- 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

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6.4 Materials

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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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