

12.4 Specific information regarding individual substances and categories of substance

U. Bagschik, Düsseldorf
 J. Fauss, Mannheim
 H. Fröhlich, Mannheim
 H. Kleine, Sankt Augustin
 H.-D. Neumann, Düsseldorf
 K. Pohl, Mainz
 I. Thullner, Frankfurt am Main
 T. von der Heyden, Sankt Augustin
 N. von Hahn, Sankt Augustin

12.4.1 Carbon dioxide

Humans and their breathing are the main source of indoor carbon dioxide (CO₂) emissions. However, they do not result in toxically relevant levels CO₂ concentrations even in unfavourable conditions, e.g. where the air exchange rate is low. As odorous substance emissions are usually proportional to humans' CO₂ emissions, CO₂ concentration levels are a suitable indicator of indoor air quality provided there are no other sources of CO₂ emissions or odours. They also indicate how effective the room ventilation is.

As described in Section 12.2.2, indoor CO₂ concentrations can be measured using detector tubes or direct-reading measuring devices. However, they can also be calculated on the basis of the human CO₂ 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 CO₂. This value can be used to calculate the maximum CO₂ concentration level that will be reached in accordance with equation (1).

$$x_{\text{CO}_2} = \frac{n \cdot m_{\text{CO}_2}}{\lambda \cdot V_R} + x_{\text{CO}_2, \text{outdoor}} = \frac{n \cdot 20\,000 \text{ ml/h}}{\lambda \cdot V_R} + x_{\text{CO}_2, \text{outdoor}} \quad (1)$$

x_{CO_2} : CO₂ concentration in ml/m³

m_{CO_2} : CO₂ emission rate per person in ml/h

λ : Air exchange rate in h⁻¹

V_R : Room volume in m³

$x_{\text{CO}_2, \text{outdoor}}$: Outdoor air CO₂ 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 CO₂ concentration – taking into account a mean CO₂ concentration of 400 ml/m³ in the outdoor air [2] – is 1,200 ml/m³ (see equation 2).

$$x_{\text{CO}_2} = \frac{2 \cdot 20,000 \text{ ml/h}}{0,5 \text{ h}^{-1} \cdot 100 \text{ m}^3} + x_{\text{CO}_2, \text{outdoor}} \quad (2)$$

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

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

0.1 vol.-%CO₂ (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 CO₂, 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 CO₂ 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.

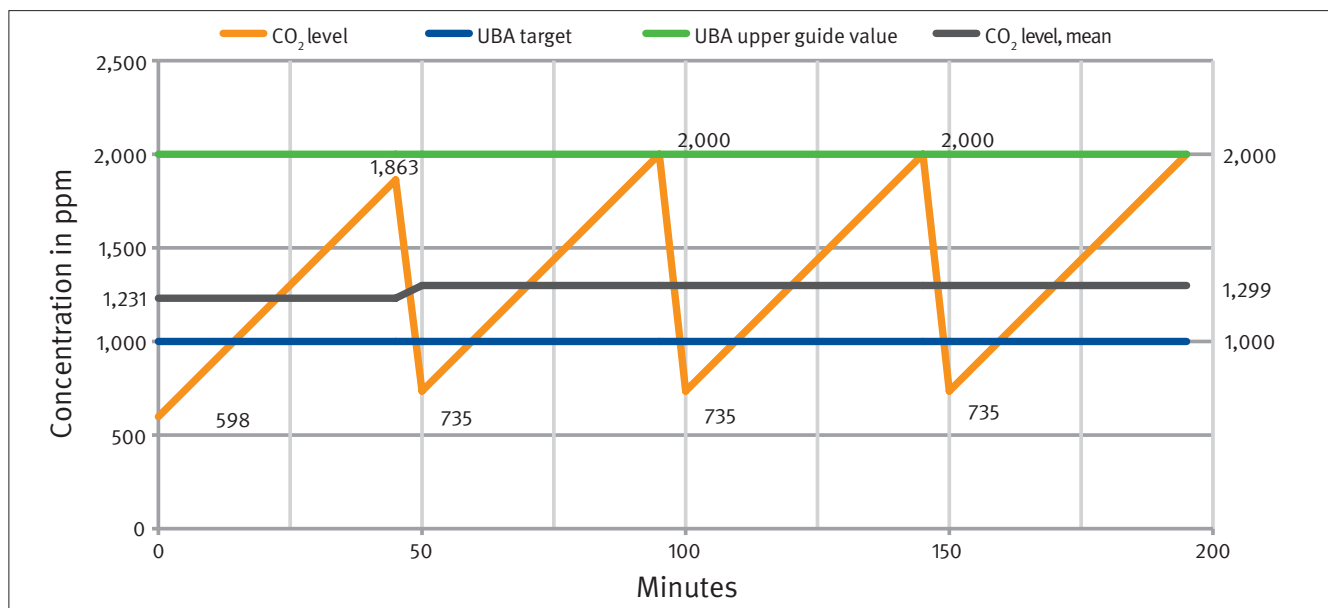
Carbon dioxide pollution in classrooms

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 CO₂ is usually the most significant air pollutant in classrooms too. According to the findings, the CO₂ 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 CO₂ 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 CO₂ concentration only rises slightly during lessons.

CO₂ 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 CO₂ 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/m ³	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/m ³ 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/m ³ 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/m ³ . The TVOC concentration should be decreased to below 3 mg/m ³ 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/m ³ during the period considered but it is still higher than 3 mg/m ³ , the action recommended in Level 4 should be taken. If, after one month, the TVOC concentration remains higher than 10 mg/m ³ 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, PM₁₀ (particulate 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 PM₁₀ 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 PM₁₀ 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 outdoors. 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 PM₁₀ 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 particulate 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 $\mu\text{g}/\text{m}^3$ 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:

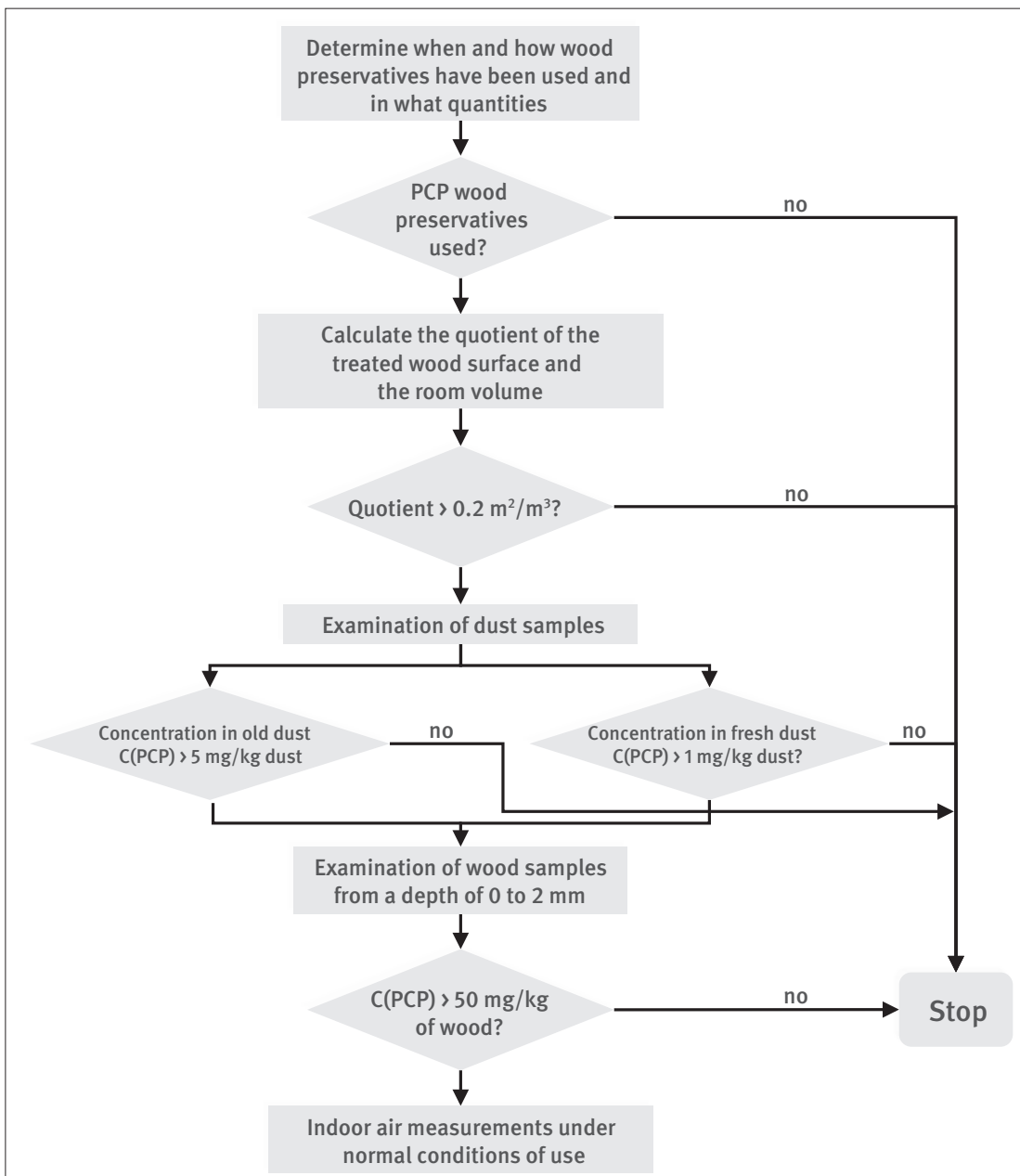
- If the investigation reveals that no PCP wood preservatives have been used, no further action is necessary.
- If there are grounds to suspect that PCP wood preservatives have been used, the first step, notwithstanding the PCP Directive, is to calculate the quotient of the treated wood surface and the room volume. Further action is only required if the quotient is $> 0.2 \text{ m}^2/\text{m}^3$.

- 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 PCB 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 resultant 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 PCB 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/m ³
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 (Chlophen 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.

12.4.11 References

- [1] *Eickmann, U.*: Berechnungsverfahren und Modellbildung in der Arbeitsbereichsanalyse. BIA-Report 3/01. Published by: Hauptverband der gewerblichen Berufsgenossenschaften (HVBG), Sankt Augustin 2001
- [2] Bekanntmachung des Umweltbundesamtes: Gesundheitliche Bewertung von Kohlendioxid in der Innenraumluft. Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz. 51 (2008) No. 11, p. 1358-1369
- [3] *Witthauer, J.; Horn, H.; Bischof, W.*: Raumluftqualität. C. F. Müller, Karlsruhe 1993
- [4] Ventilation for acceptable indoor air quality. Published by: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (1989) Vol. 62
- [5] *Neumann, H.-D.*: Luftqualität und Lüftung in Schulen. Gefahrstoffe – Reinhalt. Luft 71 (2011) No. 11/12, p. 495-497
- [6] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. OJ EC (2008) No. L 152, p. 1-44
- [7] IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol. Vol. 88. Published by: International Agency for Research on Cancer (IARC), Lyon 2006. <http://monographs.iarc.fr/ENG/Monographs/vol88/index.php>
- [8] *Cogliano, V. J.; Grosse, Y.; Baan, R. A.; Straif, K.; Secretan, M. B.; El Ghissassi, F.*: Meeting Report: summary of IARC Monographs on Formaldehyde, 2-Butoxyethanol, and 1-tert-Butoxy-2-propanol. Environm. Health Perspect. 113 (2005) No. 9, p. 1205-1208
- [9] *Schulte, A.; Bernauer, U.; Madle, S.; Mielke, H.; Herbst, U.; Richter-Reichhelm, H.-B.; Appel, K.-E. Gundert-Remy, U.*: Assessment of the carcinogenicity of formaldehyde. BfR Wissenschaft. Published by: Bundesinstitut für Risikobewertung (BfR), Berlin 2006. www.bfr.bund.de/cm/350/assessment_of_the_carcinogenicity_of_formaldehyde.pdf
- [10] Empfehlung des Umweltbundesamtes. Krebserzeugende Wirkung von Formaldehyd – Änderung des Richtwertes für die Innenraumluft von 0,1 ppm nicht erforderlich. Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz 49 (2006) p. 1169. www.umweltbundesamt.de/gesundheit/innenraumhygiene/Formaldehyd.pdf
- [11] WHO Air Quality Guidelines for Europe. 2nd ed. Published by: World Health Organization (WHO), Geneva, Suisse 2001
- [12] *Agar, J. P.; Gording, D. A.; Hartley, M. R.; Hope, L. A. E.; Mitchell, R. M.; Powell, C. B.*: Air Quality Monitoring Report – Richmond Primary School Environment Protection Authority. Adelaide, Juli 2001, p. 10
- [13] Indoor air quality – organic pollutants. Euro Reports and Studies 111. Published by: World Health Organization (WHO), Copenhagen, Denmark 1989
- [14] Bekanntmachung des Umweltbundesamtes: Beurteilung von Innenraumluftkontaminationen mittels Referenz- und Richtwerten. Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz 50 (2007) Nr. 7, S. 990-1005 www.umweltbundesamt.de/gesundheit/innenraumhygiene/innenraumluftkontaminationen.pdf
- [15] Directive 2002/95/EG of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. OJ EC (2003) No. L 37, p. 19-23; last revision by Commission Decision 2011/534/EU, OJ EG (2011) No. L 234, p. 44-45

- [16] Thullner, I.; Buchwald, K.-E.; Wegscheider, W.; Hohenberger, L.: Quecksilberemissionen bei der Sammlung und Entsorgung von Leuchtmitteln. *Gefahrstoffe – Reinhalt. Luft* 73 (2013) No. 1/2, p. 14-24
- [17] Energiesparlampen in der Diskussion. Published by: Umweltbundesamt (UBA), Dessau-Roßlau 2011
- [18] Bekanntmachung des Umweltbundesamtes: Gesundheitliche Bedeutung von Feinstaub in der Innenraumluft. *Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz* 51 (2008) No. 11, p. 1370-1378
www.umweltbundesamt.de/gesundheit/publikationen/ad-hoc/feinstaub_2008.pdf
- [19] Nilson, A.; Kihlström, E.; Lagesson, V.; Wessen, B.; Szponar, B.; Larsson, L.; Tagesson, C.: Microorganisms and Volatile Organic Compounds in Airborne Dust from Damp Residences. In: *Indoor Air 2002 – Proceedings of the 9th International Conference on Indoor Air Quality and Climate*, Monterey, 30. Juni to 5. Juli 2002, Vol. IV, p. 713-718
- [20] Mattenklott, M.; Höfert, N.: Stäube an Arbeitsplätzen und in der Umwelt – Vergleich der Begriffsbestimmungen. *Gefahrstoffe – Reinhaltung der Luft* 69 (2009) No. 4, p. 127-129
- [21] Richtlinie für die Bewertung und Sanierung schwach gebundener Asbestprodukte in Gebäuden (Asbest-Richtlinie) (01.96). *MBL. NRW* (1997) No. 51, p. 1067-1084
- [22] Technische Regeln für Gefahrstoffe: Asbest: Abbruch-, Sanierungs- oder Instandhaltungsarbeiten (TRGS 519). Ed. 1/2007. *GMBL*. (2007) No. 6/7, p. 122-163; revised *GMBL*. (2007) No. 18, p. 398
- [23] Walker, G.; Ostendorp, G.; Heinzow, B.: Künstliche Mineralfasern (KMF) und Feinstaub in Schulen und Kindergärten. *Gefahrstoffe – Reinhalt. Luft* 72 (2012) No. 3, p. 89-93
- [24] Hempfling, R.; Stubenrauch, S.: *Schadstoffe in Gebäuden*. Blottner, Taunusstein 1999
- [25] Verordnung über Arbeitsstätten (Arbeitsstättenverordnung – ArbStättV) vom 12. August 2004. *BGBl.* (2004), p. 2179-2189; last revision *BGBl.* (2010), p. 960-967
- [26] Breuer, D.; Kühn, R.; Weigl, M.; Eickmann, U.; Weiß, T.; Blome, H.; von der Heyden, T.; Schneider, W.: *Passivrauchen am Arbeitsplatz*. DGUV-UVT-Report 1/2011. 2nd ed. Published by.: Deutsche Gesetzliche Unfallversicherung (DGUV), Berlin 2011
- [27] Fromme, H.; Körner, W.; Gruber, L.; Heitmann, D.; Schlummer, M.; Völkel, W.; Bolte, G.: Exposition der Bevölkerung gegenüber Phthalaten – Ergebnisse der INES-Studie. *Gefahrstoffe – Reinhalt. Luft* 70 (2010) No. 3, p. 77-81
- [28] Nagorka, R.; Conrad, A.; Scheller, C.; Süßenbach, B.; Moriske, H.J.: Weichmacher und Flammschutzmittel im Hausstaub – Teil 1: Phthalate (A). *Gefahrstoffe – Reinhalt. Luft* 70 (2010) No. 3, p. 70-76
- [29] Viele KITAS stark mit Weichmachern belastet – BUND fordert Verbot der Schadstoffe im Umfeld von Kindern. Published by: Bund für Umwelt und Naturschutz Deutschland (BUND), Berlin 2011. http://www.bund.net/fileadmin/bundnet/pdfs/chemie/20110321_chemie_weichmacher_kitas_hintergrund.pdf
- [30] Plastikweichmacher in Kindertagesstätten. *Presseinformation* (2011) No. 17, Umweltbundesamt (UBA), Berlin 2011
- [31] <http://www.reach-info.de/dokumente/musterbrief.doc>
- [32] Winter, G.; Hoffmann, G.: Zur Dekontamination von insektizidbelasteten Flächen nach Entwesungen in Innenräumen. *Bundesgesundheitsbl. Gesundheitsforsch. Gesundheitsschutz* 43 (2000) No. 9, p. 698-714
- [33] Pentachlorphenolverbotsverordnung (PCP-V) vom 12. Dezember 1989. *BGBl.* (1989), p. 2235-2237
- [34] Corrigendum to Regulation(EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEG (OJ L 158, 30.4.2004). *OJ EC* (2004) No. L 229, p. 5-22
- [35] Richtlinie für die Bewertung und Sanierung Pentachlorphenol (PCP)-belasteter Baustoffe und Bauteile in Gebäuden (PCP-Richtlinie). *MBL. NW* (1997), p. 1058-1066
- [36] Richtwerte für die Innenraumluft: Pentachlorphenol. *Bundesgesundheitsbl.* (1997) No. 7, p. 234-236
- [37] Richtlinie für die Bewertung und Sanierung PCB-belasteter Baustoffe und Bauteile in Gebäuden (PCB-Richtlinie NRW). *MBL. NRW* (1996), S. 1260-1268
- [38] VDI 4300 Blatt 2: Messen von Innenraumluftverunreinigungen – Meßstrategie für polycyclische aromatische Kohlenwasserstoffe (PAH), polychlorierte Dibenzop-dioxine (PCDD), polychlorierte Dibenzofurane (PCDF) und polychlorierte Biphenyle (PCB) (12.97). Beuth, Berlin 1997
- [39] Verordnung zum Verbot von polychlorierten Biphenylen, polychlorierten Terphenylen und zur Beschränkung von Vinylchlorid (PCB-, PCT-, VC-Verbotsverordnung) vom 18.07.1989. *BGBl. I* (1989), p. 1482-1485
- [40] Balfanz, E.; Fuchs, J.; Kieper, H.: Innenraumluftuntersuchungen auf polychlorierte Biphenyle (PCB) im Zusammenhang mit dauerelastischen Dichtungsmassen. In: *Schadstoffbelastung in Innenräumen*. p. 205-212. Published by: Kommission Reinhaltung der Luft im VDI und DIN, Düsseldorf 1992