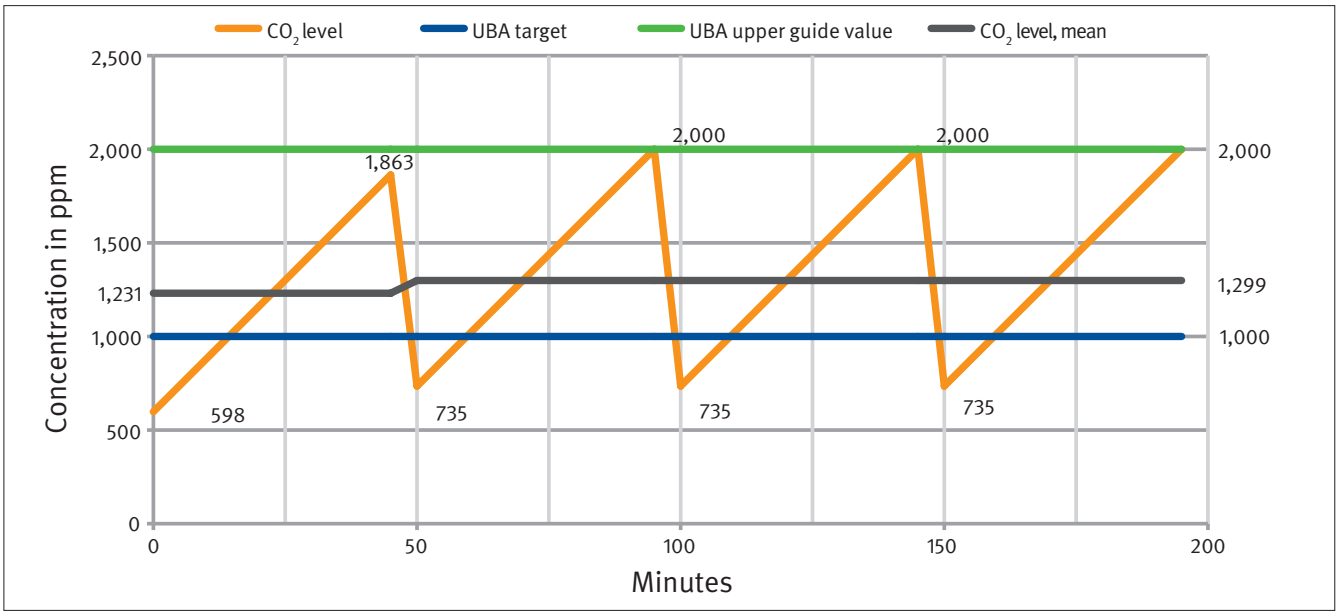
Figure 27:
Mean CO_2 pollution in classrooms aired briefly and thoroughly after each lesson; UBA = Umweltbundesamt (Federal Environmental Agency)



12.4.2 Ozone

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

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

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

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

12.4.3 Formaldehyde

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

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

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

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

12.4.4 Volatile organic compounds

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

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

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

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

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

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

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

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

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

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

Investigation

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

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

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

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

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

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

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