lighting type") and the positioning of the luminaires.

Daylight glare limitation

To minimise daylight-induced direct and reflected glare, it is important that workstations are positioned in such a way that, as far as possible, employees' line of vision runs parallel to the main window area. Installing display screens in front of windows can result in direct glare due to significant differences in

[4] Horizontal illuminance E_h is the illuminance on a horizontal surface, e.g. a bench [2].

[5] Vertical illiminance E_v ist the illuminance on a vertical surface [2].

luminance between the screen and the surroundings. Windows close behind users can reduce the legibility of the display.

In addition, suitable, adjustable solar protection solutions must be affixed to the windows in order to limit glare and excessive illuminance caused by daylight.

Light direction and shadiness

Efforts should be made to ensure a good level of shadiness at the workplace. The lighting must be designed to provide adequate shadiness so as not to impair spatial perception. On the other hand, highly directed light should be avoided too as it creates sharp-edged and long shadows.

Light colour and colour rendering

Lamps with a light colour of warm white or neutral white should be used for display screen workstations. Lamps with a daylight white light colour should not be used unless the illuminance is relatively high (≥ 1,000 lx).

Lamps must have a colour rendering index R_a of at least 80 if they are to provide good colour rendering.

Flicker-free lighting

Where artificial lighting is used, unwanted flickering can occur. Flickering leads to impaired vision and fatigue. It can be prevented by using electronic ballasts.

6.3.4 Maintenance

Lighting systems must be serviced regularly and repaired as necessary. To ensure this requirement is met, a properly qualified lighting planner should draw up a service plan for each lighting system. Service plans specify the intervals for cleaning and replacing lamps, cleaning luminaires and redecorating the room's surfaces. The service plan must be followed once the system is in operation so as to make sure the illuminance does not drop below the specified maintenance value.

If the illuminance falls below the required minimum, the lighting system must be serviced. During the course of a lighting system's useful life, the illuminance decreases as the lamps, luminaires and room age and accumulate dirt. Consequently, a higher mean illuminance value (planning value) must be assumed when planning the system.

6.3.5 Assessing lighting systems

It makes sense to check the plans and calculations during the actual planning phase to verify that the system complies with the requirements concerning lighting quality parameters. It is almost always extremely difficult to modify a lighting system that has already been installed.

Another key point is that the service plan drawn up by the planner should be adhered to and the lamps and luminaires cleaned, the lamps replaced and the rooms redecorated as specified in the plan (see Section 6.3.4, "Maintenance"). This ensures that the illuminances do not drop below the specified maintenance values.

Despite these measures, it can sometimes be necessary to carry out an assessment of an existing lighting system. This is done, for example,

- to narrow down the potential causes of non-specific health problems,
- if employees have health complaints that could be due to inadequate lighting,
- if there is concern that the requirements pertaining to the lighting quality parameters of the lighting system have not been complied with or
- if the intervals set out in the service plan are to be extended.

A qualified person (e.g. an OSH professional, occupational physician or technical inspector) can carry out an indicative assessment of whether the illuminance requirements are met.

If a detailed assessment is needed to establish whether the lighting quality parameters comply with the requirements, an assessor should be brought in to conduct the measurements described in DIN 5035-6 "Beleuchtung mit künstlichem Licht – Messung und Bewertung" (Artificial lighting – Measurement and evaluation) [6]. It is also recommended that an assessor be brought in and, where necessary, measurements be carried out if a complaint is to be made about the lighting system to, for example, the person(s) who planned or installed it or to the lessor of the premises.

Indicative assessment of illuminance

Illuminance should be measured at intervals of approximately 20 to 50 cm, depending on the size of the room or work area, with the gaps between each measurement as evenly spaced out as possible. The luxmeter used should be at least class C (for screening measurements).

The measurements are performed

- at a height of 0.75 m for horizontal illuminance E_h and
- at a height of 1.20 m for the mean vertical illuminance $\overline{E}_v$

The mean of each illuminance value is calculated based on the individual measurements. The mean vertical illuminance can be measured using a cylindrical sensor or determined by measuring and averaging vertical illuminances (e.g. in four directions, each 90 ° to each other) at one point.

The following must be considered when measuring illuminance:

- extraneous light must be eliminated as far as possible, i.e. the measurements must be conducted after dark, without daylight and with solar protection closed;

- no shadow, e.g. from the person measuring or from tall items of furniture or furnishings in the room, should fall on the luxmeter's sensor;
- the lamps must be operating stably, i.e. the lighting system must have been powered up at least 20 minutes prior to the measurement being conducted;
- the air temperature must be in the usual temperature range, e.g. 20 to 26 °C for offices; and
- the operating voltage must be as close to the rated voltage as possible.

Ensuring correct light colour and colour rendering

When lamps are replaced, it is important to ensure that their light colour and colour rendering, as well as their power consumption, are as set out in the plans. The light colour and colour rendering of the fluorescent lamps used are indicated by a three-digit code which the manufacturer applies to the lamps. The first digit refers to the colour rendering properties and the second and third digits indicate the light colour.

6.3.6 References

[1] Verordnung über Arbeitsstätten (Arbeitsstättenverordnung – ArbStättV) vom 12. August 2004. BGBl. I (2004), p. 2179-2189; last revision BGBl. I (2010), p. 960-967

[2] Technische Regeln für Arbeitsstätten: Beleuchtung (ASR A3.4). GMBl. (2011) No. 16, p. 303-317

[3] DGUV Information 215-442: Beleuchtung im Büro; Hilfen für die Planung von Beleuchtungsanlagen von Räumen mit Bildschirm- und Büroarbeitsplätzen (formerly BGI 856). Published by: Verwaltungs-Berufsgenossenschaft, Hamburg 2009

[4] DGUV Information 215-444: Sonnenschutz im Büro (formerly BGI 827). Published by: Verwaltungs-Berufsgenossenschaft, Hamburg 2005

[5] DIN EN 12464-1: Licht und Beleuchtung – Beleuchtung von Arbeitsstätten – Teil 1: Arbeitsstätten in Innenräumen (08.11). Beuth, Berlin 2011

[6] DIN 5035-6: Beleuchtung mit künstlichem Licht – Teil 6: Messung und Bewertung (11.06). Beuth, Berlin 2006

6.4 Materials

N. Kluger, Frankfurt am Main

Materials, furniture, and cleaning and care products can have a major impact on indoor air quality since they are potential sources of gaseous or particulate emissions. The best known examples are formaldehyde, which is mostly emitted by chipboard and wood preservatives.

The information available on the materials and products used is usually sparse, if it exists at all. This tends to make it difficult to determine which harmful substances in the indoor air might have caused employees' health complaints. This section therefore has two objectives, as follows:

- Firstly, it sets out to show which substances are typically emitted as particulate matter or gas from certain materials (wood panels, adhesives, carpet, cleaning agents, etc.). These potential emissions can then be compared with any substances that might already have been detected in the indoor air, thus helping to identify the sources and/or eliminate the causes. Having said that, it is generally not possible to attribute a health complaint to one specific source without conducting further investigation.
- Secondly, it seeks to help provide effective ways of preventing health complaints by taking action early, while construction and furnishing are still underway, and to devise appropriate prevention strategies. To prevent disorders developing, action should be taken directly at the source. A large share of the many volatile organic compounds (VOC) that pollute indoor air comes from continuous emitting large-surface sources, such as furniture, building components and carpets. The fewer pollutants the materials emit into the indoor air, the better the quality of that air will be. Consequently, the process of choosing which materials are to be used in a building is particularly important. But recognising and selecting low-emission products is not always easy. This section aims to provide guidance for such situations.

6.4.1 General aspects

In order to prevent health complaints of occupants, new-build, reconstruction and refurbishment projects should only use construction chemicals (carpet adhesives, paints, varnishes, etc.) that cause minimum indoor air pollution. If emissions occur despite this strategy, it can be useful to heat the room and ventilate it to let in plenty of fresh air. In many cases, the emission rate falls to a very low value after a few months. However, some materials, among them chipboard, can continue to emit significant quantities of substances for longer – even up to several years.

Measures and procedures intended to improve indoor air quality by ensuring appropriate materials are selected do not necessarily go hand in hand with an improvement in the health and safety of the construction workers who work with the materials. For instance, for reasons of safety, (wood) flooring contractors must be advised to use low-solvent or, better still, solvent-free products instead of highly volatile adhesives with high solvent

contents. The high incidence of accidents involving severe burns caused by such products lends weight to this health and safety requirement. However, products with a low solvent content often contain solvents with a higher boiling point (e.g. glycol ethers). These substances have a low vapour pressure, with the result that they continuously emit small amounts of high boiling point solvents into the indoor air, thus causing long-term pollution.

To support the construction industry in its efforts to implement the wide range of regulations, the Berufsgenossenschaft der Bauwirtschaft (BG BAU; German Social Accident Insurance Institution for the building trade) have set up an information system on hazardous substances, known as "GISBAU" [1]. One of the aims of GISBAU is to supply information about the hazards posed by construction chemicals and to outline suitable protection measures. As part of this task, GISBAU joined forces with manufacturers representing a variety of product groups (e.g. floor installation products, epoxy resin coatings and parquet coatings) to develop a coding system called "GISCODE". The system classifies the products according to health and safety risks and helps buyers choose low-emission products without being tied to a specific manufacturer/supplier. The manufacturers indicate the relevant GISCODE on their price lists, safety/technical data sheets and packaging.

In a similar move, the "Ausschuss zur gesundheitlichen Bewertung von Bauprodukten" (AgBB; Committee for Health-related Evaluation of Building Products) has published a document detailing a health-related evaluation procedure for volatile organic compound emissions from building products [2]. In accordance with this procedure, emissions from building products are investigated in emission test chambers. Products made of wood or wood-based materials, for example, undergo test-chamber investigations, particularly if they are to be awarded the RAL-UZ 38 eco-label for "Low-Emission Furniture and Slatted Frames made of Wood and Wood-Based Materials" (see Section 6.4.3) [3]. The findings derived from these investigations can be used both to determine the relevant hazardous substances that are likely in the indoor air and to choose low-emission building products.

The first key step in the process of identifying an emission source is to establish what materials and products have been introduced into the building. This step should also take into account concealed sources (e.g. flooring adhesive beneath carpets) and temporary emitters (e.g. cleaning agents used to clean the workrooms on a daily or weekly basis). Special questionnaires for investigating

- building design and room setup (S5) and
- the procedures for cleaning of buildings (S6)

can be found on the internet (www.dguv.de, webcode e650356).

If information is available about relevant labels (GISCODE, EMICODE, RAL labels, etc.) for the materials and products used, it should always be on the questionnaires since it can usually provide an insight into any emissions. Often, this knowledge is also useful when shortlisting suitable materials and products for new buildings and workrooms. It can be assumed that these labels will become more reliable as a source of information with time and that the use of classified materials will result in far lower emissions.

6.4.2 Construction materials and construction chemicals

Large quantities of chemical products are used in the construction industry. Construction chemicals such as varnishes, adhesives or cleaning products are used in order to speed up and simplify work processes and make them more efficient. In many cases, it is practically impossible to perform construction, redecoration or cleaning tasks without using chemical products. Since hazardous substances are a vital ingredient in many types of construction chemicals, such chemicals distributed over a large area are among potential sources of hazardous emissions in indoor spaces.

The construction materials and chemicals most likely to influence indoor air quality can be divided into categories as shown in Table 4.

Broadly defined, construction chemicals include cleaning products too.

Cleaning agent residues can cause long-term pollution of indoor air due to their ingredients evaporating or outgassing. Common ingredients are preservatives or disinfectants (e.g. aldehydes), solvents (glycols, isopropanol), organic acids and propellants.

Table 5 shows some examples of which classes of substance can be emitted when using construction chemicals. In addition, Annex 5 contains a table showing possible sources for individual substances.

Table 4:
Categorisation of construction materials and construction chemicals

Category	Materials
Insulating materials	Mineral wool insulating materials Organic insulating materials (e.g. cellulose insulating materials) Plastic foams (e.g. polyurethane) Miscellaneous
Wood-based materials	Solid wood Glued laminated timber Wood-based panels Cork products Inorganically bonded raw materials Miscellaneous
Floor coverings	Smooth coverings (e.g. PVC, linoleum, rubber) Parquet, laminate Rugs, carpets Miscellaneous
Wall coverings	Wallpapers Vinyl wall coverings Fibreglass or textile wall coverings Miscellaneous
Coating and sealing systems	Wood preservatives and wood stain products Wall and ceiling paints Varnishes Plaster and fillers Adhesive systems Sealants Miscellaneous
Cleaning agents	Products for basic cleaning Products for routine cleaning Sanitary cleaning agents Disinfectant cleaning agents Care products Miscellaneous
Pesticides	Insecticides Fungicides

Table 5:
Classes of substance that can potentially be released when using construction chemicals

Application	Substance class
Coating tasks	Acetates, alcohols, amines (e.g. from epoxy resins), glycols/glycol ethers, ketones, hydrocarbons, phenols
Flooring tasks	Acetates, aldehydes, alcohols, pyrrolidones, isocyanates, hydrocarbons, amines (e.g. from epoxy resins)
Tiling tasks	Alcohols, hydrocarbons, amines (e.g. from epoxy resins), acrylates, isocyanates
Cleaning tasks	Aldehydes, alcohols, biocides, fluorine compounds, glycols/glycol ethers, surfactants, hydrocarbons
Wood glues	Acetates, aldehydes, alcohols, ketones, phenols, pyrrolidones
Wood preservatives	Chromates, fluorine compounds, biocides, hydrocarbons
Expanding foams	Ethers, isocyanates, hydrocarbons

6.4.3 Furniture

The probability of emissions is particularly high with new furniture. Test-chamber methods are now in place for examining emissions from furniture components, items of furniture and other coated woods and wood-based materials. A method of this type is used, for instance, as the basis upon which the RAL-UZ 38 eco-label is awarded [3]. In this case, the products must not exceed the emission levels specified for formaldehyde, total emissions of organic compounds with a boiling range of 50 to 250 °C (equivalent to the total volatile organic compounds or TVOC) or total emissions of organic compounds with a boiling range above 250 °C (Table 6). Where products that meet these criteria are used, the indoor emissions can be expected to be significantly lower.

There are four categories of material used in furniture-making, as follows:

- wood-based materials,
- adhesives,
- liquid coatings for wood and wood-based materials and
- solid coating materials (e.g. film or veneer).

Table 6:
Maximum emission values for low-emission furniture and slatted frames made of wood and wood-based materials for RAL-UZ 38 eco-label (as at January 2013) [5]

Compound or substance	Emission value (3rd day)	Final value (28th day)
Formaldehyde	-	≤ 0.05 ppm
Total volatile organic compounds in retention range C_6 to C_{16} (TVOC)	≤ 3.0 mg/m³	≤ 0.4 mg/m³
Total semi-volatile organic compounds in retention range › C_{16} to C_{22} (TSVOC)	-	≤ 0.1 mg/m³

The following paragraphs explain which substances these materials emit into indoor air. In addition, woods can be impregnated with preservatives; these cases are covered in detail in Section 12.4.9 of these recommendations.

Wood-based materials

The term "wood-based material" refers to any panel or board derived from wood. The most common of these is chipboard, used in furniture-making and interiors. Others include plywood, hardboard and MDF (medium-density fibreboard).

The main adhesives used in the production of chipboard are urea formaldehyde resins (UF), melamine urea formaldehyde resins (MUF), phenol formaldehyde resins (PF) and "polymeric" methylene diphenyl diisocyanate (PMDI). They can be used individually or in combination (e.g. top layer PF, middle layer PMDI or a mixture of different types of resin).

The moisture resistance requirements for chipboard for furniture and interior applications tend to be quite low. As a result, virtually all of the chipboard used is bonded with urea formaldehyde resin (UF). The other adhesives each account for roughly 5% of cases. Phenol formaldehyde resins and isocyanates are used if a higher level of moisture resistance is required (construction purposes) or where it is considered very important to keep formaldehyde emissions extremely low.

In the 1980s, there was considerable public interest in the issue of wood-based materials, especially chipboard, due to their formaldehyde emissions and the impact on indoor air quality. Emission classes were introduced for assessing formaldehyde emissions from wood-based materials (see Table 7). The classes are based on the amount of formaldehyde emitted by the material under specific conditions in a defined test room.

Table 7:
Emission classes for assessing formaldehyde emissions from materials

Emission class	Amount of formaldehyde emitted in ppm
E1	‹ 0.1
E2	0.1 to 1.0
E3	1.0 to 1.4

Class E2 and E3 board was used in buildings up until the middle of the 1980s. These types of chipboard are certain to emit formaldehyde even after several years have passed. Today, German law only permits E1 products to be sold and used in interiors. The situation is different in other European countries, however, where E2 products may also be sold. It is therefore important to check the emission class when considering products from manufacturers in other countries.

"E0" board, which is referred to as "formaldehyde-free", is also commercially available. The bonding agents in these types of board are cement, magnesite or gypsum. However, since wood in its natural state contains small quantities of formaldehyde anyway, it seems unlikely that efforts to produce "formaldehyde-free" wood-based materials will bear fruit [4].

Diller [5] assumes that it is possible to conform to a formaldehyde assessment value of 0.1 ml/m³ (ppm) provided only class E1 chipboard, or better, is used and there are no other significant sources of formaldehyde. If, however, chipboard is used extensively and the air replacement rate is low, this assessment value might be exceeded.

Adhesives

In the majority of cases, the adhesives used in furniture and interior components are based on ethylene vinyl acetate and amino resins because of the technical and economic benefits they offer. Hot-melt adhesives based on ethylene vinyl acetate are used for gluing edges. Small amounts of other adhesives are also used for special applications, e.g. to glue glass or metal. Polyvinyl acetate emulsion adhesives (PVAc adhesives) are by far the most important adhesives in furniture-making and interior construction. The chief reason for this almost certainly lies in the advantages they offer users, e.g. their ability to harden without heat having to be applied.

Liquid coatings for wood and wood-based materials

The percentage breakdown of wood varnish technologies used as liquid coatings for wood-based materials varies significantly from country to country in Europe. Besides one-part and two-part polyurethane varnishes and acid-catalysed varnishes, nitrocellulose varnishes still account for a major share of the liquid coating systems used in the furniture industry. UV-curing unsaturated polyester and acrylate varnishes are also used. However, there is a clear trend away from varnishes with a high solvent content towards varnishes with a high solid content (medium solids/high solids). This development has been boosted by Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations [6] and Directive 2004/42/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes [7]. Wood varnishes with a high solvent content (such as nitrocellulose varnishes, acid-catalysed varnishes and one-part and two-part polyurethane varnishes) are gradually

being replaced by UV-curing, water-based varnishes and modern coating methods. Table 8 shows the composition of a selection of varnishes.

The solvent residues in the materials are outgassed at different rates depending on the substance category. Aromatic compounds, for instance, are outgassed twice as quickly as alcohols in the initial phase. Where solvent mixtures are used, which is true of most varnishes, this variability results in differences between the relative share of the substances in the base raw varnish and in the indoor air. The aromatic compound content of a number of varnishes is around 20% but aromatic compounds only account for 2 to 10% of the total of all highly volatile organic compounds in indoor air. By contrast, the share of esters and alcohols in the air is usually higher than in varnish.

Table 8:
Composition of furniture-coating varnishes – examples (based on [8])

Varnish type	Solvent content in %	Solvent components
Nitrocellulose varnishes	70 to 80	30 to 50% esters 20 to 25% aromatic compounds 10 to 20% alcohols 10 to 15% ketones 10% alkanes
Polyurethane base coats	70	60% esters 20% aromatic compounds 20% ketones
Polyurethane hardeners	62	90% esters 10% aromatic compounds
UV-curing unsaturated polyester varnishes	40	98 to 100% aromatic compounds 1 to 2% alcohols 0.5% esters
Water-based varnishes	11	64% alcohols 18% aromatic compounds 18% ketones

Solid coating materials

Solid coating materials are also used to protect furniture surfaces or for decorative purposes. They include veneer, film and decorative paper. Depending on the type of materials used and the technology behind them, such products can also cause solvents, volatile organic compounds (VOC), etc. to escape into the indoor air.

6.4.4 Carpets

Since carpets can carry substances that contribute to indoor pollution, they must also be included in any investigation of the building and its furnishings. The main emissions of concern are VOC.

The Gemeinschaft umweltfreundlicher Teppichboden e.V. (GuT; Association for Environmentally-Friendly Carpets) tests health-related and ecological aspects of carpets and rugs [9]. If the materials in them comply with the GuT's "bans on use", e.g. for dyes containing heavy metals, and with the criteria used in the GuT contaminant-tested (relating to harmful substances such as formaldehyde, benzene and volatile organic compounds) they are awarded the GuT label (see Figure 5).

Carpet adhesives

Carpet adhesives, in particular, can impair indoor air quality. In an effort to counter the problem, German adhesive manufacturers have set up an association, the Gemeinschaft Emissionskontrollierte Verlegewerkstoffe (GEV; Association for the Control of Emissions in Products for Flooring Installation, Adhesives and Building Materials). Its aim is to create a new generation of "very low-emission" flooring installation products, adhesives and building materials in cooperation with the raw materials industry to ensure a certain level of health protection for consumers.

The partners have also developed an emission classification system to provide consumers with the facts they need to make informed decisions when selecting products. This product labelling system, EMICODE®, is based on a precisely defined chamber test and strict classification criteria. The fact that all GEV members use EMICODE® gives everyone in the industry a reliable basis upon which to make product choices. The EMICODE® approach classifies products into three categories (Table 9) [10].

All materials bearing the EMICODE® label (Figure 6) have been emission-tested and have no added solvents. Substances that are or are suspected of being carcinogenic, mutagenic or toxic to reproduction (CMR substances) are not permitted in these materials.

Figure 5:
GuT label

Figure 6:
EMICODE label; sehr emissionsarm = very low-emission

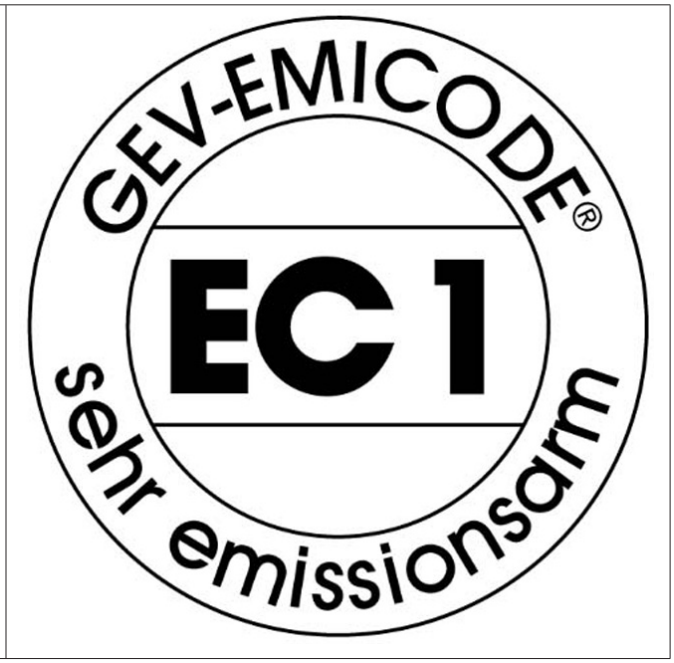


Table 9:
EMICODE® classes; *) Products classified as EMICODE EC 1 PLUS are subject to additional requirements, TVOC = total volatile organic compounds with a boiling range of 60 to 250 °C, TSVOC = total semi-volatile organic compounds with a boiling range above 250 °C

Class	Emitted concentration of volatile organic compounds in µg/m³	
	TVOC after three days	TVOC/TSVOC after 28 days
EMICODE EC 1 PLUS very low-emission*)	≤ 750	≤ 60/40
EMICODE EC 1 very low-emission	≤ 1,000	≤ 100/50
EMICODE EC 2 low-emission	≤ 3,000	≤ 300/100

6.4.5 References

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7 Workplace

It is essential that indoor workplaces correspond with the needs and attributes of the people who work in them. Otherwise, both the workplace design and the work equipment used can prompt complaints from employees. The following section gives advice on how to investigate and assess workplace design and the work equipment selected, including laser printers/copiers and display screen equipment.

7.1 Workplace design

S. Neumann, Hamburg

The Arbeitsstättenverordnung (Ordinance on Workplaces) [1], particularly its annex, and the Technical Rules for Workplaces [2] specify key requirements concerning the design of indoor workplaces.

The Bildschirmarbeitsverordnung (Ordinance on Display Screen Work) [3] sets out the general health and safety requirements for work using display screen equipment, transposing the European Display Screen Directive [4] into national law for the Federal Republic of Germany. DGUV Information 215-410, formerly BGI 650 "Bildschirm- und Büroarbeitsplätze" (Display screen and office workstations) [5] defines the ordinance's requirements in more detail. As a general rule, people who work with display screen equipment (DSE) should be offered regular eye and eyesight tests, carried out by a person with the necessary capabilities (DGUV Principle G37 [6]). The German statutory accident insurance institutions have also published various brochures [7 to 16] providing information and guidance on specific topics in the area of office workplace design.

7.1.1 Investigation and assessment of the workplace

A special questionnaire, S7, dealing with workplace environment and work equipment, is available on the internet (www.dguv.de, webcode e650356). It was developed on the basis of the above-mentioned DGUV directives, ordinances and informative publications on office workplace design. The questionnaire can be used to investigate whether particular health complaints can be attributed to non-ergonomic workplace design.

The S7 questionnaire does not include lighting, noise or indoor climate because they are covered at length in Section 6.3 and in Chapters 8 and 9. Occupational safety aspects, such as prevention of tripping hazards, are also not included.

Some of the questions on the questionnaire indicate potential solutions. For instance, the questions concerning furniture, hardware, software and positioning of work equipment give guidance on workplace design.

7.1.2 Reduction of musculoskeletal strain

The following recommendations are intended to help reduce musculoskeletal strain:

- the strain caused by poor or uneven posture (e.g. twisted posture or prolonged periods in a seated position) or repetitive movements (e.g. prolonged use of a keyboard) should be reduced by shortening the period spent on such activities. This can be done by combining different tasks, giving the employee additional tasks or ensuring sufficient breaks;

- favourable posture and changes in posture should be promoted by ensuring individually adjustable and ergonomic workstations.

7.1.3 References

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7.2 Laser printers and copiers

T. von der Heyden, Sankt Augustin

Laser printers and copiers have become an indispensable part of modern office life, used by millions of people every day. However, reports of potential health hazards due to laser printers purportedly causing exposure to toner dust have provoked public concern on more than one occasion. It was this concern that, more than a decade ago, prompted the Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA; Institute for Occupational Safety and Health of the German Social Accident Insurance, formerly known as BGIA) to conduct numerous projects on this topic in cooperation with the Verwaltungs-Berufsgenossenschaft (VBG; German Social Accident Insurance Institution for the administrative sector). The aim of this work was to identify the emissions released by laser printers and copiers and to assess whether they were potentially harmful to health [1 to 3]. In addition to the IFA's activities in this field, the Landesgewerbeanstalt Bayern (LGA Bayern; Bavarian state trade agency) emission-tested various devices and toners between 2000 and 2007 [4]. The findings of this research remain valid today since printer technology has not undergone any significant change since then. They show that laser printers and copiers do not emit significant amounts of dust or gas (see the sections on the individual substance categories).

In the interests of environmental and user protection, the "Environmental Label Jury" has developed award criteria, referred to as RAL-UZ 122 [5] and RAL-UZ 171 [6], for office equipment that has a print function (printers, copiers and multifunctional devices (MFDs)) (Figure 7). As well as general requirements, e.g. recyclability and power consumption, and toner substance requirements, a major part of the awarding process involves emission testing. Chamber tests are carried out to determine the quantities of dust, ultrafine particles (UFPs), ozone, TVOCs, benzene and styrene emitted. The emissions are assessed on the basis of the current guideline values for environmental or indoor emissions, which are far lower than the applicable occupational exposure limits (OELs).

Generally speaking, the equipment is only tested in combination with the toner and paper sold for the specific device in question. In practice, however, the toner used often comes from a different manufacturer or in a recycled toner cartridge and has not been tested in conjunction with the device. The former Fachausschuss Verwaltung (Expert Committee for the Administrative Sector) has therefore created an additional DGUV Test certification mark for toner powder, which indicates that the product has been pollutant-tested (Figure 8) [7]. The intention is that this will assist buyers of toner cartridges when judging quality and comparing products. Toners bearing this mark meet strict requirements concerning the metals, volatile organic compounds and other substances they contain as well as particle size.

Figure 7:
“Blue Angel” for office equipment with a printing function (printers, copiers and MFDs)

Figure 8:
Special DGUV Test “pollutant tested” mark

Paper is a source of emissions too. Due to the design parameters for laser printers, the paper is briefly heated to roughly 150 to 200 °C, which can cause it to give off certain substances. The award criteria for the Blue Angel RAL-UZ 14 eco-label [8] for recycled paper (Figure 9), which include numerous environmental aspects, also consider potential emissions of volatile organic compounds if the paper is of a type intended to be used with electrophotographic printers or copiers (known as copying paper).

In situations where laser printers are used a great deal or several devices are operated simultaneously, it is always recommendable to place them outside the office.

Figure 9:
“Blue Angel” for recycled paper

7.2.1 Dust

The research conducted by the BGIA (now IFA) and LGA Bayern did not reveal any significant toner dust emissions. The RAL-UZ 122 and RAL-UZ 171 award criteria give an emission rate of 4.0 mg/h of dust (usually paper dust) as the maximum permissible value during the printing phase.

7.2.2 Metals

Most black toners have an iron content of 25 to 33%, in the form of iron oxide. The research carried out at the BGIA detected parts-per-thousand levels of titanium, strontium, copper and zinc compounds.

The copper and titanium content of colour toners is usually low. The IFA (formerly BGIA) also found chromium, iron, zinc, tin and strontium in various colour toners. The cobalt and nickel content (substances that are particularly problematic because of their sensitising effect) of the toners was either zero or trace.

For a toner to be awarded the “pollutant tested” mark, it must comply with the maximum content levels shown in Table 10 for the various metals contained in toner powder, which are specified in the “Grundsätze für die Prüfung und Zertifizierung von Tonerpulver schwarz und farbig für Laserdrucker und Kopiergeräte” (Code of rules for testing and certifying black and colour toner powders for laser printers and copiers) [7].

The award criteria for the Blue Angel eco-labels RAL-UZ 122 and RAL-UZ 171 go even further. They stipulate that toners must not contain any substances whose constituent parts include mercury, cadmium, lead, nickel or chromium(VI) compounds. The exception is nickel complexes with a high molecular weight, which may be used as pigments. Contamination with heavy metals, such as cobalt or nickel oxides, caused by the manufacturing process must be kept as low as technically possible and economically viable [5; 6].

Table 10:
Limit values for metals in toners in accordance with the requirements for the DGUV-Test "pollutant tested" mark

Metal	Limit value in mg/kg
Cadmium	5.0
Cobalt	25
Nickel	70
Lead	25
Mercury	2.0
Chromate (in the form of chromium)	1.0
Organotin compounds (in the form of tin)	5.0

7.2.3 Ozone

Modern laser printers do not usually emit ozone. In fact, today's black and white laser printers mostly use ozone-free technology, which means they do not need an ozone filter. Black and white and colour devices that do produce ozone only emit negligible quantities, at a level that can be regarded as not harmful to humans, provided the ozone filter is intact and working properly. It is therefore imperative that maintenance be carried out regularly, including filter replacement where necessary. If this is not done, the ozone concentrations can increase to a much higher level. This is particularly an issue with old devices [1; 4]. In accordance with the award criteria for the Blue Angel RAL-UZ 122 and RAL-UZ 171 eco-labels, black and white devices must not exceed an ozone emission rate of 1.5 mg/h during printing and colour devices must not exceed 3 mg/h. When judging the ozone concentrations produced by laser printers during printing, it is important to bear in mind that ozone breaks down into oxygen on walls and other surfaces. The half-life for this process is approximately 30 minutes. In other words, once half an hour has passed, the amount of ozone is only half of what it was originally. If ozone is continuously emitted (from equipment or the outside air), the ozone formation and breakdown processes balance each other out.

7.2.4 Volatile organic compounds (VOCs)

All laser printers and copiers emit volatile organic compounds (VOC) during printing and copying. This is due to technical factors and practically impossible to avoid with today's technology. Consequently, when assessing laser printers it is not important to determine whether they emit VOC but rather to establish the nature and quantity of the compounds released. The award criteria for the Blue Angel eco-labels RAL-UZ 122 and RAL-UZ 171 specify the following maximum values for total volatile organic compound (TVOC) emissions:

- 10/18 mg/h
  (black and white/colour device) during printing

The award criteria for the special DGUV-Test "pollutant tested" mark specify a maximum TVOC content of 1,000 mg/kg for toners.

The criticism surrounding these devices mainly concerns benzene, which can be emitted during printing and is classified as a carcinogen [9]. Though many black and white and colour laser printers do not give off any benzene at all, some have been found to do so. The LGA Bayern investigated benzene emissions from laser printers extensively, focusing on:

- Benzene content in toners
  Based on 585 toners examined, the mean value was 3 mg/kg and the median was < 0.1 mg/kg.

- Benzene emission rates from laser printers and copiers
  Based on 266 devices examined, the mean value was 0.09 mg/h and the median was 0.04 mg/h.

When the LGA Bayern began conducting these investigations, in 2000, benzene was detected frequently. In the years thereafter (up until 2007), it only found the substance on rare occasions. Both the LGA Bayern investigations and the IFA's activities in this field have proved that most devices do not emit any benzene or only emit insignificant quantities of the substance, usually equivalent to the general level of benzene pollution in the environment.

The award criteria for the RAL-UZ 122 and RAL-UZ 171 Blue Angel eco-labels set a maximum benzene emission rate of 0.05 mg/h during printing. The award criteria for the DGUV-Test "pollutant tested" mark for toners specify a maximum benzene content of 1 mg/kg.

The Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe (Senate Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area) of the Deutsche Forschungsgemeinschaft (DFG; German Research Foundation) has classified styrene, which is also emitted from such products, as "carcinogen category 5". This means that its *"intensity (...) is considered so low that no significant contribution to the risk of cancer to humans is anticipated provided the MAK value is adhered to"* [10]. The measurements carried out by the BGIA found the concentrations to be lower than two hundredths of the OEL. A few devices, however, did exceed the indoor air guide value I (30 µg/m³) specified by the Umweltbundesamt (UBA; Germany's Federal Environment Agency) [11].

The LGA Bayern also examined styrene emissions. The mean value for the styrene emission rate for the 266 devices in the period 2000 to 2007 was 0.9 mg/h and the median was 0.27 mg/h.

The award criteria for the Blue Angel eco-label specify a maximum styrene emission rate of 1.0/1.8 mg/h (black and white/colour device) during printing. To be awarded the DGUV-Test "pollutant tested" mark for toners, toners must not exceed a styrene content of 40 mg/kg.

The devices also emit varying quantities of other volatile organic compounds, such as toluene, xylenes, ethylbenzene and trimethylbenzenes. However, all of the concentrations measured were several orders of magnitude below the current occupational exposure limits.

7.2.5 Overall assessment

The following conclusions can be drawn from the investigations described above:

- Modern laser printers and copiers do not emit significant amounts of toner dust during printing. Consequently, there is no reason to assume a heightened health risk due to toner dust being absorbed through the respiratory system. If there is a possibility that, for example, toner dust might be emitted into the air when refilling cartridges, appropriate exhaust systems must be installed.

- If cartridges are replaced as prescribed, the toner does not usually come into contact with skin. If contact with the toner cannot be ruled out for certain devices, protective gloves should be worn when replacing the cartridge. Should contact with the skin occur despite this precaution, the toner must be removed from the skin using cold water and soap. Employees who potentially have frequent contact with toner (during servicing or recycling tasks) should always wear protective gloves to rule out any chance of direct contact with toner.

- Nowadays, laser printers do not pose a problem in terms of ozone formation since many devices already have completely ozone-free technology. Where devices do produce ozone, it is crucial that the ozone filter is maintained as prescribed. Spent ozone filters can cause the ozone values to increase. People who are very sensitive to ozone should certainly look for devices with ozone-free technology. If a laser printer is to be replaced anyway, preference should be given to devices with ozone-free technology.

- All laser printers emit VOC to varying degrees. The concentrations measured are several orders of magnitude lower than the occupational exposure limits in force. With the exception of the indoor guideline value I for styrene, which is occasionally exceeded, they also comply with the considerably more stringent environmental and indoor guideline values. The emitted quantities of the carcinogenic substance benzene corresponded to the general level of benzene pollution in the environment. Nonetheless, as it is not possible to specify a threshold value for the carcinogenic effect of benzene, it is up to device and toner manufacturers to enhance today's technology to ensure that future products to not emit any benzene.

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7.3 Display screen equipment

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The display screen equipment (DSE) used at computer workstations largely falls into one of two categories. The first is liquid crystal display (LCD) equipment, often called "thin film transistor" (TFT) or "flat" screens. The second is cathode ray tube (CRT) equipment though these products only account for a fraction of new purchases today.

Although DSE work in itself does not expose workers to adverse conditions, it can lead to health problems. The causes include tasks requiring high levels of concentration, prolonged, tiring tasks, eyesight problems, poor lighting, glare and non-ergonomic workstation design. These can provoke symptoms such as fatigue, eye problems, headache, muscle tension, back problems, etc. (see the relevant sections of this report). To prevent these symptoms, DSE workstations must conform to health requirements, as set out in the Bildschirmarbeitsverordnung (Ordinance on Display Screen Work) [1]. DGUV Information 215-410, formerly BGI 650, "Bildschirm- und Büroarbeitsplätze – Leitfaden für die Gestaltung" (Display screen and office workstations – A guide to workstation arrangement)[2] gives specific guidance on how to implement the ordinance.

7.3.1 Radiation emission from display screen equipment

Depending on the type of DSE, electric and magnetic fields are generated within the equipment, as are various types of radiation. As Chapter 10 of these recommendations explains in detail, both CRT and LCD screens only cause very low emissions of electric, magnetic and electromagnetic fields. The amounts of other types of radiation emitted (see below) are also small. There is therefore no reason to be concerned about radiation emissions from DSE posing a risk to health. This is true of all DSE workstation scenarios, including multiple-monitor set-ups within one room, monitors installed at opposite workstations and pregnant women performing DSE tasks.

In contrast to LCD display screen equipment, CRT equipment is often subject to interference from electromagnetic fields, e.g. from the building's power distribution system. This can lead to flickering and changes in brightness and colour. CRT screens are particularly prone to this problem because even low-strength magnetic fields cause interference in them. For instance, a magnetic flux density of approximately 0.4 µT (caused, for example, by a passing electrically powered train) is sufficient to cause interference in sensitive equipment.

When electromagnetic fields have an impact on CRT equipment in the workplace, employees are often concerned that the fields might be harmful to humans too. However, such concerns are unfounded since interference can be caused even when the field strength is far lower than the threshold values specified for human protection.

Unlike with LCD screens, electrostatic field strengths of up to 7,000 V/m can occur at a distance of 30 cm from the surface of a CRT screen [3]. More modern CRT screens generate lower field strengths. The DGUV regulation 16, formerly BGV B11, "Elektromagnetische Felder" (Electromagnetic fields) [4] stipulates that the electrical field strength in static fields must not exceed 20,000 V/m. This value is complied with when working at CRT monitors. Charge can cause dust particles to be drawn in from the air if it is not directed away, as is the case with modern equipment.

Ionising radiation

Extensive research by the Physikalisch-Technische Bundesanstalt (PTB; Germany's national metrology institute) and measurements performed by the Karlsruhe Nuclear Research Centre (now part of the Karlsruhe Institute of Technology; KIT) show that exposure to ionising radiation at CRT screens is usually around two orders of magnitude lower than the level of natural radiation to which all humans are constantly exposed [3; 5]. This research also measured the radiation behind the monitors – an especially important aspect when several people work in one office and are consequently very close to the back of the monitor opposite them. Even in these cases, however, the additional exposure caused by X-rays emitted from the DSE was far below the level of natural radiation exposure.

Owing to the imaging technology they use, LCD screens do not generate any ionising radiation.

Optical radiation

Optical radiation is subdivided into ultraviolet radiation (UV), visible radiation (light) and infrared radiation (IR).The radiation in the visible spectrum is the desired form since screens' display functions use visible light.

All three types of radiation mentioned above are generated inside CRT equipment when the electron beam from the tube hits the fluorescent layer. IR radiation is also produced as a result of heat build-up in the tube's cathode.

Almost all of the UV radiation generated in CRT monitors is absorbed by the glass of the tube so the intensity measurable outside on the screen's surface is very low [6]. For instance, the maximum irradiance measured in the UV-A range is lower than 10 mW/m^2 [7]. The UV-B radiation values are three to six orders of magnitude below that. The UV-A exposure for an eight-hour work shift is less than 288 J/m^2, comparable with the eye exposure threshold values of 10,000 J/m^2 recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [8 to 10]. Consequently, UV radiation emission from CRT screens does not pose a risk for humans.

The intensity of the visible radiation emitted by CRT monitors in order to display information is considerably lower than the level that is potentially harmful to the eyes.

IR radiation emission from CRT display screen equipment is also negligible [6].The measured irradiance is 200 mW/m^2 [7] whilst the limit values recommended by the ICNIRP is 100,000 mW/m^2 [11]. Health risks from IR radiation emission are therefore unlikely too.

Besides the desired visible radiation, LCD screens emit UV and IR radiation. However, the UV and IR intensity is low and roughly equivalent to that of conventional fluorescent tubes. This means that LCD screens are not harmful to users either, be it through the visible radiation or UV and IR radiation emissions.

7.3.2 Display screen robustness to lighting

Display screens have optically transparent surfaces that reflect part of the light that falls on them. This reflection is either spectral (e.g. in the case of untreated screen surfaces) or diffuse (e.g. in the case of roughened screen surfaces).

Unwanted reflection is disadvantageous in DSE work because it reduces the contrast between the individual characters on the screen, making it more difficult to distinguish between them. Moreover, users have to concentrate harder in order to comprehend the information on the screen properly. The stronger the reflection, the more adverse the effect on the user, which is why screens should always have an anti-glare surface. It is therefore essential that buyers of display screen equipment ensure the equipment has good anti-glare properties. This is particularly true of notebooks, which are often used in lighting conditions that are less than ideal.

In the past, the reflective properties of display screens were divided into three reflectance classes, for positive and negative display, in accordance with DIN EN ISO 9241-7 [12] and DIN EN ISO 13406-2 [13]. The current standard, DIN EN ISO 9241-307 [14], no longer includes these reflectance classes. Instead, it specifies the test conditions under which display screen reflection should be measured (Table 11). Accordingly, today's Geprüfte Sicherheit (GS; tested safety) certificates include the following statements:

Light source with large aperture = 200 cd/m²

and

Light source with small aperture = 2,000 cd/m²,
equivalent to former reflectance class I

A display screen with these anti-glare properties can be used without hesitation in any office environment and is therefore unconditionally recommended.

Since screens' reflective properties depend on the display mode, there might be different figures given for positive and negative display. If not, the equipment either comes with positive or negative display only or it has the same reflective properties regardless of the display mode.

In addition to these anti-reflection measures, another step that can be taken is to display dark characters on a light background (positive display). This reduces the disruptive effect of any reflections that cannot be completely avoided as well as lessening the restrictions on the positioning of equipment within the work environment.

It should also be noted that colour difference, i.e. the difference between two colours, becomes more difficult to discern with increasing illumination of the screen from the ambient lighting. This is particularly true with screens that offer good anti-glare properties. The same applies to luminances and contrasts, though to a lesser degree. It is for these reasons that manufacturers now state the on-screen illuminance for which the product is suitable. Technical data sheets and GS certificates indicate the intended screen illuminance in lux. This parameter refers to the maximum permissible illuminance on the screen from the ambient lighting. The actual illuminance on a given screen can be measured at the workstation in question using a luxmeter (with the probe turned outwards).

To ensure that screens can display distinguishable colours even at workstations close to windows, it is recommended to use screens with a declared intended screen illuminance of at least 1,500 to 2,000 lux. Although reflective screens are not as sensitive to high illuminances, their higher reflectance makes them unsuitable for office environments (see above).

As filters added in front of screens often result in poorer display, they should only be used once all factors have been carefully considered. For instance, it should be possible to adjust the screen brightness to compensate for any reduction in brightness caused by attaching a filter.

Table 11:
Reflectance classes as per DIN EN ISO 9241-307 and former reflectance classes as per DIN EN ISO 13406-2; large AP = large aperture, small AP = small aperture

Reflectance classes as per DIN EN ISO 9241-307, Luminance from directed reflected light sources in cd/m²	Suitable environment	Former reflectance class as per DIN EN ISO 13406-2
$L_{large\ AP}$ = 200 and $L_{small\ AP}$ = 2 000	Screens of this type can be used in any office environment.	I
$L_{large\ AP}$ = 200 or $L_{small\ AP}$ = 2 000	In unfavourable lighting conditions or locations close to windows, unwanted reflections may appear on these screens.	II
$L_{large\ AP}$ = 200 or $L_{small\ AP}$ = 2 000	The reflection on these screens is usually so disruptive that they are not suitable for office work in normal office environments.	III

7.3.3 References

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8 Noise

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8.1 General aspects

Noise is unwanted sound that causes a nuisance, disruption, impaired performance, specific accident hazards and harm to health. Behind this general definition lies a wide range of impacts that exposure to noise can have on humans, which are classified as either auditory or non-auditory effects.

Auditory effects of noise take the form of temporary hearing loss (also known as temporary threshold shift, TTS) or irreversible damage to hearing following long-term exposure to noise at high sound pressure levels (SPLs) or a single, intense impulse sound (e.g. a bang). The exposed person's subjective perception has no bearing on the auditory effect of the noise.

The term "non-auditory" refers to all of the other effects of noise. Examples include impaired speech intelligibility, diminished concentration and physical reactions such as stress and cardiovascular problems. The non-auditory effects of noise are at least partly linked to the subjective perception of the exposed person.

Workplace noise assessments must cover both the auditory and non-auditory effects. The ordinances and guidelines currently applicable are outlined in Section 8.2.

8.2 Ordinances

Section 3.7 of the Annex to the Arbeitsstättenverordnung (Ordinance on Workplaces) [1] stipulates the following requirements for noise protection in the workplace:

"The sound pressure level (SPL) in workplaces must be kept as low as is possible for the type of organisation concerned. The SPL in workrooms must be reduced, in line with the room use and the tasks to be performed, to a level that does not impair employees' health."

Though worded in general terms, this is a relatively strict workplace design requirement. It places the employer under an obligation to ensure that employees' health is not impaired by noise in any way, using state-of-the-art methods. It is thus particularly aimed at the potential non-auditory effects of noise.

The Lärm- und Vibrations-Arbeitsschutzverordnung (Occupational Health and Safety Ordinance on Noise and Vibrations) of 6 March 2007 [2] stipulates that employers must identify and evaluate the workplace noise exposure as part of their risk assessment. To protect employees from noise hazards and thus the auditory effects of noise, the ordinance cites action values for the daily noise exposure level and the peak SPL. It also gives maximum permissible exposure values, which relate to the noise level under hearing protectors and must not be exceeded under any circumstance.

Neither the Occupational Health and Safety Ordinance on Noise and Vibrations nor the associated technical rules [3] are expanded on in the following as they merely outline the steps to be taken to provide protection against the auditory effects of noise if the lower exposure action value of $L_{EX,8h}$ = 80 dB(A) is exceeded. This is unlikely to happen in indoor workplaces.

8.3 Non-auditory effects of noise

Non-auditory, i.e. physiological, vegetative and psychological, effects of noise impact upon employees' health, safety and performance in the following ways:

- Noise affects the central nervous system and triggers physiological responses. Depending on the intensity, duration and frequency levels of the noise exposure and the individual's disposition, these responses can lead to noise-stress reactions. The consequences include, for example:
  - narrowing of blood vessels,
  - increase in blood pressure,
  - increase in heart rate,
  - reduction in electrical skin conductance,
  - acute increase in muscle tone,
  - increased release of stress hormones,
  - decrease in stomach and intestinal activity,
  - restriction of field of vision and
  - delayed signal processing in the brain.
- Noise can trigger psychological reactions such as
  - irritation,
  - tension,
  - resignation,
  - fear and
  - nervousness.
- Furthermore, noise can
  - reduce attentiveness and concentration,
  - impair voice communication and thus cause misunderstandings, leading to incorrect decisions,
  - increase error rates and
  - decrease responsiveness.

Since such non-auditory noise effects cannot be assumed to be subject to a simple dose-effect relationship, the daily noise exposure level is not a suitable means of assessing them.

8.4 Parameter and guide values for non-auditory effects of sounds in the workplace

The rating level defined in DIN 45645 [4] is commonly used as the parameter for assessing the non-auditory effect of sounds in the workplace. The rating level is composed of the equivalent continuous sound exposure level L_{pAeq} of the activity being assessed plus any necessary adjustments for the degree of the impulse and the tonality and information content of the sound. It is calculated as shown in equation (1)

$$L_r = L_{pAeq} + K_I + K_T \quad (1)$$

where

L_r: Rating level

L_{pAeq}: Equivalent continuous sound exposure level

K_I: Adjustment for degree of the impulse

K_T: Adjustment for tonality and information content

The following preconditions must be considered when conducting the assessment:

- activities that occur during a single shift and pose different requirements must be assessed separately;
- work sub-intervals with significantly different sound exposures must be assessed separately if the phase lasts at least one hour;
- inherent sounds, such as a person‘s own voice, the voice of the person they are talking to, the ringing of a person‘s own telephone or the sound of a person‘s own typing must be blocked out;
- an adjustment of up to 6 dB maximum must be applied for the degree of the impulse where impulsive sound is subjectively perceived as an annoyance and the degree of the impulse is at least 3 dB;
- an adjustment of 3 dB or 6 dB can be applied for the tonality and information content depending on how extreme they are; and
- the total adjustments must not exceed 6 dB.

The rating level therefore differs from the daily noise exposure level in that the latter refers to the total exposure during an eight-hour shift and does not include any adjustments.

In addition to the above-mentioned influencing parameters, which can be measured acoustically, the Guideline VDI 2058, Part 3 [5] also cites the non-measurable factors listed in Table 12 for use in sound assessment.

The activity-specific requirements listed in Table 12 are the essential characteristics in determining the rating level that can reasonably be applied to a given workplace. The Guideline VDI 2058, Part 3 distinguishes between three level ranges with rating levels of

- 55 dB(A) maximum,
- 70 dB(A) maximum and
- more than 70 dB(A)

and assigns them to the following three activity-based categories:

Table 12:
Acoustically non-measurable factors in the assessment of the non-auditory effect of sound [6]

Person-specific factors	• Attitude towards sound or sound source • Attitude towards activity • Amount of practice/experience • Physical and psychological prerequisites (e.g. state of health or potential to cope with stress)
Activity-specific factors	• Attentiveness and concentration requirements • Memory • Ability to learn • Responsiveness • Stamina • Creativity • Voice communication
Other factors	• Prominence of the sound • Usualness of the sound in the given location • Preventability of the sound • Spatial change in the acoustic source

- *Predominantly mental activities – rating level 55 dB(A) maximum*

  These are highly complex activities requiring creative thinking, far-reaching decisions, problem-solving and good speech intelligibility, e.g.

  – meetings or teaching activities,
  – scientific work or software development,
  – medical investigations or operations and
  – drafting, translation or correction of demanding texts.

- *Simple or predominantly automated office activities and similar activities – rating level 70 dB(A) maximum*

  These are well-practised office activities and activities of medium complexity, requiring moderate or temporary concentration/strain and a satisfactory level of speech intelligibility, or activities involving similar, repetitive tasks, e.g.

  – communicative activities, e.g. in a call centre,
  – surveillance and controlling activities, e.g. at a control centre,
  – testing and monitoring activities,
  – serving customers or selling and
  – difficult, precision assembly activities.

- *Rating level higher than 70 dB(A)*

  Where the rating level is higher than 70 dB(A), only low-complexity activities should be carried out. These are activities requiring only low or brief concentration/strain and a low level of speech intelligibility. They are mainly routine tasks or activities with repetitive content, e.g.

  – technical and industrial tasks,
  – work using production machinery and
  – repair and maintenance of technical equipment.

8.5 Guidance on performing measurements

As a rule, the rating level should be determined at the specific workplace of the person exposed to the sound. The measurements are taken at ear height, without the person being present if possible. Ear height is defined as

- for standing persons: 155 cm above the surface on which they stand

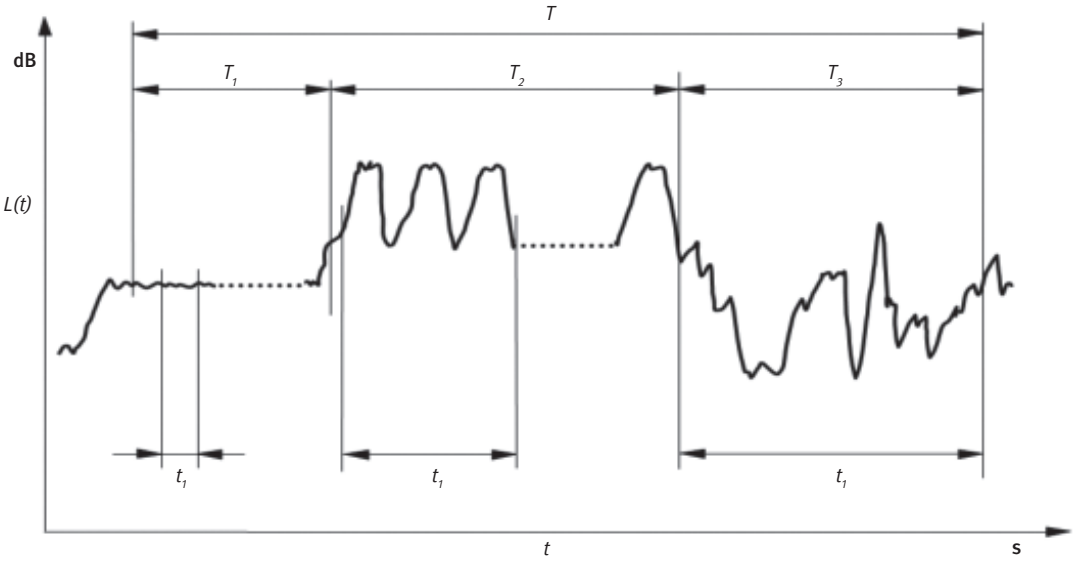
- for seated persons: 80 cm above the surface on which they sit

As far as possible, the microphone should point in the direction in which the person faces at their workplace. If the employee has to be present at their workplace during the measurement, the microphone should be positioned at their ear height (at a distance of 0.1 to 0.4 m from the ear) in such a way as to ensure the employee's body does not impede the microphone's exposure to the sound.

The measurements are performed using sound level meters of DIN EN 61672-1 [7] accuracy class 1 or 2, preferably the former. Where class 2 meters are used, a measurement uncertainty of ±3.0 dB(A) must be applied (see also Section 8.7, "Measurement uncertainty").

It is usually not necessary for the rating level to be determined by measuring sound levels throughout the entire period of exposure. If the averaging time (working time) can be split into subintervals that have their own typical sound, suitable periods can be defined for measuring the sound exposure for each period. A measurement period of approximately 20 seconds can suffice in the case of constant sounds. For periodic processes, the measurement period should last for at least one typical sound cycle (see Figure 10, page 48).

Figure 10:
Breakdown of a work shift into several sub-intervals with selected measurement periods as examples, based on DIN EN ISO 9612 [8]



where
T: Duration of work shift
T_1: Duration of activity 1
T_2: Duration of activity 2
T_3: Duration of activity 3
t_1: Measurement period within activity 1
t_2: Measurement period within activity 2
t_3: Measurement period within activity 3

8.6 Calculating the rating level based on measurements for sub-intervals

Rating level L_r [4] is calculated based on the A-weighted equivalent continuous sound exposure levels $L_{eq,m}$, determined for the individual sub-intervals T_m including any adjustments and the sub-interval lengths T_m in accordance with equation (2).

$$L_r = 10 \lg \left\{ \frac{1}{T} \sum_{m=1}^{M} T_m \cdot 10^{0{,}1 \cdot L_{p,m}} \right\} \text{ dB(A)} \qquad (2)$$

where

$L_{p,m} = L_{pAeq,m} + K_I + K_T$

A-weighted equivalent continuous sound exposure level $L_{pAeq,m}$ for sub-interval m plus the adjustments for the degree of the impulse and tonality and information content

and

T_m: time interval of sub-interval m

T: time period of all sub-intervals T_m

M: total number of m sub-intervals

If the individual sub-intervals are calculated as a percentage of the overall duration of the activity concerned, equation (3) can be used as an alternative method of calculating the rating level

$$L_r = 10 \lg \left\{ \sum_{m=1}^{M} \frac{x_m}{100} \cdot 10^{0{,}1 \cdot L_{p,m}} \right\} \text{ dB(A)} \qquad (3)$$

where

$L_{p,m} = L_{pAeq,m} + K_I + K_T$

A-weighted equivalent continuous sound exposure level $L_{pAeq,m}$ for sub-interval m plus the adjustments for the degree of the impulse and adjustment for tonality and information content

and

x_m: sub-interval m as a percentage of the overall duration of the activity, T

M: total number of m sub-intervals

8.7 Measurement uncertainty

As mentioned in Section 8.5, a measurement uncertainty factor must be included when determining the rating level. This factor depends both on the quality of the measuring equipment used (accuracy class) and the quality of the measurement (representativeness). Measurement uncertainty is particularly important when rating levels are close to prescribed sound level values (e.g. guide values given in VDI 2058, Part 3 [5]) because it determines whether it is possible to say that the actual values are higher or lower than the guide values.

DIN 45645-2 [4] lays down the following methods for simplifying the process of comparing values with prescribed sound level values and establishing a convention for doing so:

a) The calculated rating level is compared directly with the prescribed sound level value, i.e. an uncertainty factor of 0 dB is applied for the comparison, if

- *a class 1 sound level meter was used and*
- *the uncertainty during the measurement of the typical long-term (representative) sound exposure during the activity can be estimated as lower than 3 dB.*

b) An uncertainty factor of 3 dB is applied to the calculated rating level when comparing it with the prescribed sound level value if

- *a class 2 sound level meter was used and/or*
- *the uncertainty during the measurement of the typical long-term (representative) sound exposure during the activity can be estimated as lower than 6 dB.*

If an uncertainty factor of 0 dB can be achieved, as in case a), it is possible to decide with certainty whether the prescribed sound level value is complied with.

If it is only possible to achieve an uncertainty factor of 3 dB, as in case b), the prescribed sound level value must be checked to determine whether it is lower than, within or higher than the level range described by the uncertainty factor determined (L_r – 3 dB) to (L_r + 3 dB) when comparing the calculated rating level with prescribed sound level values.

If the prescribed sound level value is lower than this level range, the allowance is exceeded; if the prescribed sound level value is higher than the level range, it goes below allowance. If the prescribed sound level value is within the limit range, it is not possible to decide with certainty.

8.8 Noise in educational establishments

Implementing the assessment method presented here in educational establishments is not always a simple matter. It is sometimes difficult to block out inherent noise because, for example, teachers' own voices and their communication with the pupils need to be blocked out in order to assess teachers' noise exposure during lessons. In these cases, it can be difficult or even impossible to draw a clear distinction between inherent and extraneous noise. The procedure is simpler in teaching set-ups in which various groups work separately within one classroom. In such cases, measurements would have to be taken at a table that was not being used in order to assess the sound level generated by the other groups.

Besides noise exposure, another key criterion in educational establishments is speech intelligibility. If the reverberation times for a room are too long, intelligibility will be greatly impaired, which is why reverberation time is also an important factor when assessing rooms in educational establishments. The main requirements in this respect are set out in DIN 18041, "Hörsamkeit in kleinen bis mittelgroßen Räumen" (Acoustical quality in small to medium-sized rooms) [9]. For teaching situations in rooms with a volume of approximately 200 to 250 m³, the standard recommends a reverberation time of 0.5 to 0.6 seconds maximum when the rooms are occupied. In unoccupied rooms, the recommendation is that the reverberation time should not be more than 0.2 seconds higher than for occupied rooms. If rooms are to be used by people with impaired hearing, the recommendation is that the reverberation time should be reduced by up to 20%.

8.9 Room acoustic measures

Reflection on rooms' boundary surfaces (ceilings, walls and floors) reinforces sound. The extent of that reinforcement greatly depends on the size of the room and the nature of the room's boundary surfaces. Hard, solid surfaces (such as concrete, brick, glass or wood) reflect sound to a considerable extent. Porous materials (such as mineral fibre and acoustic foam panels and numerous special acoustic materials) absorb the sound and thus prevent up to 100% of the reflection. Equipping rooms with sound-absorbing materials such as these reduces employees' noise exposure and also decreases the reverberation time.

A brochure produced by the German Social Accident Insurance Institution for the administrative sector, entitled "Akustik im Büro" (Office acoustics) [10], provides detailed information on how to ensure good acoustics in office rooms and the results that can be achieved using different measures.

8.10 References

[1] Verordnung über Arbeitsstätten (Arbeitsstättenverordnung – ArbStättV) vom 12. August 2004. BGBl. I (2004), p. 2179-2189; last revision BGBl. I (2010), S. 960-967

[2] Verordnung zum Schutz der Beschäftigten vor Gefährdungen durch Lärm und Vibrationen (Lärm- und Vibrations-Arbeitsschutzverordnung – Lärm-VibrationsArbSchV) vom 6. März 2007. BGBl. I (2007), p. 261-277; last revision BGBl. I (2010), S. 960

[3] Technische Regeln zur Lärm- und Vibrations-Arbeitsschutzverordnung: Lärm (TRLV Lärm). GMBl. (2010) No. 18-20, p. 359-405

[4] DIN 45645-2: Ermitteln von Beurteilungspegeln aus Messungen – Teil 2: Ermittlung des Beurteilungspegels am Arbeitsplatz bei Tätigkeiten unterhalb des Pegelbereichs der Gehörgefährdung (09.12). Beuth, Berlin 2012

[5] VDI 2058 Blatt 3: Beurteilung von Lärm am Arbeitsplatz unter Berücksichtigung unterschiedlicher Tätigkeiten (02.99). Beuth, Berlin 1999

[6] *Maue, J. H.:* Lärmmessung im Betrieb. Erich Schmidt, Berlin 2011

[7] DIN EN 61672-1: Elektroakustik – Schallpegelmesser – Teil 1: Anforderungen (10.13). Beuth, Berlin 2013

[8] DIN EN ISO 9612: Akustik – Bestimmung der Lärmexposition am Arbeitsplatz – Verfahren der Genauigkeitsklasse 2 (Ingeneurverfahren) (09.09). Beuth, Berlin 2009

[9] DIN 18041: Hörsamkeit in kleinen bis mittelgroßen Räumen (05.04). Beuth, Berlin 2004

[10] VBG-Fachinformation: Akustik im Büro – Hilfen für die akustische Gestaltung von Büros (BGI/GUV-I 5141). Ed.: Verwaltungs-Berufsgenossenschaft, Hamburg 2012

Further reading

VDI 2569: Schallschutz und akustische Gestaltung im Büro (01.90). Beuth, Berlin 1990 (revision in preparation)

DIN 45645-1: Ermittlung von Beurteilungspegeln aus Messungen – Teil 1: Geräuschimmissionen in der Nachbarschaft (07.96). Beuth, Berlin 1996

Probst, W.: Bildschirmarbeit – Lärmminderung in kleinen Büros. In: Arbeitswissenschaftliche Erkenntnisse Nr. 123. Published by: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund 2003 – Loose leaf ed.

Maue, J. H.: 0 Dezibel + 0 Dezibel = 3 Dezibel. Einführung in die Grundbegriffe und die quantitative Erfassung des Lärms. Erich Schmidt, Berlin 2009

IFA-Handbuch – Sicherheit und Gesundheitsschutz am Arbeitsplatz. 2nd ed. Published by: Deutsche Gesetzliche Unfallversicherung, Berlin. Erich Schmidt, Berlin – Loose leaf ed. 2003 www.ifa-handbuchdigital.de

9 Thermal environment

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H.-D. Neumann, Düsseldorf
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The thermal environment has a major influence on people's performance, sense of well-being and their health. The two chief factors that influence people's thermal comfort (too warm, pleasant, too cold, etc.) are:

- the ambient conditions, such as the thermal environment, interior layout, building structure, and
- their physical and psychological state or the physical loads and psychological stress to which they are subjected.

Within certain limits, the human body can adapt to changes in the thermal environment, depending on the person's metabolic rate. Outside of those limits, humans' heat balance fails and they are unable to regulate their temperature. This puts increased strain on the cardiovascular system. In turn, this can cause temporary disorders, e.g. circulatory problems or nausea, or – if exposure is prolonged – illness.

Even if the overall assessment of the thermal environment is positive, individual thermal or exposure factors can cause or aggravate temporary discomfort or, if exposure is prolonged, illness if they rise above or drop below certain ranges. An example of such factors is draught.

A distinction is made between the following four work areas, based on employees' perception of the thermal environment (Figure 11):

- cold workplaces,
- thermally comfortable,
- warm workplaces and
- hot workplaces.

Thermally comfortable workplaces provide conditions in which the majority of employees have a sense of well-being. The thermal environment and exposure situations are as they usually should be in indoor workplaces and the workplace can be considered thermally neutral for the most part. There are no other exposure factors. There is an almost balanced exchange of heat between the human body and the surrounding environment. Ideally, the heat supplied and the heat dissipated balance each other out.

The exposure situations and/or thermal environment in warm workplaces (e.g. indoor swimming pools) lead to increased perspiration and strain on the cardiovascular system. Prolonged exposure has an adverse effect on employees' perception of climate. So, warm workplaces are workplaces with exposure situations that, whilst they do not directly damage health, do diminish people's performance.

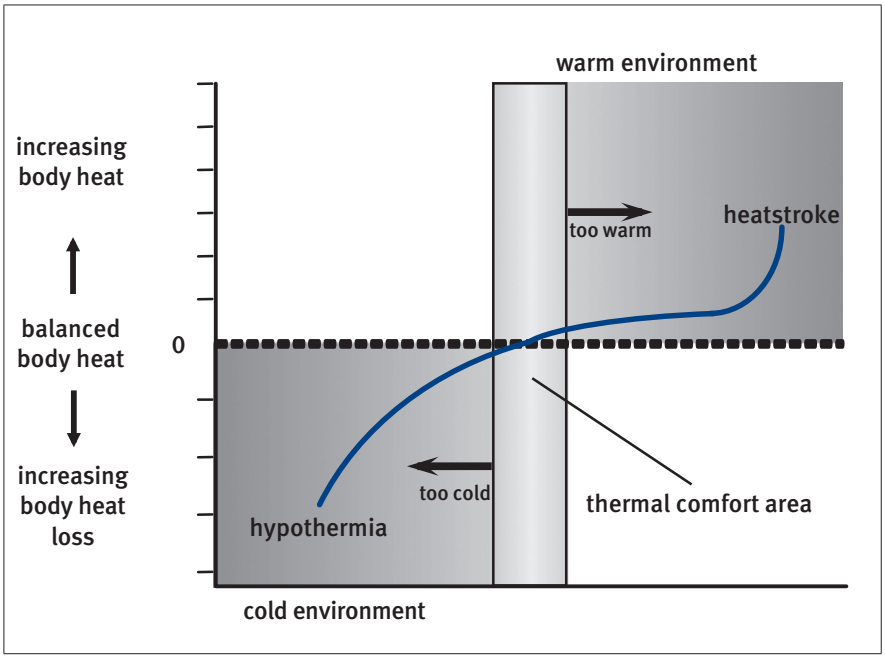

Figure 11:
Breakdown of work areas by climate (general development of climate perception)

Assessment criteria

Guidance on assessments and requirements for thermal environment can be found in the following:

- DGUV information 215-510, formerly BGI/GUV-I 7003 – Beurteilung des Raumklimas (Assessment of indoor climate) [1]
- DGUV information 215-520, formerly BGI 7004 – Klima im Büro: Antworten auf die häufigsten Fragen (Climate in the office: Answers to the most frequently asked questions) [2]
- Technical Rules for Workplaces ASR A3.6 – Ventilation [3]
- Technical Rules for Workplaces ASR A3.5 – Room temperature [4]
- DIN EN ISO 7730 – Ergonomie der thermischen Umgebung – Analytische Bestimmung und Interpretation der thermischen Behaglichkeit durch Berechnung des PMV- und PPD-Indexes und Kriterien der lokalen thermischen Behaglichkeit [5]
- DIN EN ISO 7726 – Umgebungsklima – Instrumente zur Messung physikalischer Größe [6]
- DIN 33403 – Climate at the workplace and in its environments – Part 2: Effect of the climate on the heat balance of human beings [7]
- DIN 33403 – Climate at the workplace and its environments – Part 3: Assessment of the climate in the warm and hot working areas based on selected climate indices [8]
- DIN 33403 – Climate at the workplace and its environments – Part 5: Ergonomic design of cold workplaces [9]

9.1 General check of the thermal environment

Determining the air temperature and humidity usually delivers adequate data to be able to gain a general idea of the thermal environment. However, this is only true if there are no major sources of thermal radiation (e.g. solar irradiation or ceiling heating) or cold surfaces (e.g. wall or ceiling cooling). If draughts occur, the air velocity must also be determined.

Technical Rule for Workplaces, ASR A3.5 – Room temperature [4], requires separate checks for workplaces that have high relative humidity, thermal radiation or air velocity. In such cases, these parameters have to be assessed individually or based on a climate index.

Special questionnaire S9 (which is available on the internet at www.dguv.de, webcode e650356) is intended as an aid for such indicative thermal environment checks. If the indoor air temperature and the relative humidity drop below or rise above the values listed in Section 9.2, further investigation is necessary, for which an expert should be brought in. The thermal environment assessment then required is explained in the following section.

9.2 Assessment of the thermal environment

The thermal environment in workplaces is mainly influenced by the following physical parameters:

- air temperature,
- radiation temperature,
- air velocity and
- relative humidity

and the following case-specific factors:

- physical activity and
- insulation rating of clothing.

By establishing a method of calculation that takes into account the thermal environment parameters, activity and clothing, DIN EN ISO 7730 [5] provides a way of scaling people's sense of comfort in rooms and predicting the percentage of thermally dissatisfied people. The following paragraphs will first present the requirements for each of the parameters before moving on to explain these climate indices in more detail.

Air temperature

ASR A3.5 [4] specifies that the air temperature in workrooms must be no lower than the values given in Table 13.

Table 13:
Air temperatures in workrooms as a function of working position and work intensity, as specified in ASR A3.5

Main working position	Work intensity		
	Low	Medium	High
Seated	+20 °C	+19 °C	---
Standing, walking	+19 °C	+17 °C	+12 °C

These minimum temperatures must be ensured throughout the entire work period. In addition, the air temperature must not exceed +26 °C. Where the outdoor temperature is higher than +26 °C, incremental measures are defined for 26/30/35 °C, as outlined below:

- Up to 26 °C:
  Required range
- › 26 °C to 30 °C:
  Can be tolerated if measures such as sun protection and/or thermal load reduction are taken and, if appropriate, additional organisational measures

- › 30 °C to 35 °C:
  Effective measures are needed to reduce adverse effects; technical and organisational measures have priority over personnel measures ("TOP"; T = technical, O = organisational, P = personnel)

- › 35 °C:
  Not suitable for use as a work room unless TOP measures are taken; to be considered a hot working environment

Apart from air temperature, another significant influence on thermal comfort is the vertical temperature gradient – the difference in air temperature between the head and the ankles – which is not supposed to not exceed 3 °C ("cool head and warm feet") [5].

Radiation temperature asymmetry

Boundary surfaces with different temperatures (e.g. cold windows and warm ceilings) can result in local discomfort. The difference in temperature between the ceiling and the floor should be a maximum of 5 °C; the difference between cold windows and the surface opposite them should be a maximum of 10 °C [5].

It should also be pointed out that both excessively warm and excessively cold floors can be perceived as causing discomfort. The floor temperature should be between 19 and 29 °C [5].

Operative room temperature

The effect of the air temperature and the radiation temperature is usually given as the operative room temperature index, often shortened to just "room temperature". It is calculated on the basis of the following approximate equation [6]:

$$t_0 = {}^1/_2 \left[t_a + \bar{t}_r \right]$$

where

t_0: local operative room temperature in °C
t_a: local air temperature in °C
$\bar{t}_r$: mean local radiation temperature in °C

If the radiation temperature of the room's boundary surfaces is relatively consistent throughout the room, there is no need to determine the radiation temperature. In such cases, the operative room temperature will be approximately equal to the air temperature. Direct solar irradiation, large, cold windows, poorly insulated walls and cold or warm machinery can cause inconsistent distribution of radiation temperature within a room.

The operative room temperature should be measured, using a globe thermometer for example, at 0.1, 1.1 and 1.7 m above floor level in the case of employees who work in a standing position and at 0.1, 0.6 and 1.1 m above floor level for seated workstations [6].

The recommended operative room temperature based on current outdoor temperature is shown as a dotted line in Figure 12. There is a tolerance range of ±2 °C. The values given assume a low level of activity on the part of the room's users (1.2 met, see activity) and apply to clothing insulation ratings between 0.3 and 1 clo (see clothing insulation).

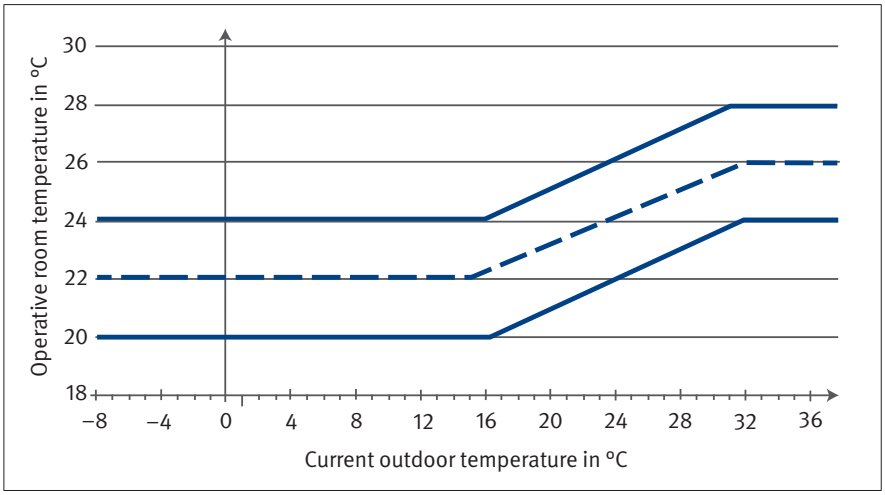

Figure 12:
Operative room temperature as a function of current outdoor temperature [10]

Air velocity

One parameter that has a major impact on thermal comfort is air movement. Air velocity should be measured using a non-directional device at 0.1, 1.1 and 1.7 m above floor level in the case of employees who work in a standing position and at 0.1, 0.6, and 1.1 m above floor level for seated workstations [6].

The air velocity limit values for thermal comfort depend on air temperature and air flow turbulence and can be derived from Figure 13 [10].

Employees must not be exposed to unreasonable levels of draught, a requirement that must also be taken into account when planning ventilation and air conditioning systems. Draught levels are primarily determined by air temperature, air velocity in combination with turbulence (air velocity distribution over time) and the nature of the activity being carried out. At an air temperature of +20 °C with a mean air velocity below 0.15 m/s and 40% turbulence, there is usually no unreasonable draught [3].

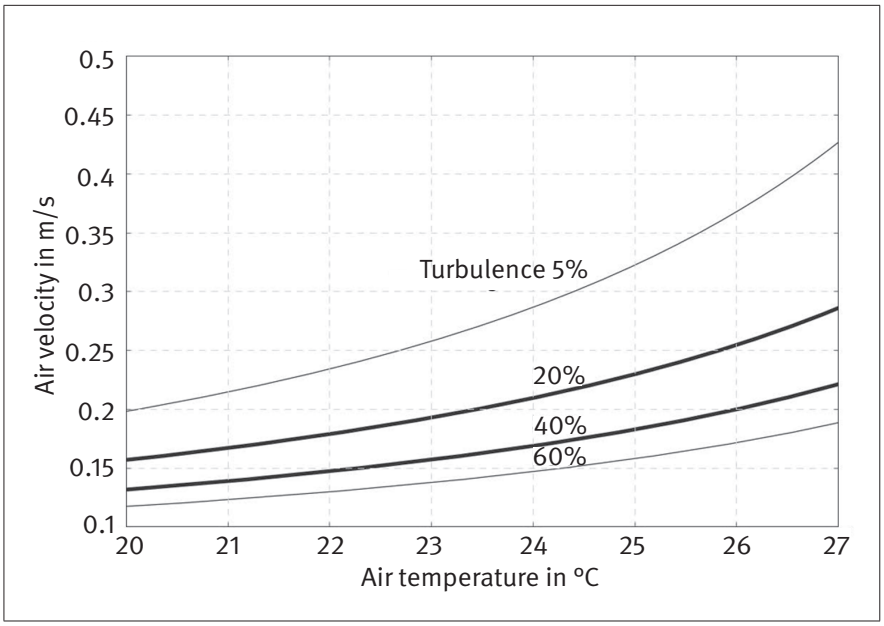

Figure 13:
Mean air velocity as a function of air temperature and turbulence in thermally comfortable workplaces used for low-intensity, seated activities wearing normal office attire [10]

Humidity

The relative humidity should not exceed the values listed in Table 14 [3].

Table 14:
Recommended maximum relative humidity as a function of air temperature

Air temperature in °C	Relative humidity in %
20	80
22	70
24	62
26	55

A high level of relative humidity can cause damp patches to form on cold walls, providing ideal conditions for microorganisms to grow and prosper. This can result in an increase in the mould spores present in the breathable air, potentially causing allergic disorders such as asthma, allergic rhinitis and skin allergies. Cold and damp rooms also promote rheumatic attacks in rheumatism sufferers.

In the winter months, the water content in the outdoor air can be between 2 and 3 g/kg of dry air. This equates to a relative humidity of approximately 60% at 0 °C. If that air is heated to 20 °C, the relative humidity decreases to less than 20%. It is even possible for values lower than 10% to occur when the outdoor temperature is extremely low. There are frequent reported cases of various complaints such as dry mucous membranes. However, a thorough study of the literature [11] showed that there are no symptoms that are demonstrably attributable to humidity, making it impossible to provide unequivocal recommendations for a minimum level of relative humidity. Low relative humidity was only found to aggravate symptoms in persons who already had an illness, e.g. neurodermatitis.

Accordingly, each case needs to be examined individually to ascertain whether humidity was responsible for the complaints presented. If the air is to be humidified, the relative humidity should be at least 30%. DIN EN 13779 [12], which describes design criteria for (partial) air conditioning systems, puts forward suggestions for humidifier design where there are no specified parameters for the case in question. These proposals take into consideration energy issues, climatic conditions in the winter/summer, condensation risks and possibilities for controlling indoor humidity. The standard states, "*For example, 6 g/kg can be specified as a winter minimum, corresponding 22 C/40 %; while 12 g/kg can be specified as a summer maximum, corresponding 26 C/60 %.*". These values are mainly based on technical aspects.

Activity

A person's total thermal output is determined by his or her physical activity. The energy required for the activity is released through the person's metabolism. The units used to quantify activity are watts, watts per m² of body surface area (based on 1.8 m² of body surface area) and met (metabolism). One met is equivalent to the metabolic rate of a seated person at rest. Annex B of DIN EN ISO 7730 [5] lists the metabolic rates for various physical activities (see Table 15).

Clothing

The body's ability to give off heat depends on the insulation rating of the clothing being worn. In accordance with DIN EN ISO 7730 [5], the unit used to quantify the insulation level is clo (clothing). One clo is equivalent to 0.155 m² · K/W. Table 16 shows examples of insulation ratings based on DIN EN ISO 7730.

Assessment of thermal environment using climate indices

The PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) indices are used to provide a detailed assessment of thermal comfort levels. The former predicts the mean opinion of a large group of people and the latter indicates the likely percentage of dissatisfied people for a specific PMV. Where the PMV = 0, people usually perceive the thermal environment as being thermally neutral (comfortable) (Table 17).

Table 15:
Metabolic rates for various physical activities as given in DIN EN ISO 7730 [5]

Activity	Metabolic rate	
	W/m²	met
Leaning	46	0.8
Sitting, at rest	58	1.0
Seated activity (office, home, school, laboratory)	70	1.2
Standing, low-intensity activity (shopping, laboratory, low-intensity industrial work)	93	1.6
Standing, medium-intensity activity(selling, housework, machinery operation)	116	2.0

Table 16:
Insulation ratings for various garments in a dry state [5]

Outfit	Insulation rate	
	in clo	in m² · K/W
Unclothed	0	0
Shorts	0.06	0.009
Panties, T-shirt, shorts, light socks, sandals	0.3	0.050
Underpants, short-sleeved shirt, light trousers, light socks, shoes	0.5	0.080
Underpants, shirt, boiler suit, socks, shoes	0.8	0.125
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1.0	0.155
Underwear with short sleeves and legs, shirt, trousers, waistcoat, jacket, socks, shoes	1.5	0.230

Table 17:
Climate perception in correlation with PMV and PPD climate indices [5]

Perception	Hot	Warm	Quite warm		Neutral		Quite cool	Cool	Cold
PMV	+3	+2	+1	+0.5	0	-0.5	-1	-2	-3
PPD in %	99	75	25	10	5	10	25	75	99

Since no thermal environment will satisfy all of the people all of the time, the minimum PPD index gives 5% dissatisfaction, meaning that 5% of respondents are dissatisfied with the thermal situation. DIN EN ISO 7730 divides the PPD index into three levels (A, B, C) of dissatisfaction at 6, 10 and 15%. As a rule, the aim should be not to exceed a dissatisfaction level of 10%.

The PMV and PPD indices can be determined using special measuring instruments, software and the tables shown in the annex of DIN EN ISO 7730.

9.3 References

[1] DGUV Information 215-510: Beurteilung des Raumklimas (formerly BGI/GUV-I 7003). Published by: Deutsche Gesetzliche Unfallversicherung (DGUV), Berlin 2010

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[12] DIN EN 13779: Lüftung von Nichtwohngebäuden – Allgemeine Grundlagen und Anforderungen für Lüftungs- und Klimaanlagen und Raumkühlsysteme (09.07). Beuth, Berlin 2007

10 Electrostatic and electromagnetic fields

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M. Fischer, Cologne

10.1 Electrostatic fields

Static electricity can occur when two different materials are rubbed against each other and then separated (this is known as "frictional electricity"). The friction generates heat, resulting in a momentary change in the structure of both materials' surfaces. This leads electrons to migrate from one surface to the other, producing an excess charge on both surfaces, equal in size but with opposite polarities. If these charges cannot move away when the surfaces are separated, in other words if they are not able to equalize each other out, the result is an electrical field known as "static electricity".

The size and polarity of the field depend on

- the nature of the materials involved, particularly their relative position in the electrochemical series,
- the intensity of the contact/separation process,
- the surface conductivity and
- the ambient conditions (e.g. the relative humidity).

Charges occur whenever there is contact and movement between different, non-conductive materials. This mostly happens between synthetic materials, e.g. when

- someone walks across a synthetic carpet,
- fabric is separated,
- tape is unwound from a roll,
- materials are shredded, sprayed or atomised and
- substances, e.g. liquids or dust, flow along walls.

People can become charged through movement or charge transfer (electrostatic induction). Garments that do not provide sufficient conductivity promote charge build-up. Touching charged objects can also cause charge transfer. Table 18 shows the voltage levels generated by electrostatic charges during typical office activities.

Table 18:
Voltage levels that can be generated by electrostatic charge

Activity	Voltage in V
Walking across a carpet	1,500 to 35,000
Walking across an untreated vinyl floor covering	250 to 12,000
Working at a desk	700 to 6,000
Inserting a sheet of paper into a vinyl document wallet	600 to 7,000
Picking up a plastic bag from a desk	1,200 to 20,000

For electrostatic charge to be produced, the surface resistance of the materials involved must be higher than 109 W and the relative humidity lower than 45%.

If charged objects or persons come into contact with earthed, electrically conductive substances or other persons or get so close to them that sparks are caused due to the strength of the electrical field, electrostatic discharge can occur. Some of the factors that influence the discharge process are the:

- electrostatic voltage level,
- speed at which the electrostatically charged object approaches the conductive or earthed object,
- ambient conditions, e.g. temperature, air pressure, humidity, dust particles and
- geometric and surface features of the objects.

Some discharge effects are familiar to us from our everyday lives. The best known are sparks when touching door handles, banisters or car bodies and the crackling or even sparks that occur when removing a synthetic garment.

Hazards posed by electrostatic fields

Generally speaking, electrostatic fields do not pose a hazard to humans. In fact, we do not even notice the charging process. However, there is a risk of people being startled and then reacting incorrectly when discharge suddenly occurs in people or mobile objects (such as chairs, trolleys or cleaning devices) after an electrostatic charge.

Humans notice electrostatic discharge when it exceeds approximately $5 \cdot 10^{-4}$ J, which is equivalent to a discharge voltage of 2,000 to 3,100 V with a typical human body capacitance of 100 to 250 pF relative to the earth. In office scenarios, the voltage

level can be higher than that even when routine activities are being carried out (see Table 18).

To rule out the possibility of electrostatic discharge causing hazards, the energy transferred via the human body should not exceed 350 mJ or the charge transferred by the body should be no higher than 50 µC. When discharge occurs on electronic equipment, these levels of energy stored in humans are enough to destroy semiconductor components inside the equipment. In particular, a person with a charge of just a few volts can cause irreparable damage to a semiconductor component if they come into direct contact with the terminal for that component. For instance, a discharge voltage of

- 100 V is sufficient to delete a piece of information from a magnetic data storage medium,
- 50 V is sufficient to generate a spark that can ignite explosive gases and
- 5 V is sufficient to cause damage to the highly sensitive reading head of a hard disk.

In addition to this direct damage, electrostatic charge can cause particles to collect on smooth surfaces, resulting in such phenomena as grime on monitors or dust deposits.

Protection against static electricity

Experience has shown that electrostatic charges cannot be completely prevented in practice. Often they are so strong that circuit breakers in electronic devices cannot fully discharge them. It is therefore necessary to take precautions in order to reduce or discharge electrostatic charge, which can be done by the following means:

- Reducing contact areas:

  Electrostatic charges can be reduced if the contact surface is decreased or changed, e.g. by roughening (matting) it. This is a common course of action with films or film-based products, e.g. transparent document wallets.

- Earthing:

  If earthing is carried out correctly, any charge will be quickly discharged. It must be ensured that the bleeder is lower than 10^9 Ω. Correct earthing can be achieved by installing conductive or antistatic floor coverings, earthing any conductive furniture and work surfaces and fitting conductive rollers or wheels to chairs and carrying aids.

- Decreasing surface resistance and increasing relative humidity:

  Reducing surface resistance by ionising air or increasing humidity is seldom an option in indoor workplaces. Ambient air can only be ionised locally and it only takes effect once a minimum voltage level has been reached. This approach only makes sense in industrial workplaces where electrostatic charges have a disruptive effect. If the humidity is increased, the thermal environment requirements described in these recommendations (see Chapter 9) must be observed.

Static electricity protection requirements should be observed from an early stage, when selecting materials, as this reduces the need for action to be taken later.

10.2 Electric, magnetic and electromagnetic fields

In the modern world, humans are surrounded by natural and technically generated electric, magnetic and electromagnetic fields (EM fields). Examples of natural fields include the Earth's own magnetic field and electric fields arising from storms. Technically generated fields come about when electrical energy is produced, distributed and consumed.

Relatively high EM fields can occur in workplaces where they are used in accordance with the regulations for such things as part processing (in forging systems, furnaces, etc.). This section does not cover these types of workplace.

In indoor workplaces, EM fields can only occur in the immediate vicinity of electrical devices and systems operated there. It should be noted, though, that these fields are considerably weaker than those used to process parts. Nonetheless, it is a common concern that exposure to EM fields could have adverse effects in these workplaces too.

The frequency spectrum of EM fields ranges from static fields with a frequency of 0 Hz to alternating fields with frequencies of up to 300 GHz. Figure 14 shows examples of the different frequencies of EM fields and their applications and effects.

Static fields do not vary with time. Electric and magnetic static fields – two separate fields – have practically no relevance in indoor workplaces. However, active medical implants such as pacemakers, defibrillators, insulin pumps or cochlear implants can be affected by nearby permanent magnets.

The low-frequency EM field range covers all frequencies between 0 Hz and 30 kHz. Because of the low frequencies, the electrical field and the magnetic field are virtually disconnected and can be considered separately. Consequently, the electric field depends only on the voltage U and the magnetic field only on the current I. In systems and devices with high working currents, it is generally the magnetic field that is dominant. Conversely, high-voltage systems have a dominant electric field.

Any low-frequency fields that occur are primarily determined by the location of the electrical wiring and equipment. Both the electric and magnetic field strengths decrease as the distance from the field source increases. Figure 15 shows how the magnetic field strength varies depending on the distance from and the shape of the field source.

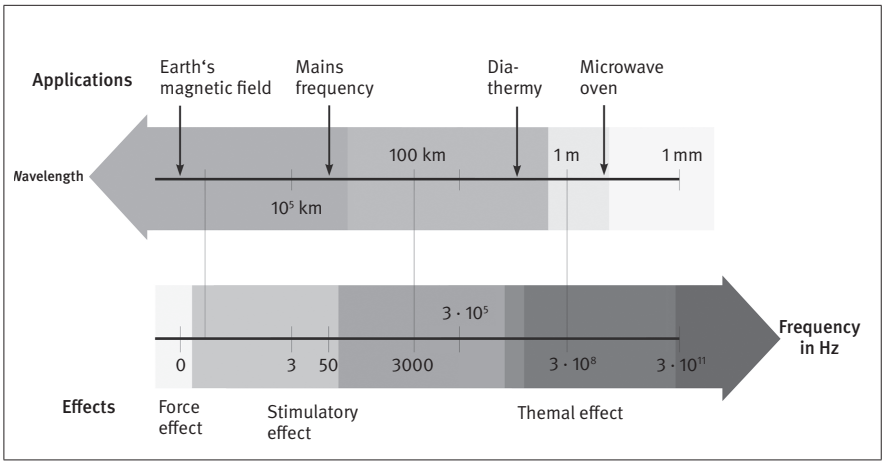


Figure 14:
Frequency spectrum of electromagnetic fields and their effects

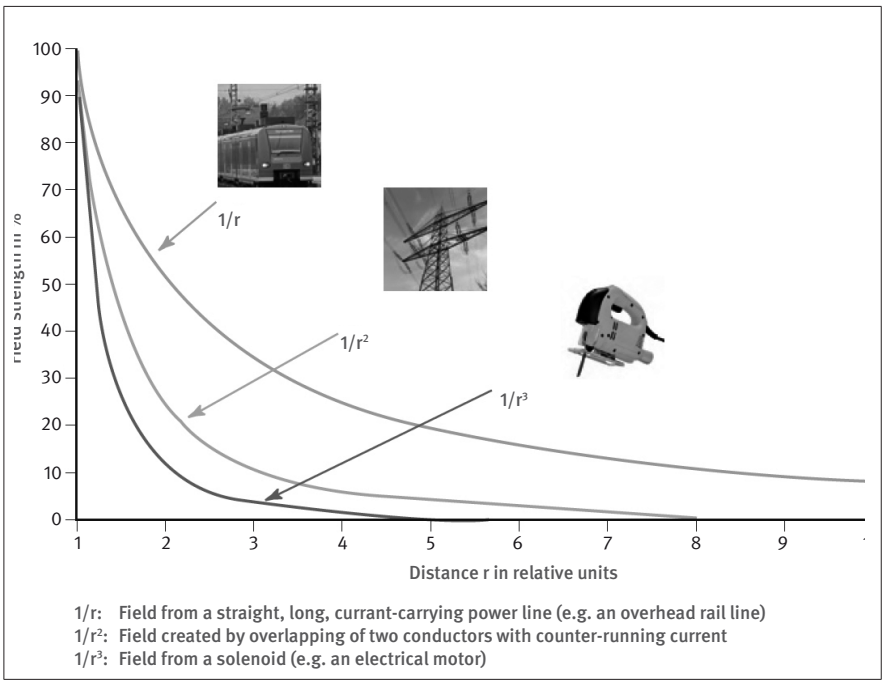


Figure 15:
Decline in the magnetic field strength of various sources in correlation with distance
(Source: Landesamt für Umwelt, Messungen und Naturschutz Baden-Württemberg. State Institute for Environment, Measurements and Nature Conservation Baden-Wuerttemberg [1], *Schutterstock*)

Electric fields can easily be altered by conductive materials, which have a distortive or shielding effect. By contrast, reducing magnetic fields is an extremely complex process because they are able to penetrate non-magnetic substances virtually unhindered [2].

The high frequency range starts at frequencies above 30 kHz and extends to the end of the microwave region at 300 GHz. It is not possible to consider the electric and magnetic field components separately in this frequency range because of the close connection between the two. The fields can detach themselves from their source, e.g. from an antenna, and spread across large distances. They are then referred to as electromagnetic waves. Unlike other waves, electromagnetic waves do not need a carrier or a propagation medium, which means they are also able to spread in a vacuum. Their propagation speed in this case is equivalent to the speed of light ($c = 3 \cdot 10^8$ m/s). Electromagnetic energy is transported in the direction of the propagation. Power flux density, expressed in W/m², can be used to quantify the energy flux. The term power flux density is used interchangeably with power density, energy flux density and radiation density.

Effects of EM fields

EM fields can have direct and indirect effects. Direct effects of low-frequency electric fields are displacement currents induced in the human body and electric fields in the tissue. In strong electric fields, other effects can be a tingling sensation or hair standing on end on the skin's surface. Low-frequency magnetic fields induce eddy currents in the human body and electric fields in the tissue. If the currents and/or fields induced in the body/tissue exceed certain threshold values, they can excite nerve and muscle cells. Table 19 (page 60) shows examples of the effects on the human body as a function of flux density.

Current scientific knowledge indicates that induced electrical field strengths of 50 mV/m and electrical flux densities of less than 10 mA/m² are not likely to cause adverse effects on the human body [3 to 5].

High-frequency electromagnetic fields, on the other hand, can cause heat build-up in the human body. When electromagnetic waves hit the human body, a portion of them is reflected and another portion penetrates the body and is absorbed by it. The depth of penetration depends on the type of tissue and the frequency of the electromagnetic field. The energy from the

radiation absorbed in the body is converted into heat, which brings about an increase in body temperature – initially at the site of absorption. However, heat conduction and the body's temperature regulation system can cause the temperature to rise in other areas of the body as well. The temperature regulation system endeavours to maintain the core body temperature at a constant 37 °C. A high increase in core body temperature can cause damage; an increase to above 42 °C is fatal. To prevent damage, the extent to which electromagnetic fields are absorbed by the human body must be restricted to ensure that any resulting temperature increase is no higher than 1 °C.

Table 19:
Effects in the body as a function of flux density

Flux density in mA/m²	Effects
‹ 1	No substantiated biological effects
1 to 10	No confirmed effects; unsubstantiated reports of discomfort in specific individuals
10 to 100	Well-substantiated effects; visual sensations; effects on the nervous system; reports of accelerated healing of bone fractures
100 to 1,000	Potentially harmful to health; discomfort thresholds; confirmed change in the excitability of the central nervous system
› 1,000	Potential damage; heart contractions possible, ventricular fibrillation

One unit for measuring the extent to which the body absorbs energy from high-frequency electromagnetic fields is the specific absorption rate (SAR), which is expressed in W/kg.

Apart from these scientifically substantiated direct effects of EM fields, there is public debate about other possible, though as yet unproven, effects. They range from such phenomena as malaise to headaches, sleeping disorders, influences on the hormonal system and even cancer. There are frequent calls for the permissible values for electromagnetic fields to be lowered, citing these suspected effects. In most cases, the term electrosmog is used rather than electromagnetic field – the intention being to make it clear that electromagnetic fields are present everywhere in our normal environment and are considered a potential risk.

The Strahlenschutzkommission (German Commission on Radiological Protection) constantly monitors the latest findings and publishes them on its website [6] and elsewhere. In terms of causal links between exposure to EM fields and the incidence of certain effects, the Commission distinguishes between what it refers to as hints, suspicions and proof. There are hints for numerous effects and a suspicion for two effects caused by low-frequency EM fields. But there is no scientifically substantiated proof apart from for the direct effects outlined above.

The indirect effects include force effects exerted on ferromagnetic materials and effects on electronic devices. Force effects occur, for example, in the immediate vicinity of MRI scanners. However, such effects do not play a role in indoor workplaces. A further indirect effect is interference with active medical implants.

Electric, magnetic and electromagnetic fields can cause interference with other electronic devices as well as with active medical implants. In the past, magnetic fields often caused faults in cathode ray tube (CRT) monitors but this no longer happens with TFT display screen equipment, which is mostly used today.

EM field occurrence in indoor workplaces

Most appliances in or near indoor workplaces generate electric and magnetic fields with a mains frequency of 50 Hz.

High-power electrical appliances create quite substantial magnetic fields. In addition, magnetic fields occur in the immediate vicinity of small transformers. The electric field strengths of appliances in indoor workplaces are very low and can therefore be disregarded.

Table 20 shows examples of low-frequency field sources and their emissions measured at various distances. These values can be used to assess the relevance of potential field sources in indoor workplaces and to distinguish between significant and insignificant sources.

Indoor workplaces can also be located close to power supply and distribution systems (see Figure 16, page 62). Measurements of various systems have produced results considerably lower than the permitted values in the DGUV regulation 15 [9]. This is also true of the electrical wiring in buildings. However, distribution systems located in offices can interfere with IT systems.

Generally speaking, the electric and magnetic field values recorded near low-voltage and medium-voltage underground cables are much lower than the permissible values as the underground location of the cables means the workplaces are a certain distance away from the cables.

Near overhead lines, the electric and magnetic fields depend on the distance from the line, the voltage level and the current. The electrical field strengths and magnetic flux densities are much lower than the permissible values. This is due to the height of the power line systems and the minimum distance from the lines specified in electrical safety requirements. Electrical field strengths of several kV/m are possible directly below overhead lines (where there are no buildings). Magnetic flux densities of up to 20 mT have been observed where the current level was 1 kA. By way of comparison, the lowest values permitted in the DGUV regulation 15, formerly BGV B11, "Electromagnetic fields" [9], are 6.6 kV/m for electric fields and 424 mT for magnetic fields. In public areas, the values permitted by the 26th Bundesimmissionsschutzverordnung (BImSchV; Federal Immission Control Ordinance) [12] are 5 kV/m and 100 µT respectively.

Furthermore, buildings, trees, bushes and any conductive materials distort and shield electric fields, making electric and magnetic field strengths that pose a hazard to humans unlikely in indoor workplaces located beneath overhead lines.

Table 20:
Examples of low-frequency electric and magnetic fields from electrical appliances [7; 8]

Appliance	Frequency in Hz	Distance in cm	Electric field strength in V/M	Magnetic flux densitiy in µT
Drill	50	3 30 100	- - -	400 to 800 2 to 3.5 0.08 to 0.2
Computer	50	3 30	- -	0.5 to 3.0 ‹ 0.01
Slide projector	-	3 30 100	- - -	240 4.5 0.15
Television	15 k 50	30 3 30 100	1 to 10 - 60 -	0.2 2.5 to 50 0.04 to 2 0.01 to 0.15
Dishwasher	50	3 30 100	- - -	3.5 to 20 0.6 to 3 0.07 to 0.3
Halogen lamp (low voltage)	-	3 30	- -	25 to 80 0.6 to 1.7
Fan heater	-	30	-	10 to 20
Space heater	-	3 30 100	- - -	10 to 180 0.15 to 5 0.01 to 0.25
Coffee maker	50	3 30	- 60	1 to 25 0.1 to 0.2
Kitchen stove	-	3 30 100	- - -	1 to 50 0.15 to 0.5 0.01 to 0.04
Refrigerator	50	3 30 100	- 120 -	0.5 to 1.7 0.01 to 0.25 ‹ 0.01
Base station for handsets	50	30	-	1.5
Fluorescent lamp	-	3 30 100	- - -	40 to 400 0.5 to 2 0.02 to 0.25
Humidifier	-	30	-	10 to 20
PC monitor	-	3 30 100	- - -	0.5 to 10 0.45 to 1.0 ‹ 0.01 to 0.3
Radio (portable)	-	3 100	- -	16 to 56 ‹ 0.01
Vacuum cleaner	50	3 30 100	- 50 -	200 to 800 2 to 20 0.13 to 2
Immersion heater (1 kW)	-	3 30 100	- - -	12 0.1 ‹ 0.01
Desk lamp (60 W)	-	3 30	- 5	0.1 to 0.2 0.01
Clock (mains powered)	50	3 30 100	- 30 -	300 2.25 ‹ 0.01
Video recorder	-	3 30 100	- - -	1.5 ‹ 0.1 ‹ 0.1
Kettle (1 kW)	-	3 30 100	- - -	5.4 0.08 ‹ 0.01

Figure 16:
Example of a power distribution system

High-frequency fields occur in indoor workplaces where, for example, radio systems are in use. Examples of high-frequency electromagnetic field sources and the respective permissible values are listed in Table 21.

EM field emission from selected appliances

- Monitors
  PC monitors generate, among other things, low-frequency and high-frequency electromagnetic fields. However, the field emission is so low that it is significantly lower than the values permitted by DGUV regulation 15. Consequently, there is no hazard for people who work with PC display screens.

- Wireless LAN systems
  Wireless Local Area Networks (WLANs) are local data networks for wireless data transmission between devices such as PCs, servers and printers, primarily inside buildings. In Germany, these devices operate in the 2.4 and 5 GHz frequency bands. Depending on the frequency band, transmission power levels of up to 100 mW (2.4 GHz) or 1 W (5 GHz) are allowed. As a result, even at a distance of just a few centimetres from the antenna, the values recorded are lower than those permitted by DGUV regulation 15.

- Mobile network transmitters
  In recent years, a system of fixed and mobile transmitters (Figure 17) has been set up in the Federal Republic of Germany to facilitate use of today's information and communication technologies. Table 22 gives an overview of the various mobile networks and the characteristics of their fixed-site transmitters.

Operators of mobile network fixed-site transmitters (base stations) must be in possession of a "site certificate". These are issued by the Bundesnetzagentur (Federal Network Agency) provided it has been ensured that the site in question complies with the values permitted by the 26th Bundes-Immissionsschutzverordnung (BImSchV) [12], which are intended to protect people in electromagnetic fields. The Bundesnetzagentur specifies the minimum distances (safety distances) to be kept from the transmitters, taking into account the field strengths at the site, and indicates them in the site certificate. Suitable measures must be taken (e.g. fencing or barriers) to ensure that unauthorised persons adhere to the required safety distance.

Table 21:
Examples of exposure from high-frequency electromagnetic fields in indoor workplaces and the maximum permitted values (exposure area 2 as defined in DGUV regulation 15) [10; 11]

Field source		Distance	Typical exposure values	Permissible values
Anti-theft device		In the area under surveillance	< 2 mW/m²	4.5 W/m²
Microwave oven		5 m from appliance	0.62 W/m²	10 W/m²
Mobile telecommunication	Base station	50 m	0.06 W/m²	4.45 to 10 W/m² depending on frequency band
	Mobile phone	3 cm from antenna	< 2 W/kg	2 W/kg
High frequency exposure in dwellings near mobile network transmitters		None given	3 µW/m² to 5.2 mW/m²	2 W/m²

Figure 17:
Mobile network transmitter

Table 22:
Mobile telecommunication networks and characteristics of their fixed-site transmitters (basestations)

Mobile network	Carrier frequency in MHz	Antenna input power	Notes
D-net	890 to 960	10 W typical 50 W possible	Digital Pulsed 217 Hz
E-net	1,710 to 1,880	10 W	Digital Pulsed 217 Hz
UMTS	1,920 to 2,170	20 to 40 W	FDMA[2]) and TDMA[3])
Tetra (BOS)	380 to 395	Up to 40 W ERP[1)]	TDMA[3]) (four time slots per carrier)
Tetrapol	70 to 520	Up to 50 W	FDMA[2])
City call	470	100 W	Regional call display
Analogue trunked radio Public access	410 to 430	Up to 200 W ERP1)	Closed user groups
Digital Mobile Radio (DMR)	136 to 174 403 to 470	Up to 40 W	TDMA[3]) (two time slots per carrier)
Wireless LAN (WLAN)	2,400 to 2,480 5,100 to 5,800	‹ 100 mW EIRP [4)] ‹ 1 W EIRP [4)]	-

[1)] ERP: Effective Radiated Power
[2)] FDMA: Frequency Division Multiple Access
[3)] TDMA: Time Division Multiple Access
[4)] EIRP: Effective Isotropical Radiated Power

Since access to fixed transmitters is restricted and the safety distance is larger, indoor workplaces near mobile network base stations are certain to comply with the maximum values permitted by the 26th Bundes-Immissionsschutzverordnung (BImSchV). It is therefore unlikely that mobile network transmitters will pose a hazard to people who work in indoor workplaces.

- Mobile communication devices

  Mobile communication devices (e.g. mobile phones) have variable transmission power levels. In-vehicle devices work with transmission power levels of up to 8 W; mobile phones' transmission power levels go up to 2 W.

  Some of the high-frequency energy produced in mobile communication is absorbed by the mobile phone user's head. The actual amount depends on the phone's design, the way in which it is used, the antenna type, the position of the antenna in relation to the head, the frequency and the transmission power.

  The current requirement is that mobile communication devices must not exceed a specific absorption rate (SAR) of 2 W/kg [3]. Based on current scientific knowledge, adverse effects on health are not likely if this value is complied with.

- DECT systems

  DECT (Digital Enhanced Cordless Telecommunications) is a mobile telephony standard for access to mobile communication networks. In practice, however, it is actually a standard for cordless telephones. It describes a mobile communication system comprising at least one transmitter station (base station) and one mobile communication device, i.e. a cordless telephone. DECT systems enable several base stations/repeaters (Figure 18, see page 64) and cordless telephones to be used, which means that, for example, a relatively large area (e.g. building complex) can be covered and/or several telephone conversations can be conducted simultaneously.

  In Europe, the system has been defined for the 1,880 to 1,900 MHz frequency range. Theoretically, the transmission power level of a DECT system is a maximum of 250 and on

average approximately 10 mW. The criteria for cordless telephone use are the same as for mobile phone use but the transmission power level of cordless telephones is considerably lower than that of mobile phones. DECT systems do not present a hazard to people in indoor workplaces.

Figure 18:
Access point for DECT systems

- Microwave ovens

  Microwave ovens use high-frequency energy (typically 2,455 MHz) to heat food. The energy is absorbed by the food and converted into thermal energy. Shielding ensures that the values permitted outside the appliance are complied with.

  According to research by the Bundesamt für Strahlenschutz (Federal Office for Radiation Protection), the leakage radiation from domestic microwave ovens, measured as power density, is equal to 1% of the permissible emission limit value [13]. The emitted power density decreases as the distance increases (at a distance of 30 cm, only roughly 5 to 10% of the power density measured on the oven's surface has any effect). Consequently, microwave ovens in indoor workplaces will not exceed the 10 W/m² permitted by DGUV regulation 15 for category 2 exposure areas, assuming the oven is intact. However, if there are obvious defects in the shielding (e.g. faulty door seals), this cannot be guaranteed. It is therefore important to ensure that faulty microwave ovens are not used.

10.3 Regulations and limit values

Germany has regulations to provide protection against electric, magnetic and electromagnetic fields in both the public domain and the workplace.

26th BundesImmissionsschutzverordnung (BImSchV)

The public domain is regulated by the 26th BImSchV [12] which was enacted in 1997. It lays down requirements concerning the protection of the general public and neighbouring communities against harmful environmental effects caused by EM fields.

The Ordinance applies to the installation and operation of low-frequency and high-frequency systems for commercial use or use in connection with business undertakings. As per the Ordinance definition, low-frequency systems are stationary installations for transforming and transmitting electricity, i.e.:

- Overhead lines and underground cables with a frequency of 50 Hz and a voltage of 1,000 V or higher
- (Overhead) traction current lines, including transformers and switchgear, with a frequency of 16.67 or 50 Hz
- Electrical transformers, including switchgear bays, with a frequency of 50 Hz and a high voltage of 1,000 V or more

As defined by the 26th BImSchV, high-frequency systems are stationary transmitters with a transmission power level of 10 W EIRP (Effective Isotropical Radiated Power) or higher in the 10 MHz to 300 GHz frequency range. Transmitters with power levels of › 10 W are commissioned on the basis of the "Gesetz über Funkanlagen und Telekommunikationsendeinrichtungen" (Act on Radio Equipment and Telecommunications Terminal Equipment). The commissioning procedure is described in the "Verordnung über das Nachweisverfahren zur Begrenzung elektromagnetischer Felder" (Ordinance concerning the Controls for the Limitation of Electromagnetic Fields). Such systems must always be installed and operated in such a manner that the fields they emit do not exceed the threshold values.

The 26th BImSchV also defines the areas to be examined, primarily areas in buildings or on land in which people are not only intended for temporary human presence. However, the Ordinance is also applied to areas requiring a particularly high level of protection, which include hospitals, schools, nurseries, playgrounds and similar facilities. It does not apply to employed work, i.e. the field covered by occupational health and safety requirements.

"Electromagnetic fields" accident prevention regulation

Where health and safety requirements apply, the DGUV regulation 15 – the accident prevention regulation on "Electromagnetic fields" [9] – should be used. Its content is explained in more detail in the German Social Accident Insurance Institutions' rule that accompanies it, DGUV rule 103-013 [14]. DGUV regulation 15 applies wherever employees are exposed to electric, magnetic or electromagnetic fields in the 0 Hz to 300 GHz frequency range.

When checking workplaces for possible exposure to electric, magnetic or electromagnetic fields, the employer must define exposure areas, determine the electromagnetic fields that occur and compare them with the permissible values. The exposure levels must be determined by a properly qualified person and can take the form of calculations, measurements, consideration of information supplied by the manufacturer or comparison with other systems.

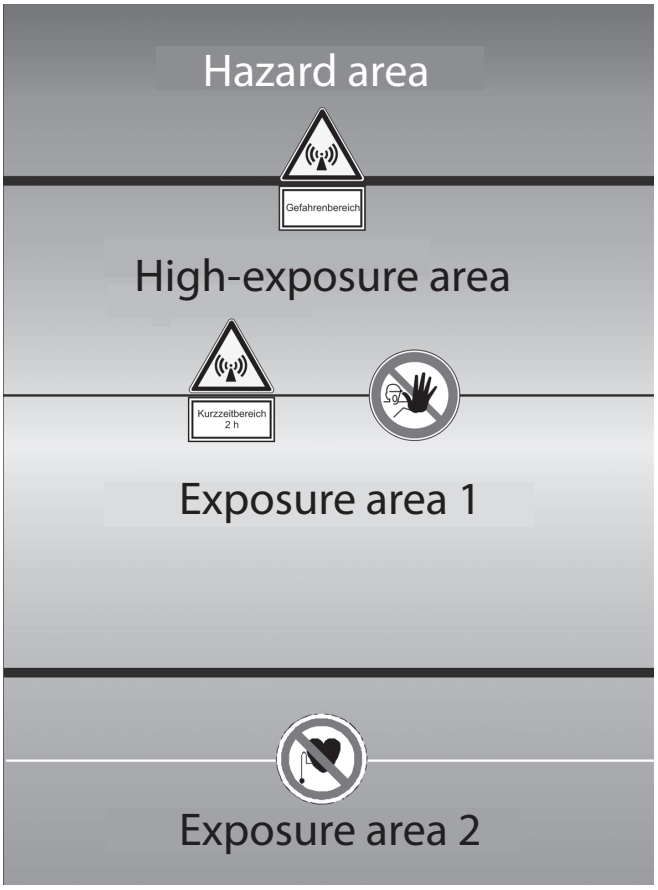
DGUV regulation 15 makes a distinction between exposure area 2, exposure area 1 and high-exposure areas (Figure 19).

Exposure area 2 covers all areas for which there is no special access control. Generally accessible indoor workplaces therefore

fall into this category, which is subject to the lowest permissible workplace values. Higher values are permitted in exposure area 1, which comprises all controlled-access areas.

In addition to the two areas mentioned above, there are high-exposure areas, where the values permitted for exposure area 1 may be exceeded temporarily provided special precautions have been taken.

Figure 19:
Exposure areas as defined in DGUV regulation 15 [9]



Values permitted by DGUV regulation 15

Permissible values have been specified at the international level in such a way as to rule out any biologically relevant effects that might cause damage, hazards or other unwanted phenomena. Since the effects of electromagnetic fields are frequency-dependent, the permissible values have also been defined based on frequency. They are given as basic values and values derived from those basic values.

The basic values are the current density in A/m², the specific absorption rate (SAR) in W/kg, power density in W/m² and the field strength in the body tissue in V/m. They (see also DGUV regulation 15 [9]) stem from physical, biological and medical findings and are internationally recognised and recommended [4].

Since measuring these basic values is an extremely complex process, permissible values for the field sizes (the electric field strength and the magnetic flux density/field strength) have been derived from the basic values for use in the workplace. Compliance with these derived values ensures that the basic values are also adhered to within the body. The values for electric field strength and magnetic flux density permitted by DGUV regulation 15 are shown in Figures 20 and 21.

Table 23 lists the permissible values for whole-body exposure at 50 Hz (a common mains frequency). The permissible values for exposure area 2 are generally not exceeded in indoor workplaces.

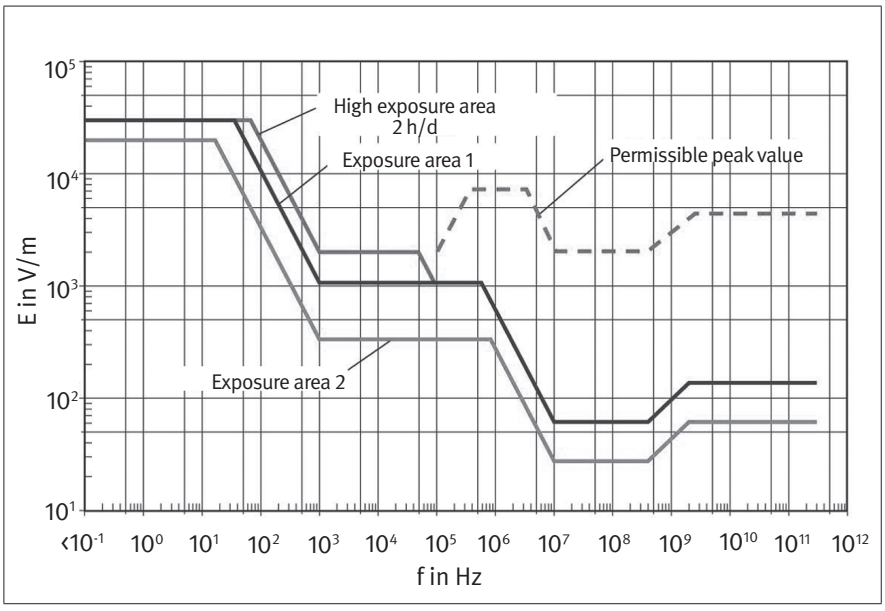


Figure 20:
Permissible values for electric field strength *E* in exposure areas 1 and 2 and high-exposure areas, as specified in DGUV regulation 15 [9]

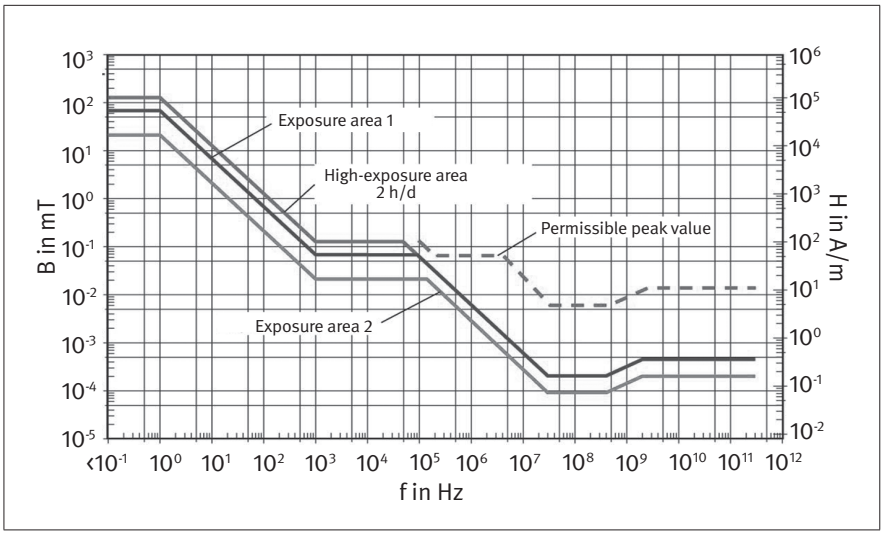


Figure 21:
Permissible values for magnetic flux density *B* in exposure areas 1 and 2 and high-exposure areas, as specified in DGUV regulation 15 [9]

Table 23:
Values permitted by DGUV regulation 15 [9] at a frequency of 50 Hz

Exposure area	Permissible electric field strength in kV/m	Permissible magnetic flux density in mT
Exposure area 2	6.7	0.42
Exposure area 1	21.2	1.36
High-exposure area	30.0	2.54

Measures required by DGUV regulation 15

No measures are required in the case of indoor workplaces where the values permitted for exposure area 2 are not exceeded. The equipment typically used for office communication and work (particularly display screen equipment) has such low emission values that they fall below the permissible values for exposure area 2 (see section on "EMF occurrence in indoor workplaces"). This is also true of electrical tools, domestic appliances, electrical systems within buildings and engines, drives, etc. with low connected loads.

However, at sites located in the immediate vicinity of industrial installations with high electrical power levels, it is not possible to rule out values exceeding those permitted by DGUV regulation 15. In accordance with this regulation [9], measures are required if this does happen. These measures include, for example, drawing up operating instructions, conducting briefings, marking and implementing access controls.

Permissible values for people with active medical implants

Even though the values in indoor workplaces lie below those permitted for exposure area 2, active medical implants such as pacemakers can be influenced by electromagnetic fields. In such cases, a special risk assessment must be carried out and, if appropriate, the area must be marked accordingly (Figure 22).

Influences on active implants depend on various parameters, such as the sensitivity setting, the design and installation of the electrodes and the implants' immunity to interference. Assessments at workplaces must therefore always be on a case-by-case basis, taking into consideration the settings (entered in the pacemaker ID card) and the information supplied by the manufacturer. The potential effects of EM fields on medical implants and the risk assessment required are described in DGUV information 203-043, formerly BGI/GUV-I 5111, "EM field influence on implants – A guide for the workplace" [15].

Figure 22:
"No pacemakers" sign

10.4 Summary

Though electrostatic charges can occur in indoor workplaces, the electrostatic fields they generate do not generally pose a hazard for employees. However, discharge processes can potentially result in startle responses as well as damage to electronic components. Electrostatic charge should therefore be avoided as far as possible in indoor workplaces. Possible ways of doing this are choosing appropriate materials, reducing contact areas and earthing.

Indoor workplaces can also be subject to electric, magnetic or electromagnetic fields. In office workplaces, they are generated by the (electrical) equipment typically found there. However, the electric, magnetic and electromagnetic fields emitted by such equipment are small. The maximum permitted values for these fields are generally complied with in offices and hazards to humans are unlikely.

Values above the permissible values can also be ruled out for indoor workplaces near power supply and distribution units. Individual risk assessment may be necessary for people with active medical implants (e.g. pacemakers).

10.5 References

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11 Ionising radiation (radon)

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11.1 Natural radiation exposure

Human beings are constantly exposed to low levels of ionising radiation from natural radiation sources. This natural background radiation exposure has the following main origins:

- Inhalation of radioactive substances and above all of radon and its derived products
- Nutritional intake of radioactive substances (food and drink)
- Radiation from the environment, e.g. from the building materials of surrounding walls and ceilings
- Radiation from space

The average radiation exposure of the population in Germany to natural radiation sources is roughly 2.1 millisievert (mSv) per year. The inhalation of radon and its derived products accounts for about half of this. Natural radiation exposure is supplemented by a dose of another approximately 2 mSv per year due to the use of artificial radiation sources, mainly in medicine. The population's mean radiation dose changes only very little over the years. The radiation dose of individuals, however, can deviate greatly from the mean value – firstly, due to regional differences in the natural background radiation, but above all due to medical treatment and diagnosis. The Bundesumweltministerium (Federal Ministry of the Environment) publishes a report on the current radiation exposure of the population every year [1].

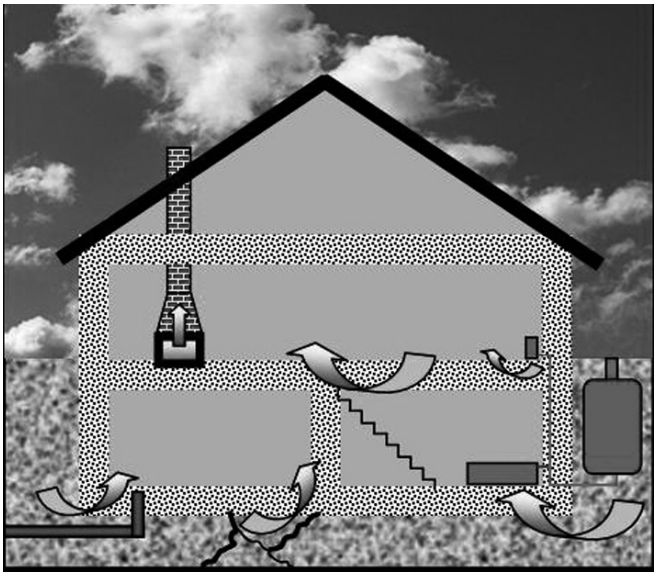
11.2 Radon

The lion's share of the dose from natural radiation sources is contributed by the radioactive noble gas radon and its derived products. Radon is not only odourless but also otherwise imperceptible to the human sense organs. In our surroundings, i.e. also in offices or office-like rooms, it is constantly present in greater or lesser concentrations. Radon is part of the natural decay chains of uranium and thorium. The concentrations of uranium and thorium (and hence also of radon) in the ground depend on the ground's geological structure. A high activity concentration in the soil air is encountered in certain areas of the Ore Mountains, Bavarian Forest and Black Forest, for example.

Under normal ambient conditions (temperature and pressure), radon is gaseous. It can also be carried over long distances dissolved in water. Due to convection and diffusion from the soil, it can enter the atmosphere, yielding the small share of radon in the air. The Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) has published a general map of radon concentrations in the soil air [2]. The values are typically of the order of a few kilobequerel per cubic metre (kBq/m³).

Radon gas can enter not only the ambient air, but also the cellars of buildings (see Figure 23). Due to low pressure differences, occurring particularly during the heating period, radon can rise out of cellars into the storeys above.

Figure 23:
Penetration of radon from the ground into cellars and upper storeys. Source: German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors, Radiation Protection Group



In the rooms of a building, the magnitude of the radon concentration depends among other things on the following factors:

- Geology of the ground

  The radon concentration increases with increasing uranium and thorium content in the ground. The mobility of radon in the ground depends on its fissuration

- Storey on which the room in question is located

  The radon concentration decreases with height above the cellar level.

- Mode of construction

  Radon penetrates into buildings via leaks in the base slab and cellar walls (e.g. via penetrations for pipes and cables) and via joints.

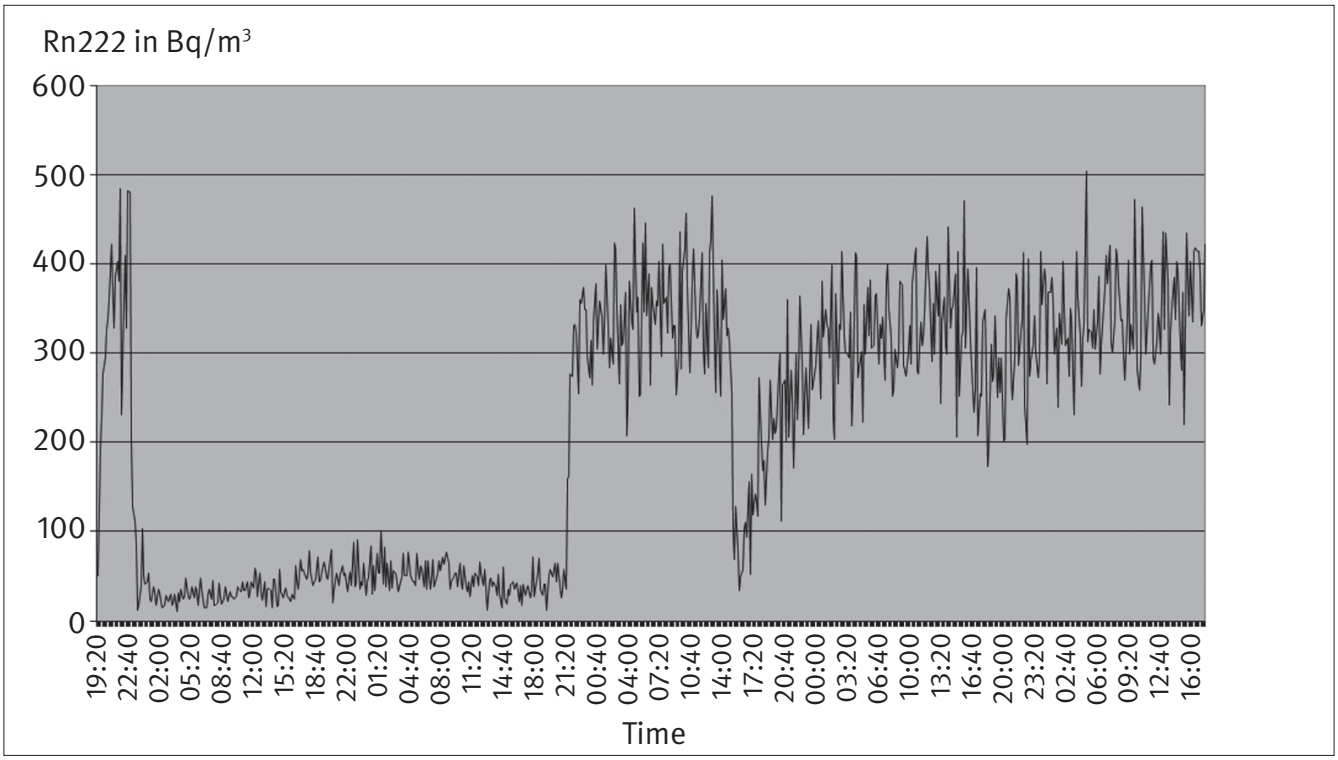
- Ventilation

  Lower radon concentrations can be expected in artificially ventilated than in naturally ventilated rooms.

The radon concentration in a room shows addition seasonal and daily variations. These depend on such meteorological parameters as temperature, humidity, wind speed and wind direction.

The values in buildings range typically from a few Bq/m³ to several hundred Bq/m³. An example of the change in radon concentration in an office room over several hours is presented in Figure 24. The effect of ventilation is clearly visible. The radon concentration drops from an initial roughly 450 Bq/m³ to an average of approximately 50 Bq/m³ after the windows are opened. When the windows are closed, the concentration increases relatively quickly back to the original value.

Figure 24:
Change in radon concentration in an office room over several hours, measurement by the Radiation Protection Group of the German Social Accident Insurance Institution for the energy, textile, electrical and media products sectors



11.3 Biological impact

When radon is inhaled as a noble gas, it is not absorbed by the body, but exhaled. The radiation exposure proper therefore comes only to a small extent from radon itself and to a much greater extent from its non-gaseous products of degradation such as polonium 218, lead 214, bismuth 214 and polonium 214. These degradation products attach in the air to superfine aerosols and can be inhaled with them and absorbed by the body. The emission of ionising radiation by radon's derived products then exposes the body to radiation, mainly in the lungs. The magnitude of this lung dose also depends on the ratio of radon activity to daughter product activity. Reference is made in this context to the so-called equilibrium factor. This is usually a value of about 0.4, i.e. the activity concentration of the daughter product is about 40 % of radon's activity concentration.

This radiation exposure does not cause any direct harm. No acute symptoms occur from the inhalation of radon and its derived products. However, delayed radiation damage and above all lung cancer can, however, occur. The probability of the occurrence of such damage depends among other things on the magnitude of the activity of inhaled derived products of radon and thus on the radon concentration in the ambient air. The Strahlenschutzkommission (German Commission on Radiological Protection) estimates the risk due to radon as follows: If the radon concentration increases by 100 Bq/m³, approximately 10 % more cases of lung cancer can be expected than without radon [3].

11.4 Radon at workplaces

Elevated radon concentrations in the air can be expected at a number of workplaces owing to the special conditions prevailing there. These include workplaces in underground mines, radon spas and water extraction plants. For these workplaces, there is an obligation under the Strahlenschutzverordnung (Radiation Protection Ordinance) [4] to investigate the radiation exposure due to radon and its derived products, to comply with the specified limit values and, if necessary, to take action to reduce the concentration of radon and its derived products.

For workplaces in offices and office-like rooms, there is no statutory obligation to measure the radiation exposure to due radon or to comply with limit values. In general, the expected radiation exposure in offices is low and on the same level as the mean natural background radiation. Nevertheless, there are also cases in which the radon concentration in offices is elevated and above the mean value.

11.5 Investigation

If there is any suspicion of an elevated radon concentration in an office or office-like room, this should be investigated more closely. The investigation comprises a preliminary investigation and a measurement.

In the preliminary investigation, it must be ascertained first whether an elevated radon concentration is in fact probable. The following factors should be borne in mind in this connection:

- Activity concentration in the soil air

  If the soil air of the ground on which the building stands has a high radon concentration, a precondition for a high radon concentration in the building is fulfilled. The Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) publishes a map showing the radon concentration in the soil air in Germany [2]. With the aid of this map, it is possible to determine whether the building in question lies in a region with elevated radon activity.

- Position of the room in the building

  The lower the position of a room in the building, the higher the radon concentration is likely to be. This applies, for example, to rooms in cellars or basements and also to rooms on the ground floors of buildings without cellars. The higher a room in a building, the lower the radon concentration. In the upper storeys of a high-rise building, the radon concentration tends to be low.

- Room ventilation

  The radon concentration may be higher if the room is only naturally ventilated. The lack of openable windows also hampers the movement of air and increases the radon concentration. In artificially ventilated rooms, the radon concentration in the room tends to be low.

If the preliminary investigation suggests an elevated radon concentration or at least the impossibility of excluding such a concentration, the radon concentration should be precisely determined by measurement and the result assessed by comparison with the guide values. Instructions for the measurement of radon can be found in a brochure published by the Strahlenschutzkommission (German Commission on Radiological Protection) [5].

11.6 Assessment

The International Commission on Radiological Protection (ICRP) has published recommendations for the maximum permissible radon concentration. On this basis, the German Commission on Radiological Protection has repeatedly issued its own recommendations for the limitation of radiation exposure due to radon. The recommendation of 1994 contains „Radiation protection principles for the limitation of radiation exposure due to radon and its degradation products in buildings“ [6]. The guide values contained in them for radon concentrations in homes are given as mean values over the period of a year:

- A radon concentration of 250 Bq/m³ marks the upper end of the normal range of the radon concentration in residential buildings in the Federal Republic of Germany. If the values are within the normal range, no action is considered necessary.

- The range from 250 to 1,000 Bq/m³ is considered the discretionary range for simple measures to reduce exposure to radon. Information is also given on which action can be taken by whom (residents, specialised firms).

- The range exceeding 1,000 Bq/m³ is considered the rehabilitation range. The radon concentration should be reduced here in all cases even if elaborate measures are necessary for this.

For workplaces exposed to elevated natural radiation, the Strahlenschutzverordnung (Radiation Protection Ordinance) contains instructions and legal requirements [4]. As already mentioned, normal office workplaces are not covered. It is nevertheless possible to draw appropriate conclusions by analogy.

Given 2,000 working hours per year and an equilibrium factor of 0.4, a radon concentration of 1,000 Bq/m³ corresponds to a dose of roughly 6 mSv per year. Values above this dose at the workplaces named in Annex XI of the Radiation Protection Ordinance must be reported to the authorities. The group of persons engaged in the work activities mentioned are subject to a limit value of 20 mSv per year. If the annual radon exposure is less than 6,000,000 Bq*h/m³, compliance with the limit value can be assumed [4]. Given 2,000 hours spent at the workplace, this amounts to an average radon concentration of 3,000 Bq/m³.

However, one must also bear in mind that, in areas with elevated radon concentrations, the dose consists not only of the occupationally related radiation exposure due to radon, but also of the radon exposure arising outside work.

To observe the minimisation requirement of the Radiation Protection Ordinance, it is advisable to apply the same yardsticks to workplaces as to homes and not to permit any elevated radon concentration. For workplaces in areas with high radon activity, radon concentrations from 250 to 1,000 Bq/m³ should therefore also be regarded as the discretionary range and radon concentrations over 1,000 Bq/m³ as the rehabilitation range with rehabilitation measures being taken if required .

11.7 Measures

Measures to reduce the radiation exposure due to radon can include:

- Changing the use of a room exposed to above-average radon levels

  For instance, rooms in basements could be abandoned as office rooms and – assuming this is possible – converted into storage rooms.

- Gas-tight sealing of base slabs, cellar walls, penetrations and joints
- Improving ventilation by increasing the air change rate

  This includes more frequent and more vigorous airing in the case of natural ventilation and the installation of artificial ventilation.
- Extraction of radon gas on the cellar level or beneath the building (drainage ventilation)

Some simple measures, such as more frequent airing, can be taken by room users themselves and are very effective. For more elaborate measures, specialised firms must be consulted. Which measure is suitable in the given case depends among other things on the level of radon concentration and the building structure and conditions. Detailed instructions on radon protection measures can be found on the website of the Bundesamt für Strahlenschutz (Federal Office for Radiation Protection) [7]. In areas with high radon soil concentrations, suitable measures are to be taken at the design stage for new buildings.

11.8 References

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12 Chemical exposure

Health complaints arising in indoor workplaces are often felt to be directly linked to the presence of harmful substances in the air. Typical examples of this are formaldehyde and wood preservatives.

Odour (see Chapter 4), acute complaints, results of medical examinations and press reports, for example, can point to the presence of hazardous substances or cause their presence to be suspected. However, they do not constitute actual evidence of their presence.

In such cases, appropriate investigations (Section 12.1) must be carried out to determine whether there are any grounds to suspect exposure to hazardous substances before conducting hazardous substance measurements, which usually entail significant technical and staffing effort. Frequently, the findings of such investigations enable decisions to be made as to the necessary measures (e.g. redevelopment) without hazardous substance measurements having to be performed.

The action to be taken must be decided on the basis of the findings. If the suspected exposure to hazardous substances cannot be confirmed, other causes for the complaints must be sought. However, if the initial suspicion (i.e. the suspected presence of hazardous substances in the workplace air) is confirmed, specific hazardous substance measurements can take place, as described in Section 12.2, based on the findings of the investigation.

Section 12.3 provides general advice on how to assess measurement results. Information on specific substances and categories of substance is given in Section 12.4.

12.1 General guidance on investigating chemical exposures

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The potential sources of indoor air pollution are manifold. Table 24 shows possible sources and the most important substances they emit. Further information can also be found in Section 6.4, “Materials”, among other places. The questionnaires on building design and decoration of rooms (S5) and procedures for cleaning of buildings (S6), which deal with the matters covered in Section 6.4, are available on the internet (www.dguv.de, webcode 650356), and are also useful tools for this investigation.

Section 12.4 provides substance-specific information. A table showing frequently detected substances and their possible sources is presented in Annex 5.

Table 24:
Sources of indoor air pollution and the most important substances they emit, based on DIN EN ISO 16000, Part 1 [1]

Source/cause	Process/activity	Products used, more precise definition of source	Substances emitted
Biological sources			
E.g. humans, animals, insects, mites	Breathing		Carbon dioxide, water vapour, naturally occurring odorant substances , odorant substances from foodstuffs
	Perspiration		Water vapour, odorant substances
	Digestion, excretion		E.g. bowel gases, odorant substances, excrements, decomposition products
	Hair loss, shedding of skin		E.g. bowel gases, odorant substances, excrements, decomposition products
Indoor plants	Transpiration, mould infestation	Substrate	Terpenes and other odorant substances, water vapour, microbial VOCs
Building sources			
Building structure and materials	Product processing, outgassing, ageing, abrasion, decomposition, mould infestation	Construction materials, building protection and anti-corrosion products, insulating materials, sealant materials, paints, concrete admixtures	Gaseous and particulate substances, e.g. solvents, plasticisers, wood preservatives, flame retardants, fibres (asbestos, mineral wool), radon (e.g. from granite), amines, ammonia, microbial VOCs
Ventilation and air conditioning systems	Operation and maintenance	Washers, filters, insulation and sealant materials, deposits, heat exchangers	Dust, fibres, biocides, odorant substances

Source/cause	Process/activity	Products used, more precise definition of source	Substances emitted
Building sources			
Furniture and furnishings	Product processing, decoration, outgassing	Furniture, floor coverings, home textiles, varnishes and paints, wallpaper	Monomers and oligomers from plastics, resins, surface coatings, adhesives (e.g. formaldehyde); fibres, solvents, plasticisers, stabilisers, biocides (e.g. pyrethroids)
Indoor activities			
Use as office	Office work	Office items, IT equipment, copiers	Organic solvents, semi-volatile organic substances (plasticisers, flame retardants), toner ingredients, ozone
Hygiene and personal care products	Personal care, cosmetic treatments	Personal care products and articles of daily use	Solvents, propellants, perfumes, inorganic and organic aerosols (colouring agents, pigments, varnishes, resins), haloforms
Room cleaning	Cleaning and furniture care; pest control	Washing and cleaning agents, polishes, disinfectants, pest control products	Water, ammonia, chlorine, organic solvents (e.g. ethanol), bactericides (formaldehyde), insecticides (organophospates, pyrethroids, carbamates) and chlorine compounds; house dust
Cooling and heating	Combustion processes (heating, cooking), use of open fire (e.g. including candles)	Coal, heating oil, gas, wood, foodstuffs	Gas (town gas, bottled gas, natural gas), heating oil vapour, carbon dioxide, carbon monoxide, water vapour, suspended particulate matter, hydrocarbons and many other organic substances (combustion products and char)
Outdoor air			
Emissions from human activity	Ventilation, infiltration and diffusion through the building envelope	Industrial enterprises, transport, domestic heating, agriculture, outdoor fires, landfills, contaminated waste	Inorganic and organic gases and aerosols (e.g. solvents, ammonia, odorant substances, polycyclic aromatic hydrocarbons)
Biogenic and geogenic emissions	Ventilation, soil air penetration, dust raising	Plants in bloom, uranium deposits in the earth, sea spray, soil resuspension, natural rotting	Pollen, radon, methane and other volatile organic compounds (hydrocarbons, organohalogen compounds), odorant substances, dusts, sea salt
Living organisms	Excretion	Bowel gases, odorant substances, excrements, decomposition products	Ammonia and sulphur compounds

Reference

[1] DIN EN ISO 16000-1: Innenraumluftverunreinigungen – Teil 1: Allgemeine Aspekte der Probenahmestrategie (06.06). Beuth, Berlin 2006

12.2 Measurement of chemical exposures

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H.-D. Neumann, Düsseldorf
S. Peters, Sankt Augustin

Continuous pollutant monitoring, as practised in industrial workplaces, is usually not possible in indoor workplaces. On-site measurements should be conducted using easy-to-handle devices that cause little disruption to the workflow. Indoor pollutants have numerous sources (cf. Section 12.1), whose emission characteristics differ significantly. There are

- continuous sources, which can emit pollutants over a long period (e.g. building materials or furnishings), and
- intermittent sources, which can cause short-term peak exposure to pollutants (e.g. cleaning agents and, in the past, tobacco smoke).

Figure 25 shows examples of emission characteristics for specific sources.

When selecting a measuring strategy, it is important to know the emission characteristics of the pollutant source. For pollutants from continuous sources, passive samplers are particularly useful whilst active sampling systems make more sense for pollutants emitted from discontinuous sources.

A key problem in indoor pollutant measurement is the variety of possible pollutants and source characteristics. Information about the nature and location of sources and about potential pollutants should therefore be gathered, if possible, when carrying out hazardous substance investigations, in addition to information about emission characteristics. These findings can then be used to determine where measurements should be taken, for how long, how frequently and how many.

If the investigations do not yield any concrete evidence concerning the hazardous substances, indicative measurements can be performed based on the MGU measuring system for indoor measurements (see Section 12.2.2). This system covers volatile organic compounds, aldehydes and carbon dioxide.

At any stage of the measurements, the result can be that

- the source is identified and eliminated or
- no heightened pollution levels are identified.

If no heightened chemical exposure levels are identified, no further measurements should be conducted. If increased chemical exposure is detected, it must be assessed and, where appropriate, action taken. Such action must be in keeping with the case in question and further steps must be defined. Where necessary, additional measurements can be performed in accordance with the VDI 4300 series of guidelines [2] and parts of the BS (EN) ISO 16000 series of "indoor air" standards [3].

Figure 26 illustrates the procedure that can be followed when measuring pollutants. In many cases, indoor measurements can be carried out as shown in this flowchart.

Figure 25:
Emission characteristics for specific sources of indoor air pollution [1]

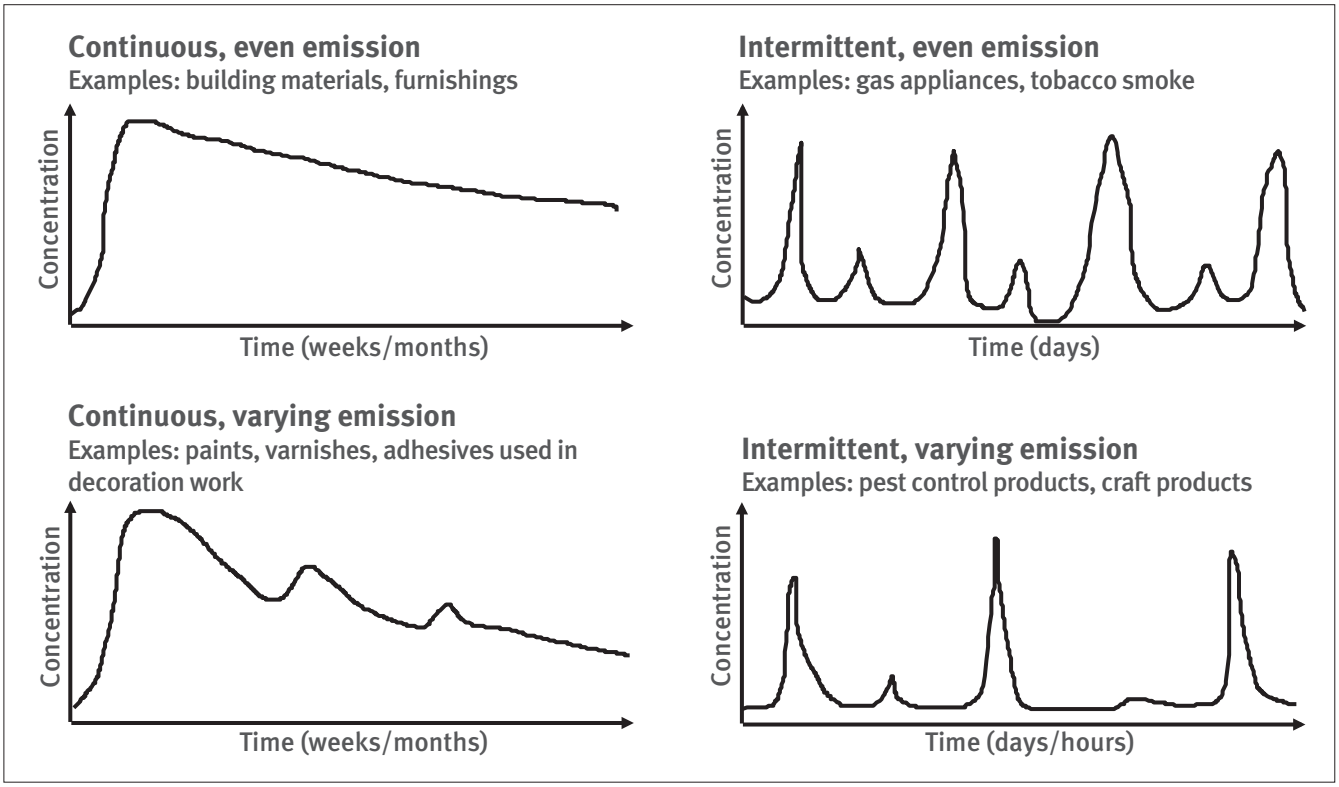
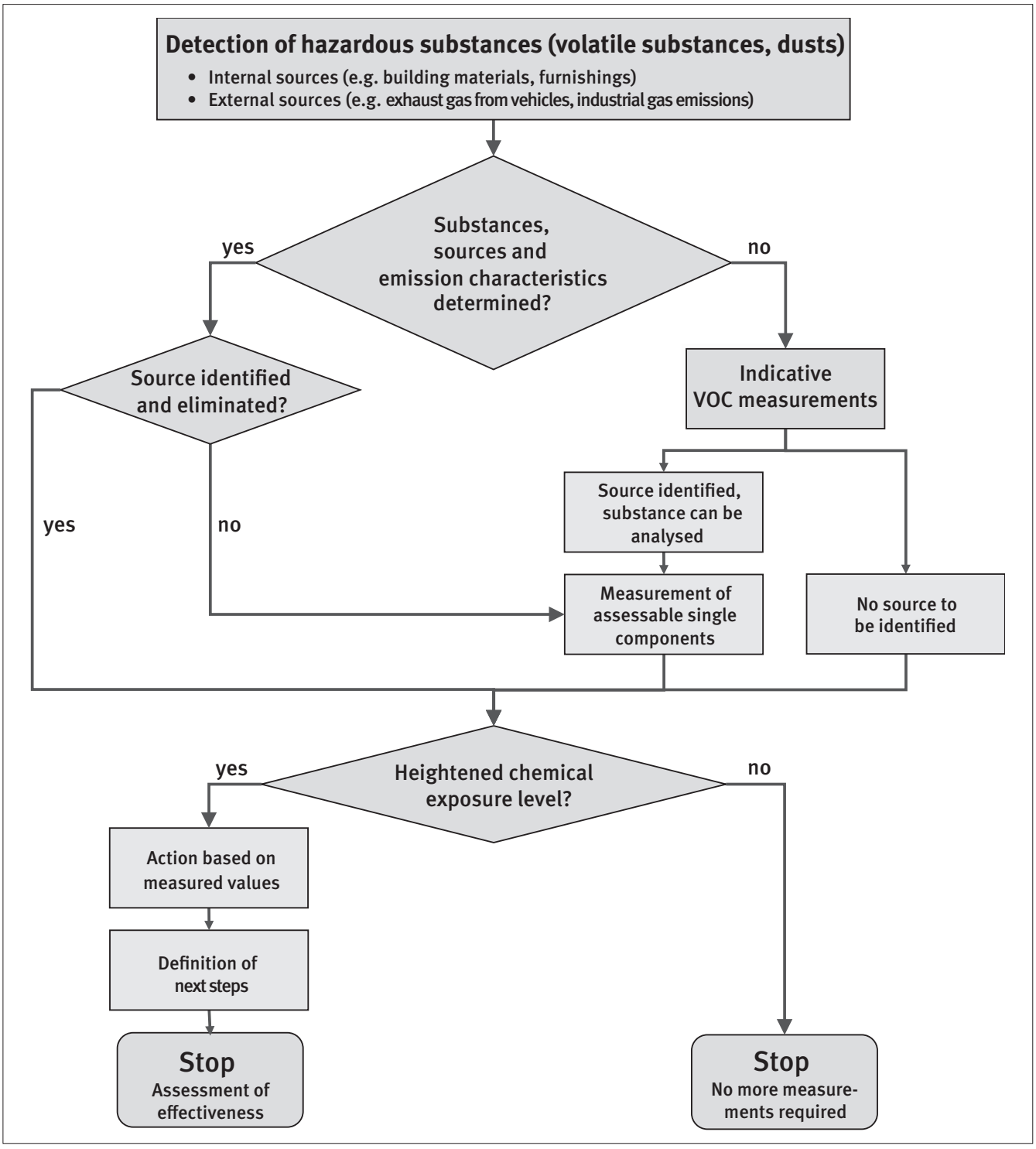


Figure 26:
Detection of hazardous substances (flowchart)



12.2.1 Measuring strategy

The sampling periods must be long enough to enable the substance in question to be identified and quantified. In addition to the time factor, the features of the measuring site must also be taken into account. All ambient conditions (temperature, humidity, air movement, measurement site, etc.) must be documented as part of the measuring procedure.

In buildings with ventilation and air conditioning systems, any information available regarding the supply and extract air must always be taken into account. In such buildings, it is often possible for pollutant sources to be located somewhere else than in the room in which the measurement is being performed.

The type of room involved is also an important factor. The measuring conditions that are suitable in large rooms (e.g. open plan offices) are different to those in smaller office rooms.

Choosing a suitable sampling site is particularly important. The middle of the room is generally felt to be a good place for measurements. Sampling should be carried out at breathing height, i.e. 1 to 1.5 m above floor level for a seated activity. In the case of open plan offices, it can be beneficial to measure at various

locations. This is also true if concentration gradients are possible within one room.

In the case of short-term measurements, it must be ensured that the parameters do not change significantly during sampling (e.g. due to windows being opened). Long-term measurements should be carried out under typical working conditions where possible. If passive samplers are used for long-term measurements, the air movement and positioning in the room must always be checked in order to prevent, for example, the results recorded in corners of rooms being lower than the true values.

The basic conditions of the measurement must always correspond to the measurement site. The sampling strategy can only be decided on once the site has been inspected. A working group at the Deutsche Forschungsgemeinschaft (German Research Foundation) is currently drafting a workplace sampling policy.

12.2.2 MGU system for indoor measurements

The German Social Accident Insurance Institutions' MGU measuring system for exposure assessment has been recording hazardous substance measurements from indoor tests for more than 10 years. The measurement procedures that MGU uses for this purpose [4; 5] were developed and introduced on the basis of DIN EN ISO 16017-1 [6]. These procedures are used to measure concentrations of

- volatile organic compounds, as described in [4],
- aldehydes, especially formaldehyde, as described in [5] and
- carbon dioxide.

The system analyses both the total volatile organic compound (TVOC) concentration and, as far as possible, concentrations of certain individual substance. Over the years, the list has grown from the 25 individual substances originally examined to 40 today. These additions were necessary for two reasons. Firstly, sample assessments using the "indoor measurement" system repeatedly detected certain substances. And secondly, substances such as naphthalene and hydrocarbon mixtures with low aromatic contents (chain length C_9 to C_{14}) were added, for which the Ausschuss für Innenraumrichtwerte (Committee on Indoor Guide Values, formerly: Ad Hoc Working Group on indoor guide values) of the Umweltbundesamt (Federal Environmental Agency) and the supreme federal state health authorities had drawn up guide values in the meantime.

Sampling

Before concentrations of volatile organic compounds and aldehydes can be measured, indoor rooms that are naturally ventilated must be thoroughly ventilated (15 minutes) and then have their doors and windows closed for a period of at least eight hours. It is simplest to do this overnight.

The sampling is then carried out with the doors and windows still closed. There must be no smoking in the rooms after ventilation and up until the end of the measurement process. Work can continue in the rooms during measurement.

When carrying out investigations in rooms with forced ventilation or air conditioning system, said system should run for three hours in operating conditions typical for the room in question prior to sampling.

In line with DIN EN ISO 16000-1, the procedure is the same for rooms for which ventilation instructions are defined (for example, schools and nurseries). The standard states that a complete and typical usage cycle must pass prior to measurement in such rooms. During school time, this would usually be no more than the duration of one lesson. This type of ventilation would significantly reduce the indoor concentration levels, making it extremely difficult to identify the causes of poor air quality resulting from sources in the building or in the furniture and furnishings as would otherwise be necessary in naturally ventilated rooms. This would mean that any problem in schools and nurseries could be "remedied by ventilation and measurement" [7]. However, this should not be standard practice, especially in places where children and young people are present. It is therefore recommended that these rooms are also kept closed for at least eight hours prior to sampling so that the sources can be detected.

If the indoor measurements are being carried out due to complaints concerning indoor air quality, it is useful to conduct a parallel measurement in a reference room for which no complaints have been made. This enables room-specific differences to be identified as well as potential sources. As far as possible, the reference room should be located close to the room with air quality issues and be similar in size and use.

A further reference measurement that can be taken is the concentration of volatile organic compounds and aldehydes in the outdoor air. If measurements are to be taken in several polluted rooms and if the measurements are carried out on different days, it is advisable to perform an outdoor air reference measurement for each of the days. The outdoor air measurement should be performed near to the building being investigated, at the same height if possible. The measurements should be taken at a sufficient distance from the building (› 2 m).

The VOC concentration is determined by sampling air using a TENAX TA thermal desorption tube at a flow rate of 4 l/h (66.6 ml/min) for a period of 30 minutes. This is followed by aldehyde sampling for a period of one hour at a flow rate of 80 l/h (1.333 l/min) using a Waters Sep-Pak XpoSure sampler. The aldehyde sampling must not take place at the same time as the VOC sampling because the Waters Sep-Pak XpoSure samplers contain acetonitrile, which could find its way into the ambient air and thus onto the TENAX TA sampler during the measurement process.

The carbon dioxide concentrations can be determined using either detector tubes and a hand pump recommended by the tube manufacturer or with direct-reading devices. The detector tubes mainly serve the purpose of obtaining an initial idea of the usual situation in the room. To verify whether the carbon dioxide concentration in a room provides optimum hygiene conditions, measurements must be carried out continuously over a long period using a direct-reading device under normal conditions of use and with the usual number of room inhabitants. Before

measurement starts, the room must be thoroughly ventilated once. The initial carbon dioxide concentration is then that of the outdoor air. The room parameters, e.g. number of windows open and number of persons present, must be documented.

The measurement is carried out at the employees' breathing height, around 1 to 1.5 m above floor level and at a distance of at least 1 to 2 m from the walls. Measures must be taken to prevent the air inhaled and exhaled by persons nearby influencing the measurement (this also includes the person carrying out the sampling). As a rule, one sampling site is sufficient for relatively small rooms up to 50 m². An outdoor air measurement is taken on the same day to provide a reference value.

If the measurements are carried out indoors without any people present in the room, there is no need to measure the CO_2 levels unless there is evidence that there are CO_2 sources in the room.

Analysis

To analyse the VOCs, the TENAX-TA tubes are heated, causing the substances collected to desorb. A gas chromatography analysis is then performed. A flame ionisation detector (FID) is used for quantification. As a rule, the substances shown in Table 25 are quantified and the detector is calibrated based on a single substance calibration.

Calibration curves are used for the quantitative assessment. Toluene calibration is used to quantify any additional individual substances, which are then identified using a mass spectrometer. The list of substances to be analysed is continuously adapted in line with the list of substances for which the Umweltbundesamt (German Environmental Protection Agency) has drawn up indoor air guide values. In addition, substances frequently determined by means of toluene calibration are also added to the list.

The total volatile organic compounds (TVOCs) include all substances that appear in the gas chromatogram between the signals for n-hexane and n-hexadecane following separation using a non-polar capillary column. The butanone and ethyl acetate concentrations are also included.

The Waters Sep Pack cartridges are first eluted with acetonitrile before the aldehyde levels are determined. The quality and quantity are established by means of high performance liquid chromatography (HPLC). The quantitative evaluation is done using calibration curves. Currently, the aldehydes listed in Table 25 are given as individual components. See Section 12.3 for an explanation of how the measurement results are assessed.

Table 25:
VOCs and aldehydes included in the analysis

Substance category	Individual substances
Alkanes	n-Heptane, n-octane, n-nonane, n-decane, n-undecane, n-dodecane, n-tridecane, n-tetradecane, n-pentadecane, n-hexadecane
Aromatic compounds	Benzene, toluene, ethylbenzene, xylene (all isomers), 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene (mesitylene), styrene, naphthalene, phenol
Alcohols	n-Butanol, 2-ethylhexanol
Ketones	Butanone, acetophenone[1)]
Esters	Ethyl acetate, n-butyl acetate, 2-butoxyethyl acetate, 2-(2-butoxyethoxy)ethyl acetate
Glycols/glycol ethers	2-Butoxyethanol, 2-(2-butoxyethoxy)ethanol, 2-phenoxyethanol
Terpenes/sesquiterpenes	α-Pinene, 3-carene, limonene, (+)-longifolene
Aldehydes	Formaldehyde, acetaldehyde, propionaldehyde[1)], acrylaldehyde (acrolein), butyraldehyde, furfural, glyoxal, glutaraldehyde, hexanal[2)]
Siloxanes	Hexamethylcyclotrisiloxane, octamethylcyclotetrasiloxane, decamethylcyclopentasiloxane, dodecamethylcyclohexasiloxane[1)]

[1)] Method in preparation
[2)] Unlike other aldehydes, hexanal are determined using the VOC method

12.2.3 Determining the air exchange rate

The air exchange rate is an important parameter in indoor air quality assessment. It measures the air replaced as the volume of supply air in relation to room volume. Adequate air replacement ensures that sufficient fresh air is supplied to indoor rooms, pollutants and odorant substances are removed and damage due to excessive humidity is prevented. In rooms that only have natural ventilation, air is replaced via windows, doors and leaks in the building envelope.

Method

One way of determining the air exchange rate is the concentration-decay method described in VDI 4300, Part 7 [8] and BS EN ISO 12569 [9].This method calculates the exchange rate on the basis of the decay in the concentration of an indicator gas (e.g. sulphur hexafluoride) over time. It can only be applied if it can be assumed that the air in the room is thoroughly mixed. To determine the air exchange rate, a certain quantity of sulphur hexafluoride is introduced into the room to be measured. The gas must be distributed evenly throughout the room. The concentration of the indicator gas is then determined at various

points in time. The degree to which the concentration decreases over time can be used to calculate the air exchange rate.

Application

Indoor pollutant concentrations depend on various factors, including the source strength, the air exchange rate and the volume of the room. If the pollutant concentration in a room and the air exchange rate are determined in identical ventilation conditions, the source strength can be calculated using the following formula:

$$q = (\beta - \beta_0) \cdot n \cdot V_R$$

Where

q: Source strength in mg/h

β: Pollutant concentration in room in mg/m³

β_0: Pollutant concentration in outdoor air in mg/m³

n: Air exchange rate in 1/h

V_R: Room volume in m³

Knowing the source strength and the air exchange rate makes it possible, for example, to better compare the substance concentrations measured in polluted rooms with those of unpolluted reference rooms.

The sampling of the indicator gas sulphur hexafluouride to determine the air exchange rate can be done at the same time as the sampling required to determine VOC and aldehyde levels, described in Section 12.2.2.

12.2.4 Methods for measuring other substances

As a rule, the measurement methods developed by the IFA are not indoor measurement methods. The majority of them are intended to monitor compliance with the occupational exposure limits set out in TRGS 402 [10]. These measurement methods are designed for a measuring period of up to eight hours. It is usually not possible to monitor compliance with the guide values recommended for indoor rooms using these methods. In particular, long-term measurements are not possible because, for example, of a lack of experience with passive samplers. Please also refer to Section 12.4 for information on how to measure individual substances or categories of substance.

12.2.5 References

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12.3 Assessment of chemical exposures

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The values to be used for assessing air quality in indoor workplaces such as offices are frequently the subject of some debate.

The potential health risks to humans as a result of hazardous substances in the air they inhale are generally assessed on the basis of limit values defined for specific areas. The TRGS 900 [2] sets out occupational exposure limits (OELs) for the workplace substances that the Gefahrstoffverordnung (GefStoffV; Ordinance on Hazardous Substances) [1] describes as hazardous. However, these OELs only apply to workplaces at which the hazardous substances concerned are either used in or are produced during the activities performed there, according to the definition given in the Gefahrstoffverordnung. There are no specified occupational exposure limits for indoor workplaces that do not fall within the scope of the ordinance.

Instead, such workplaces are subject to the general guidance on ventilation given in Annex 3.6 of the Arbeitsstättenverordnung (Ordinance on Workplaces) [3], according to which there must be sufficient healthy air in work rooms. As per ASR A3.6 Ventilation [4], this requirement is met if the quality of the air is essentially the same as that of the outdoor air.

However, the immission values and other assessment values specified for outdoor air cannot automatically be applied to indoor air since they may have been drawn up with the aim, for example, of protecting vulnerable plant or animal life, not human beings. Furthermore, using the quality of the outdoor air as a standard against which to compare the quality of the indoor air causes problems in practice if the outdoor air is polluted.

As a result, the values currently used in Germany to assess exposure in indoor workplaces vary considerably in terms of their nature and origin. Unlike occupational exposure limits, these values are not presented in one, binding rule and, in particular, they do not have consistent legal relevance. Almost all values for indoor rooms are merely recommendations. The most important values used for assessing indoor air are described in the following. In addition, the main assessment values for outdoor air can be found in the latest list of limit values published by the IFA [5]. Values for assessing individual substances and categories of substance are presented in Section 12.4.

12.3.1 Indoor air guide values set by the Federal Environmental Agency (UBA)

The Committee for Indoor Guide Values, set up by the UBA's Indoor Air Hygiene Commission and the highest state health authorities, has drawn up guide values for indoor rooms in general, including rooms in dwellings, based on toxicological evidence. These values best meet the criteria for a valid assessment of air quality in indoor workplaces. A distinction is drawn between guide value II and guide value I, as follows:

"Guide value II (RW II) is an effect-related value based on current toxicological and epidemiological knowledge of a substance's effect threshold that takes uncertainty factors into account. It represents the concentration of a substance which, if reached or exceeded, requires immediate action as this concentration could pose a health hazard, especially for sensitive people who reside in these spaces over long periods of time. Depending on how the substance concerned works, guide value II may be defined either as a short-term value (RW II K) or a long-term value (RW II L).

Guide value I (RW I) represents the concentration of a substance in indoor air for which, when considered individually, there is no evidence at present that even life-long exposure is expected to bear any adverse health impacts. Values exceeding this are associated with exposure that is undesirable for health reasons. For the sake of precaution, there is also need for action in the concentration range between RW I and RW II. RW I can act as a target value during clean-up efforts, which should be undercut rather than merely complied with. Guide value I is derived from guide value II through the introduction of an additional factor based on convention."

Whilst the occupational exposure limits relate to eight-hour periods, the guide values usually refer to long-term periods (24 hours a day, seven days a week) and also apply to children and people with an illness. They are not used extensively because they are currently only available for a very limited number of individual substances (see Table 26).

12.3.2 WHO Air Quality Guidelines

In 2009, the World Health Organization (WHO) published its first guidelines for indoor air quality, intended to protect public health against the risks posed by damp and associated microorganism growth [7]. Additional guidelines were added in 2010 for a number of chemicals commonly found in indoor air (Table 27 on page 82) [8].

Table 26:
Guide values established for indoor air up to May 2013 [6]

Compound	Guide value II [1] in mg/m³	Guide value I [1] in mg/m³	Year established
2-Furaldehyde	0.1	0.01	2011
Aldehydes, C_4 to C_{11} (saturated, acyclic, aliphatic)	2	0.1	2009
Alkyl benzene, C_9 to C_{15}	1	0.1	2012
Benzaldehyde	0.2	0.02	2010
Benzyl alcohol	4	0.4	2010
Dearomatized hydrocarbon solvents (C_9 to C_{14})	2	0.2	2005
Dichloromethane	2 (24 h)	0.2	1997
Diethylene glycol butyl ether (DEGBE)	1	0.4	2013
Diethylene glycol dimethyl ether (DEGDME)	0.3	0.03	2013
Diethylene glycol methyl ether (DEGME)	6	2	2013
Diethylene glycol monoethyl ether (DEGEE)	2	0.7	2013
Diisocyanates	See notes [2]		2000
Dipropylene glycol 1-methyl ether (D-PGME)	7	2	2013
Ethylbenzene	2	0.2	2012
Ethylene glycol butyl ether (EGBE)	1	0.1	2013
Ethylene glycol butyl ether acetate (EGBEA)	2	0.2	2013
Ethylene glycol hexyl ether (EGHE)	1	0.1	2013
Ethylene glycol monoethyl ether (EGEE)	1	0.1	2013
Ethylene glycol monoethyl ether acetate (EGEEA)	2	0.2	2013
Ethylene glycol monomethyl ether (EGME)	0.2	0.02	2013
2-Ethylhexanol	1	0.1	2013
Carbon monoxide	60 (0.5 h) 15 (8 h)	6 (0.5 h) 1.5 (8 h)	1997
Cresols	0.05	0.005	2012
Methyl isobutyl ketone	1	0.1	2013
Monocyclic monoterpenes (guiding substance: d-limonene)	10	1	2010
Naphthalene	0.020	0.002	2004
Pentachlorophenol (PCP)	0.001	0.0001	1997
Phenol	0.2	0.02	2011
2-Propylene glycol 1-ethyl ether (2PG1EE)	3	0.3	2013
2-Propylene glycol 1-methyl ether (2PG1ME)	10	1	2013
2-Propylene glycol 1-tert-butyl ether (2PG1tBE)	3	0.3	2013
Mercury (as metallic vapour)	0.00035	0.000035	1999
Nitrogen dioxide (NO_2)	0.35 (30-minute value) 0.06 (7-day value)	-	1998
Styrene	0.3	0.030	1998
Bicyclic terpenes (guiding substance: α-pinenes)	2	0.2	2003
Toluene	3	0.3	1996
Tris(2-chloroethyl) phosphate (TCEP)	0.05	0.005	2002
Cyclic dimethylsiloxanes D3-D6 (total guide value)	4	0.4	2011

[1] These are usually long-term values. Where this is not the case, the averaging period is indicated in parentheses, e.g. 24 hours (h).
[2] The working group felt that it did not make sense to specify a guide value II for diisocyanates (DIs) (see explanation in the publication). Where varnishes and adhesives containing diisocyanates are used, the concentration in the indoor air is initially relatively high (concentration approximately equal to the MAK value) but it drops sharply and long-term pollution is unlikely once the hardening process has finished. As a rule, however, rooms in which products containing diisocyanates are processed should be well ventilated.

Table 27:
Summary of the WHO guidelines for selected pollutants in indoor air [9]

Pollutant	Guidelines
Benzene	• No safe level of exposure can be recommended • Unit risk[1] of leukaemia per 1 µg/m³ air concentration is $6 \cdot 10^{-6}$ • The concentrations of airborne benzene associated with an excess lifetime risk[2] of 1/10,000, 1/100,000 and 1/1,000,000 are 17, 1.7 and 0.17 µg/m³, respectively
Formaldehyde	0.1 mg/m³ (30-minute average)
Carbon monoxide	• 15 minutes – 100 mg/m³ • 1 hour – 35 mg/m³ • 8 hours – 10 mg/m³ • 24 hours – 7 mg/m³
Naphthalene	0.01 mg/m³ (annual average)
Polycyclic aromatic hydrocarbons	• No threshold can be determined and all indoor exposures are considered relevant to health • Unit risk for lung cancer for PAH mixtures is estimated to be $8.7 \cdot 10^{-5}$ per ng/m³ of B[a]P • The corresponding concentrations for lifetime exposure to B[a]P producing excess lifetime cancer risks of 1/10,000, 1/100,000 and 1/1,000,000 are approximately 1.2, 0.12 and 0.012 ng/m³, respectively
Radon	• The excess lifetime risk of death from radon-induced lung cancer (by the age of 75 years) is estimated to be $0.67 \cdot 10^{-5}$ per Bq/m³ for lifelong non-smokers and $15 \cdot 10^{-5}$ per Bq/m³ for current smokers (15 to 24 cigarettes per day); among ex-smokers, the risk is intermediate, depending on time since smoking cessation • The radon concentrations associated with an excess lifetime risk of 1/100 and 1/1,000 are 67 and 6.7 Bq/m³ for current smokers and 1670 and 167 Bq/m³ for lifelong non-smokers, respectively
Nitrogen dioxide	• 200 µg/m³ (1-hour average) • 40 µg/m³ (annual average)
Trichloroethylene	• Unit risk estimate of $4.37 \cdot 10^{-7}$ per µg/m³ • The concentrations of airborne trichloroethylene associated with an excess lifetime cancer risk of 1 : 10,000, 1 : 100,000 and 1 : 1,000,000 are 230, 23 and 2.3 µg/m³, respectively
Tetrachloroethylene	• 0.25 mg/m³ (annual average)

[1] Unit risk: Risk of developing cancer as a result of lifelong exposure to a concentration of 1 µg/m³
[2] Lifetime risk: Probability of developing, for example, cancer during an average lifetime

12.3.3 Derivation of reference values for individual substances

Statistically derived reference values can be used to assess those substances for which there are no guide values yet. In accordance with an international convention, the 95 percentile value of a sufficiently large set of data can be used as a reference value. This assumes (without a toxicological assessment being carried out) that the "normal conditions" that are present in the rooms investigated and do not give rise to illness or health complaints can be deemed generally acceptable. Unlike guide values, reference values cannot be used to assess health risks. As such, if the actual values are lower than the reference values this does not necessarily mean that there is no risk to health. By the same token, if the values are higher it does not automatically mean that there is a risk [10].

Having said that, a value that is significantly higher than the reference value may be an indication that the room contains emission sources that might impair health. For reference values to be usable, it must be possible to compare the reference room and the indoor room being investigated. The main parameters that determine whether this is the case are the fittings and furnishings, the way in which the rooms are used, the measuring method and the measuring strategy.

Reference values for assessing indoor workplaces (e.g. offices)

Reference values for assessing indoor workplaces, based on measurement data compiled by the statutory accident insurance institutions, were published for the first time in 2004 [11]. They were reviewed in 2010 and updated in line with the findings of a statistical evaluation of all of the measurement data documented in the IFA's MEGA exposure database up to September 2010 [12].

This statistical evaluation only considered data from stationary measurements gathered in offices without mechanical ventilation and where the sampling duration was as specified in the measuring procedures [13; 14]. The results can be considered statistically reliable since, in most cases, more than 700 measurements were evaluated per compound. The German statutory accident insurance institutions apply the lower 90 percentile value instead of the 95 percentile value when deriving reference values, in contrast with international convention, for prevention purposes. The values have been rounded strictly to 2 decimal places. The indoor workplace reference values derived in 2011 are listed in Table 28. They are only applicable in conjunction with the MGU measurement programme for indoor measurements (including the associated measurement strategy) described in Section 12.2.2.

Reference values for assessing classrooms

A study conducted between 2004 and 2009 monitored concentrations of aldehydes and VOCs in 421 unpolluted classrooms in 119 schools in the German state of North Rhine-Westphalia [15]. The measuring and analysis methods used were similar to those in the MGU measuring programme for indoor measurements. The data was used to derive classroom reference values as was

done for indoor workplaces [16]. The classroom reference values are shown in Table 29.

Table 28:
Indoor workplace reference values set by the German statutory accident insurance institutions

Compound	Indoor workplace reference value in mg/m³
TVOCs	1
Hydrocarbon mixtures, aliphatic (C_9 to C_{14})	0.07
Alkanes	
n-Heptane	0.02
n-Octane	0.01
n-Nonane	0.01
n-Decane	0.01
n-Undecane	0.02
n-Dodecane	0.01
n-Tridecane	0.01
n-Tetradecane	0.01
n-Pentadecane	0.01
Aromatic compounds	
Toluene	0.04
Ethylbenzene	0.01
o-Xylene	0.01
m-Xylene	0.02
p-Xylene	0.01
1,2,4-Trimethylbenzene	0.01
Styrene	0.01
Alcohols	
n-Butanol	0.04
2-Ethylhexanol	0.02
Ketones	
Butanone	0.01
Esters	
Ethyl acetate	0.02
n-Butyl acetate	0.02
Ethers	
2-Butoxyethanol	0.01
2-Phenoxyethanol	0.01
Terpenes	
α-Pinene	0.02
Limonene	0.03
3-Carene	0.01
Aldehydes	
Formaldehyde	0.06
Acetaldehyde	0.05
Hexanal	0.03
Siloxanes	
Hexamethylcyclotrisiloxane (D3)	0.03
Octamethylcyclotetrasiloxane (D4)	0.02
Decamethylcyclopentasiloxane (D5)	0.06

Table 29:
Classroom reference values set by the German statutory accident insurance institutions [16]

Compound	Classroom reference value in mg/m³
TVOCs	0.68
Hydrocarbon mixtures, aliphatic (C_9 to C_{14})	0.03
Alkanes	
n-Heptane	0.01
n-Undecane	0.01
n-Dodecane	0.01
n-Tridecane	0.01
Aromatic compounds	
Toluene	0.03
Ethylbenzene	0.01
Xylene (all isomers)	0.02
m-Xylene	0.01
1,2,4-Trimethylbenzene	0.01
Styrene	0.01
Phenol	0.01
Alcohols	
n-Butanol	0.03
2-Ethylhexanol	0.02
Ketones	
Butanone	0.01
Esters	
Ethyl acetate	0.01
n-Butyl acetate	0.01
Ethers	
2-Butoxyethanol	0.02
2-(2-Butoxyethoxy)ethanol	0.03
2-Phenoxyethanol	0.02
Terpenes	
α-Pinene	0.02
Limonene	0.02
3-Carene	0.01
Aldehydes	
Formaldehyde	0.06
Acetaldehyde	0.05
Hexanal	0.02
Siloxanes	
Hexamethylcyclotrisiloxane (D3)	0.03
Octamethylcyclotetrasiloxane (D4)	0.02
Decamethylcyclopentasiloxane (D5)	0.02

Reference values set by other institutions

As well as the statutory accident insurance institutions, other bodies have drawn up reference values for assessing indoor air [17 to 19]. The measurements were conducted in a variety of indoor rooms, including in dwellings, and are decades old in some cases. Irrespective of whether this data can be applied to office workplaces, it should be borne in mind that there have

been major changes in indoor furnishings, fittings and equipment and the way in which rooms are used. Those changes, of which new interior decoration materials and different cleaning methods are just a few examples, have affected air pollution levels too. Another problematic aspect is that different measuring methods and strategies were used in the studies. As such, they offer limited comparability, which is a key prerequisite for reference values to be used. They can therefore only be applied to indoor workplaces subject to certain provisos.

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12.4 Specific information regarding individual substances and categories of substance

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12.4.1 Carbon dioxide

Humans and their breathing are the main source of indoor carbon dioxide (CO_2) emissions. However, they do not result in toxically relevant levels CO_2 concentrations even in unfavourable conditions, e.g. where the air exchange rate is low. As odorant substance emissions are usually proportional to humans' CO_2 emissions, CO_2 concentration levels are a suitable indicator of indoor air quality provided there are no other sources of CO_2 emissions or odours. They also indicate how effective the room ventilation is.

As described in Section 12.2.2, indoor CO_2 concentrations can be measured using detector tubes or direct-reading measuring devices. However, they can also be calculated on the basis of the human CO_2 emissions and the number of people present, their activities and the air exchange rate (ventilation efficiency) [1]. When engaged in non-strenuous activities, a human emits around 20,000 ml/h of CO_2. This value can be used to calculate the maximum CO_2 concentration level that will be reached in accordance with equation (1).

$$x_{CO_2} = \frac{n \cdot m_{CO_2}}{\lambda \cdot V_R} + x_{CO_2,\,outdoor} = \frac{n \cdot 20\,000\,^{ml}/_{h}}{\lambda \cdot V_R} + x_{CO_2,\,outdoor} \qquad (1)$$

x_{CO_2} : CO_2 concentration in ml/m³

m_{CO_2} : CO_2 emission rate per person in ml/h

λ : Air exchange rate in h^{-1}

V_R : Room volume in m³

$x_{CO_2 outdoor}$: Outdoor air CO_2 concentration in ml/m³

n : number of people

For example, if the volume of an office used by two people is 100 m³ and if a natural air exchange rate λ of 0.5 h^{-1} is assumed for the office, the maximum possible CO_2 concentration – taking into account a mean CO_2 concentration of 400 ml/m³ in the outdoor air [2] – is 1,200 ml/m³ (see equation 2).

$$x_{CO_2} = \frac{2 \cdot 20{,}000\,^{ml}/_{h}}{0{,}5\ h^{-1} \cdot 100\ m^3} + x_{CO_2\,outdoor} \qquad (2)$$

$$= 800\,^{ml}/_{m^3} + 400\,^{ml}/_{m^3} = 1{,}200\,^{ml}/_{m^3}$$

For assessment purposes, the general rule is that the concentration level should not exceed

0.1 vol.-%CO_2 (1,000 ppm or 1,800 mg/m³)

(*Pettenkofer* value, see e.g. [3; 4]). In 2008, the Ad Hoc Working Group on Indoor Guide Values derived the following guide values for momentary concentrations of CO_2, based on health and hygiene aspects and the findings of intervention studies. These values have since been incorporated into ASR A3.6 "Ventilation" [2]:

- Carbon dioxide concentration lower than 1,000 ppm = Safe hygiene standard
- Carbon dioxide concentration between 1,000 and 2,000 ppm = Critical hygiene standard
- Carbon dioxide concentration higher than 2,000 ppm = Unacceptable hygiene standard

In accordance with these guide values, ventilation is recommended where the momentary CO_2 concentration level exceeds 1,000 ppm. If the concentration level is over 2,000 ppm, ventilation is compulsory. If ventilation is not sufficient to bring the concentration down to below the guide value of 2,000 ppm (a ventilation plan may have to be introduced), further organisational, ventilation-system or structural measures are necessary. These include, for example, reducing the number of people present in the room or installing a ventilation system.

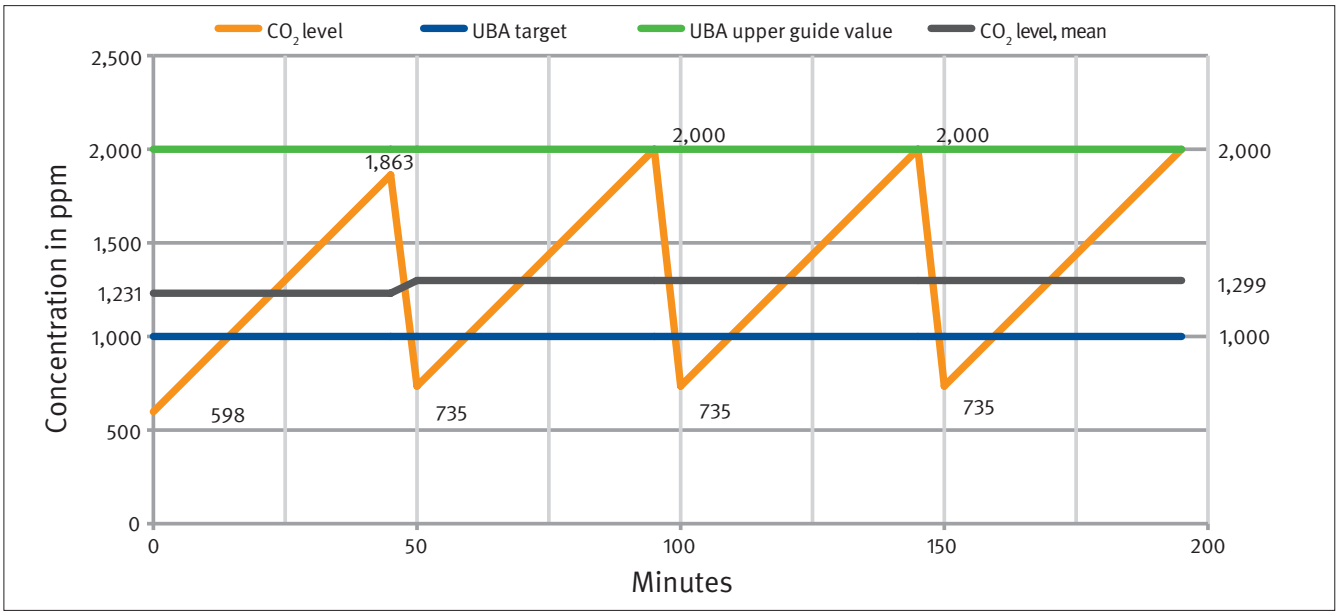
Carbon dioxide pollution in classrooms

A study conducted by the North Rhine-Westphalian Social Accident Insurance Institution for the public sector in 379 classrooms in 111 schools [5] confirmed that CO_2 is usually the most significant air pollutant in classrooms too. According to the findings, the CO_2 concentration in the classroom during lessons increases substantially if the room is not ventilated (Figure 27, page 86). Airing the room thoroughly during breaks can briefly reduce the CO_2 concentration to below the guide value of 1,000 ppm but it is exceeded again just a few minutes after closing the windows.

The guide value can only be constantly maintained by airing the room again briefly halfway through the lesson or by keeping the windows tilted open for the duration of the lesson. The latter option does not necessarily require the window area to be large. In the winter months, approximately 1 m² of open window is sufficient on average to ensure hygienically safe air. In the summer, an average of 1.8 m² of open window ensures that the CO_2 concentration only rises slightly during lessons.

CO_2 concentrations of 1,000 ppm can also be permanently achieved with the help of mechanical ventilation, be it in the form of a central ventilation or air conditioning system for the building or a room-specific solution.

Figure 27:
Mean CO_2 pollution in classrooms aired briefly and thoroughly after each lesson; UBA = Umweltbundesamt (Federal Environmental Agency)



12.4.2 Ozone

The main source of indoor ozone pollution is contamination through outdoor air as a result of ventilation (e.g. open windows). Ozone formation caused by operating laser printers and copiers is no longer a problem today (see Section 7.2.3).

Ozone is produced in the outdoor air by means of solar irradiation and photochemical smog reactions. Ventilation, especially in the form of open windows and doors, enables it to make its way from the outdoor air into the indoor air. Ventilation systems, on the other hand, break down part of the ozone as it travels through the filter and the pipes towards the work area. Indoors, ozone decomposes with a half-life of approximately 30 minutes, partly by reacting with other volatile substances.

Directive 2008/50/EC of the European Parliament and the Council on ambient air quality and cleaner air for Europe [6] stipulates an ozone value of 120 µg/m³ as the maximum eight-hour average for one day in order to protect human health. This value may be exceeded on no more than 25 days per year. For the one-hour value, the directive also lays down an information threshold of 180 µg/m³ (the public must be informed when this value is exceeded) and an alert threshold of 240 µg/m³.

High concentrations, resulting in the assessment values being exceeded, are particularly likely during sunny weather at the height of summer. On such days, it is advisable to keep windows and doors closed as far as possible to prevent too much ozone entering indoor rooms. The preferred option should always be to air rooms briefly and thoroughly and then close the doors and windows again.

12.4.3 Formaldehyde

Formaldehyde is a basic chemical that serves as an inexpensive precursor for a variety of chemical products. For instance, it is used in the production of phenol formaldehyde resins and aminoplasts, which in turn are used, for example, to glue chipboard, plywood and edge-glued panels (see Section 6.4.3).

Other formaldehyde sources of relevance in indoor spaces include in situ foams made from urea formaldehyde resin, varnishes (mainly acid-catalysed coatings for wooden floors and furniture), veneers, textiles, carpets and fibre mats containing binders. Aqueous solutions used as disinfectants and preservatives also contain formaldehyde and it can also be detected in personal care and cleaning products.

In 2004, a working group at the International Agency for Research on Cancer (IARC) classified formaldehyde as category 1, carcinogenic to humans [7; 8]. Germany's Bundesinstitut für Risikobewertung (BfR; Federal Institute for Risk Assessment) responded in the spring of 2006 by suggesting an air concentration level of 0.1 ppm (0.12 mg/m³) as a safe level in view of the carcinogenic effect of formaldehyde on human beings [9]. The Ad Hoc Working Group on Indoor Guide Values followed step in the autumn of 2006 [10].

The WHO proposes a 30-minute average of 0.1 mg/m³ (0.08 ppm) as a precaution against sensory irritation in the general public [11]. Where exposure is prolonged, the recommendation is not to exceed a concentration of 0.06 mg/m³ (0.05 ppm) [12].

12.4.4 Volatile organic compounds

Volatile organic compounds (VOCs) can be classified as shown in Table 30. The very volatile and volatile organic compounds are almost exclusively found in the ambient air. The semi-volatile organic compounds, such as biocides and phthalates, and the organic compounds associated with particulate organic matter (POM) are mostly found in sedimented house dust and attached to airborne dust. These cases can only be assessed adequately by examining the dust deposits.

Table 30:
VOC classification based on the World Health Organization method [13]

Classification	Abbreviation	Boiling range in °C
Very volatile organic compounds	VVOC	‹ 0 to 50-100
Volatile organic compounds	VOC	50-100 to 240-260
Semi-volatile organic compounds	SVOC	240-260 to 380-400
Organic compounds associated with particulate (organic) matter	POM	› 380

The airborne VOCs consist of a huge range of substances, which can be classified as follows:

- aliphatic hydrocarbons,
- aromatic hydrocarbons,
- alcohols,
- ketones,
- esters, primarily acetates and acrylates,
- glycol compounds, both glycol esters and glycol ethers,
- terpenes and
- siloxanes (D3 to D6 siloxane).

Although aldehydes are also VOCs, the methods used to analyse them are different and they are therefore often considered separately.

There are a number of potential sources of volatile organic compounds in indoor spaces. They can be divided into the following three categories:

- building-related sources,
- sources related to human activity and
- sources related to the outdoor air.

Almost any of the materials used in modern buildings can constitute a building-related VOC source. The range of substances reflects the changes in the composition of the materials used. For instance, more dibasic esters (DBEs) – a substance category that is used as a substitute for conventional solvents – will be detected in the future. In addition, materials such as bricks, mortar and other elements of buildings, which used to be low in emissions, now contain aggregates that have plastics and solvents in them. Other potential sources are wall panelling, floor coverings, insulation materials, sealants, furniture, paints, varnishes and solvents used in interiors (see Section 6.4).

Human activities cause VOCs to enter rooms in the form of cleaning and furniture care products, cosmetics, disinfectants, plant protection products and tobacco. VOC contamination is also possible through the outdoor air (e.g. from road traffic).

Investigation

When identifying potential VOC sources, the first step should be to ascertain whether redecoration work has been carried out or new furniture, equipment, etc. installed recently (see questionnaire G2 in Annex 3). In such cases, the VOC concentrations can often be reduced by ventilating the room for a prolonged period whilst simultaneously heating it. The investigation should also check whether any specific cleaning agents or air fresheners used could be sources. Questionnaire G2 also includes aspects such as the location of the building, thus covering contamination from outside too.

A key parameter in any assessment of indoor air quality is the total of the VOCs in the 50 to 260 °C boiling range (see Table 30), referred to as TVOCs (total volatile organic compounds). This boiling range includes the majority of substances that can be detected analytically on a non-polar column in the elution range between n-hexane and n-hexadecane [14].

Although there are no substantiated dose-effect relationships and TVOC concentrations should not be used as the sole criterion when assessing the healthiness of indoor air quality, the TVOC concentration levels can be used to assess VOC-related adverse effects on the indoor air. For instance, the probability of irritation and perception of odours increases as the TVOC concentration rises. The Committee on Indoor Guide Values recommends Seifert's five-level approach from 1999 for assessing TVOC concentration levels (see Table 31, page 88) [14]. Generally speaking, the VOC assessment must provide answers to the following:

- Have guide values been exceeded? (See Section 12.3.1)
- Are there any abnormal instances of the reference values being exceeded? (See Section 12.3.3)
- Does the thermal environment (air exchange, temperature, humidity) comply with the requirements (see Chapter 9)?

Annex 5 contains a table listing possible sources of individual substances.

Table 31:
Hygiene ratings for TVOC values and resulting recommendations for action to be taken [14]

Level	Concentration in mg/m³	Hygiene rating	Recommendations
1	≤ 0.3	Hygienically safe Usually no complaints	No further action
2	› 0.3 to 1	Still hygienically safe provided no guide values for individual substances or categories of substance have been exceeded. Complaints or perception of odours in individual cases, e.g. following small-scale redecoration work or installation of new furniture in the weeks preceding	Sufficient ventilation, especially after redecoration work Identify VOC sources (e.g. by inspecting the room), check use of cleaning agents, follow-up measurements to monitor compliance with guide values under conditions of use
3	› 1 to 3	Critical in terms of hygiene Use of regularly used rooms only acceptable for limited periods (‹ 12 months) Within approx. 6 months, the TVOC concentration should be decreased to considerably lower than the value initially measured. Cases of complaints or perception of odours, e.g. following large-scale redecoration work	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health In all cases: search for source and review ventilation patterns: ventilate thoroughly and, where appropriate, specify conditions of use and ventilation Control/follow-up measurement recommended after approx. one month (under conditions of use)
4	› 3 to 10	Hygienically unsafe Use of regularly used rooms only acceptable for limited periods (‹ 1 month) The TVOC concentration should be decreased to below 3 mg/m³ within one month. Multiple cases of complaints or perception of odours, e.g. following large-scale redecoration work	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health. Toxicological assessment of individual substances or categories of substance necessary In all cases: search for source, ventilate thoroughly and, where appropriate, specify conditions of use and ventilation and take appropriate steps to minimise concentration levels. Where people are required to spend time in the room concerned, the in-room time per day must be limited over a maximum period set by the Gesundheitsamt (public health department) (hours per day/time limit). Control/follow-up measurement recommended after approx. one month (under conditions of use) If, after one month, the TVOC concentration remains higher than 3 mg/m³ despite the recommended action, appropriate remediation measures must be planned.
5	› 10	Hygienically unacceptable. Room should not be used as far as possible. People should only spend time in the room if it is limited to a certain number of hours per day/a certain amount of time. The room must not be used at all if the values are higher than 25 mg/m³. The TVOC concentration should be decreased to below 3 mg/m³ within one month. Usually complaints and noise annoyance, e.g. following incorrect use or accidents.	Immediate follow-up measurement under conditions of use to check whether guide values have been exceeded Check critical instances of reference values being exceeded to determine whether they are relevant in terms of health. Toxicological assessment of individual substances or categories of substance necessary. In all cases: search for source, ventilate thoroughly, specify conditions of use and ventilation and take appropriate steps to minimise concentration levels. Where people are required to spend time in the room concerned, the in-room time per day must be limited over a maximum period set by the public health department (Gesundheitsamt) (hours per day/time limit). Control/follow-up measurement recommended after approx. one month (under conditions of use) If minimisation efforts reduce the concentration level to below 10 mg/m³ during the period considered but it is still higher than 3 mg/m³, the action recommended in Level 4 should be taken. If, after one month, the TVOC concentration remains higher than 10 mg/m³ despite the recommended action, the room should not be used and appropriate remediation measures must be taken.

12.4.5 Mercury in compact fluorescent lamps (energy-saving light bulbs) and fluorescent tubes

Compact fluorescent lamps (energy-saving lamps) and fluorescent tubes contain small amounts of mercury, which is required for the illumination process in these lighting products. Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment [15] restricts the quantity of mercury that can be used in lamps in the European Union and requires manufacturers to reduce the levels further. Since January 2012, manufacturers have had to mark the mercury content on the packaging of the lamps.

No mercury is emitted from lamps when they are used as intended. However, when energy-saving lamps or fluorescent tubes are replaced or otherwise handled (when being collected for recycling, for example), there is a risk that they might be damaged. If they break, mercury vapours can be released [16].

Measurements conducted by the UBA on new energy-saving lamps on the market have shown that there are no significant concentrations of mercury following lamp breakages when the broken lamp is disposed of completely and the room immediately aired [17]. It can therefore be assumed that mercury does not pose any health risks.

To minimise the risk of mercury exposure, any new lamps purchased should contain as little mercury as possible. Faulty lamps should not be replaced while still hot because hot lamps give off more mercury vapours when broken than cold ones do. Spent lamps must be disposed of at appropriate collection centres (e.g. recycling centres or retailers), not along with household waste, and breakage should be kept to a minimum.

12.4.6 Dust

Up to 50% of the dust that occurs indoors originates in the outdoor air. Other sources of dust in the rooms used include dust attached to room users' shoes and clothes, sedimented particles being raised or disturbed mechanically (e.g. when vacuum cleaners are used or paper is handled) and work equipment. The concentration and composition of indoor dust varies significantly depending on how the room in question is used [18]. For instance, large deposits of dust in rooms that are otherwise cleaned normally or situations in which large quantities of paper are handled, e.g. archives and during copy processes are an indication that the dust levels in the ambient air will be high.

Bar a few exceptions, dusts do not have harmful or unwanted effects provided the concentration in the indoor air is roughly equivalent to that in the outdoor air. It should, however, be borne in mind that semi-volatile organic compounds (SVOCs), biocides, polycyclic aromatic hydrocarbons, and plasticisers, among other things, may accumulate on the dust particles thereby potentially causing unwanted, irritating or harmful effects [19].

The potential health hazards posed by exposure to dust are assessed on the basis of dust fractions, which depend on the particle size. The fractions commonly used in the field of occupational safety and health are "respirable dust" and "alveolar dust". These are not identical to the fractions commonly used in the area of environmental protection, PM_{10} (particular matter) and $PM_{2.5}$, which provide a first approximation of the total of all airborne dust particles with a diameter of up to 10 and up to 2.5 µm respectively [20].

The recommended practice for assessing dust exposure in indoor workplaces is to use the $PM_{2.5}$ and PM_{10} fractions defined for environmental protection purposes since the indoor concentration levels are mainly influenced by the outdoor air, for which assessment values are available. The Committee on Indoor Guide Values suggests that, where there are no combustion processes (e.g. tobacco smoke), the 25 µg/m³ daily value defined by the WHO be used as the assessment value for the $PM_{2.5}$ fraction [18].

The working group does not propose an assessment value for the PM_{10} fraction, however, citing the fact that the concentration levels for this fraction are considerably higher indoors than they are outdoors. This means that the main sources of this particle fraction are to be found indoors. A conclusive assessment is not possible because there are no further details available on the composition of this fraction [18].

In general, it should be ensured that the PM_{10} fraction concentration does not exceed the EU dust limit for tropospheric air of 50 µg/m³ [6].

The Committee on Indoor Guide Values recommends that rooms be sufficiently ventilated in order to reduce indoor dust exposure. In addition, every effort should be made to find and minimise known sources of particular matter [18].

Fibrous dust

The effects of fibrous dust are such that it requires a separate assessment. The main indoor sources are textile fibres, e.g. interior textiles or clothing, and natural and man-made mineral fibres, e.g. in thermal insulating materials. Asbestos fibres are no longer of relevance indoors, provided the Asbestos Directive's [21] requirements concerning assessment of the urgency of clean-up measures are complied with as well as the criteria set out in TRGS 519 "Hazardous Substances" [22] regarding the protection of employees and third parties in connection with clean-up measures.

Fibrous dust is considered harmful to health if it can be inhaled and is "bio-persistent". According to a WHO definition, fibres can be inhaled if they have a length of › 5 µm, a diameter of ‹ 3 µm and a length-to-diameter ratio of › 3 : 1 (these are known as "WHO fibres"). The level of bio-persistence depends on the fibre material. Since 1998, man-made mineral fibres (MMMFs), as used in mineral-wool insulating materials, have only been allowed to be sold if their bio-solubility half-life (breakdown by endogenous substances) is less than 40 days.

Mineral-wool insulating materials can cause fibrous dust exposure if they come into direct contact with the ambient air (as in open applications such as sound-absorbing panels in louvre systems) and, in particular, if they are subjected to vibrations or

accelerated air velocity. Only in these cases are measurements potentially useful.

The irritant effect of MMMFs, which is occasionally the subject of debate, is linked to fibres larger than the WHO variety and only occurs if mineral-wool insulating materials have not been installed properly or the cladding has become damaged over time and there are visible fibrous dust deposits. According to *Walker* et al. [23], there are no health-related grounds for removing old MMMF insulating materials that have been properly installed.

Asbestos fibre dust poses much more of a hazard. If it is suspected that asbestos fibres have been released in the building in question, further investigation must be carried out using the customary procedures, as described at length in [24] for example. If necessary, a refurbishment plan must be drawn up in line with the requirements of the Asbestos Directive [21].

Tobacco smoke in indoor workplaces

Tobacco smoke in indoor air is classified as carcinogenic for humans. By law, employees are entitled to a smoke-free workplace. Section 5 (1) of the Arbeitsstättenverordnung (Ordinance on Workplaces) [25] states:

"Employers must take the measures necessary to ensure effective workplace protection for non-smoking employees against the health hazards of tobacco smoke."

There are various ways of complying with the legal requirement to protect non-smokers. The most effective is to impose a universal ban on smoking throughout the building concerned. Once such a ban is in place, there is no longer any need to include tobacco smoke when investigating sources of air pollution.

The German statutory accident insurance institutions published a report in 2011 on the topic of tobacco smoke pollution in workplaces, including an in-depth review of exposure situations in indoor workplaces [26].

12.4.7 Phthalates

Phthalates continue to be manufactured on a large scale. Around 1 million tonnes are currently produced every year in Western Europe, roughly 90% of which is used for plasticising in polyvinyl chloride (PVC) production [27]. Indoor applications include plastic floor coverings, additives including additives in building materials such as concrete, coatings or sealants and in condensers, wallpapers and textiles. As phthalates can be used as solubilising agents, they can also be found in paints, varnishes, adhesives, cosmetics and personal care products.

Unusually high levels of butanol and/or 2-ethylhexanol detected in the VOC analysis can be an indication of increased phthalate concentrations since they can be released from dibutyl phthalate (DBP) and di(2-ethylhexyl)phthalate (DEHP) plasticisers by means of hydrolysis.

Usually DEHP dominates indoors and has been found at concentrations around the low µg/m³ mark in the air in homes examined in a number of studies [27]. The total phthalate content usually detected in house dust can be up to 1,000 mg/kg though this increasingly includes longer-chain phthalate substitutes, e.g. diisononyl phthalate, in addition to the main component, DEHP [28].

Due to their hormonal properties and toxicity to reproduction, phthalate plasticisers in dust in nurseries can be a particular problem. The average phthalate level in such dust is more than three times higher than that of dust in homes [29]. The main sources are furnishings made of soft PVC – for instance, PVC floors, vinyl wallpaper, gym mats, plastic tablecloths or imitation leather upholstery. By contrast, there has long been a ban, for example, on the use of phthalates in children's toys, which used to be common.

The UBA has recommended nurseries not to buy soft PVC products so as to reduce phthalate levels. Instead, nurseries and parents should opt for products that do not contain any of the plasticisers listed as being "of high concern" [30]. Retailers and distributors must provide consumers with the relevant information on request. Parents and nurseries should take advantage of this right. The UBA has drawn up a template letter for contacting retailers to find out more [31].

12.4.8 Insecticides

Although insecticides, i.e. products for insect pest control, are primarily used in agriculture and forestry, they are also used extensively indoors for the following purposes:

- to preserve wood and protect fabric (e.g. permethrin in wool carpets);
- to provide mosquito protection (electric vaporisers and sprays);
- to protect plants against pests;
- to treat parasitic skin diseases in humans and animals; and
- to eliminate pests (e.g. cockroaches, silverfish) by means of decontamination.

The following categories of substance currently play a role in indoor applications:

- Pyrethroids

  Pyrethroids serve as active ingredients in more than half of the insecticides used indoors. They go by various names, including permethrin, cypermethrin, cyfluthrin, deltamethrin, allethrin and tetramethrin. Recently, there has been much debate about their effect on human beings. The target organ for pyrethroids is the nervous system – both in insects and in warm-blooded animals. Incorrect handling can cause acute poisoning in humans but there is also some debate as to the possibility of the substances penetrating the skin. The chronic neurotoxic potential is deemed to be low. Unlike the natural product pyrethrum, pyrethroids are extremely persistent by virtue of their absorption capacity, low vapour pressure and

high photostability. As a result, rooms that have been subject to pyrethroid exposure may have to be decontaminated [32].

- Phosphoric esters

  Another class of insecticides frequently found are phosphoric esters, also known as organophosphates. The main types found indoors are dichlorvos, chlorpyrifos and diazinon. They appear in various products, including many insecticides found in the home, most of which are sprayed or applied in powder form. Dichlorvos is commonly found in insect strips because its relatively high vapour pressure means that it is distributed evenly throughout the room. As a result of recent findings concerning the properties of this substance, it has been removed from the list of active ingredients permitted in plant protection products. All phosphoric esters have a high acute toxicity for warm-blooded animals. As with the pyrethroids, they attack the nervous system but their method of attack is to inhibit important enzymes that are involved in muscle control processes. They also inhibit the breakdown of a pyrethroid-cleaving enzyme, thus reinforcing the effect when phosphoric esters are used in combination with pyrethroids.

- Carbamates

  Carbamates are not very widespread in insecticide products, apart from those used in agriculture. They work in much the same way as organophosphates though their effect is not quite as strong. The main type is propoxur, which is mostly used in combination with active ingredients from the other two categories mentioned.

All insecticides can be emitted into the indoor air even quite some time after they are applied. This is due to a variety of processes such as vaporisation, desorption or attachment to dust. In practice, they can pollute the air for anything from a few days (as in the case of pyrethrum) to several weeks (dichlorvos) and months or longer (deltamethrin, permethrin).

Since many insecticides accumulate in dust, analysing dust deposits can deliver important information about the substances that have been applied indoors and the doses used. For instance, samples are taken from the air, airborne dust, house dust and surfaces (swipe samples) in order to analyse indoor pyrethroid levels.

Special polyurethane foam filter heads are suitable for air sampling. The airborne dust is separated off onto a fibreglass filter. Household dust is collected using conventional vacuum cleaners; selected sieve fractions with an upper grain size of 2 mm or 63 µm are then examined. Swipe sampling involves a defined surface being wiped with a swipe material (usually cotton) containing a solvent.

12.4.9 Pentachlorophenol (PCP) and lindane wood preservatives

With their biocidal agents, chemical wood preservatives prevent damage to wood. A distinction is made between fungicides, which prevent wood being destroyed or discoloured by fungi, and insecticides for preventing wood damage caused by insects.

In terms of indoor air quality, the wood preservatives pentachlorophenol (PCP) and lindane play a particularly significant role especially due to their widespread use, toxic effects and emission patterns.

Pentachlorophenol (PCP)

Due to its wide spectrum of activity, PCP was used to combat bacteria, fungi, dry rot, algae, snails and insects. It was primarily used as a fungicide in wood preservatives but it was also used in the textile and leather industry, e.g. for marquees and tents. It was approved for large-scale indoor coating between the end of the 1960s and 1978. The substance used was almost always technical-grade PCP, contaminated with dioxins and furans. The contamination levels reached up to 0.3%.

Following a ban on indoor PCP use in 1986, production of PCPs was banned in former West Germany in 1989 [33].

Lindane

PCP's significance as a fungicide was matched by lindane's as an insecticide wood preservative. Since 1983, at least 99% of the content of lindane has been γ-hexachlorocyclohexane – an effective insecticide. Lindane used to be the most commonly used insecticide in chemical wood protection, but substitutes such as pyrethroids (see Section 12.4.8) have largely taken its place.

Lindane was usually combined with PCP (see above) or dichlorodiphenyltrichloroethane (DDT). In the German Democratic Republic, the lindane/DDT mixture was used under the name "hylotox 59" up until 1988, especially in attics and sometimes in indoor rooms. Remaining supplies of hylotox products were allowed to be used until the end of June 1991. Since September 2006, there has been an EU-wide ban on the use of lindane indoors [35].

The active ingredients in the wood preservatives are emitted from the treated materials over a period of several years. Consequently, like many of the insecticides described in Section 12.4.8, they can be detected in many indoor rooms. An effective approach is to examine the treated materials and the house dust as well as taking air samples.

Investigation

To determine the level of pollution from wood preservatives, it is first necessary to establish when and how the wood preservative in question was used and in what quantity. Based on the PCP Directive [35], the following steps are then taken:

- If the investigation reveals that no PCP wood preservatives have been used, no further action is necessary.

- If there are grounds to suspect that PCP wood preservatives have been used, the first step, notwithstanding the PCP Directive, is to calculate the quotient of the treated wood surface and the room volume. Further action is only required if the quotient is › 0.2 m^2/m^3.

- If the quotient is exceeded, an analysis of “fresh dust” or “old dust” is required. The fresh dust, which is approximately one week old, is collected using vacuum cleaners. Old dust, i.e. dust deposits that have accumulated over a long period, as can be found behind panelling, for example, is merely collected passively, e.g. with the aid of a brush and spatula.

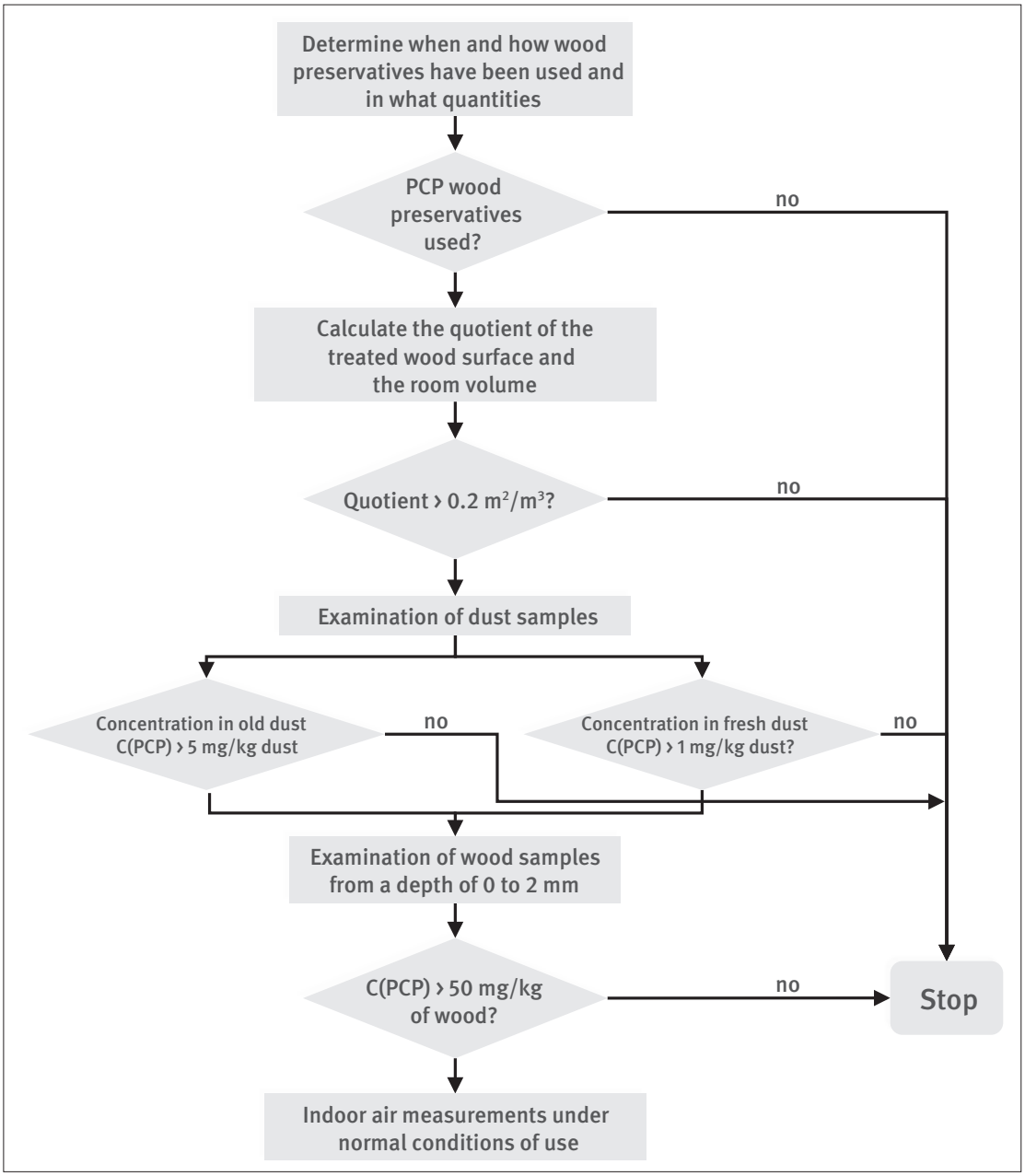
- If the concentrations are higher than 1 mg PCP/kg of fresh dust or more than 5 mg PCP/kg of old dust, the next step is to take samples from a depth of 0 to 2 mm in the wood concerned. Past wood preservation practice meant that PCPs were mainly only found at the edges of the wood.

- If the resulting value is higher than 50 mg PCP/kg of wood, the annual mean indoor air pollution level must be determined. The PCP Directive stipulates that remediation is necessary if the annual mean concentration is above 1 µg PCP/m³ of air.

The individual steps are shown in Figure 28. The same procedure can be used for lindane.

There are special cases in which people regularly spend more than eight hours a day over a prolonged period in indoor rooms whose purpose is such that exposure to dust, foodstuffs, etc. is likely (e.g. in nurseries or care homes). Where this is the case, the anticipated annual mean air pollution must be checked to determine whether it is higher than the target refurbishment value of 0.1 µg PCP/m³ of air [36]. If it is not, it is unlikely that there is any hazard to health. If the indoor air pollution levels are between 0.1 and 1.0 µg PCP/m³ of air, blood and urine tests must be conducted before making a decision [36]. The remaining procedure is described in the PCP Directive [35].

Figure 28:
Flowchart for investigation of PCP pollution from wood preservatives in indoor rooms (based on the PCP Directive [35])



12.4.10 Polychlorinated biphenyls (PCBs)

From around 1950, PCBs were often to be found as plasticisers in a number of open applications as well as in fluorescent lamp capacitors and other closed applications. Open applications using PCBs are particularly likely in buildings erected before the end of the 1970s. Based on current knowledge, open PCB applications are unlikely in buildings constructed after 1980.

In particular, open PCB applications can be contained in permanent elastic sealants in the form of

- building joints,
- expansion joints between precast concrete products,
- connecting joints (windows, door frames),
- connecting joints between glass and window frames and
- joints in sanitary facilities (rare).

In addition, PCBs can be contained in

- paints,
- adhesives,
- ceiling panels (as plasticisers or flame retardants),
- plastics and
- cable sheaths.

One of the most common applications in this area was PCB used as a plasticiser in polysulphide resin-based sealants. The products used for this purpose contained 30 to 60% chlorine by weight. They were marketed under names such as Clophen, Arodor, Kanechlor and Fenchlor.

The PCB products used in open applications up until around 1975 can still pollute indoor air today. The extent of that pollution depends on the type of PCB, the PCB content in the product concerned, the type of material contaminated, the quantity and nature of the PCP products in the room, the thermal environment in the room, the building's surface temperatures and the weather conditions. In such rooms, it is also possible for components and items that do not contain PCBs to be contaminated over time by substances that do contain PCBs and thus contribute to pollution in the indoor air themselves. A distinction must therefore be drawn between primary and secondary sources.

"Primary sources are products to which PCBs have specifically been added in order to change the product's characteristics. These products, e.g. sealants or coatings, usually contain more than 0.1% PCB by weight, and experience to date indicates that they can cause a significant increase in PCB indoor air pollution. Besides the PCB content, the ratio of contaminated surface to room volume and the type of PCB mixture have a major influence on the resultin pollution of the indoor air" [37].

According to VDI 4300, Part 2 [38], the following are possible primary sources of PCBs in indoor air:

- faulty capacitors, e.g. in lights,
- faulty transformers,
- paints and varnishes containing flame retardants,
- plasticisers used in plastics, e.g. sealants for expansion joints in precast concrete buildings,
- form oil used in concrete construction and
- dust ingress from emission sources and contaminated sites.

"Secondary sources are components (e.g. walls or ceilings) or items (e.g. furniture or furnishings such as carpets or curtains) that have usually absorbed PCBs from the polluted indoor air over a prolonged period. They can gradually release the PCBs that have accumulated on their surfaces back into the indoor air. Large-scale secondary contamination can cause indoor air PCB concentrations to remain high even after the primary sources have been completely removed" [37].

Primary sources that have not been removed to a sufficient depth and secondary sources that have not been sufficiently removed can cause heightened indoor air pollution levels years after remediation measures have been taken.

Investigation

When identifying potential PCB sources, the first step is to verify the age of the building product or electronic component suspected of containing PCBs (see Questionnaire G2 in Annex 3). It is usually possible to assume that the following points hold true:

- no open applications since 1978 (when the PCP Directive came into force),
- no PCBs in lamp capacitors or other capacitors since 1981,
- production stopped in 1983 and
- complete ban as of 1989 (PCB-Verbotsverordnung/Ordinance Banning PCBs [39]).

If this first step does not eliminate the possibility of PCB pollution in buildings, the following method should be employed:

- an inspection of the workplace should be carried out by people with relevant expertise, representative samples should be taken and any suspicious materials analysed (precise records should also be kept);
- representative indoor air samples should be taken (the sampling strategy should also be justified and documented); and
- a pollutant register should be drawn up (material samples, layer profiles, air samples) as a basis for a refurbishment

plan and for determining the pollution situation for the whole building.

The findings thus obtained must then be assessed.

Assessing PCB pollution and urgency of refurbishment measures

The health risk for users of PCB-polluted rooms rises as the PCB concentration in the indoor air increases and is influenced by the room's use and the duration of exposure.

The toxicological assessment of PCBs in the air in permanently used rooms carried out by the former Bundesgesundheitsamt (Federal Health Office) and the Arbeitsgemeinschaft der Leitenden Medizinalbeamten der Länder (hospital commission study group of governing medical officials) [37], is used to assess how urgently remediation is required:

- *"Indoor air concentrations below 300 ng PCB/m³ of air are deemed tolerable in the long term (precautionary value).*
- *Where indoor air concentrations lie between 300 and 3,000 ng PCB/m³ of air, the source of the indoor air contamination must be identified and eliminated in the medium term by means proportionate to the risk. In the interim, the rooms should be ventilated regularly, cleaned thoroughly and dust removed in an effort to reduce the PCB concentration level. The target is a value below 300 ng PCB/m³ of air (refurbishment guide value).*
- *Where the indoor air concentration level is higher than 3,000 ng PCB/m³ of air (intervention value for immediate action), acute health hazards cannot be ruled out. If such values are detected, control analyses should be carried out immediately. If they confirm the initial result, immediate action must be taken – in line with the pollution level – to reduce the PCB concentration levels in the indoor air in order to prevent health risks in the rooms concerned. Here too, the target is a value lower than 300 ng PCB/m³ of air."*

To date, it has not been possible to confirm any clear link between the PCB content of sealant materials and the PCB concentration in the indoor air. Nonetheless, approximate estimations of the PCB concentrations in indoor air are possible on the basis of data given in the literature (see Table 32) [40].

Table 32:
Guide values for indoor air PCB concentrations as a function of PCB content in sealant materials [40]

Clophen type[1)]	Maximum PCB concentration in sealant (%)	Indoor air PCB concentration in µg/m³
A 40	21 maximum	Approx. 0.2 to 6.0
A 50	35 maximum	Approx. 0.2 to 2.5
A 60	47 maximum	0.55 maximum

[1)] Technical-grade PCB mixture produced by Bayer

Where there are large-scale primary sources, e.g. (fire retardant) paints or ceiling panels, which often contain a highly chlorinated PCB mixture (Chlopen A 50/60), the possibility of direct cutaneous or oral absorption of contaminated particles resulting from abrasion must also be taken into account. A material's dioxin and furan content also usually increases as the PCB content increases [37].

Recommendations for building refurbishment

The aim of refurbishment measures for PCB-polluted buildings is to achieve a permanent reduction in the indoor air pollution caused by products containing PCBs. This can be done, for example, by removing, stripping or coating PCB products. However, coating primary sources has not proved successful so far.

Refurbishment of primary sources

Generally speaking, the only way to ensure permanent refurbishment of PCB-polluted rooms is to remove the primary sources, e.g. sealants, paints or ceiling panels. The methods described below have proved successful in practice but this does not mean that other procedures that yield equivalent results are not possible. However, heat-treating PCB materials, e.g. flame-cleaning, and methods that entail PCB materials being heated to › 100 °C are not suitable.

Permanent elastic sealants must only be removed using tools that generate little dust or by hand. They are then collected in containers suitable for disposal. Any backfill material should be removed. Dust should be collected where it occurs, using a suitable vacuum cleaner, e.g. of dust category H. The edges of seals should be removed, if possible, taking into account structural requirements and the depth of the PCB penetration. As with the sealants, they must be removed by hand or with the help of low-dust-emission tools and techniques with constant suction removal or in a self-contained system. If it is not possible to remove the edges, they must be completely freed of any remaining sealant and coated with a suitable diffusion-inhibiting material. Once the joint has been coated and new backfill material installed, the joint can be resealed.

Large-scale primary sources, such as paints or coatings, must be removed in a dust-free process with constant suction removal or in a self-contained system. If there is any residual contaminant, the approach to be taken is the same as that for handling secondary sources.

Removable primary sources, such as ceiling panels, must be cleaned and then removed without allowing any dust to escape, using suction if necessary.

Refurbishment of secondary sources

If the measures aimed at refurbishing primary sources do not reduce the indoor air PCB concentration to below the refurbishment guide value of 300 ng PCB/m³ of air, refurbishment of the secondary sources is also necessary.

As with primary sources, refurbishment of secondary sources should take the form of removal. If this method is not chosen, indoor air PCB pollution arising from contaminated components can also be adequately reduced by means of low-dust processes to remove the surfaces of these components, with

constant suction removal or in self-contained systems, e.g. by stripping off paint layers and surface coatings. Based on current knowledge, products such as diffusion-inhibiting insulating wallpapers, emulsion paints with a high binding agent content, particularly those based on acrylate, and two-part epoxy resin and polyurethane coatings are suitable for this purpose.

Another option is to separate secondary sources from the indoor air using airtight methods, e.g. permanently sealed panelling. However, they must then be labelled and documented so that they can be disposed of separately later. This type of approach requires permanently sealed joints, including joints with ancillary building components, and must be carefully examined to determine the impact on the physics of the building and the thermal environment.

Contaminated items, such as furniture, carpets or curtains, should be cleaned thoroughly and checked for any residual contamination before being used again.

The long-term success of these measures must be documented by means of measurements.

Cleaning

Once refurbishment has been completed, the entire area that has been refurbished must be cleaned thoroughly, starting with all building component and furnishing surfaces, which must be cleaned using a suitable vacuum cleaner. This is followed by a wet clean of all surfaces that can be cleaned in this manner and any furniture that is to be reused. The cleaning must be done manually using conventional cleaning products. High pressure cleaners are not suitable as the cleaning fluid cannot be fully collected.

Monitoring

The PCB concentration in the indoor air must be measured using a strategy set out in the PCB Directive so as to document the success of the remediation process.

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13 Biological exposure

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13.1 Introduction

Health problems such as watery eyes, sneezing attacks, ticklish throats, malaise and unpleasant odours are often thought to be linked to the presence of organisms such as mould, bacteria, mites or their metabolites and excrements. Frequently, the microbiological pollution of the indoor air is attributed to the operation of air conditioning systems or visible or suspected damp damage in the building, and measurements are requested to determine the cause.

However, steps to improve the workplace situation can often be initiated without the need for measurements if the workplace is inspected by an expert and the causes eliminated. If measurements are still needed, a measurement plan must be drawn up for the specific issues involved.

This chapter brings together the knowledge currently held by the German statutory accident insurance institutions on investigations of indoor problems due to biological exposure. It makes example recommendations on how to assess the occurrence of biological agents in indoor workplaces. The information is mainly derived from research and measurements taken when investigating damp problems caused by structural faults and water damage, and hygiene assessments of ventilation and air conditioning systems [1] (see also Section 6.2, "Ventilation and air conditioning systems").

13.2 Occurrence of biological agents

Biological agents occur all around us. As part of human skin and mucous membrane flora, they are a natural safeguard against pathogens. Humans themselves emit microorganisms into indoor workplace environments by means, for example, of exhalation or shedding of skin. However, these recommendations do not cover this natural bio-emission, which can also contain potentially pathogenic microorganisms, nor excretion of pathogenic microorganisms by people with an illness. The hazards posed by microbiological metabolites, e.g. MVOCs and mycotoxins, and cellular components such as endotoxins, have also been omitted since the scientific data regarding them has not yet been fully substantiated.

Potential causes and sources of biological agents in indoor workplaces are listed in Table 33.

Ventilation and air conditioning systems (VACs) are frequently a key factor in workplace pollution caused by indoor biological exposure. Table 34 shows potential sources of biological agents in such systems and the hygiene problems that can ensue. Thanks to improved hygiene regulations concerning VAC maintenance [2], diseases of the respiratory tract are a seldom occurrence nowadays.

Table 33:
Examples of possible sources of biological agents in indoor workplaces

Cause/source	Effects
Outdoor air	
Farms, composting/waste-sorting facilities, sewage plants in the immediate vicinity	Contamination with microorganisms from the surrounding environment, e.g. due to natural ventilation via windows, doors or VACs' outdoor air intake
Indoor air	
Inadequately maintained plant pots, hydroculture; prolonged storage of organic waste	Colonisation with microorganisms (e.g. stagnant water in plant pots), especially mould colonisation
Condensation resulting from thermal bridges; building damage, e.g. due to water ingress or due to the building design	When dampness reaches a certain level: colonisation with microorganisms, particularly mould, on wallpaper, paper, cardboard, drywalls, insulating materials, brickwork, wood and joints
Inadequate removal of damp due to incorrect ventilation	See "condensation"
Contamination in the form of, e.g. spilt foods or hair, flakes of skin in dust	Basis for in situ growth of various microorganisms; see "condensation" Plus colonisation with household dust mites, especially in upholstered office chairs or carpets

Table 34:
Potential sources of biological agents in indoor workplaces due to incorrectly installed/operated ventilation and air conditioning systems [2]

Source	Effects
Intake of outdoor air Intake and recirculation air filters missing Grid missing in front of inlet passage	Intake of microorganisms and dusts from environmental sources, e.g. farms, waste/sewage treatment plants or composting facilities; intake of mist from cooling towers/recooling plant; access for animals, animal faeces in outdoor air pipes
Exhaust air outlet	Repeat intake of polluted extracted air; short-circuit between outdoor and exhaust air
Humidifiers Condensate collecting plate Fans	Colonisation of the circulating water with microorganisms, formation of biofilms on appropriate surfaces
Air coolers Heat regenerators	Colonisation of the condensation with microorganisms; formation of biofilms on appropriate surfaces
Air pipes	Colonisation of dust deposits and condensate with microorganisms
Air filters	High dust accumulation, contamination of indoor air with microorganisms or microbial components
Servicing and repairs	Release of dust, contamination of indoor air with microorganisms or microbial components if not carried out properly

13.3 Intake and effect of biological agents

Since the main route of exposure to biological agents in indoor workplaces is the respiratory tract, this section does not cover other routes. Most biological agents are so small that they can be inhaled. This is particularly true of the main components of microbial aerosols, such as airborne mould spores, and bacterial cells and fragments of bacterial cell walls, most of which can be assumed to be respirable too. Table 35 shows the dimensions of biological agents and various particles of biological origin that can be contained in respirable bioaerosols.

Table 35:
Dimensions of possible bioaerosol components (based on [3])

Biological particle	Aerodynamic diameter in µm
Viruses	0.02 to 0.03
Actinomycetes, airborne spores	0.5 to 1.5
Bacteria	0.2 to 10
Mould, airborne spores	2 to 8
Moss spores	5 to 30
Fungal cells, hyphae	10
Amoebae	10 to 40
Mites, faecal and body particles	10 to 40
Fern spores	20 to 60
Pollen	5 to 250
Microbiological cellular wall components (e.g. endotoxins, glucans)	Considerably smaller than the respective organisms

By way of comparison:
Particle › 100 µm inhalable, › 10 µm thoracic, › 4 µm respirable (Johannesburg Convention)

In many cases, there is a lack of conclusive evidence regarding the links between the occurrence of biological agents in indoor workplaces and incidence of illness. However, based on the knowledge currently available, the assumption is that damp and/or mould-infested rooms pose a particular risk for allergy sufferers and people with chronic respiratory/skin diseases who spend time in those rooms. Allergic reactions and mucous membrane irritations in the eyes and respiratory tracts are probably the most significant health disorders associated with mould [4].

Allergic effects

A person's tendency to develop an allergy depends on various factors, i.e.:

- the allergological relevance, i.e. level of the allergen's sensitising potential,
- the individual's predisposition,
- the allergen concentration in the respirable air,
- the duration and frequency of exposure and
- any other aggravating factors such as simultaneous occurrence of other allergenic substances.

Sensitisation itself is not an illness but it can cause allergies to develop at a later stage and affect the extent of such allergies. A high level of prolonged contact with the allergen is normally necessary for sensitisation to occur. In individuals who are already sensitised, even small amounts of allergens are enough to trigger allergic reactions.

Allergic effects of mould and actinomycetes

Airborne actinomycete and mould spores are major allergy triggers. Actinomycetes are "Gram positive"[1] bacteria that grow in much the same way as mould, which is why they are also known as "ray fungi". Where building materials have been damaged by damp, a wide range of actinomycetes can be present, some of them at high concentrations [5]. However, it is rare for detectable

[1] Gram staining is a bacteriological staining method, invented by *Hans Christian Gram* in 1884. Due to their multilayered cellular wall structure, Gram positive bacteria retain the dye and appear violet under a microscope. Gram negative bacteria, on the other hand, have a single-layer cellular wall structure, which means that they do not retain the dye and therefore appear light red under a microscope.

concentrations of actinomycete spores from these materials to find their way into the indoor air.

The allergen levels measured to date in the air in mould-infested indoor workplaces are much lower than in work areas with a high level of microbial pollution, e.g. as in agricultural or waste-sorting workplaces. Though the risk of sensitisation cannot be completely ruled out, it is relatively low.

Various studies have shown that the incidence of mould allergies in people with respiratory symptoms is between 1 and 10%, and in people with a predisposition for allergic hypersensitivity reactions (atopic individuals) as much as 30%. Around 5% of the population are thought to be sensitised to mould.

The only cause-effect relationships to have been substantiated to date with regard to mould exposure concern allergies, infections and respiratory illnesses at high-exposure workplaces. According to the WHO "Guidelines on Dampness and Mould", there is sufficient evidence of a link between the presence of mould/dampness indoors and the occurrence of symptoms such as asthma, certain respiratory complaints and respiratory infections. Consequently, excessive levels of dampness and/or mould indoors must be considered a potential hazard [6]. However, these findings cannot be used to derive guide values for harmful indoor mould concentrations. It is only possible to provide an approximate classification of the hazards to room users though individual predisposition to react with an illness must also be taken into account (as in the case of allergy sufferers, individuals with an immunodeficiency or people with chronic respiratory illnesses) [7].

Allergic effects of mites

Mites can be found in such places as mattresses, bed linen and upholstered furniture. The optimum development conditions for most species of mite are an ambient temperature of around 25 °C combined with approximately 70% relative humidity. Studies dealing with the occurrence of mite allergens in indoor workplaces are few and far between. Following their study of 14 office rooms in which employees had sick building syndrome symptoms, *Janko* et al. suggested that upholstered office chairs be cleaned regularly [8]. The method used to detect exposure to mite allergens is to examine dust deposits. Measuring methods for detecting mites (and mite allergens) are described in the literature [9].

Currently, the main method used to sample the air to detect allergen exposure in the workplace is filtration. A research project by the IFA aims to test a newly developed sampling procedure [10].

Irritative and toxic effects

One of the irritative/irritative-toxic complaints linked to exposure to biological agents is mucous membrane irritation (MMI) [11]. It occurs at average mould concentration levels (› 10^3 spores/m^3 of air) and is also observed indoors [4; 10; 12]. Possible symptoms of MMI are non-specific irritation of the mucous membranes in the eyes (e.g. stinging or watery eyes), the nose (e.g. sneezing attacks, secretion and obstruction of the sinuses) and the throat (e.g. a dry feeling or a need to clear one's throat).

Infections

The infection potential of biological agents that occur in indoor workplaces is low. For instance, individuals exposed to mould will only develop an infection if they are immunocompromised. Infections caused by bacteria in indoor workplaces are also extremely rare. They are often felt to be linked to contaminated ventilation and air conditioning systems, particularly in the case of legionella. The research carried out by the German statutory accident insurance institutions to date has not detected any legionellae in the humidifier water in ventilation and air conditioning systems [1].

13.4 Investigation and measuring method

Before determining whether an elaborate microbiological examination is necessary, the health complaints must be documented. Then the conditions within the work environment (building, rooms, furnishings, etc.) must be assessed (see Questionnaire G2 in Annex III and the S2 questionnaire available at www.dguv.de/ifa (webcode 650356)) to identify any links between them and the complaints. This step should be used for fact-finding, as illustrated in the special S10 questionnaire available on the internet (www.dguv.de/ifa, webcode 650356), which uses mould as an example.

In many cases, the information available and the visual evidence are sufficient for a conclusive assessment without having to carry out measurements. This is particularly true if there is clear visual evidence of damage caused by mould or damp and it is therefore obvious that action is needed.

Where inspection of the workplace does not permit a conclusive assessment of the situation, microbiological sampling may be necessary in the following instances:

- if action is required in order to protect health, e.g. in order to initiate any necessary remediation,
- when the bio-emission sources are not clear, e.g. contamination from ventilation and air conditioning systems, or
- as part of investigations into suspected cases of formally recognised occupational disease

The subsequent procedure depends on, among other things, whether there are visible changes in the room, e.g. mould infestation or watermarks. The following two case studies explain the approach.

Case study 1

Employees complain of health problems that are linked to certain rooms. There are no visible changes such as mould or

watermarks but there are frequent cases of subjective odour perception.

In these cases, the first step is to investigate the odour. If it smells of chemical substances, e.g. solvents, paints, adhesives, rubber, cardboard or freshly treated wood, microbiological measurement is not necessary. The action to be taken to determine the cause is described in Chapter 12, "Chemical exposure".

If, on the other hand, the odour smells of substances typical of the metabolic activity of microorganisms, e.g. musty, putrid, mouldy or like alcoholic fermentation, a workplace inspection should be conducted to attempt to identify the source of the odour. There may be concealed damage, e.g. behind panels, units, in false floors or suspended ceilings. Stagnant water in plant pots can also be a source of odour.

If no odour source is identified despite thorough investigation and if there are still grounds to suspect exposure to biological agents, indicative microbiological measurements can be performed. The following methods can be used for this:

- Air measurement

  Determination of the mould spore count (particle sampling, e.g. using a PS 30 particle sampler, "Holbach sampler") compared to the total viable count of the mould (sieve plate impactor, e.g. Microbial Air Sampler, MAS) and the respective reference values in the outdoor air or in apparently unexposed rooms.

  Standardised measurement procedures for air-sampling of bacteria, actinomycetes and mould are described in various sources [13 to 18].

- Surface sampling

  Contact sampling (with "Rodac plates"), preferably in conjunction with tape-stripping samples to compare with non-suspicious surfaces.

  A further possibility is determination of material moisture levels (see [19]).

Indicative assessments do not usually determine the species of mould present. Their findings cannot be used to draw conclusions as to individual health hazards or remediation requirements. Instead, they merely indicate the presence and quantity of any mould at the site examined.

Case study 2

There is visible discolouration, e.g. mould or watermarks, which is thought to be linked to employee health complaints.

If the discolouration on the wall is obviously due to damp ingress, countermeasures need to be taken to preserve the building's structure. In such cases, microbiological measurement or sampling is not necessary. Where there are extraordinary circumstances that warrant such action, contact sampling or examination of a material sample can be used to determine whether the discolouration is due to mould or which types of mould are involved. Information on the standardised procedure for sampling materials is given in the literature [16; 19].

13.5 Assessment

Since activities involving biological agents are not carried out on indoor workplaces, these workplaces must be assessed on the basis of the Arbeitsstättenverordnung (Ordinance on Workplaces) [21], not the Biostoffverordnung (Ordinance on Biological Substances) [20].

The "Quality assurance – Mould in indoor spaces" working group at the Landesgesundheitsamt Baden-Württemberg (LGA; Baden-Württemberg State Health Agency) in Stuttgart has produced a comprehensive position paper on this topic [19]. Entitled "Mould in indoor spaces – Detection, assessment, quality management", it describes various sampling methods and the criteria for assessing the findings from a hygiene point of view.

The Federal Environmental Agency's Indoor Air Hygiene Commission also published a "Mould guide", in December 2002, which deals with the assessment of indoor mould problems [12]. It states that it is not possible to make a blanket judgement as to whether visible mould poses a health risk to room users. The company physician should be consulted to help establish whether employees can continue to work in the rooms affected until refurbishment has been completed, if the rooms are properly ventilated.

Assessment of mould in material samples

Tables 36 and 37 show suggestions for assessing mould occurrence [22]. The proposals are based on research conducted by the IFA and the Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW; German Social Accident Insurance Institution for the health and welfare services) over a period of many years, and the experience gained in the assessment of indoor problems connected to mould occurrence, based on the findings of that research. They do not take health complaints into account.

If water damage is refurbished without eliminating the cause (e.g. new wallpaper/plaster, fungicidal paint), mould will recur in the building material in the space of a few weeks.

Ideally, samples from new/unused material or from similar rooms but without health problems should be examined along with the suspicious material. The results of the comparison can then be used as a reference for the materials to be assessed.

Tape-stripping samples can be used to distinguish between active fungal infestations and airborne spores on surfaces, making it possible to indentify acute mould infestations. This cannot be done with contact samples.

Table 36:
Assessment of results of indoor material sample examinations [22]

Total mould in CFUs*)/g material	Rating
‹ 10^3	Normal background to low mould contamination, usually no damp problems
10^3 to 10^5	High mould contamination, damp problems/water damage, etc.
10^6 to 10^8	Very high mould contamination, damp problems/water damage, etc.

*) CFU = Colony-forming unit

Table 37:
Assessment criteria table for visibly mould-infested indoor surfaces [19]

Visibly mould-infested surfaces	Assessment
‹ 20 cm²	Minor damage
‹ 0.5 m²	Moderate damage
› 0.5 m²	Major damage

The assessment should also consider the spectrum of mould species found in the various material samples as this information can be used, for example, to draw conclusions concerning the presence of damage caused by damp. Special attention must be given to mould species that are typical indicators of very high levels of damp or that have high pathogenic potential. The following genera and species of mould have been described as examples that provide a strong indication of damp-induced indoor damage [19]:

- *Acremonium* spp.
- *Aspergillus penicillioides*
- *Aspergillus restrictus*
- *Aspergillus versicolor*
- *Chaetomium* spp.
- *Phialophora* spp.
- *Scopulariopsis brevicaulis/fusca*
- *Stachybotrys chartarum*
- *Tritrachium album* and
- *Trichoderma* spp.

Other mould species often found in connection with damp-induced indoor damage are, for example, *Penicillium chrysogenum* and *Cladosporium sphaerospermum*.

Assessment of mould occurrence in air samples

In some cases, the concentrations of biological agents in indoor workplaces exceed the natural background exposure level by more than a power of ten. In other words, they are higher than the microorganism content of the outdoor air or of a similar room deemed to be a suitable reference. This should be considered an indication of potential contamination.

Indoor material samples that reveal large numbers of mould species typical of damp are a clear indication of damage due to damp. In the case of air samples, however, the mould sources must be carefully investigated as the fungal spores are distributed diffusely throughout the air and can come from a variety of sources.

The spore sampling process can also include mould spores that cannot be cultivated in the laboratory and can therefore not be detected when determining the colony count.

The spore concentration and the total colony count determined in the air can only ever reflect the situation at the time of measurement. But mould does not distribute its spores evenly throughout the indoor air. Consequently, the results of the measurements may underestimate or overestimate the actual level of mould exposure in the indoor air.

At present, there are no mandatory exposure limit values or guide concentration levels in Germany for assessing the biological parameters of air in indoor workplaces. It is recommended that the “reference outdoor air value” and the “normal indoor air pollution level” be used to characterise the level of microbial pollution in the indoor air. Section 3.6, “Ventilation”, of the annex to the Arbeitsstättenverordnung (Ordinance on Workplaces) [21] states that “*an adequate amount of healthy, breathable air must be ensured in work areas*”. This is not the case in rooms with evident mould infestations because the possibility of mould spores being released and thus of inhalation exposure to mould cannot be ruled out. Nor should it be forgotten that spores can become airborne at any time despite air sample measurements yielding negative results.

As a general guide, Table 38 (see page 102) lists the microorganism concentrations measured in the outdoor air during workplace measurements conducted by the German statutory accident insurance institutions and the IFA.

In the warm months, the higher level of airborne spores can cause the concentration in the outdoor air to increase, leading to a rise in the indoor air values if windows and/or doors are opened for the purpose of natural ventilation. Values of several thousand CFUs of mould per m³ of outdoor air are common during these months (cf. also [16]).

If it is suspected that external sources are masking an indoor mould source (e.g. outdoor air or contamination from a different part of the building), it may be possible to confirm or disprove the suspicion by comparing the species spectrums in the respective air samples.

Table 39 (see page 102) shows suggested criteria for assessing the results of mould measurements in indoor air [22].

Further suggestions for assessment criteria tables can be found in the guides produced by the LGA in Stuttgart and the UBA [12; 19; 24; 25].

Table 38:
Concentrations of mould and bacteria in the outdoor air [23]

Month	Number of results evaluated	Minimum	Arithmetic mean	Median	Maximum
Mould in CFUs/m³					
January	54	4	195	188	1,286
February	60	28	314	132	3,457
March	59	10	551	157	17,571
April	57	4	812	809	25,715
May	51	4	2,201	1,005	28,571
June	59	26	1,715	2,429	10,512
July	79	316	4,189	2,243	26,280
August	59	328	3,208	937	26,280
September	58	1	1,330	850	10,000
October	86	143	1,244	372	10,512
November	40	57	646	471	3,500
December	3	202	436	188	634
Bacteria in CFUs/m³					
January	25	4	232	57	2,886
February	15	28	367	71	3,571
March	26	10	178	61	945
April	29	4	98	43	630
May	9	4	804	1,115	1,555
June	19	28	198	154	943
July	25	33	268	143	1,055
August	18	57	429	229	2,985
September	20	28	565	157	8,000
October	20	30	229	123	1,429
November	10	30	158	150	339

Table 39:
Assessment criteria table for results of microbiological measurements of indoor air [22]

Determining parameters in CFUs/m³ of air	Assessment criterion	Result of assessment
Total mould and/or spectrum of mould species	Indoor air has significantly higher mould spore content than outdoor air and/or significantly different spectrums of species in indoor and outdoor air *)	Indicates mould pollution in room
Occurrence of special indicator species (see above)	Presence of such species	Indicates damp problem
Occurrence of pathogenic species	Presence of such species	Unacceptable for reasons of general hygiene

*) In the case of typical outdoor air species, e.g. *Cladosporium*, indoor sources cannot be ruled out if the indoor air values are 1.5 times those in the outdoor air; where the values are twice as high as those for the outdoor air, indoor sources should be considered likely [19]

13.6 Prevention and refurbishment measures

According to a landmark ruling by Germany's Bundesgerichtshof (Federal Court of Justice), *"Mould in a building constitutes a defect even if it does not pose a specific hazard to health."* [26].

In addition to the aspects illustrated in this chapter, further general information and recommendations concerning prevention and refurbishment measures designed to prevent hazards caused by indoor mould is available from a variety of sources [12; 19; 24; 25; 27].

Extensive, complicated and/or recurrent instances of mould damage should be examined by a qualified building surveyor.

Refurbishment measures can involve several different contractors. For instance, repairing a wall that has been damaged by water brings little benefit if the cause, e.g. a leaking roof, a broken water pipe or a thermal bridge, has not been refurbished.

Those at most risk of coming into contact with mould from infested building materials are the people who carry out refurbishment. DGUV Information 201-028 (formerly BGI 858) provides comprehensive information on the health hazards posed by biological agents during building refurbishment and on the measures to protect workers from exposure [28].

13.7 References

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14 Psychological aspects of adverse indoor workplace conditions

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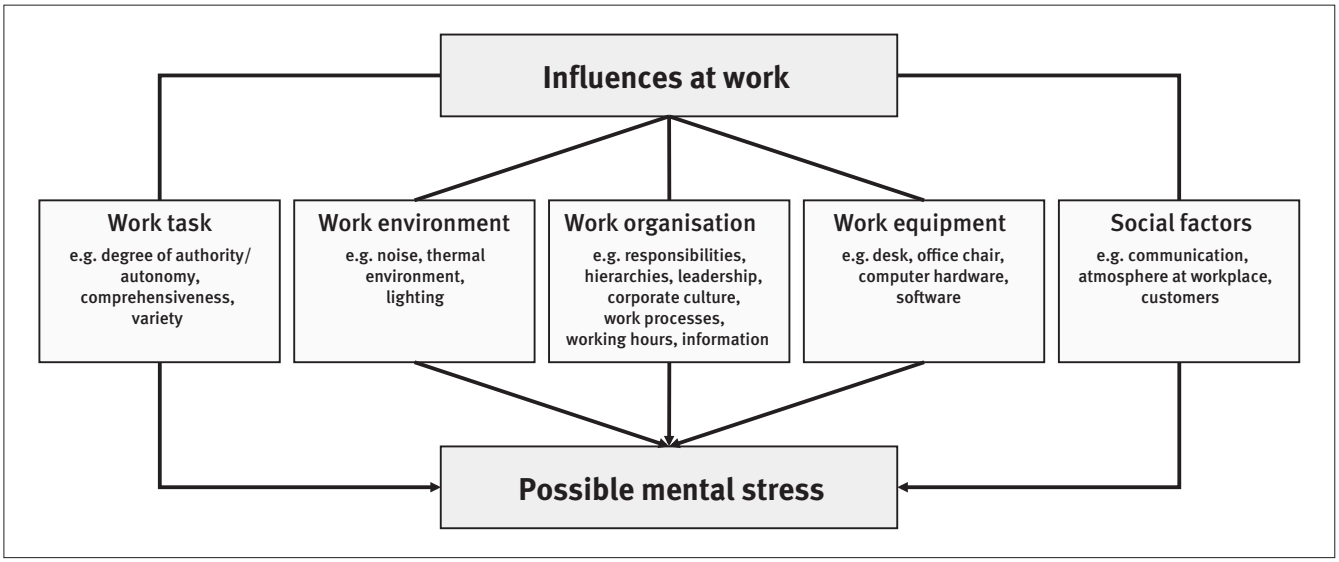
Any attempt to arrive at a better understanding of mental stress in indoor workplaces and the psychological aspects of adverse indoor workplace conditions must be based on a consistent definition of the terms mental stress and mental strain. These definitions are set out in DIN EN ISO 10075-1 [1], where mental stress is deemed to be "*the totality of all influences that people are subject to from the world around them and that affect them mentally*". Put simply, employees are subject to influences at work that can stem from the work task, work environment, work organisation, work equipment or social factors (Figure 29).

Having said that, mental stress and the impairing effects that can result from it can come from any aspect of a person's life – not just their work. This makes it difficult to separate work-related incidences of stress from those that originate outside the workplace, such as problems at home.

Figure 29:
Influences of work on people and the mental stress and impairing effects they can cause



Mental stress can lead both to positive (learning or training effects, activation) and negative (monotony, mental satiation, mental fatigue and stress in general) consequences of strain. The same incidence of stress can produce different strains in different people. Several factors determine whether stress generates impairing or stimulating effects, among them the resources available to the individual.

There is a complex web of causes behind complaints and disorders in employees, in which noxae, attribution and stress-related impairing strain play a role. There may be overlaps with Multiple Chemical Sensitivity Syndrome (MCS), Sick Building Syndrome (SBS) and Building-Related Illness (BRI) and differential diagnosis will be required. The following personal factors are known to influence complaints and the way they are perceived:

- risk perception,
- anxiety,
- somatisation disorders,
- attribution (errors) and
- impairing strain.

Group dynamics can have a major effect on the extent and proliferation of complaints and symptoms but real organic illnesses can also be the cause. This aspect must therefore always be taken into account before embarking on time-consuming, potentially counterproductive measurement of possible chemical, biological or physical exposure. If multiple complaints occur following extensive redecoration work, relocation or restructuring, the factors mentioned above may be the cause if there is no evidence of harmful exposure.

14.1 Data collection methods

The checklists developed by the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA; Federal Institute for Occupational Safety and Health) for identifying consequences of impairing strain (Checklisten zur Erfassung von Fehlbeanspruchungen, ChEF) [2] give an indication of whether such consequences exist and any workplace-specific factors that may have given rise to them. The checklists cover general stress, mental fatigue, monotony and mental satiation, each with 15 to 18 statements to be used for self-assessment and third-party assessment. They

provide an overview of the different impairing consequences that can arise from mental stress during work. The time required to complete all four lists is roughly 20 to 30 minutes per person. They are recommended as a method of documenting the aspects mentioned above so as to gain an initial impression.

14.2 Application

Owing to the checklists' indicative nature, there are certain practical consequences for users of this method:

- It cannot be used to deliver a comprehensive assessment of individuals' level of strain. The intention is merely to give the user an indication of what changes could be made to work activities.
- The completed questionnaires should primarily be evaluated in qualitative terms.
- It is essential to have the consent of all persons in authority and all stakeholders (employers, management, employees, employee representatives) before using the checklists in the workplace.

A separate assessment is carried out for each work activity task though activities performed at various workplaces can be considered one unit. It is also possible to assess activities performed by several employees. The statements on the checklists are responded to with a "yes" or a "no." No response is given in the case of factors that cannot be judged. There are separate lists for third-party assessment, e.g. by technical inspectors, and self-assessment by employees. Additional worksheets are provided for comparing the self-assessment and third-party assessment.

The ChEF procedure includes questionnaires for self-assessment, filled in by the employees, and questionnaires for third-party assessment, which are completed by people conducting workplace investigations. The parts concerning performance and experiences are blacked out on the questionnaires to be completed by third parties since these are factors that cannot be observed. The process of comparing third-party assessments and self-assessments using the worksheets points to action that could be taken to optimise workplace-specific factors. If it is not possible to conduct third-party and self-assessments, each type of assessment can be employed on its own.

The BAuA tool box, which can be found in the German version of the practical experience (Informationen für die Praxis) section at www.baua.de, lists other suitable methods.

14.3 References

[1] DIN EN ISO 10075-1: Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung – Teil 1: Allgemeines und Begriff (11.00). Beuth, Berlin 2000

[2] Checklisten zur Erfassung von Fehlbeanspruchungsfolgen. Published by: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund. www.baua.de/de/Informationen-fuer-die-Praxis/Handlungshilfen-und-Praxisbeispiele/ChEF.html

Annex 1:
Investigating the incidence and nature of health complaints
– Questionnaire G1 –

Investigating the incidence and nature of health complaints	Questionnaire G1 #

Dear employee,

As you may know, some of your fellow workers have informed us that they have health complaints that they feel are linked to their workplace. We are investigating this issue and this questionnaire is intended to help determine whether and where health is adversely affected within our organisation. We are also seeking to establish whether there is a link with the building itself, the rooms in it or the furnishings and building service systems.

Consequently, this questionnaire is obviously only concerned with illnesses or other health complaints that arise or have previously arisen in connection with your work. It does not address health problems caused by accidents, inherited diseases or any other illnesses developed elsewhere. If you are in doubt, please consult your organisation's occupational physician.

Completion of the questionnaire is voluntary and your answers will be recorded anonymously. If you do choose to give information, we would be very grateful if you could supply as much detail as possible. We will only be able to draw meaningful conclusions if as many employees as possible take part in the survey.

Place of employment (name, address):
Unit/dept.:
Date questionnaire completed: **Questionnaire number:**

1 Do you have any health complaints that you feel are linked to your workplace?
☐ No ☐ Yes (please specify)
If you answered „No", please continue to question 5

2 Which health complaints are the worst in your opinion?

Investigating the incidence and nature of health complaints Questionnaire G1

3 Information concerning medical treatment

3.1 Have you been examined by a doctor in connection with these complaints?
☐ No ☐ Yes (please specify)

3.2 Are you being treated for these complaints?
☐ No ☐ Yes (please specify)

3.3 Have you ever been written off sick due to these complaints?
☐ No ☐ Yes (please specify how often and for how long)

4 Information concerning the timing of the complaints

4.1 When did the health complaints start?
Please give the month and year

4.2 When exactly do they occur?
E.g. season, day of the week oder time of day

4.3 Do the complaints subside when you are not at your workplace?
☐ No ☐ Yes
- ☐ When I‘ve finished work
- ☐ At the weekend
- ☐ On holiday

4.4 What do you think causes your health complaints?

5 Information concerning your workplace

5.1 What sort of workplace do you have?
- ☐ Own office
- ☐ Office with _____ workstations
- ☐ Other: a(n) _____ with _____ workstations

5.2 Are there any factors you feel are disruptive to your work? (E.g. noise, odours, thermal environment, lighting)?
☐ No ☐ Yes (please specify)

5.3 Have there been any changes at your workplace recently?
☐ No ☐ Yes
- ☐ Redecoration
- ☐ Restructuring of the organisation
- ☐ Restructuring of the department
- ☐ Staff changes
- ☐ Changes in responsibilities
- ☐ Other changes (please specify)

Investigating the incidence and nature of health complaints Questionnaire G1

6 Personal information

6.1 Please indicate your gender

☐ Male ☐ Female

6.2 How old are you?

☐ Younger than 20 years
☐ 20 to 29 years
☐ 30 to 39 years
☐ 40 to 49 years
☐ 50 to 59 years
☐ 60 years or older

6.3 Do you have any allergies?

☐ No ☐ Yes (please specify)

6.4 Do you smoke?

☐ No ☐ Yes

Annex 2:
Evaluation table for Questionnaire G1

As a rule, a point should be made of evaluating the questionnaires one by one. However, in the case of relatively large groups a breakdown of the health complaints is often useful. This can be done using the following evaluation table: ☞

Questionnaire number	Number of people without/ with complaints				Which complaints occur?	Worst complaints in employees' opinion	Complaints started occuring ...	Do complaints subside when employee is not at workplace?		Suspected causes	Disruptive factors at workplace	Following changes have occured at workplace recently
	without		with									
	m[1]	f[2]	m[1]	f[2]				No	Yes			
1	☐	☐	☐	☐				☐	☐			
2	☐	☐	☐	☐				☐	☐			
3	☐	☐	☐	☐				☐	☐			
4	☐	☐	☐	☐				☐	☐			
5	☐	☐	☐	☐				☐	☐			
6	☐	☐	☐	☐				☐	☐			
7	☐	☐	☐	☐				☐	☐			
8	☐	☐	☐	☐				☐	☐			

[1] m = male
[2] f = female

Evaluation:

The main health complaints can be identified by determining the frequency distribution. Information as to whether the complaints subside when the employee is not at the workplace indicates whether they can be directly linked to the person's work. If the questionnaires are also completed by room users who do not have any health complaints, additional conclusions can be drawn regarding disruptive factors at work and changes in the workplace.

The answers to the following questions usually point to the main health complaints and provide initial input as to the possible causes, which is why it has proven particularly useful to evaluate them together:

- Which of the health complaints were considered the worst? (Question 2),
- What caused the health complaints? (Question 4.4),
- Which factors are disruptive to the work (e.g. noise, odours, indoor climate, lighting)? (Question 5.2) and
- Recent changes at the workplace (Question 5.3)

Example of an evaluation

Questionnaire number	Number of people without/ with complaints				Which complaints occur?	Worst complaints in employees' opinion	Complaints started occuring ...	Do complaints subside when employee is not at workplace?		Suspected causes	Disruptive factors at workplace	Following changes have occured at workplace recently
	without		with									
	m	f	m	f				No	Yes			
1	☐	☐	☐	☒	Blocked nose, increased infection rate, nausea, hair loss	Hair loss	5 months	☒	☐	General stress, indoor air	Air quality	New work organisation
2	☐	☐	☐	☒	Dry eyes, hair loss	Dry eyes, hair loss	3 months	☐	☒	General stress, indoor air	Air quality, thermal environment	New work organisation in connection with new office
3	☐	☐	☐	☒	Dry eyes, blocked nose	Blocked nose	6 months	☒	☐	General stress, indoor air, dust	Air quality	
4	☐	☐	☒	☐	Dry eyes, headaches, increased infection rate	Headaches	6 months	☒	☐	General stress	Lighting	New office
5	☐	☐	☐	☒	Dry eyes, blocked nose, headaches, increased infection rate, muscle tension	Increased infection rate	6 months	☒	☐	Mental stress, indoor air	Noise, odours	New work organisation in connection with new office
6	☒	☐	☐	☐				☐	☐		Noise	New work organisation in connection with new office
7	☐	☒	☐	☐				☐	☐		Noise, thermal environment	New work organisation in connection with new office
8	☐	☐	☐	☒	Dry eyes, headaches, muscle tension	Headaches	6 months	☒	☐		Air quality	
9	☐	☐	☒	☐	Dry eyes, headaches, muscle tension	Headaches	4 months	☐	☒	Indoor air	Noise, air quality	New work organisation in connection with new office
10	☐	☐	☐	☒	Dry eyes, blocked nose, increased infection rate, muscle tension, back problems			☒	☐	General stress, indoor air	Air quality	
	10%	10%	20%	60%	7 x dry eyes 5 x blocked nose and increased infection rate 4 x headaches 2 x hair loss 1 x nausea 1 x back problems			60%	20%	6 x general stress 6 x indoor air	6 x air quality 4 x noise 2 x thermal environment 1 x lighting	6 x new work organisation 6 x new office

This example evaluation indicates that the employees are suffering from increased general stress, partly as a result of changes in the way their work is organised. A move to new offices has caused a sense of unease. The recommended action would be to conduct interviews with the employees concerned and their line managers in order to find ways of improving the work organisation and avoiding general stress. This could be followed by special investigations of the air quality, noise and the lighting in the offices of the employees who stated that these factors were disruptive to their work.

Annex 3:
Investigating the work environment
– Questionnaire G2 –

Investigating the work environment Questionnaire G2

Dear respondent,

Problems in indoor workplaces can be caused by various factors, including the building itself, the furniture and furnishings in it and its technical systems. This questionnaire is intended to help identify the causes of health complaints. We would therefore ask you to answer in as much detail as possible.

Place of employment (Name, address):
Unit/dept.:
Workplace:
Questionnaire completed by: **Completed on:**

1 General building data

When was the building built?

2 Size of building

2.1 How many employees work in the building?

2.2 How many storeys does the building have?

2.3 Are there any building plans or construction documentation?
(it might be necessary to contact the relevant planning authority)
☐ No ☐ Yes (if possible, please enclose)

3 General purpose for which building is used

Storey/floor	Type of use	Notes

4 Location of building

4.1 Where ist the building located?
- ☐ in the city/town center
- ☐ in an industrial/a commercial area
- ☐ in a mixed-use area
- ☐ in a residential area
- ☐ on a busy road/next to a motorway/railway line
- ☐ elsewhere, please specify

If possible, please enclose a map or sketch of the surroundings

Investigating the work environment Questionnaire G2

4.2 Is there any industrial plant in the immediate vicinity of the bulding?
☐ No ☐ Yes (please specify)

4.3 Are there any vent stacks/external pollutant sources known to be located in the area surrounding the building?
☐ No ☐ Yes (please specify)

4.4 Are there any high-noise enterprises in the immediate vicinity of the building?
☐ No ☐ Yes (please specify)

5 Work areas or building sections in which employees have developed health complaints

5.1 What are the work areas/building sections used for?

Work area/ building section	Size of rooms	Type of use (e.g. display screen workstation)	Notes

5.2 Were the work areas/neighbouring building sections previously used for a different purpose?
☐ No ☐ Yes (please specify)
Please Indicate the nature and duration of the past use in the following table

Work area/ building section	Type of use	Duration	Notes

5.3 Have any external-source odours been detected in the work area?
☐ No ☐ Yes (please specify)

5.4 Have any external-source noises or vibrations been detected in the work area?
☐ No ☐ Yes (please specify)

5.5 Is there any unwanted exposure to sunlight?
☐ No ☐ Yes
Time of day:
Duration:
Notes (e.g. glare, heat sensation):

6 Building ventilation

6.1 Are the rooms ventilated naturally (via windows)?
☐ No ☐ Yes
Notes:

Investigating the work environment Questionnaire G2

6.2 Can the windows each be opened separately?
☐ No ☐ Yes
Notes:

6.3 Do the rooms have ventilation systems?
☐ No ☐ Only for supply and extract air
☐ Yes, an air conditioning system
☐ With humidification
Notes:

6.4 If there is a ventilation/air conditioning system, is it regularly inspected?
☐ No ☐ Yes, by
☐ Documentation available

7 Temperature control in the building

7.1 How are the rooms/work areas heated?
☐ Heating appliancees in the rooms (radiators, convectors)
☐ Underfloor heating
☐ Ceiling or wall heating
☐ Ventilation/air conditioning system
☐ Other (please specify)

7.2 How is the thermal environment (air temperature, humidity) controlled?
☐ No control
☐ Individual control
☐ Central control
☐ Other control (please specify)
☐ Air temperature control in ☐ summer ☐ winter
☐ Humidity control
Notes (e.g. control range too small, control sluggish):

7.3 Are the rooms or building sections cooled?
☐ No ☐ Yes, by
☐ Supply air cooling system/air conditioning system
☐ Cooling ceiling system
☐ Concrete core cooling system
☐ Other (please specify)

8 Technical Equipment in the work area

8.1 What type of lighting is used in the work areas?
☐ Daylight
☐ Permanent artificial lighting all hours of the day, all year around
☐ Artificial lighting is only switched on when needed
☐ Other (please specify)

8.2 Are there any appliances, machines or other devices (e.g. printers or copiers) in the work area that give off unwanted emissions (e.g. noise, odours)?
☐ No ☐ Yes (please specify number and type)

8.3 Is this equipment serviced and inspected regularly?
☐ No ☐ Yes, by
☐ Documentation available

Investigating the work environment Questionnaire G2

9 Changes to the building

9.1 Has any redecoration/reconstruction, extension or conversion taken place?

☐ No ☐ Yes

Please indicate the nature and scope of the changes in the following table.

Duration	Nature and scope of the changes to the building (e.g. painting, new flooring, extra windows, thermal insulation, seals, asbestos clean-up measures)

9.2 Are specific products used or have they been used in the room?

☐ No ☐ Yes

- ☐ Cleaning agents
- ☐ Disinfectants
- ☐ Air fresheners
- ☐ Insecticides, fungicides, pest control products
- ☐ Other (please specify)

Annex 4:
Example of how to determine the rating level

In a foreman's office in a mechanical workshop (separate booth, with windows), there are three distinct phases depending on the production processes and machine utilisation, i.e.:

Phase 1: Background noise
(hydraulic systems, fans, idle machines)
Approx. 15% of the shift

Phase 2: Majority of the processing machinery in operation
Approx. 80% of the shift

Phase 3: Majority of the processing machinery and the guillotine shears in operation
Approx. 5% of the shift

Each of these phases is assumed to be a sub-interval and the sound exposure levels are calculated separately as described below.

- Sub-interval 1

An equivalent continuous sound exposure level $L_{pAeq,m}$ of 47.2 dB(A) is determined for the background noise (mean of two measurements). Since there is a hydraulic unit that makes one single, very distinct sound, an adjustment of 3 dB(A) is specified for the tonality and information content.

- Sub-interval 2

When the processing machinery is operating as usual, an equivalent continuous sound exposure level $L_{pAeq,m}$ of 61.8 dB(A) is determined (mean of two measurements). The noise is not felt to be tonal, i.e. no adjustments need to be made.

- Sub-interval 3

The guillotine shears are used at irregular intervals throughout the day. Since the results of the first two measurements of the equivalent continuous sound exposure level differ by 2.4 dB(A), a total of four measurements are taken in the booth. This yields a mean equivalent continuous sound exposure level $L_{pAeq,m}$ of 67.4 dB(A). The degree of the impulse K_I for each measurement is determined at the same time, producing a mean value of 4.3 dB(A).

The rating level can be calculated using the following formula

$$L_r = 10 \lg \left(\sum_{m=1}^{M} \frac{x_m}{100} 10^{0,1 \cdot L_{p,m}} \right) \text{dB(A)}$$

Table 40, which shows the levels for each sub-interval and their duration as a percentage, illustrates how the calculation is carried out.

Table 40:
Calculation of the rating level based on sub-interval levels

Activity m	Sub-interval level $L_{p,m}$ in dB(A)	Sub-interval duration x_m in %	Formula value $\frac{x_m}{100} \cdot 10^{0.1 \cdot L_{p,m}}$
1	47.2 + 3 = 50.2	15	15.71 · 10³
2	61.8 + 0 = 61.8	80	1,210.85 · 10³
3	67.4 + 4.3 = 71.7	5	739.55 · 10³
		Σ	**1,966.11 · 10³**

The values for each sub-interval are added together in the last column of the table to calculate a rating level L_r of approximately 63 dB(A) by means of a logarithm and multiplication by 10:

$L_r = 10 \lg (1{,}966.11 \cdot 10^3)$ dB = 62.9 dB(A)

Based on VDI Guideline 2058-3, Part 2 (see Section 8.4. of these recommendations), the workplace in the foreman's booth is suitable for "simple or predominantly mechanised office work".

Annex 5:
Guidance for identifying sources

Table 41 lists the volatile organic compounds (VOCs) routinely examined in the MGU measuring programme for indoor measurements, plus the potential indoor sources. The list is not exhaustive and is merely intended to provide initial guidance.

Table 41:
Potential sources of the indoor air substances routinely examined in the MGU measuring programme for indoor measurements [1]

Substance/substance category	Potential sources and main uses	Perceived odour
Hydrocarbon mixtures, aliphatic (C_9 to C_{14}) [2]	Solvent in paints, varnishes and other coating products; dry cleaning products; car, shoe and floor care products; furniture polish; secondary component in water-based paints	Petrol-like, minor
Alkanes		
n-Heptane	Solvent for (fast-drying) varnishes and adhesives	Weak, petrol-like
n-Octane	Solvent (e.g. paint thinners); in acrylic products	Petrol-like
n-Nonane	Used in surfactant production; ingredient in petrol, fuel and lamp oil; solvent	Petrol-like
n-Decane	Solvent Contained in petrol	Petrol-like
n-Undecane	Contained in petrol	Petrol-like
n-Dodecane n-Tridecane n-Tetradecane	Contained in petrol Contained in petrol, oil fuel, paints, varnishes Contained in petroleum	Petrol-like
n-Pentadecane	Contained in petrol, oil fuel, paints, varnishes	Petrol-like
n-Hexadecane	Contained in petroleum jelly, petrol and petroleum	Petrol-like
Aromatic compounds		
Benzene	Solvent and cleaning agents; anti-knock additive in fuels; formerly used as solvent for rubber paints, waxes, resins and oils	Aromatic
Toluene [3]	Increased toluene concentration levels are generally likely in the vicinity of toluene-emitting facilities (printing works, petrol stations) and in rooms immediately adjacent to garages. In building materials that contain toluene; in freshly printed materials; solvent (as a benzene substitute) in paints, varnishes (e.g. including nail varnish), adhesives, furniture care products, rubber, greases	Flowery, pungent
Ethylbenzene	Solvent in paints and coatings; contained in polymer materials such as floor coverings and floor backings	Aromatic
o-Xylene m-Xylene p-Xylene	Most technical-grade xylene mixtures contain the three isomers o-xylene (20 to 24 vol.-%), m-xylene (42 to 48 vol.-%), p-xylene (16 to 20 vol.-%) plus ethylbenzene (10 to 11 vol.-%). Solvent in natural and synthetic resins, greases, waxes; contained in petrol; used in the production of varnishes, paints, printing inks, adhesives, building protection products, insecticides, etc.	Aromatic
1,2,3-Trimethylbenzene 1,2,4-Trimethylbenzene 1,3,5-Trimethylbenzene (mesitylene)	Used in the production of medicinal products and dyes; intermediate in the production of odorous substances	Aromatic
Styrene [4]	Numerous consumer products (e.g. household appliances, packaging, carpets) can contain monomer residues and thus cause styrene pollution in the indoor air. Solvent and reactant for unsaturated polyester resins; mounting media for anatomical specimens; used in the production of polystyrene (for packaging, insulating materials, components, etc.) and polystyrene copolymers with acrylonitrile, butadiene, maleic anhydride, etc. and thermoplasts	Sweet People become accustomed to the odour Strong-smelling

Substance/substance category	Potential sources and main uses	Perceived odour
Naphthalene [5]	In mothballs and insecticides; bitumen damp-proofing, powder-proofing (beneath packed beds) or joints in wooden floors glued using bitumen; occasionally rubber floor coverings; leaks in mineral oil tanks in basements; in some countries in and outside of Europe, naphthalene is used to preserve natural products (e.g. leather, natural bristles).	Like moth powder and bitumen Strong-smelling
Phenol [6]	In the past, phenol was widely used as a disinfectant, e.g. in laundries and in care products, but this practice was stopped over a decade ago. Solvent; used in the production of phenol resins, plasticisers, anti-oxidants, soaps, shampoos, adhesives, lubricants, dyes, etc.	Penetrating odour Strong-smelling
Alcohols		
n-Butanol	Solvent in varnishes, paints, resins, rubber; decomposition product resulting from plasticiser hydrolysis, therefore indicates damp damage or high levels of residual moisture in building structures (hydrolysis of dibutyl phthalate)	Ethanolic People become accustomed to the odour
2-Ethylhexanol	Solvent for greases, waxes, oils and resins; dispersing agents for pigments; plasticisers; decomposition product resulting from hydrolysis of the most common plasticiser, DEHP, therefore indicates damp damage or high levels of residual moisture in building structures	Alcoholic Strong-smelling
1-Hexanol [7]	Occurs in, for example, wallpaper, carpets, evaporation-type metres on radiators	Sweet
Ketones and esters		
Butanone	Solvent for vinyl resins and nitrocellulose varnishes; denaturants for ethanol	Acetone-like
4-Methyl-2-pentanone	Solvent; contained in coating substances that use cellulose nitrate as a binding agent, including natural resins, synthetic resins and epoxy resins; contained in printing inks as a solvent for dyes and binding agents	Pleasant People become accustomed to the odour
Esters	Solvent in varnishes and adhesives, perfumes and air fresheners	Pleasant, fruity odour
Ethyl acetate	Main ingredient in many special-purpose solvents; used in the production of nail varnish and nail varnish remover; used to flavour liqueurs, sweets, fizzy drinks and medicinal products; important solvent in the production of cellophane, celluloid, collodion wool, varnishes, synthetic resin, etc.	Fruity (typical “UHU” smell)
n-Butyl acetate	Solvent for varnishes; extraction agents; used in the production of essences, stain removers, glossy paper, nail care products; contained in paint removers, building chemicals	Fruity
Acrylates (Acrylic acid esters)	Predominantly used as methyl methacrylate in acrylic resins, adhesives or sealants	Pungent
Glycol ethers and esters		
2-Butoxyethanol	Solvent for printing inks; thinners; finishing agents; used in the production of varnishes	Weak ethereal odour
2-Butoxyethyl acetate	Contained in flexographic, gravure printing and silkscreen printing inks; used for leather and textile prints	Weak, ester-like odour
2-(2-Butoxyethoxy)ethanol	Contained in surface-cleaning products, drilling and cutting oils, firefighting foams; used in the production of plasticisers	Weak, fruity, almost odourless
2-(2-Butoxyethoxy)ethyl acetate	Contained in printing inks, ballpoint pen pastes, outdoor/indoor paints and synthetic resin plaster, wood stain, furniture polish and cleaning agents	Fruity

Substance/substance category	Potential sources and main uses	Perceived odour
Glycol ethers and esters		
2-Phenoxyethanol	Solvent in inks, ballpoint pen pastes, printing pastes and stamping inks; fixative for perfumes and soaps; used in the production of plasticisers, air fresheners	Weak aromatic odour
Terpenes		
α-Pinene [8]	Volatile component in conifer resin oil; main component in turpentine oil; used as a solvent in surface-treatment products and adhesives, in household products (e.g. shoe polish, floor cleaners); used as a fragrance additive in cosmetics; natural component of fruits and vegetables (e.g. oranges, lemons, carrots); contained in medicinal products	Pine-like
Limonene [9]	Contained in citrus oil but also in many other essential oils, e.g. fennel and caraway, and in many food crops; used as a solvent in the varnish industry and in do-it-yourself and household products, e.g. paint removers, brush cleaners, glaze, care products, polishes; used as a fragrance in cosmetics; used to flavour foods; in essential oils used as treatments for colds; increased values occur, for instance, when citrus fruits are peeled (circa 2 mg/m³); contained in alkyd resin varnishes (oil varnishes), shoe polishes, floor wax	Pleasant, citrus-like
3-Carene	Volatile component in conifer resin oil; used as a solvent in surface-treatment products and adhesives, in household products (e.g. shoe polish, floor cleaners); used as a fragrance additive in cosmetics; natural component of fruits and vegetables (e.g. oranges, lemons, carrots); contained in medicinal products	Pleasantly sweet
Aldehydes		
Aldehydes	Linoleum, alkyd resin varnishes, linseed oil varnish and other drying oils, PVC floor coverings, scented oils, perfumes, cooking and baking vapours	
Formaldehyde	Auxiliary agent in the textile, leather, fur, paper and wood-making industries; preservative and disinfectant in medicine and engineering; mostly used to make resins with urea (bonding agent with chipboard), phenols and melamine; anhydrous, pure formaldehyde is used in the production of thermoplastics	
Acetaldehyde	Flavouring that gives a fresh, fruity taste in such products as alcoholic beverages; by-product of alcoholic fermentation, e.g. during dough-making; product of the human metabolism; created by breakdown processes, e.g. protein breakdown in domestic dust	Pungent
Propionaldehyde	Used in the production of plastics, plasticisers, rubber auxiliary agents, vulcanisation accelerators, phenol resins, demulsifiers, flavourings and fragrances, agrochemicals, pest control products and medicinal products	Pungent
Butyraldehyde	Used in the production of synthetic resins, plasticisers, solvents, synthetic tanning and odorous substances, vulcanisation accelerators	Pungent
Glutaral (glutaraldehyde)	Preservative used for disinfection of equipment and instruments in the cosmetic industry and in medicine; hardener for gelatine; tanning agent for treating leather; water repellents for paper, wallpaper, etc.	Acrid, unpleasant smell

Substance/substance category	Potential sources and main uses	Perceived odour
Aldehydes		
Higher aldehydes such as pentanal, hexanal (capronaldehyde), heptanal, octanal, nonanal or decanal [10]	Contained in natural wood, thus also contained in, for example, wooden flooring or alkyd resin products Occurs as a result of secondary emission, due to fatty acid breakdown in resins and oils; therefore contained in linoleum, natural oil products (especially those based on linseed) and adhesives; Main aldehydic compound in many indoor rooms	Fatty, rancid or pungent, very strong smell (especially octanal, nonanal and decanal)
Siloxanes [11]	Contained in numerous consumer products, such as hair care and personal care products, cosmetics, washing and cleaning products, furniture polishes, in dummies for babies, baking moulds and electronic components; contained in joint sealants, paints, varnishes, paper materials and textiles; D5 is usually the siloxane with the highest concentration	Odour hardly perceptible

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Annex 6:
List of abbreviations

Abbreviation	German	English
AgBB	Ausschuss zur gesundheitlichen Bewertung von Bau-produkten	Committee for Health-related Evaluation of Building products
ASR	Arbeitsstättenrichtlinie	Technical Rule for Workplaces
BAuA	Bundesanstalt für Arbeitschutz und Arbeitsmedizin	Federal Institute for Occupational Safety and Health
BfR	Bundesinstitut für Risikobewertung	Federal Institute for Risk Assessment
BG BAU	Berufsgenossenschaft der Bauwirtschaft	German Social Accident Insurance Institution for the building trade
BGI	Berufsgenossenschaftliche Information	Information of the Social Accident Insurance
BGR	Berufsgenossenschaftliche Regel	Rule of the Social Accident Insurance
BGV	Berufsgenossenschaftliche Vorschrift	Regulation of the Social Accident Insurance
BGW	Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrts-pflege	German Social accident Insurance Institution for the health and welfare services
BRI	---	Building-related illness
CRT	---	cathode ray tube
DBP	Dibutylphthalat	dibutyl phthalate
DECT	---	Digital Enhanced Cordless Telecommunications
DEHP	Di(2-ethylhexyl)phthalat	di(2-ethylhexyl)phthalate
DFG	Deutsche Forschungsgemeinschaft	German Research Foundation
DGUV	Deutsche Gesetzliche Unfallversicherung	German Social Accident Insurance
DIN	Deutsches Institut für Normung	German Institute for Standardization
DSE	---	display screen equipment
EHA	---	exhaust air
EMF	elektromagnetische Felder	electromagnetic fields
EM fields	elektromagnetische Felder	electromagnetic fields
ETA	---	extract air
GefStoffV	Gefahrstoffverordnung	Ordinance on Hazardous Substances
GEV	Gemeinschaft Emissionskontrollierte Verlegewerkstoffe	Association for the Control of Emissions in Products for Flooring Installation, Adhesives and Building Materials
GS	Geprüfte Sicherheit	tested safety
GuT	Gemeinschaft umweltfreundlicher Teppichboden e.V.	Association for Environmentally-Friendly Carpets
ICNIRP	---	International Commission on Non-Ionzing Radiation Protection
IFA	Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfall-versicherung	Institute for Occupational Safety and Health of the German Social Accident Insurance
ICRP	---	International Commission on Radiological Protection
IR radiation	Infrarot-Strahlung	infrared radiation
LCD	---	liquid crystal display
LGA Bayern	Landesgewerbeanstalt Bayern	Bavarian state trade agency
MCS	---	Multiple Chemical Sensitivity Syndrome
MIA	---	mixed air
MMI	---	mucous membrane irritation
MMMFs	---	man-made mineral fibres
MUF	Melamin-Harnstoff-Formaldehyd-Harz	melamine urea formaldehyde resins
ODA	---	outdoor air
ODT	---	odour detection threshold

Annex 6: List of abbreviations

Abbreviation	German	English
OEL	---	occupational exposure limit
OSH	---	occupational safety and health
PCB	polychlorierte Biphenyle	polychlorinated biphenyls
PCP	Pentachlorphenol	pentachlorophenol
PF	Phenol-Formaldehyd-Harz	phenol formaldehyde resins
PM	---	particular matter
PMDI	polymeres Diphenylmethandiisocyanat	“polymeric” methylene diphenyl diisocyanate
PMV	vorausgesagtes mittleres Votum	predicted mean vote
POM	---	particulate organic matter
PPD	vorausgesagter Anteil Unzufriedener	predicted percentage of dissatisfied
PVC	Polyvinylchlorid	polyvinyl chloride
RAL	RAL Deutsches Institut für Gütesicherung und Kennzeichnung	German Institute for Quality Assurance and Certification
RAL-UZ	RAL Umweltzeichen	RAUL environmental label
RCA	---	recirculating air
SAR	spezifische Absorptionsrate	specific absorption rate
SBS	---	sick building syndrome
SPL	---	sound pressure level
SRU	Sachverständigenrat für Umweltfragen	Advisory Council on the Environment
TFT	---	thin film transistor
TOP measures	technische, organisatorische, persönliche Maßnahmen	technical, organisational, personnel measures
TRGS	Technische Regel für Gefahrstoffe	Technical Rule for Hazardous Substances
TRLV	Technische Regeln zur Lärm- und Vibrations-Arbeitsschutz-verordnung	Technical Rules pursuant to the ordinance on noise and vibration protection
TTS	---	temporary hearing loss, temporary threshold shift
TVC	---	total viable count
TVOC	Summe der flüchtigen organischen Stoffe	totale volatile organic compounds
UBA	Umweltbundesamt	Environmental Protection Agency
UF	Harnstoff-Formaldehyd-Harz	urea formaldehyde resin
UFP	ultrafeine Partikel	untrafine particles
UGR	---	unified glare rating
UV radiation	ultraviolette Strahlung	ultraviolet radiation
VAC	---	ventilation and air conditioning
VBG	Verwaltungs-Berufsgenossenschaft	German Social Accident Insurance Institution for the administrative sector
VDI	Verein Deutscher Ingenieure	The Association of German Engineers
VOC	flüchtige organische Stoffe	vorlatile organic compounds
WHO	Weltgesundheitsorganisation	World Health Organization
WLAN	---	Wireless Local Area Newtworks