12.4 Specific information regarding individual substances and categories of substance

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12.4.1 Carbon dioxide

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

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

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

x_{CO_2} : CO_2 concentration in ml/m³

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

λ : Air exchange rate in h^{-1}

V_R : Room volume in m³

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

n : number of people

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

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

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

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

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

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

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

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

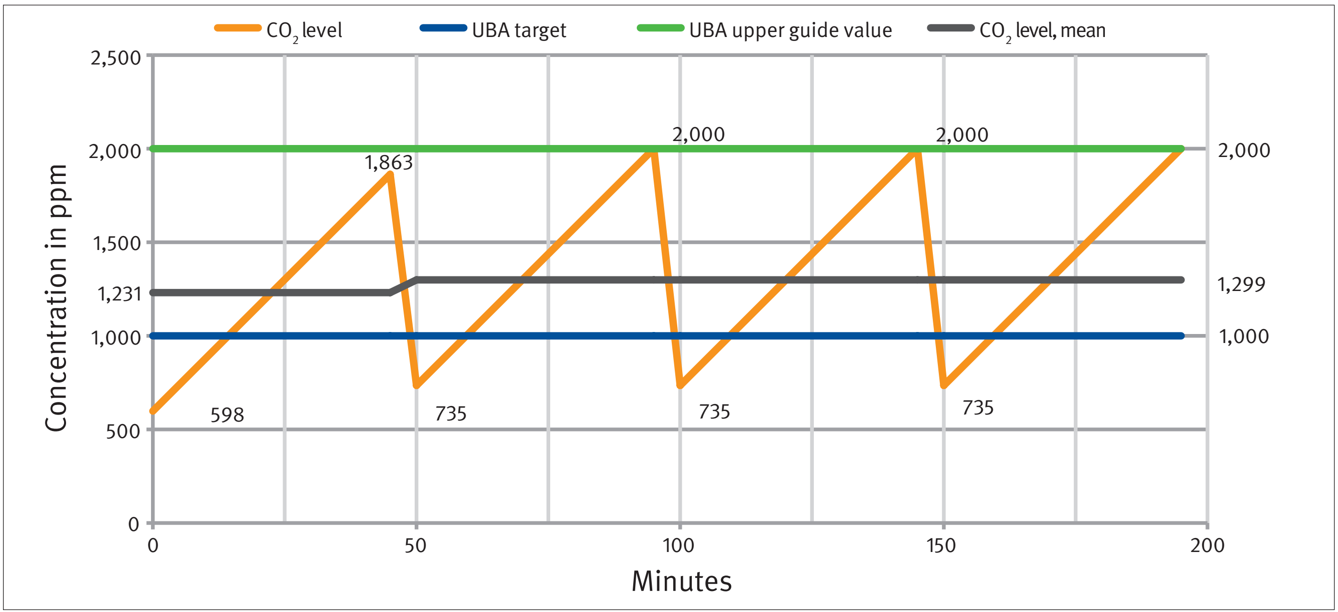
Carbon dioxide pollution in classrooms

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

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

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

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



12.4.2 Ozone

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

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

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

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

12.4.3 Formaldehyde

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

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

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

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

12.4.4 Volatile organic compounds

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