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

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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).

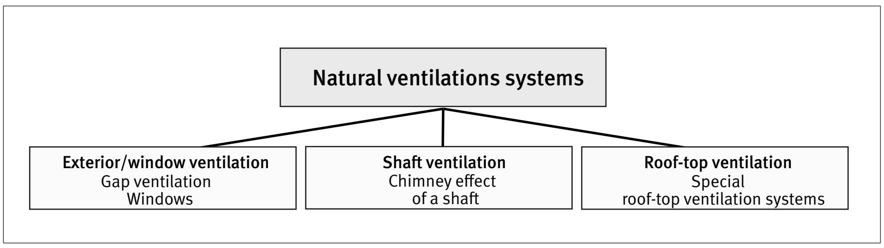


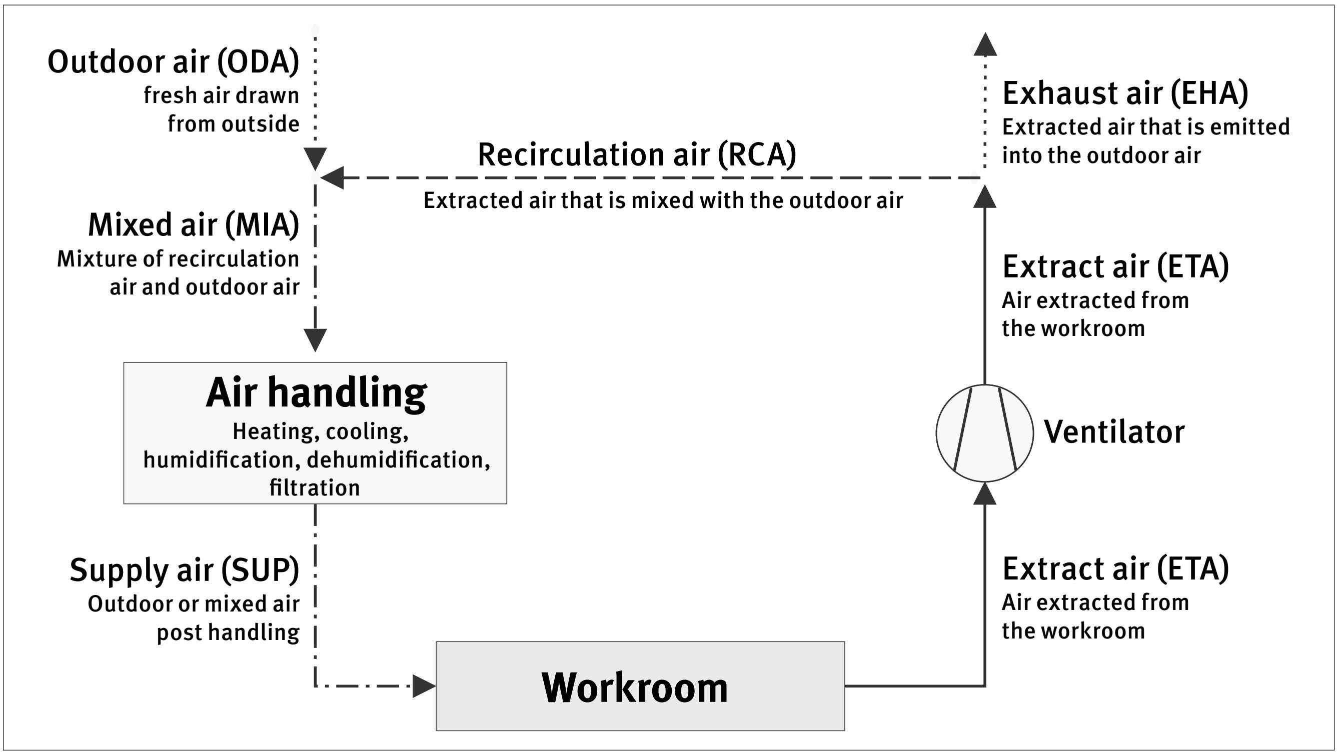
Figure 3:
Natural ventilation system types

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

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