Guidelines for Ventilation Requirements in Buildings
EUROPEAN CONCERTED ACTION
INDOOR AIR QUALITY & ITS IMPACT ON MAN
(formerly COST Project 613)

Report No. 11

Guidelines
for
Ventilation Requirements in Buildings

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ABSTRACT

European Concerted Action "Indoor Air Quality and Its Impact on Man", Report No. 11: Guidelines for Ventilation Requirements in Buildings. Office for Publications of the European Communities, Luxembourg, 1992. These Guidelines recommend the ventilation required to obtain a desired indoor air quality in a space. The first step is to decide the air quality aimed for in the ventilated space. A certain air quality is prescribed to avoid adverse health effects while a decision is required on the level of perceived air quality aimed for in the ventilated space. Three different comfort levels are suggested. The next step is to determine the pollution load on the air caused by pollution sources in the space. The total pollution load is found by adding the loads caused by the building and by the occupants. The available outdoor air quality and the ventilation effectiveness of the ventilated space are also considered.

The ventilation rate required to provide the desired indoor air quality is then calculated based on the total pollution load, the available outdoor air quality and the ventilation effectiveness. The ventilation rates required for health and comfort are calculated separately and the highest value is used for design.
0 PREFACE

Ventilation is supply to and removal of air from a space to improve the indoor air quality. The idea is to capture, remove and dilute pollutants emitted in the space to reach a desired, acceptable air quality level. Existing ventilation guidelines or standards in European countries and elsewhere assume that the occupants of a space are the dominating or exclusive polluters. Unfortunately, compliance with existing guidelines or standards has not prevented exposure to pollutants with potentially adverse effects and widespread complaints about indoor air quality in many buildings. Recent studies have documented that the materials in a building are often more important polluters than the occupants and contribute significantly to the complaints.

The present Guidelines consider the total pollution load caused by materials in the building, occupants and their activities. The goal is to protect the occupants from adverse health effects and to provide an indoor air quality which is perceived as acceptable by the large majority of the occupants.

In contrast to existing documents these Guidelines do not just prescribe a given quantity of outdoor air to be supplied to a space. Instead a certain indoor air quality is prescribed to avoid adverse health effects and a decision is required on the level of perceived air quality aimed for in the ventilated space. Three different comfort levels of perceived air quality are suggested. The available outdoor air quality and the ventilation effectiveness of the ventilated space are also considered. The ventilation rate required to provide the selected indoor air quality can then be calculated based on all present pollution sources, the available outdoor air quality and the ventilation effectiveness of the ventilated space. The ventilation rates required for health and comfort are calculated separately and the highest value is used for design.

The information used in these Guidelines on the pollution load caused by the building and on the ventilation effectiveness is based on relatively few data. Further studies to enlarge the data base should therefore be encouraged.
1 PURPOSE

This document recommends the ventilation required to obtain a desired indoor air quality in a space. Selection of low-polluting materials and products in buildings is recommended.

2 SCOPE

This document applies to spaces for human occupancy in non-industrial buildings. Guidelines for the thermal environment, i.e. air temperature, thermal radiation, air velocity are not included. The thermal requirements may be specified based on the international standard for thermal comfort, ISO 7730 (1).

3 INDOOR AIR QUALITY

The occupants in a space have two requirements of the air in that space. First, the health risk of breathing the air should be negligible. Secondly, the air should be perceived fresh and pleasant rather than stale, stuffy and irritating.

There are large individual differences in human requirements. Some persons spend a large part of their time in the same indoor environment, others do not. Some persons are very sensitive and have high requirements of the air they are breathing. Other persons are rather insensitive and have lower requirements of the air. The quality of the indoor air may be expressed as the extent to which human requirements are met. The air quality is high if few people are few dissatisfied and there is a negligible health risk.

Indoor air quality in a building is not constant. It is influenced by changes in building operation, occupant activity and outdoor climate. Indoor air quality may be controlled by a combination of source control and ventilation. In these Guidelines the ventilation required for controlling the health risk from specific air pollutants will be discussed separately from the ventilation required to obtain a desired perceived air quality. It is recommended to use the highest of these values for design.

4 HEALTH ASPECTS OF INDOOR AIR QUALITY

Exposure to pollutants in the air may provide a certain health risk. Adverse health effects may comprise distinct, acute adverse effects or long-term adverse effects like cancer. Other health aspects as defined by the World Health Organization, like for instance odour annoyance and effects on the social well-being, are not included in this section.

To limit the health risk to a low level, it would be useful to establish an extensive list of maximum permissible concentrations and the corresponding exposure times for individual chemicals in the air. For industrial premises Threshold Limit Values (TLV) exist. They apply to work places where chemicals are used routinely in the production process. On industrial premises workers are typically exposed to one or a few chemicals at a time. In offices and similar work places exposure to any individual pollutant is typically much lower than in industry. Instead the exposure is characterized by a wide spectrum of compounds at low levels from building materials, furniture, office equipment, human metabolism, environmental tobacco smoke and outdoor air. Due to the multitude of pollutants, much lower levels of individual chemicals should be aimed at. This applies also to dwellings where people spend a longer time than at the work place, and the occupants include more susceptible persons (e.g. children and elderly). The World Health Organization has published "Air Quality Guidelines for Europe" (2). In this publica-
tion the health effects of certain air pollutants have been evaluated and guideline values for more than 25 chemicals are listed (see Appendix C). They apply to both outdoor air and indoor air. The guideline values in this brief list may be used as limits for individual chemicals in indoor air.

Severe limitations hamper the evaluation of health effects of complicated pollutant mixtures. The combined effect of two pollutants may be synergistic \((C>A+B)\), additive \((C = A+B)\), antagonistic \((C<A+B)\) or independent. When many pollutants at low levels are present, their combined health effects on individuals are not predictable with present knowledge. The preferred method for indoor air quality management is control of the pollution sources. The choice methods for controlling the dominant sources are source removal/replacement, isolation and local ventilation.

Further information on the impact on health of chemicals in indoor air is given in the European Concerted Action Report No. 10 “Effects of Indoor Air Pollution on Human Health” (3).

For different reasons, a number of substances are of special concern for human health. Among these substances are radon, gases from landfill or waste sites, combustion products, environmental tobacco smoke, formaldehyde, volatile organic compounds, metabolic gases, humidity and micro-organisms. They are discussed separately below.

4.1 Radon

Radon is a radioactive gas which occurs in the indoor air. It increases the risk of lung cancer. Risk estimates for radon are given in “Air Quality Guidelines for Europe” (2) published by the World Health Organization (see Annex C). The major source of indoor radon is usually soil gas under the building. Radon occurs in high concentrations in soil gas with large variations due to local geology. Soil gas with radon may enter a building by infiltration through cracks and other openings in floors and walls separating the building from the soil. The best way of controlling the indoor radon level is to control the source. This can be done by sealing the building against the entry of soil gas or, where possible, by venting the air in subfloor spaces to the atmosphere. Where no subfloor space exists, radon sumps under the floor may be used.

As radon entry from the soil is generally pressure driven, care must be taken, when increased ventilation of the building is used as a remedial technique, that an underpressure of the building air does not arise which may cause an increase in the infiltration of radon-laden soil gas. Further information is given in the European Concerted Action Report No. 1 “Radon in Indoor Air” (4).

4.2 Gases from Landfill and Waste Sites

In special situations, e.g. areas of waste disposal, a broad range of potentially toxic chemicals may be present and a case-by-case evaluation of a possible health risk may be necessary. Landfill gas is produced by the action of micro-organisms on organic waste material deposited in landfill sites. The gas principally consists of methane and carbon dioxide but other gases such as hydrogen and hydrogen sulphide may be present. Over a hundred trace volatile organic compounds have also been detected in landfill gas including: aliphatic and aromatic hydrocarbons, alcohols, esters, ethers and organosulphur compounds. However, these compounds make up less than one per cent of the total gas mixture and in general represent more of an odour nuisance rather than a toxic hazard. The major hazard that landfill gas represents is that of explosions: methane is flammable when mixed with air in the concentration range 5 to 15%. There have been numerous incidents where an explosive mixture of landfill gas has been ignited in a building damaging the structure and injuring the occupants. There is also a risk of asphyxiation from landfill gas. Buildings constructed on or near sites where there are high levels of these hazardous gases need to be sealed to prevent gas ingress and a means to disperse the gases provided, for example a ventilated subfloor void.
4.3 Combustion Products

Carbon monoxide (CO) is generated by incomplete combustion. Every year carbon monoxide from malfunctioning gas, coal and kerosene heaters, from wood stoves, and from infiltration of combustion gases from garages, etc. kills hundreds of persons in Europe. Nitrogen dioxide (NO₂) is another toxic gas generated by combustion of fossil fuels at high temperatures. Major indoor sources are appliances for cooking with gas and unvented domestic water heaters.

The proper way of controlling indoor combustion products is to avoid or reduce the pollution sources. Unvented combustion appliances for heating of spaces should be avoided, unvented combustion appliances for heating of domestic hot water should be used only if ventilation provisions and safety devices of the appliance permit a safe operation. Underpressure caused by ventilation systems should not interfere with the proper functioning of open flues. Leakages from garages etc. to occupied spaces should be sealed. It is recommended that gas appliances for cooking be provided with a proper hood for local exhaust of the combustion products. Further information on nitrogen dioxide is given in the European Concerted Action Report No. 3 "Indoor Pollution by NO₂ in European Countries" (5).

4.4 Environmental Tobacco Smoke

Environmental tobacco smoke (ETS) comprises several thousand chemicals. The most commonly occurring and rapidly experienced health effects of ETS are irritation of the mucous membranes of the eyes, nose and throat. Children of smokers suffer more often than others from respiratory diseases. ETS resulting in about 2 ppm CO₂ leads to irritation and discomfort among 20% of those exposed (6,7). It is suspected that ETS may increase the risk of lung cancer. Elimination of any health risk caused by ETS requires that smoking does not take place in the space.

4.5 Formaldehyde

Formaldehyde is the simplest aldehyde. It is a colourless, very reactive gas with a pungent smell. It has many uses, but the main area of application is the fabrication of synthetic resins. Therefore, formaldehyde may occur in indoor air as an emission from particle boards containing adhesives based on urea-formaldehyde resins or from urea-formaldehyde foam insulation. The formaldehyde concentration in the air caused by chipboards depends on the quality of the chipboards, and on the temperature, the relative humidity and the air exchange rate. Possible adverse health effects due to formaldehyde exposure in indoor environments depend on the concentration and the duration of the exposure. Formaldehyde may cause irritation of the eyes and respiratory system. In experiments with rats, high (6 and 14 ppm) and long-lasting exposure led to tumours of the nasal epithelium. It is likely that the massive, irritative effect of such high concentrations is a necessary condition for the occurrence of the tumours. As humans are not exposed to such high concentrations over prolonged periods of time, the risk of developing a tumour is negligible. Further information is given in Appendix C and in the European Concerted Action Report No. 7 "Indoor Air Pollution by Formaldehyde in European Countries" (8).

4.6 Volatile Organic Compounds

Volatile organic compounds (VOC), other than formaldehyde, are emitted by humans (see metabolic gases below), by many natural materials and most importantly by a large number of man made building materials, furnishing and equipment used in buildings. The VOC are defined by WHO as having melting points below room temperature and boiling points ranging from 50 to 260°C. Other more detailed classifications are in use. The VOC detectable in a single building may consist of hundreds of different organic compounds, which makes analysis, risk
assessment (including combined effects) and guideline setting for these compounds an exceptionally difficult task.

People perceive the VOC by their olfactory and chemical senses. Little adaptation occurs during a VOC exposure. Human response to VOC in indoor air has been classified as acutely perceived deterioration of the environment, acute or subacute inflammation-like reactions in skin or mucous membrane, or subacute and weak stress-like reactions.

Two practical approaches for indoor air quality guidelines for VOC (excluding formaldehyde and carcinogenic VOC) have been proposed, one for total VOC (TVOC) (9), the other based on gas chromatographic separation and quantification (10).

The former approach (9) is generalized from the toxicological responses published in indoor air pollution literature. The following exposure-range classification relative to the TVOC level as measured by flame ionization detector calibrated against toluene is suggested: comfort range (<200 µg/m³), multifactorial exposure range (200-3000 µg/m³), discomfort range (3000-25000 µg/m³), and toxic range (>25000 µg/m³).

In the latter approach (10), the analyzed compounds are ranked according to their concentrations and divided into the following classes (class target guideline for ten first in each class in parenthesis): alkanes (100 µg/m³), aromatics (50 µg/m³), terpenes (30 µg/m³), halocarbons (30 µg/m³), esters (20 µg/m³), carbonyls (excluding formaldehyde) (20 µg/m³), and "other" (50 µg/m³). The classes are then added to get the TVOC value. The proposed target guideline value for the TVOC is 300 µg/m³, and no individual compound should exceed 50% of its class target or 10% of the TVOC target guideline value. These target guideline values are not based on toxicological considerations, but on existing levels and on a professional judgment about the achievable levels.

Although the two suggested approaches are different, they almost agree in the practical outcome. The first approach suggests a comfort range of <200 µg/m³, the latter proposes a target guideline value of 300 µg/m³ for the TVOC. As the TVOC are emitted by certain building materials, furnishings, consumer products and equipment, it is recommended to select materials and designs that minimize the emission of VOC.

4.7 Metabolic Gases

The metabolic processes of the occupants in a space require oxygen and produce carbon dioxide, moisture, aldehydes, esters and alcohols. To avoid adverse health effects, an acceptable long-term exposure range for CO₂ in the residential indoor air of <6.3 g/m³ (<3500 ppm) has been recommended (11). The ventilation rate required to maintain this safe level is very low. This means that carbon dioxide per se will very seldom pose a health problem in real buildings. Other metabolic gases (bioeffluents) never reach harmful concentrations in practice but have an unpleasant odour which requires much more ventilation than the carbon dioxide production. This is discussed in detail in the section on perceived air quality.

4.8 Humidity

The humidity in the indoor air may directly or indirectly have an impact on the occupants. High air humidity, condensation or ingress of moisture stimulates the growth of moulds and other fungi etc., which may cause allergy and malodours. Increased humidity may also enhance the emission of chemicals like formaldehyde from materials. A low humidity may cause a sensation of dryness and irritation of skin and mucous membranes of some occupants (12). Normally few problems occur when the relative humidity is between 30 and 70%, assuming that no con-
Densation takes place (13,14). However, a high relative humidity stimulates the growth of house dust mites which may pose a serious allergy risk especially in bedrooms (15). It is, therefore, particularly important to avoid high humidity in bedrooms (16). Where water occurs, e.g. at cooling coils or humidifiers in ventilation systems, there is a risk of growth of fungi and other micro-organisms. To avoid this careful design, cleaning and maintenance are essential.

4.9 Micro-organisms

The micro-organisms of most concern in indoor air are bacteria, viruses and fungi. Many bacteria and viruses originate from humans and they can cause infectious diseases. Other sources are poorly maintained humidifiers causing humidifier fever and water systems which may spread legionella. Some micro-organisms may produce metabolites which can be toxic or irritating. Abnormal levels of fungal spores originate from moist surfaces and building materials and they may induce allergic and hypersensitive reactions.

Micro-organisms can be controlled by controlling surface moisture levels and bioeffluents. No health effects based on permissible levels can be given. A detailed discussion on micro-organisms and proper ways of evaluating and controlling them in the indoor environment is given in the European Concerted Action Report "Strategies for Sampling Biological Particles in Indoor Environments" (17).

5 PERCEIVED AIR QUALITY

Humans perceive the air by two senses. The olfactory sense is situated in the nasal cavity and is sensitive to several hundred thousand odorants in the air. The general chemical sense is situated all over the mucous membranes in the nose and the eyes and is sensitive to a similarly large number of irritants in the air. It is the combined response of these two senses that determines whether the air is perceived fresh and pleasant or stale, stuffy and irritating.

Perceived air quality may be expressed as the percentage of dissatisfied, i.e. those persons who perceive the air to be unacceptable just after entering a space. For air polluted by human bioeffluents Fig. 1 shows the percentage of dissatisfied as a function of the ventilation rate per standard person (average sedentary adult office worker feeling thermally neutral). The pollution generated by such a standard person is called one olf.

The strength of most pollution sources indoors may be expressed as person equivalents, i.e. the number of standard persons (olf/s) required to make the air as annoying (causing equally many dissatisfied) as the actual pollution source (18).

One decipol is the perceived air quality in a space with a pollution source strength of one olf, ventilated by 10 l/s of clean air, i.e. 1 decipol = 0.1 olf/(l/s) (18). Fig. 2 shows the relation between air quality expressed by the percentage of dissatisfied visitors and expressed in decipol. Perceived air quality may also be expressed by measures based on dilution factors related to defined odour levels, such as the odour unit (21) which relates to the odour threshold. Measures of perceived air quality such as the Master Scale unit (22) have also been used for expressing perceived air quality caused by other sources than human bioeffluents. Observer's judgments have then been made as magnitude estimates of perceived strength in a joint context with odorous or irritating reference chemicals.
Figure 1. Dissatisfaction caused by a standard person (one olf) at different ventilation rates. The curve is based on European studies where 168 subjects judged air polluted by bioeffluents from more than one thousand sedentary men and women (18). Similar studies in North America (19) and Japan (20) by other research groups show close agreement with the present European data. The curve is given by these equations:

\[ PD = 395 \cdot \exp(-1.83 \cdot q^{0.25}) \quad \text{for } q \geq 0.32 \text{ l/s \cdot olf} \]
\[ PD = 100 \quad \text{for } q < 0.32 \text{ l/s \cdot olf} \]

Figure 2. The relation between perceived air quality expressed by the percentage of dissatisfied and expressed in decipol (18). The three indoor air quality levels, categories A, B and C are shown.
To determine the ventilation rate required from a comfort point of view, it is essential to select the desired level of air quality in the ventilated space. In Table 1 three levels of perceived air quality are proposed. Each quality level (category) corresponds to a certain percentage of dissatisfied. In some spaces with modest requirements it may be sufficient to provide an air quality of category C with about 30% dissatisfied. In many spaces an air quality of category B with about 20% dissatisfied would be selected, while in other spaces with high requirements an air quality of category A with only about 10% dissatisfied may be desired. These three levels of perceived air quality are also shown in Figure 2. The decision on the desired level of air quality in a space depends mainly on economic considerations and on the application of the space.

Table 1. Three levels of perceived indoor air quality (examples)

<table>
<thead>
<tr>
<th>Quality level (category)</th>
<th>Perceived air quality</th>
<th>Required ventilation rate*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% dissatisfied</td>
<td>decipol</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>1.4</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>2.5</td>
</tr>
</tbody>
</table>

* The ventilation rates given are examples referring exclusively to perceived air quality. They apply only to clean outdoor air and a ventilation effectiveness of one.

The perceived air quality in Table 1 refers to people's initial judgment when entering a space (visitors). The first impression is essential, i.e. it is important that the air is immediately perceived as acceptable. However, for odours adaptation commonly takes place during the first 15 minutes of occupancy. The adaption to human bioeffluents is considerable and typically some adaptation occurs to tobacco smoke (at moderate levels). Usually little adaptation, if any, takes place to mucosal irritating components of tobacco smoke and to many pollutants from mixtures of building materials etc. (23,24).

It is important to realize that some harmful air pollutants are not sensed at all and that the sensory effects of other pollutants are not quantitatively linked with their toxicity. Therefore, perceived air quality is not a universal measure of adverse health effects. Yet, it is also true that when poor perceived air quality in a building is improved by removing pollution sources and increasing ventilation, the risk of adverse health effects is normally also reduced.

5.1 Carbon Dioxide

Humans produce carbon dioxide (CO₂) proportional to their metabolic rate. By quantity it is the most important human bioeffluent. At the low concentrations typically occurring indoors CO₂ is harmless and it is not perceived by humans. Still it is a good indicator of the concentration of other human bioeffluents being perceived as a nuisance. As an indicator of human bioeffluents, CO₂ has been applied quite successfully for more than a century (6,25). Fig. 3 shows the percentage of dissatisfied visitors as a function of the CO₂ concentration (above outdoors) for spaces where sedentary occupants are the exclusive pollution sources. In lecture theatres, assembly halls and similar rooms with a high occupancy which may change in a short time, CO₂-monitoring is a well-established practice for controlling the supply of outdoor air (26). Although CO₂ is a good indicator of pollution caused by sedentary human beings, it is often a poor general indicator of perceived air quality. It does not acknowledge the many perceivable pollution sources not producing CO₂ (22) and certainly not the non-perceivable hazardous air pollutants such as carbon monoxide and radon.
Fig. 3  Carbon dioxide as an indicator of human bioeffluents. The curve shows the perceived air quality (% dissatisfied) as a function of the carbon dioxide concentration. It applies to spaces where sedentary occupants are the exclusive pollution sources and is based on the same data as Fig. 1. The concentration of carbon dioxide outdoors is typically around 350 ppm (700 mg/m³) (see Table 5).

6 AIR POLLUTION SOURCES

Pollution sources in a building comprise the occupants and their activities, including possible tobacco smoking. Furthermore, materials in the building, including furnishing, carpets, household chemicals and the ventilation system may contribute significantly to the pollution of the air. Some materials pollute a lot, some a little, but they may all contribute to the deterioration of the indoor air quality. It is recommended to select low-polluting materials for use in buildings. It is also important to reduce pollution sources in the ventilation system, see Appendix A.

The strength of some pollution sources is not constant. The source strength may change with temperature, humidity, age and pollution level in the space.

Many pollution sources emit hundreds or thousands of chemicals but usually in small quantities. The pollution sources provide a pollution load on the air in the space. This load may be expressed as a chemical pollution load and as a sensory pollution load. Other expressions of pollution load based on biological effects are possible, like mutagenic activity, but are not discussed here. The chemical load can be expressed as the emission of individual chemicals from the sources. The sensory load can be quantified by the olf unit which integrates the effect of the many chemicals as perceived by human beings. The chemical and sensory pollution loads are discussed separately below.

6.1 Chemical Pollution Load

The source strength of a material may be expressed as the emission rate (or emission factor) of individual chemicals in μg/s or (μg/m²·s). The chemical pollution load of each individual chemical on the air in the space can then be estimated by addition of the sources and expressed in μg/s. Unfortunately little information is available on the emission rate from the many materials used in practice. And it may be rather impractical to account for the source strength of each of the hundreds or thousands of chemicals occurring in indoor air. But in some cases where an individual chemical is suspected of being an important pollutant because of its toxic potential, an estimate of the pollution load of that particular chemical in a space may be possible. The chemical load may also be given as the total emission of a group of chemicals, e.g. volatile organic compounds (TVOC). An example of the chemical load caused by the
building is given in Table 2, expressed by TVOC. Table 3 lists the chemical load caused by smoking and non-smoking occupants, expressed by CO and CO₂.

6.2 Sensory Pollution Load

The sensory pollution load on the air is caused by those pollution sources having an impact on the perceived air quality. The sensory pollution load in a space may be found by adding the loads caused by all the different pollution sources in the space. The pollution sources usually comprise the occupants and the building, including furnishing, carpeting and ventilation system.

The occupants emit bioeffluents and some produce tobacco smoke. A standard person (non-smoking) produces 1 olf, while an average smoker produces 6 olf (19). Table 3 lists the pollution load from adult occupants engaged in different activities (27) with no smoking and with different percentages of smokers among the occupants. The pollution load from children is also given (28,29). Furthermore, Table 3 lists the human production of carbon dioxide, carbon monoxide and water vapour. Table 4 lists examples of occupancy per m² floor in various spaces.

The pollution load from the building may be found by adding the loads from individual materials present. But information is available for only a few materials at present. A more feasible approach is now to estimate the entire pollution load per m² floor caused by the building, including furnishing, carpeting and ventilation system. Table 2 comprises such data from measured pollution loads in different types of existing buildings (28,29,30,31). The pollution load caused by the building is often high and varies widely from building to building. It is essential that new buildings be designed as low-polluting buildings. The pollution loads listed in Table 4 for low-polluting buildings are target values for the design. They require a systematic selection of low-polluting materials for the building including furnishing, carpets and ventilation system. Many existing buildings need to be renovated to reduce the pollution load. The present Guidelines provide a strong encouragement to design low-polluting buildings since this decreases the ventilation requirement.

Table 2. Pollution load caused by the building, including furnishing, carpets and ventilation system

<table>
<thead>
<tr>
<th>Sensory pollution load Chemical pollution load</th>
<th>olf/(m² floor)</th>
<th>TVOC µg/s·(m² floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td><strong>Existing buildings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offices 1)</td>
<td>0.3</td>
<td>0.02-0.95</td>
</tr>
<tr>
<td>Schools (class rooms) 2)</td>
<td>0.3</td>
<td>0.12-0.54</td>
</tr>
<tr>
<td>Kindergartens 3)</td>
<td>0.4</td>
<td>0.20-0.74</td>
</tr>
<tr>
<td>Assembly halls 4)</td>
<td>0.5</td>
<td>0.13-1.32</td>
</tr>
<tr>
<td>Dwellings 5)</td>
<td>0.2</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td><strong>Low-polluting buildings</strong></td>
<td>0.05-0.1</td>
<td></td>
</tr>
<tr>
<td>(target values)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) Data for 24 mechanically ventilated office buildings (30,31)
2) Data for 6 mechanically ventilated schools (28)
3) Data for 9 mechanically ventilated kindergartens (29)
4) Data for 5 mechanically ventilated assembly halls (30)
5) Data for 3 naturally ventilated dwellings (32)
6) Data not yet available
Table 3. Pollution load caused by occupants

<table>
<thead>
<tr>
<th>Sensory pollution load</th>
<th>Carbon dioxide</th>
<th>Carbon monoxide</th>
<th>Water vapour</th>
</tr>
</thead>
<tbody>
<tr>
<td>olf/occupant</td>
<td>I/(h· occupant)</td>
<td>I/(h· occupant)</td>
<td>g/(h· occupant)</td>
</tr>
<tr>
<td>Sedentary, 1-1.2 met</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0% smokers</td>
<td>1</td>
<td>19</td>
<td>50</td>
</tr>
<tr>
<td>20% smokers 4)</td>
<td>2</td>
<td>19</td>
<td>11·10⁻³</td>
</tr>
<tr>
<td>40% smokers 4)</td>
<td>3</td>
<td>19</td>
<td>21·10⁻³</td>
</tr>
<tr>
<td>100% smokers 4)</td>
<td>6</td>
<td>19</td>
<td>53·10⁻³</td>
</tr>
<tr>
<td>Physical exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low level, 3 met</td>
<td>4</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Medium level, 6 met</td>
<td>10</td>
<td>100</td>
<td>430</td>
</tr>
<tr>
<td>High level (athletes), 10 met</td>
<td>20</td>
<td>170</td>
<td>750</td>
</tr>
<tr>
<td>Children</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kindergarten, 3-6 years, 2.7 met</td>
<td>1.2</td>
<td>18</td>
<td>90</td>
</tr>
<tr>
<td>School, 14-16 years, 1-1.2 met</td>
<td>1.3</td>
<td>19</td>
<td>50</td>
</tr>
</tbody>
</table>

1) 1 met is the metabolic rate of a resting sedentary person (1 met = 58W/m² skin area, i.e. approx 100 W for an average person)
2) from tobacco smoking
3) applies for persons close to thermal neutrality
4) average smoking rate 1.2 cigarettes/hour per smoker, emission rate 44 ml CO/cigarette

Table 4. Examples of occupancy in spaces

<table>
<thead>
<tr>
<th>Occupants/(m² floor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
</tr>
<tr>
<td>Conference rooms</td>
</tr>
<tr>
<td>Assembly halls, theatres, auditoria</td>
</tr>
<tr>
<td>Schools (class rooms)</td>
</tr>
<tr>
<td>Kindergartens</td>
</tr>
<tr>
<td>Dwellings</td>
</tr>
</tbody>
</table>

It is recommended to calculate the total sensory pollution load in a space by simple addition of the loads from the individual pollution sources in the space. This has been shown to provide a reasonable first approximate method of combining many pollution sources (33). Future studies may show that some pollution sources when occurring in the same space, provide a stronger or weaker total pollution load than predicted by simple addition of the individual loads.

7 OUTDOOR AIR QUALITY

The required ventilation depends also on the quality of the available outdoor air. Table 5 lists characteristic levels of outdoor perceived air quality and of typical outdoor pollutants. The World Health Organization has published "Air Quality Guidelines for Europe" (2), where guideline values for certain substances in the outdoor (and indoor) air are given. These guideline values are listed in Appendix C. The outdoor air quality can be much worse than shown in Table 5 or given in "Air Quality Guidelines for Europe". In such cases it may be necessary to clean the air before it is suitable for ventilation.
Table 5. Outdoor levels of air quality*

<table>
<thead>
<tr>
<th>Perceived air quality decipol</th>
<th>Carbon dioxide mg/m³</th>
<th>Carbon monoxide mg/m³</th>
<th>Nitrogen dioxide μg/m³</th>
<th>Sulfur dioxide μg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>At sea</td>
<td>0</td>
<td>680</td>
<td>0-0.2</td>
<td>2</td>
</tr>
<tr>
<td>In towns, good air quality</td>
<td>&lt; 0.1</td>
<td>700</td>
<td>1-2</td>
<td>5-20</td>
</tr>
<tr>
<td>In towns, poor air quality</td>
<td>&gt; 0.5</td>
<td>700-800</td>
<td>4-6</td>
<td>50-60</td>
</tr>
</tbody>
</table>

* The values for the perceived air quality are typical daily average values. The values for the four air pollutants are annual average concentrations.

It is the quality of the outdoor air at the air intake that counts. Proper location of the air intake is discussed in Appendix A.

8 VENTILATION EFFECTIVENESS

The air quality may not be the same throughout a ventilated space. What really counts for the occupants is the air quality in the breathing zone. Such an inhomogeneity of the air quality in a space has an impact on the ventilation requirement. This is expressed by the ventilation effectiveness ($\varepsilon_v$) defined as the relation between the pollution concentration in the exhaust air ($C_e$) and in the breathing zone ($C_i$)

$$\varepsilon_v = \frac{C_e}{C_i}$$

The ventilation effectiveness depends on the air distribution and the location of the pollution sources in the space. It may, therefore, have different values for different pollutants. If there is complete mixing of air and pollutants, the ventilation effectiveness is one. If the air quality in the breathing zone is better than in the exhaust, the ventilation effectiveness is higher than one, and the desired air quality in the breathing zone can be achieved with a lower ventilation rate. If the air quality in the breathing zone is poorer than in the exhaust air, the ventilation effectiveness is lower than one and more ventilation is required.

To estimate the ventilation effectiveness, it is often useful to divide a space into two zones. One is the air supply zone and the other zone comprises the rest of the room. In mixing ventilation the supply zone is usually above the breathing zone. The best conditions are achieved when the mixing is so efficient that the two zones are transformed into one. In displacement ventilation there is a supply zone, occupied by people, and an exhaust zone above. The best conditions are achieved when there is minimal mixing between exhaust and supply zone.

Ventilation effectiveness is a function of location and characteristics of air terminal devices and of pollution sources. It is furthermore a function of temperature and flow rate of the supply air. The ventilation effectiveness may be calculated by numerical simulation or measured experimentally. When such data are not available, the typical values given in Table 6 for different ventilation principles may be used (34,35). The values in Table 6 consider the impact of air distribution but not of the location of the pollution sources in the space. The pollution sources are assumed to be evenly distributed throughout the ventilated space.
Table 6. Ventilation effectiveness in the breathing zone of spaces ventilated in different ways

<table>
<thead>
<tr>
<th>Ventilation Principle</th>
<th>Temperature difference between supply air and air in breathing zone, ( t_s - t_l ) ( ^\circ C )</th>
<th>Ventilation Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixing ventilation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( t_s \rightarrow C_e )</td>
<td>( t_l \rightarrow C_i )</td>
<td>(&lt; 0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0 - 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 2 - 5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( &gt; 5)</td>
</tr>
<tr>
<td>Mixing ventilation</td>
<td></td>
<td>( t_s \rightarrow C_e )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0 - -5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( &gt; 0)</td>
</tr>
<tr>
<td>Displacement ventilation</td>
<td></td>
<td>( t_s \rightarrow C_e )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( 0 - 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt; 0)</td>
</tr>
</tbody>
</table>

9 REQUIRED VENTILATION

The ventilation rate required for health and comfort should be calculated separately and the highest value used for design.

The ventilation required from a health point of view is calculated by this equation:

\[
Q_h = \frac{G}{C_i - C_o} \cdot \frac{1}{\varepsilon_v}
\]  

[1]
where

\[ Q_h = \text{ventilation rate required for health (l/s)} \]
\[ G = \text{pollution load of chemical (ug/s)} \]
\[ C_i = \text{allowable concentration of chemical (ug/l)} \]
\[ C_o = \text{outdoor concentration of chemical at air intake (ug/l)} \]
\[ \epsilon_v = \text{ventilation effectiveness} \]

\( C_i \) and \( C_o \) may also be expressed as ppm (vol/vol). In this case the chemical pollution load \( G \) has to be expressed as l/s.

The ventilation required for comfort is calculated by this equation:

\[ Q_c = 10 \cdot \frac{G}{C_i - C_o} \cdot \frac{1}{\epsilon_v} \]  \hspace{1cm} \[2\]

where

\[ Q_c = \text{ventilation rate required for comfort (l/s)} \]
\[ G = \text{sensory pollution load (olf)} \]
\[ C_i = \text{perceived indoor air quality, desired (decipol)} \]
\[ C_o = \text{perceived outdoor air quality at air intake (decipol)} \]
\[ \epsilon_v = \text{ventilation effectiveness} \]

Equations [1] and [2] apply to steady-state conditions. Adsorption and desorption of air pollutants at surfaces in the space may significantly prolong the period it takes to obtain steady-state air quality. Chemical reactions of pollutants in the space may also modify Eqs. [1] and [2].

9.1 Procedure to Determine the Required Ventilation Rate

The following procedure should be used to determine the ventilation requirement in a building.

In practice comfort usually determines the required ventilation. Therefore, the ventilation rate required for comfort is usually calculated first. This calculation begins with a decision on the desired indoor air quality in the ventilated space. Table 1 offers three levels (categories) of air quality corresponding to 10, 20 or 30% dissatisfied. Then the perceived outdoor air quality available should be estimated (Table 5).

The next step is to estimate the sensory pollution load. The pollution load per occupant is given in Table 3, depending on physical activity and the tobacco-smoking behaviour of the occupants. Examples of occupancy, i.e. the number of people per m² floor are given for different spaces in Table 4. The pollution caused by the building including furnishing, carpets and ventilation system can be estimated from Table 2. The sensory pollution load is found by adding the loads from the occupants and the building. Depending on the principle of ventilation used in the space, the ventilation effectiveness may be estimated from Table 6. The ventilation required for comfort is then found from Eq. [2].

An analogous calculation of the ventilation rate required to avoid health problems is then performed by using Eq. [1]. To perform this calculation it is necessary to identify the most critical chemical (or group of chemicals, e.g. TVOC), and estimate the pollution load (the source
strength) of that chemical in the space. Furthermore, a permissible concentration should be available for that chemical (Appendix C). A decision should be made on what types of health effects to be considered (cancer, allergy, irritation etc.) and the sensitivity of the occupant groups intended to be protected. If these data are available, the ventilation rate required for health can be calculated. The highest of the two ventilation rates for comfort and health is then used for design.

Unfortunately it is still rather difficult to calculate the ventilation rate required for health in practice. There are several reasons for this. First it may be difficult to identify the most critical chemical. Second, data for the pollution sources are usually not available and the chemical pollution load may therefore be difficult to predict. Furthermore, the guideline values used in Appendix C cover only a small number of the many chemicals occurring in non-industrial buildings.

Field studies in many buildings indicate, however, that for spaces ventilated for comfort, the concentration of chemicals will usually be very low, i.e. lower than the guideline values in Appendix C prescribe, and typically several orders of magnitude lower than the TLV values. Still, pollution sources of concern from a health point of view may occur. Rather than diluting the pollutants from such sources by ventilation, it is recommended to avoid or control such sources and apply low-polluting materials in the building.

9.2 Examples of Determination of Required Ventilation Rate

Existing office building situated in a town with excellent outdoor air quality, i.e. $C_o = 0$ decipol and the levels of outdoor air pollutants are of no health concern (Table 5). An indoor air quality of category C is desired, i.e. 30% dissatisfied or $C_i = 2.5$ decipol (Table 1). Smoking is allowed and 40% are estimated to be smokers, i.e. 3 off/occupant (Table 3). The occupancy is 0.07 occupants/(m$^2$ floor) (Table 4). Standard materials are used in the building, i.e. 0.3 off/(m$^2$ floor) (Table 2). Displacement ventilation is applied with an estimated ventilation effectiveness of 1.3 (Table 6).

$$\text{Occupants} \cdot 3 \cdot 0.07 = 0.2 \text{ off/(m}^2\text{ floor)}$$
$$\text{Building} \quad 0.3 \text{ off/(m}^2\text{ floor)}$$
$$\text{Total sensory pollution load} \quad 0.5 \text{ off/(m}^2\text{ floor)}$$

Required ventilation rate for comfort $Q_c = 10 \cdot \frac{0.5}{2.5} \cdot \frac{1}{1.3} = 1.5 \text{ l/s(m}^2\text{ floor)}$

From a health point of view there is a risk of eye irritation caused by environmental tobacco smoke. With a CO production of $21 \cdot 10^{-3}$ l/h-occupant (Table 3) and a CO-limit of 2 ppm for tobacco smoke irritation, the required ventilation rate for health is

$$Q_h = \frac{0.07 \cdot 21 \cdot 10^{-3}}{3600 \cdot 2 \cdot 10^{-6}} \cdot \frac{1}{1.3} = 0.2 \text{ l/s(m}^2\text{ floor)}$$

The ventilation rate required for comfort $Q_c = 1.5 \text{ l/s(m}^2\text{ floor)}$ is selected for design since this is higher than the ventilation required for health.

New office building, situated in a town with excellent outdoor air quality, i.e. $C_o = 0$ decipol and the levels of outdoor air pollutants are of no health concern (Table 5). Indoor air quality of category B is desired, i.e. 20% dissatisfied or $C_i = 1.4$ decipol (Table 1). No smoking, i.e. 1 off/occupant (Table 3). The occupancy is 0.07 occupants/(m$^2$ floor) (Table 4). Systematic use of low off materials in the building, i.e. 0.1 off/(m$^2$ floor) (Table 2). Displacement ventilation is applied with an estimated ventilation effectiveness of 1.3 (Table 6).

$$\text{Occupants} \cdot 1 \cdot 0.07 = 0.07 \text{ off/(m}^2\text{ floor)}$$
$$\text{Building} \quad 0.1 \text{ off/(m}^2\text{ floor)}$$
$$\text{Total sensory pollution load} \quad 0.17 \text{ off/(m}^2\text{ floor)}$$
Required ventilation rate for comfort \( Q_c = 10 \cdot 0.17 \cdot \frac{1}{1.40} = 0.9 \text{ l/s(m}^2 \text{ floor)} \)

If instead an indoor air quality of category C (30% dissatisfied) is sufficient, the required ventilation rate is

\[ Q_c = 10 \cdot 0.17 \cdot \frac{1}{2.50} = 0.5 \text{ l/s(m}^2 \text{ floor)} \]

If, on the other hand, an indoor air quality of category A (10% dissatisfied) is prescribed, the required ventilation rate is

\[ Q_c = 10 \cdot 0.17 \cdot \frac{1}{0.50} = 2.2 \text{ l/s(m}^2 \text{ floor)} \]

New school situated in a town with fair air quality, i.e. \( C_e = 0.3 \) decipol and the levels of outdoor air pollutants are of health concern (Table 5). In such circumstances smoking and indoor combustion should be avoided. An indoor air quality of category C is desired, i.e. 30% dissatisfied or \( C_i = 2.5 \) decipol (Table 1). No smoking, i.e. 1.3 olf/occupant (Table 3). The occupancy is 0.5 occupants/(m² floor) (Table 4). Systematic use of low-polluting materials in the building, i.e. 0.1 olf/(m² floor) (Table 2). Ventilation effectiveness is 1.0.

\[
\begin{align*}
\text{Occupants} & \quad 1.3 \cdot 0.5 = 0.65 \text{ olf/(m}^2 \text{ floor)} \\
\text{Building} & \quad 0.1 \text{ olf/(m}^2 \text{ floor)} \\
\text{Total sensory pollution load} & \quad 0.75 \text{ olf/(m}^2 \text{ floor)} \\
\end{align*}
\]

Required ventilation rate for comfort \( Q_c = 10 \cdot 0.75 \cdot \frac{1}{2.5 \cdot 0.3} \cdot \frac{1}{1.0} = 3.4 \text{ l/s(m}^2 \text{ floor)} \)

From a health point of view it has been recommended (16) to maintain the relative humidity below 45% for some time each winter to reduce the dust mite population. At 22°C this corresponds to 7 g water vapour/kg air. With a typical outdoor air humidity of 3 g water vapour/kg air and a water vapour production in the dwelling of 2500 g/day · person the required ventilation rate for health is

\[
Q_h = 2500 \cdot 0.05 \cdot 7.3 \cdot 0.24 \cdot 3.6 \cdot 1.2 = 0.3 \text{ l/s(m}^2 \text{ floor)}
\]

The ventilation rate required for comfort \( Q_c = 3.4 \text{ l/s(m}^2 \text{ floor)} \) is selected for design since this is higher than the ventilation rate required for health (even for sensitive groups).
10 AIR FLOW BETWEEN ROOMS

Flow of air from toilets, bathrooms, kitchens etc. to other rooms in the building should be avoided. This can be prevented by maintaining a proper underpressure in these rooms. Exhaust devices in such service rooms can provide the necessary underpressure.

11 DESIGN AND OPERATION

The present guidelines may be used both during the design phase and the operation of the building. It is essential that the assumptions for the design calculations be documented. It is of particular importance to identify what pollution load the ventilation system is designed to handle. The assumptions should be listed in the operational guide for the ventilation system. It should be stated that the indoor air quality designed for can only be accomplished if these assumptions are complied with. This may prevent the future introduction of a higher pollution load from new products or materials during renovation or changed application of spaces without remedial measures to maintain indoor air quality. It may also promote proper maintenance and cleaning of spaces and ventilation systems (see Appendix A).

It may be required to verify that the indoor air quality designed for has been accomplished in a building. Methods to do this are dealt with in Appendix B.

12 REFERENCES


(23) Yaglou CP, Riley EC, Coggins DI (1936) Ventilation requirements. ASHVE Trans. 42:133-162.


13 LITERATURE


APPENDIX A

VENTILATION SYSTEMS

It is essential to diminish or avoid pollution sources in new ventilation systems and to sustain this effort during their service life.

Rooms for Air Handling Units. Rooms where air handling units are situated should not be used as passage-ways or for storage. The doors of the rooms should remain closed. The pressure difference to surrounding rooms should be zero or slightly positive. The air handling units including their doors should be airtight in accordance with Eurovent standard. The inner surfaces of the units and equipment should be easy to clean and abrasion-resistant. Sufficient space for cleaning and for access to the units should be provided.

Air Filters. To protect the system from being polluted by particulates in outdoor air, air filters of at least quality EU 4 should be placed at the intake. A second filter better than EU 7 should be located on the supply side of the air handling unit behind a fan or any aerosol producing device, e.g. a spray washer. Further necessary filters, e.g. HEPA filters, should be installed close to the room. There should be an adequate seal between the air filters and the walls of the surrounding ducts or units. All filters should be protected from being wetted by spray washers, coolers, snow, rain etc. It should be possible to assess the condition of the filter at any time, e.g. the pressure drop, the contamination and the installation.

Humidifiers. To avoid the growth of micro-organisms like bacteria or fungi, humidifiers should be designed in a manner that all their parts, including drip eliminators, be accessible for thorough cleaning and disinfection. The water for humidifiers should be treated only physically. If chemical treatment cannot be avoided, the products used should be substances proven to be both toxicologically harmless and without any significant effect on perceived air quality. Correct and thorough cleaning and maintenance of humidifiers are essential. A water temperature between 20 and 55°C should be avoided, even when the ventilation system is not operating. Steam humidifiers should not contain any antisuoreses hazardous to health or with any significant effect on perceived air quality. To avoid growth of micro-organisms, water condensation must be prevented in air ducts located downstream of the humidifiers.

Air Coolers. Bacteria and fungi can settle and multiply in the condensate of air coolers. Correct and thorough cleaning on a regular basis is essential.

Fans. It should be possible to clean the inside of the housing of centrifugal fans. It can be necessary to provide cleaning openings for this purpose.

Heat Exchangers. Access for cleaning and correct and thorough cleaning are essential.

Air Ducts. The inner surfaces of ducts for supply and recirculated air should be smooth and resistant to abrasion to avoid dust accumulation. Provisions should be made for inspection and efficient cleaning of the ducts. Installations unrelated to the ventilation system should not be installed in the ducts.

Outdoor Air Intake. The outdoor air intake should be situated at a point where the least possible contamination by dust, soot, odours, exhaust gases and exhaust air or heating is expected to occur. Owing to the accumulation of dirt and the growth of fungi and bacteria, intakes should not be located at ground level or in pits and not close to cooling towers. Similarly, the outdoor air can be more heavily contaminated immediately above flat roofs. It is recommended to situate the outdoor air intake as close as possible to the central air handling unit in order to avoid long ducts conducting unfiltered air.
With complex buildings and unfavourable aerodynamic ambient conditions, wind tunnel model tests concerning air flow and pressure distribution around the building are recommended to determine the optimal location of the intake.

Recirculated Air is air removed from the ventilated spaces and intended for use as supply air. The return air may pollute the surface of the ducts, especially when it contains particulates or aerosols, e.g. from smoking. It is therefore advisable not to use recirculated air which is moved through the return air duct system to other rooms.

Start of Operation. The entire ventilation system should be clean before operation starts. If the system is used for heating and cooling while the building is under construction, it should be protected by filters against soiling.
**APPENDIX B**

**MEASUREMENTS**

In a building it may be necessary to verify that the indoor air quality designed for has been established. Chemical measurements may be needed to verify that the health requirements and the assumed ventilation effectiveness are met. Measurements of perceived air quality may be necessary to verify that the comfort requirements are met. It may also be useful to determine the pollution load on the air in a building. Measurements should be taken under characteristic operating conditions of the building. This appendix specifies how the perceived air quality and the pollution load can be measured in a building.

**Perceived Air Quality.** Perceived indoor air quality can be measured by an untrained or a trained panel of persons judging the air. Due to adaptation the panel should judge the air just after entering the space and before the judgment they should refresh their senses by breathing air of good quality either outdoors or in a special room.

An *untrained* panel comprises a group of impartial persons, unrelated to the building under study (11). Each panel member is asked to judge whether the air quality is acceptable or not, imagining that s/he be exposed to such air during her/his daily work. The percent of dissatisfied calculated from the judgments provides the perceived air quality. A panel of minimum 20 persons is recommended. Table 1 lists statistical requirements for verifying that a certain level (category) of perceived air quality has been established.

**Table 1.** For different sizes of an untrained panel the table identifies the number of dissatisfied persons required to state (with 80% statistical confidence) that the measured air quality belongs to (or is better than) a certain category of perceived air quality.

<table>
<thead>
<tr>
<th>Perceived air quality category</th>
<th>% dissatisfied</th>
<th>Number of persons in panel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10*</td>
<td>20</td>
</tr>
<tr>
<td>A</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>

* with 10 panelists it is not possible to distinguish between categories A and B.

A *trained* panel comprises a group of persons who are trained to judge air by comparing it to references with known levels of perceived air quality as shown in Fig. 1. An initial training period of 1-2 hours and a 30-min retraining on the day of the judgment is recommended. The training should take place in a space with high air quality. A panel of minimum six persons is recommended.
References for judging perceived air quality by a trained panel. Each panel member is trained to judge the unknown air quality X by comparison to known references. A reference gas is generated (e.g. by passive evaporation) in each jar to provide a desired perceived quality of the air leaving the diffusor (flow rate > 0.8 l/s). For propanone as reference gas (37) the following relation between air quality (C) in decipol and gas concentration (P) in ppm has been used: 

\[ C = 0.8 + 0.22 \cdot P \]

Pollution Load. The pollution load in a space may be determined from Eqs. [1] or [2]. Determination of the sensory pollution load (31) requires a measurement of the outdoor air supply to the space and of the perceived indoor air quality as discussed above. Determination of the chemical pollution load requires a measurement of the outdoor air supply and of the concentration of chemicals in the indoor air. A measurement without occupants in the space provides the pollution load caused by the building itself. Measurements should take place during steady-state conditions.
Summary of the guidelines

The term "guidelines" in the context of this book implies not only numerical values (guideline values), but also any kind of guidance given. Accordingly, for some substances the guidelines encompass recommendations of a more general nature that will help to reduce human exposure to harmful levels of air pollutants. For some pollutants no guideline values are recommended, but risk estimates are indicated instead. Table 1 summarizes the different endpoints on which guideline values and carcinogenic risk estimates have been based for organic and inorganic substances, showing that all relevant biological effects (endpoints) were evaluated and sometimes more than one endpoint was considered for guideline recommendations.

The numerical guideline values and the risk estimates for carcinogens (Tables 2-5) should be regarded as the shortest possible summary of a complex scientific evaluation process. Scientific results are an abstraction of real life situations, and this is even more true for numerical values and estimates based on such results. Numerical guideline values, therefore, are not to be regarded as separating the acceptable from the unacceptable, but rather as indications. They are proposed in order to help avoid major discrepancies in reaching the goal of effective protection against recognized hazards. Moreover, numerical guidelines for different substances are not directly comparable. Variations in the quality and extent of the scientific information and in the nature of critical effects result in guideline values which are only comparable between pollutants to a limited extent.

Owing to the different bases for evaluation, the numerical values for the various air pollutants should be considered in the context of the accompanying scientific documentation giving the derivation and scientific considerations. Any isolated interpretation of numerical data should therefore be avoided and guideline values should be used and interpreted in conjunction with the information contained in the appropriate sections.

It is important to note that guidelines are for individual chemicals. Pollutant mixtures can yield differing toxicities, but data are at present insufficient for guidelines relating to mixtures (except that of sulfur dioxide and suspended particulates) to be laid down.

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Guideline Values based on Effects other than Cancer

The guideline values for individual substances based on effects other than cancer and odour are given in Table 2. Guideline values for combined exposure to sulfur dioxide and particulate matter are indicated in Table 3.

The emphasis in the guidelines is placed on exposure, since this is the element that can be controlled to lessen dose and hence lessen response. As stated earlier, the starting-point for the derivation of guideline values was to define the lowest concentration at which adverse effects are observed. On the basis of the body of scientific evidence and judgements of protection (safety) factors, the guideline values were established.

However, compliance with the guideline values does not guarantee the absolute exclusion of undesired effects at levels below the guideline values. It means only that guideline values have been established in the light of current knowledge and that protection factors based on the best scientific judgements have been incorporated, though some uncertainty cannot be avoided.

For some of the substances, a direct relationship between concentrations in air and possible toxic effects is very difficult to establish. This is especially true of those metals for which a greater body-burden results from ingestion than from inhalation. For instance, available data show that the food chain is, for most people, the critical route of nonoccupational exposure to lead and cadmium. On the other hand, airborne lead and cadmium may contribute significantly to the contamination of food by these metals. Complications of this kind were taken into consideration and an attempt was made to develop air quality guidelines which would also prevent those toxic effects of air pollutants that resulted from uptake through both ingestion and inhalation.

For certain compounds, such as organic solvents, the proposed health-related guidelines are orders of magnitude higher than current ambient levels. The fact that existing environmental levels for some substances are much lower than the guideline levels by no means implies that pollutant burdens may be increased up to the guideline values. Any level of air pollution is a matter of concern, and the existence of guideline values never means a licence to pollute.

The approach taken in the preparation of the air quality guidelines was to use expert panels to evaluate data on the health effects of individual compounds. As part of this approach, each chemical is considered in isolation. Inevitably, there is little emphasis on such factors as interaction between pollutants that might lead to additive or synergistic effects and on the environmental fate of pollutants (e.g. the role of solvents in atmospheric photochemical processes leading to the formation or degradation of ozone, the formation of acid rain and the propensity of metals and trace elements to accumulate in environmental niches). These factors militate strongly against allowing a rise in ambient pollutant levels. Many uncertainties still remain, particularly regarding the ecological effects of pollutants, and therefore efforts should be continued to maintain air quality at the best possible level.

Unfortunately, the situation with regard to actual environmental levels and proposed guideline values for some substances is just the opposite,
Table 1. Established guideline values and risk estimates

<table>
<thead>
<tr>
<th>Substance</th>
<th>IARC Group classification</th>
<th>Risk estimate based on carcinogenic endpoint</th>
<th>Guideline value(s) based on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>toxicological endpoint</td>
</tr>
<tr>
<td>Organic substances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrylonitrile</td>
<td>2A</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>1</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>2B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polynuclear aromatic hydrocarbons (Benzo[a]pyrene)</td>
<td>b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Styrene</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inorganic substances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asbestos</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Inorganic substances (contd)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Group</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>2B</td>
<td>x</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Chromium (VI)</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Lead</td>
<td>3</td>
<td>x</td>
</tr>
<tr>
<td>Manganese</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Mercury</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Nickel</td>
<td>2A&lt;sup&gt;c&lt;/sup&gt;</td>
<td>x</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Ozone/photochemical oxidants</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Radon</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Sulfur dioxide and</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>particulate matter</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Vanadium</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

<sup>a</sup> Not classified, but sufficient evidence of carcinogenicity in experimental animals.


<sup>c</sup> Exposures from nickel refineries are classified in Group 1.
### AIR QUALITY GUIDELINES

**Table 2. Guideline values for individual substances based on effects other than cancer or odour/annoyance**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Time-weighted average</th>
<th>Averaging time</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>1-5 ng/m³</td>
<td>1 year (rural areas)</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>10-20 ng/m³</td>
<td>1 year (urban areas)</td>
<td></td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>100 μg/m³</td>
<td>24 hours</td>
<td>7</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>100 mg/m³&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15 minutes</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>60 mg/m³&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30 minutes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 mg/m³&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1 hour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 mg/m³</td>
<td>8 hours</td>
<td></td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>0.7 mg/m³</td>
<td>24 hours</td>
<td>8</td>
</tr>
<tr>
<td>Dichloromethane (Methylene chloride)</td>
<td>3 mg/m³</td>
<td>24 hours</td>
<td>9</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>100 μg/m³</td>
<td>30 minutes</td>
<td>10</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>150 μg/m³</td>
<td>24 hours</td>
<td>22</td>
</tr>
<tr>
<td>Lead</td>
<td>0.5-1.0 μg/m³</td>
<td>1 year</td>
<td>23</td>
</tr>
<tr>
<td>Manganese</td>
<td>1 μg/m³&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1 year&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24</td>
</tr>
<tr>
<td>Mercury</td>
<td>1 μg/m³&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1 year&lt;sup&gt;d&lt;/sup&gt;</td>
<td>25</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>400 μg/m³</td>
<td>1 hour</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>150 μg/m³</td>
<td>24 hours</td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>150-200 μg/m³</td>
<td>1 hour</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>100-120 μg/m³</td>
<td>8 hours</td>
<td></td>
</tr>
<tr>
<td>Styrene</td>
<td>800 μg/m³</td>
<td>24 hours</td>
<td>12</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>500 μg/m³</td>
<td>10 minutes</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>350 μg/m³</td>
<td>1 hour</td>
<td></td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>—&lt;sup&gt;e&lt;/sup&gt;</td>
<td>—</td>
<td>30</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>5 mg/m³</td>
<td>24 hours</td>
<td>13</td>
</tr>
<tr>
<td>Toluene</td>
<td>8 mg/m³</td>
<td>24 hours</td>
<td>14</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>1 mg/m³</td>
<td>24 hours</td>
<td>15</td>
</tr>
<tr>
<td>Vanadium</td>
<td>1 μg/m³</td>
<td>24 hours</td>
<td>31</td>
</tr>
</tbody>
</table>

<sup>a</sup> Information from this table should not be used without reference to the rationale given in the chapters indicated.

<sup>b</sup> Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 hours.

<sup>c</sup> Due to respiratory irritancy, it would be desirable to have a short-term guideline, but the present data base does not permit such estimations.

<sup>d</sup> The guideline value is given only for indoor pollution; no guidance is given on outdoor concentrations (via deposition and entry into the food chain) that might be of indirect relevance.

<sup>e</sup> See Chapter 30.

**Note.** When air levels in the general environment are orders of magnitude lower than the guideline values, present exposures are unlikely to present a health concern. Guideline values in those cases are directed only to specific release episodes or specific indoor pollution problems.
Table 3. Guideline values for combined exposure to sulfur dioxide and particulate matter\(^a\)

<table>
<thead>
<tr>
<th>Averaging time</th>
<th>Sulfur dioxide (µg/m(^3))</th>
<th>Reflectance assessment: black smoke(^b) (µg/m(^3))</th>
<th>Total suspended particulates (TSP)(^c) (µg/m(^3))</th>
<th>Thoracic particles (TP)(^d) (µg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term</td>
<td>24 hours 125</td>
<td>125</td>
<td>120(^e)</td>
<td>70(^f)</td>
</tr>
<tr>
<td>Long term</td>
<td>1 year 50</td>
<td>50</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^a\) No direct comparisons can be made between values for particulate matter in the right- and left-hand sections of this table, since both the health indicators and the measurement methods differ. While numerically TSP/TP values are generally greater than those of black smoke, there is no consistent relationship between them, the ratio of one to the other varying widely from time to time and place to place, depending on the nature of the sources.

\(^b\) Nominal µg/m\(^3\) units, assessed by reflectance. Application of the black smoke value is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

\(^c\) TSP: measurement by high volume sampler, without any size selection.

\(^d\) TP: equivalent values as for a sampler with ISO-TP characteristics (having 50% cut-off point at 10 µm); estimated from TSP values using site-specific TSP/ISO-TP ratios.

\(^e\) Values to be regarded as tentative at this stage, being based on a single study (involving sulfur dioxide exposure also).
AIR QUALITY GUIDELINES

i.e. guideline values are below the existing levels in some parts of Europe. For instance, the guideline values recommended for major urban air pollutants such as nitrogen oxides, ozone and sulfur oxides point to the need for a significant reduction of emissions in some areas.

For substances with malodorous properties at concentrations below those where toxic effects occur, guideline values likely to protect the public from odour nuisance were established; these were based on data provided by expert panels and field studies (Table 4). In contrast to other air pollutants, odorous substances in ambient air often cannot be determined easily and systematically by analytical methods because the concentration is usually very low. Furthermore, odours in the ambient air frequently result from a complex mixture of substances and it is difficult to identify individual ones; future work may have to concentrate on odours as perceived by individuals rather than on separate odorous substances.

Table 4. Rationale and guideline values based on sensory effects or annoyance reactions, using an averaging time of 30 minutes

<table>
<thead>
<tr>
<th>Substance</th>
<th>Detection threshold</th>
<th>Recognition threshold</th>
<th>Guideline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon disulfide in viscose emissions</td>
<td>0.2-2.0 µg/m³</td>
<td>0.6-6.0 µg/m³</td>
<td>7 µg/m³</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>70 µg/m³</td>
<td>210-280 µg/m³</td>
<td>70 µg/m³</td>
</tr>
<tr>
<td>Styrene</td>
<td>8 mg/m³</td>
<td>24-32 mg/m³</td>
<td>8 mg/m³</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>1 mg/m³</td>
<td>10 mg/m³</td>
<td>1 mg/m³</td>
</tr>
</tbody>
</table>

Guidelines based on Carcinogenic Effects

In establishing criteria upon which guidelines could be based, it became apparent that carcinogens and noncarcinogens would require different approaches. These are determined by theories of carcinogenesis which postulate that there is no threshold for effects (i.e. that there is no safe level). Therefore, risk managers are faced with two decisions: either to prohibit a chemical or to regulate it at levels that result in an acceptable degree of risk. Indicative figures for risk and exposure assist the risk manager to reach the latter decision. Therefore, air quality guidelines are indicated in terms of incremental unit risks in respect of those carcinogens for which at least limited evidence of carcinogenicity in humans exists (Table 5).
**SUMMARY OF THE GUIDELINES**

Table 5. Carcinogenic risk estimates based on human studies

<table>
<thead>
<tr>
<th>Substance</th>
<th>IARC Group classification</th>
<th>Unit risk$^b$</th>
<th>Site of tumour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylonitrile</td>
<td>2A</td>
<td>$2 \times 10^{-5}$</td>
<td>lung</td>
</tr>
<tr>
<td>Arsenic</td>
<td>1</td>
<td>$4 \times 10^{-3}$</td>
<td>lung</td>
</tr>
<tr>
<td>Benzene</td>
<td>1</td>
<td>$4 \times 10^{-6}$</td>
<td>blood (leukaemia)</td>
</tr>
<tr>
<td>Chromium (VI)</td>
<td>1</td>
<td>$4 \times 10^{-2}$</td>
<td>lung</td>
</tr>
<tr>
<td>Nickel</td>
<td>2A</td>
<td>$4 \times 10^{-4}$</td>
<td>lung</td>
</tr>
<tr>
<td>Polynuclear aromatic hydrocarbons (carcinogenic fraction)$^c$</td>
<td>9 $\times 10^{-2}$</td>
<td>lung</td>
<td></td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>1</td>
<td>$1 \times 10^{-6}$</td>
<td>liver and other sites</td>
</tr>
</tbody>
</table>

$^a$ Calculated with average relative risk model.

$^b$ Cancer risk estimates for lifetime exposure to a concentration of 1 µg/m³.

$^c$ Expressed as benzo[a]pyrene (based on benzo[a]pyrene concentration of 1 µg/m³ in air as a component of benzene-soluble coke-oven emissions).

Separate consideration is given to risk estimates for asbestos (Table 6) and radon daughters (Table 7) because they refer to different physical units and are indicated in the form of ranges.

Unfortunately, the recent reclassification of dichloromethane by IARC has not allowed sufficient time to publish a detailed risk estimate which takes into account important information on the metabolism of the compound. The risk estimate for cancer from the animal bioassay is not used for this reason in the guidelines.

Table 6. Risk estimates for asbestos

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Range of lifetime risk estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 F$^*$/m³ (0.0005 F/ml)</td>
<td>$10^{-6} - 10^{-5}$ (lung cancer in a population where 30% are smokers)</td>
</tr>
<tr>
<td></td>
<td>$10^{-5} - 10^{-4}$ (mesothelioma)</td>
</tr>
</tbody>
</table>

$^a$ See Chapter 18 for an explanation of these figures.

*Note.* F$^*$ = fibres measured by optical methods.
Table 7. Risk estimates and recommended action level\textsuperscript{a} for radon daughters

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Lung cancer excess lifetime risk estimate</th>
<th>Recommended level for remedial action in buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \text{ Bq/m}^3 \text{ EER}$</td>
<td>$(0.7 \times 10^{-4}) - (2.1 \times 10^{-4})$</td>
<td>$\geq 100 \text{ Bq/m}^3 \text{ EER}$ (annual average)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} See Chapter 29 for an explanation of these figures and for further information.

Formaldehyde represents a chemical for which cancer bioassays in rats have resulted in nonlinear exposure response curves. The nonlinearity of the tumour incidence with exposure concentrations led Starr & Buck\textsuperscript{a} to introduce the “delivered dose” (amount of formaldehyde covalently bound to respiratory mucosal DNA) as the measure of exposure into several low-dose extrapolation models. Results showed considerable differences in the ratio between risk estimates based on the administered dose and those based on the delivered dose, with a great variance of ratios between models. Since estimates vary because of the inherent differences in approach, cancer risk estimates are referred to but not used for the guidelines. In addition, such estimates should be compared with human epidemiological data when an informed judgement has to be made.

The evidence for carcinogenicity of 1,2-dichloroethane in experimental animals is sufficient, being based on ingestion data. No positive inhalation bioassays are available. Consequently, an extrapolation from the ingestion route to the inhalation route is needed to provide a cancer risk estimate from the bioassay data. Such extrapolations are best conducted when detailed information is available on the kinetics of metabolism, distribution and excretion. Two estimates calculated from data on oral studies are provided for the risk of cancer through inhalation of 1,2-dichloroethane, but they lack detailed data for the route-to-route extrapolation and are not used in the guidelines.

It is important to note that quantitative risk estimates may give an impression of accuracy which in fact they do not have. An excess of cancer in a population is a biological effect and not a mathematical function, and uncertainties of risk estimation are caused not only by inadequate exposure data but also, for instance, by the fact that specific metabolic properties of agents are not reflected in the models. Therefore, the guidelines do not indicate that a specified lifetime risk is virtually safe or acceptable.

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