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Building environment design — Indoor air quality — Methods of expressing the quality of indoor air for human occupancy

Conception de l'environnement des bâtiments — Qualité de l'air intérieur — Méthodes d'expression de la qualité de l'air intérieur pour une occupation humaine

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16814 was prepared by Technical Committee ISO/TC 205, *Building environment design*.

Introduction

This document is one of a series of International Standards intended for use in the design of buildings and heating, ventilation and air conditioning systems. This series of International Standards specifies the methods of deriving design criteria for new buildings and systems and the retrofit of existing buildings for acceptable indoor environment. The indoor environment includes thermal, acoustic and lighting conditions, and indoor air quality (IAQ).

This International Standard covers methods of expressing IAQ and incorporating the goal of achieving good IAQ into the design process.

This International Standard recognizes that local laws, directives and regulations always apply and this document allows a compliance path which is consistent with such requirements.

The framework is established by the general principle documents.

This document does not prescribe a specific method but rather refers to existing methods in published standards and guidance, as referenced in this document. The referenced methods can be used to specify ventilation rates and other design requirements. The methods have in common the fact that they are based on a consideration of human health and/or comfort requirements. Therefore, the aim of the methods is to control indoor air pollutants to concentration levels below which, under the prevailing hygro-thermal conditions, the pollutants do not have the potential to

— cause a significant risk of adverse health effects,

— adversely affect the comfort of the majority of occupants.

The pollutants considered include human bioeffluents, which have often been the principal consideration for IAQ and ventilation, but also all groups and sources of pollutants that can reasonably be anticipated to occur in the building being designed. The pollutants to be considered can, depending on the sources present, include

— volatile organic compounds (VOCs) and other organics, such as formaldehyde,

— environmental tobacco smoke (ETS),

— radon,

— other inorganic gases, such as ozone, carbon monoxide and oxides of nitrogen,

— viable particles, including viruses, bacteria and fungal spores,

— non-viable biological pollutants, such as particles of mites or fungi and their metabolic products,

— non-viable particles, such as dusts and fibres.

In addition, carbon may be considered as an indicator of the ventilation rate rather than as a health risk in its own right.

Depending on the method selected, the designer can apply a range of approaches to achieve a good IAQ. In addition to the provision of ventilation, some consideration is given to sources of pollution and their control. When specific contaminant sources are present, it is necessary to consider alternative or additional control measures, such as air cleaning or local exhaust ventilation.

Again, depending on the method selected, the designer has the option of setting different target levels of IAQ. Furthermore, different methods can lead to different decisions in relation to, for example, ventilation rate. It is also true that different designers can reach different decisions, even when using the same method, where the method requires the designer to make assumptions or interpretations. Nevertheless, following a rational and documented process is expected to (a) enhance the design and (b) make it easier to address any problems that do arise and incorporate experience gained into future designs.

NOTE See Reference [44] for WHO recommendations on smoking areas in buildings.

Building environment design — Indoor air quality — Methods of expressing the quality of indoor air for human occupancy

1 Scope

This International Standard is intended

- to specify methods to express the quality of indoor air suitable for human occupancy,
- to allow several acceptable target levels of IAQ, depending on local requirements, constraints and expectations.

This International Standard applies to

- the design of new buildings and their systems and the retrofit of existing buildings and systems,
- indoor environments where the major concern is that of human occupants,
- buildings having any combination of mechanical and natural ventilation,
- commercial and institutional buildings.

This International Standard does not apply to residential buildings, industrial buildings and hospitals although those parts of such buildings that are similar to commercial buildings are covered.

The requirements of this International Standard might not achieve acceptable IAQ for all people in all buildings, due to one or more of the following sources of uncertainty.

- The outdoor air brought into the building can be unacceptable or might not be adequately cleaned.
- Indoor air has a wide diversity of sources and contaminants.
- There are many factors that affect occupant perception and acceptance of IAQ, such as air temperature, humidity, noise, odours, lighting and psychological stress.
- There is a range of susceptibility and preference in the population.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16813, *Building environment design — Indoor environment — General principles*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
acceptable IAQ
air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and that is not likely to contain contaminants at concentrations leading to exposures that pose a significant health risk

3.2
acceptable perceived IAQ
air in an occupied space toward which a substantial majority of occupants express no dissatisfaction on the basis of odour and sensory irritation

NOTE Acceptable perceived IAQ is necessary, but not sufficient, to meet acceptable IAQ.

3.3
adapted person
occupant
person who has occupied a space for a sufficient period of time to become adapted to the odours in a space

3.4
air change effectiveness
measure of the effectiveness of outdoor air distribution to the breathing level within the ventilated space

3.5
air change rate
air flow rate to a space, expressed as volume per unit time, divided by the volume of the space in consistent units

NOTE Air change rate is often expressed as air changes per hour.

3.6
air cleaning
process that removes or controls particulate (chemical or microbial) or gaseous contaminants in the air, usually carried out by equipment

3.7
airflow rate

3.7.1
mass airflow rate
q_{m}
flow of air, expressed in units of mass, passing a given plane divided by time

3.7.2
volume airflow rate
q_{V}
flow of air, expressed in units of volume, passing a given plane divided by time

3.8
biological contaminant
biocontaminant
any micro-organism or part of a living organism or substance of biological origin capable of producing an adverse effect on human health or discomfort or damage to human property

NOTE Biological contaminants do include microbial contaminants and other substances, such as insects or dander.

3.9
design documents
drawing, specification, project manual, and other volumes used to document construction requirements and basis of design

3.10
dilution index
DI
ratio of the removal of a contaminant from an enclosure to the rate of its generation

NOTE An enclosure with a higher dilution index represents a less contaminated enclosure. Dilution indices are calculated for each contaminant generated within the enclosure and the lowest DI value applied.

3.11
emission
⟨building environment design⟩
release of contaminant(s) from indoor source(s) into indoor air

3.12
emission factor
ratio of the rate at which an air pollutant is entitled as a result of some activity, to the rate of that activity

NOTE 1 Adapted from ISO 4225:1994 [46].

NOTE 2 The point or area from which the discharge takes place is called the “source”. The term is used to describe the discharge and the rate of discharge. The term can also be applied to noise, heat, etc.

3.13
emission rate
mass (or other physical quality) of pollutant transferred into the atmosphere per unit time

[ISO 4225:1994 [46]]

3.14
enclosure
individual room, space or part thereof

3.15
environmental tobacco smoke
ETS
particulate and vapour-phase contaminants emitted to the atmosphere during the smoking of tobacco products, including side-stream smoke and exhaled mainstream smoke, also known as second-hand smoke (SHS)

3.16
exhaust air
air, other than recirculated air, removed from an enclosure and discharged to the atmosphere

3.17
guideline value
concentration of a pollutant in the air, below which the risk for occurrence of adverse health effects is negligibly low

NOTE It is linked to a time-averaged value.

3.18
HVAC system
system that provides heating, ventilation or air conditioning for buildings

3.19
indoor air
air within an enclosed space, e.g. dwelling or public building

[ISO 4225:1994 [46]]

3.20
infiltration air
uncontrolled passage of air into a space through leakage paths in the building envelope

3.21
local exhaust
extraction of objectionable or hazardous contaminants close to the source and discharged safely to the external atmosphere

3.22
mechanical ventilation
ventilation provided by mechanically powered equipment

3.23
microbial contaminant
fungal, bacterial, or viral organisms, toxins they produce, or particles bearing such organisms or toxins that are airborne or deposited on indoor surfaces and that can cause disease, irritation, allergic reaction, discomfort or damage to human property

3.24
natural ventilation
ventilation through leakage paths (infiltration) and intentional openings (ventilation) in the building envelope or room enclosure, which relies on pressure differences without the aid of powered air-moving components

3.25
occupancy density
number of persons in a space, per unit of net occupiable area

NOTE Expressed in units of persons per square metre or persons per cubic metre.

3.26
occupational exposure limit
occupational exposure standard value
OEL
values set by competent national authorities or other relevant national institutions as limits for concentrations of hazardous compounds in workplace air to prevent adverse health effects on healthy adult workers

3.27
occupational exposure time-weighted average values
ES-TWA
airborne concentration standard values set by competent national authorities as limits for time-weighted average (TWA) concentration of hazardous compounds over an 8/h working day, for a 5/day working week

3.28
occupied zone
area designed for occupancy that is dependent on the geometry and the use of the room and specified case by case

NOTE Usually used only for areas designed for human occupancy and defined as a volume of air that is confined by horizontal and vertical planes. The vertical planes are usually parallel with the walls of the room.

3.29
odour
quality of a substance that stimulates the sense of smell

NOTE Adapted from ISO 4225:1994 [46].

3.30
outdoor air intake
any opening through which outdoor air is admitted

3.31
outdoor air
air entering the system, or opening from outdoors before any air treatment

3.32
particulate matter
solid or liquid particles in air, typically in the size range 0,01 µm to 100 µm in diameter

NOTE PM$_{10}$ is particulate matter smaller than 10 µm in aerodynamic diameter.

3.33
perceived air quality
PAQ
quality of the air perceived by the occupants and expressed by the percentage of persons that perceive the air quality as unacceptable (percent dissatisfied)

3.34
relative humidity
mass of water vapour in the air by volume divided by mass of water vapour by volume at saturation at the same temperature

3.35
recirculated air
air removed from a space and reused as supplied air

3.36
respirable particle
particle that can penetrate into, and be deposited in, the nonciliated portion of the lung

3.37
sensory pollution load
pollution load caused by those pollution sources that have an impact on the perceived air quality

NOTE The load is often expressed by a sensory unit, the olf.

3.38
sink
object on which contaminants are deposited and remain, either permanently or temporarily

NOTE Sinks can become sources when they release deposited contaminants.

3.39
source
persons, materials or processes (activities) from which indoor air contaminants are released

NOTE A source can also be a route of entry of contaminants from outdoor (e.g. air, soil, clothes).

3.40
source control
source management
manner of controlling IAQ by preventing or reducing the emission of air contaminants or entry of air contaminants into an occupied space

3.41
supply air
air introduced into an enclosure by mechanical or natural means

3.42
total organic vapours
total volatile organic compounds
TVOC
sum of organic vapours in air measured by an appropriate sampling and analysis procedure

3.43
unadapted person
visitor
person entering a space from another area with acceptable perceived IAQ whose sensory perception has yet to become desensitized to some air constituents (such as body odours) in the space

3.44
ventilation
process of supplying or removing air by natural means or mechanical means to or from a space for the purpose of controlling air contaminant levels, humidity, odours or temperature within the space

3.45
ventilation rate
airflow rate at which outdoor air enters a building or enclosed space

3.46
ventilation effectiveness
ε_V
measure of the relationship between the pollutant concentration in the exhaust air and the pollutant concentration in the breathing zone

4 Methods of expressing indoor air quality (IAQ)

4.1 General

IAQ may be expressed as the extent to which human requirements are met. Humans have two basic requirements for IAQ: the risk of any adverse health effects of breathing the air should be low and the air should be perceived as acceptable in relation to comfort. These two requirements should be met whenever it is practicable to do so. Corresponding to these two requirements, there are two direct methods of expressing IAQ. A third alternative is an indirect method based on the ventilation rate. Each of these three methods is summarized below. The various guidelines and standards use one or more of these methods to express IAQ, as detailed in Annex B of this document.

4.2 Method based on health

Exposure to pollutants in the air can cause some risk of adverse health effects. Such effects can be short-term, distinct and acute (e.g. eye irritation) or develop over an extended period (e.g. cancer). To limit the health risk, maximum permissible concentrations and corresponding exposure times for individual chemicals are available. Annex C contains recommended guideline values for common pollutants found in indoor and outdoor air. It is based on guidelines published by the World Health Organization. The relation between the actual concentration and the guideline value for a given chemical expresses IAQ as regards the health effect of that particular chemical. Depending on the nature of the health effect, it might not be reasonable to set a guideline concentration below which no significant health effect is expected. This would generally be the case for carcinogens. For some such pollutants, it is possible to estimate the magnitude of risk associated with a given concentration level.

4.3 Method based on perceived air quality

People vary widely in their sensitivity to air pollutants and the discomfort that they experience. Some are very sensitive and difficult to satisfy, while others are less sensitive and are easier to satisfy. To cope with these individual differences, the perceived IAQ can be expressed by the percentage of persons who perceive the air quality as unacceptable (percent dissatisfied). If there are few dissatisfied, the IAQ is high; if there are many dissatisfied, the IAQ is low.

4.4 Method based on the ventilation rate

An indirect method of expressing IAQ is to determine a certain minimum ventilation rate estimated to meet requirements for perceived air quality and/or health in the occupied zone. The relation between the actual and the minimum ventilation rate provides an expression for the IAQ.

5 Conformance

A building, including any ventilation or air-conditioning system, should be designed to provide the required IAQ under specified conditions. The designer shall document the conditions and any assumptions made, including the IAQ requirements that the system is designed to meet. In order to claim that the design process on a specific project complies with the requirements of this document, the following documentation requirements shall be met:

a) project information, including

- application and flexibility of the space, including a specification of the occupied zone,
- typical, best and worst outdoor air quality conditions, e.g. corresponding to a certain percentage of a normal year;

b) design criteria and requirements for the project, including

- whether the design should be for adapted or unadapted persons,
- pollution load caused by materials applied in the building, including carpets and furnishings,
- physical properties of the materials used in the building (e.g. adsorption/desorption of chemicals, thermal insulation);

c) building-use assumptions, including

- number of occupants present (per square metre floor area and per zone) and their estimated activity and clothing preferences,
- total area of all the zones,
- percentage of smokers, if smoking is permitted,
- possibility of opening the windows;

d) cost constraints;

e) initial design alternatives considered;

f) basis for selection of final design;

g) local regulations and requirements considered;

h) method selected to express IAQ and, where applicable, the target level of IAQ selected within that method;

i) calculations carried out using the selected method;

j) documentation of minimum operation and maintenance requirements, including

- proper commissioning and maintenance of the ventilation or air-conditioning system,

— proper system balancing,

— proper cleaning of the spaces,

— proper use of the ventilation or air-conditioning system;

k) any other design decision processes resulting from following the guidance in Clause 6.

The design assumptions shall be listed in the operational guide for the ventilation or air-conditioning system and it shall be stated that the indoor environmental criteria for which the system is designed can be achieved only if these conditions are met. Owners and users of the building shall be warned that changes to the application of spaces or pollution load can result in the inability of the system to meet the indoor environmental requirements for which it was designed.

6 Design process

Creating a building that has good IAQ is not just a matter of working to certain design targets. The whole process that the designer goes through has an important impact on the final product. Therefore, this clause outlines the approach that should be adopted. It is cross-referenced to subsequent chapters, which provide detail on issues relevant to this International Standard. In order to achieve good IAQ, HVAC equipment shall be designed, installed and operated properly.

The flowchart in Figure 1 provides a summary of the process, with cross-references to other clauses and subclauses. It illustrates the different steps that the designer should take in order to choose a design method that takes into account the objectives of the building. The end point of the flow chart shows the different methods that are used to express the IAQ, one of which shall be used by the designer. Tables B.1 and B.2 list various factors that are considered by different methods. These factors should be taken into account in order to determine the method to be used in a specific project. Depending on the method chosen, the outcome is unique for each project; this is why it is important that all assumptions be well documented as required in Clause 5. While the order in which the activities depicted in the flowchart are carried out may vary to some extent, all the activities are essential.

Step 1. Define the constraints placed on the design by the client, the location, site conditions, and by local codes/regulations, etc.; see 7.2. These constraints shall be considered in discussion of the brief and decisions documented. If the outdoor air quality is judged to be unacceptable, pretreatment to remove pollutants from the outdoor air shall be considered.

Step 2. Combine the information from step 1 with the detailed design objectives, such as the expected/specified number of occupants and the activities that are likely to be carried out in the building; see 7.2. The system shall be designed so as to facilitate easy cleaning, maintenance and service operation; see EN 12097 [5] for guidance. Information shall be given to the owner about the maintenance required (primarily for filters). The systems requirements for balancing shall be specified.

Step 3. Define the IAQ criteria that will guide the process of selecting an IAQ target level. This includes whether the design takes into consideration the health or comfort of adapted or unadapted persons. It is also necessary to consider at this point the times and locations to which the criteria apply; see 7.3. The designer shall be explicit about which criteria and method will be applied in designing for good IAQ.

Step 4. Identify the pollution sources taken into account; see Annex A.

Step 5. Evaluate options to reduce the concentration levels of pollutants; see Annex A. Air shall not be recirculated or transferred from an enclosure in which smoking is permitted to another enclosure in which it is prohibited. If filtration is used, the filters shall be designed to achieve required levels of cleanliness under all conditions during which the system is running, i.e. variations in pressure differential, etc.

Step 6. Check whether there are special requirements that should be followed, such as local requirements (laws, directives, regulations, guidance, calculation methods, rating methods), which can impose minimum values (or special considerations that influence the choice of a method) or special pollutants to be taken in account. If there is a local requirement, determine whether the intention is for IAQ to exceed that requirement; see Annex B.

Step 7. Choose and apply a method to express IAQ; examples of methods of expression of IAQ are given in Annex B.

The flowchart as expressed in Figure 1 fulfils the project definition for IAQ and states the stages of design, in accordance with ISO 16813. IAQ criteria obtained are considered as input at the different stages of the design building process, from conceptual design to detailed design and final design. If target criteria are not matched, assumptions for IAQ shall be revised.

7 Design brief parameters and assumptions

7.1 Objectives

When designing a building (including the building services), it is important that the designer and the client recognize that the IAQ in a building is the result of several factors, not only ventilation rate. Consideration shall be given to all the relevant elements in the early stages of the design process. The client shall normally provide the designer with a brief, which specifies certain required characteristics of the building, site, indoor environment or occupancy. The designer and client shall work together to define as clearly as possible their objectives concerning the IAQ design. Buildings are designed for a variety of uses: the more detailed the brief is, the more the designer can tailor the building to the client's needs.

Cultural differences, economic parameters and the intended use of the building should be considered when designing a building. The designer should obtain this information from the client, building owner or other expected occupants so that appropriate levels of IAQ can be targeted, using methods that are compatible with the way in which the building is likely to be used. Although the client and designer may discuss and agree, at some point in time the brief comes to represent a set of constraints on the design. In 7.2 are detailed some of the more important constraints that can emerge from the brief, some of them based on assumptions that the designer should clarify with the client (or with other parties as appropriate). The brief sometimes makes statements about the required quality of the indoor environment. Criteria are discussed in 7.3. In addition to all the technical issues and user requirements, budgetary constraints are a major consideration in designing a building and its systems. Although first cost is generally a determining factor, life-cycle costing should be used to support the case for superior design. The growing emphasis on environmental impact and energy savings should result in increased use of life-cycle costs as a preferred method. Recent studies have shown a direct relationship between productivity improvements and improved IAQ; see 7.3.4. The expected economic benefits of such productivity improvements should be quantified when practicable. The designer is encouraged to propose both types of economic analysis to the building owner so that he/she can make an informed decision.

7.2 Constraints

7.2.1 Constraints due to the location of the building

7.2.1.1 Climate

The climate where a building is located can have a major impact on the IAQ of the building. For example, if the climate is cold and dry, the ventilation air has a tendency to lower the humidity level in the building. Conversely, in climates where the outdoor air is humid, the system designer shall consider appropriate dehumidification of the ventilation air. Some degree of dehumidification is often associated with refrigerated cooling. Where humidity levels are intentionally or unintentionally altered because of comfort considerations, adequate attention shall be given to the possible effects on microbiological growth in the ventilation system or inside the building.

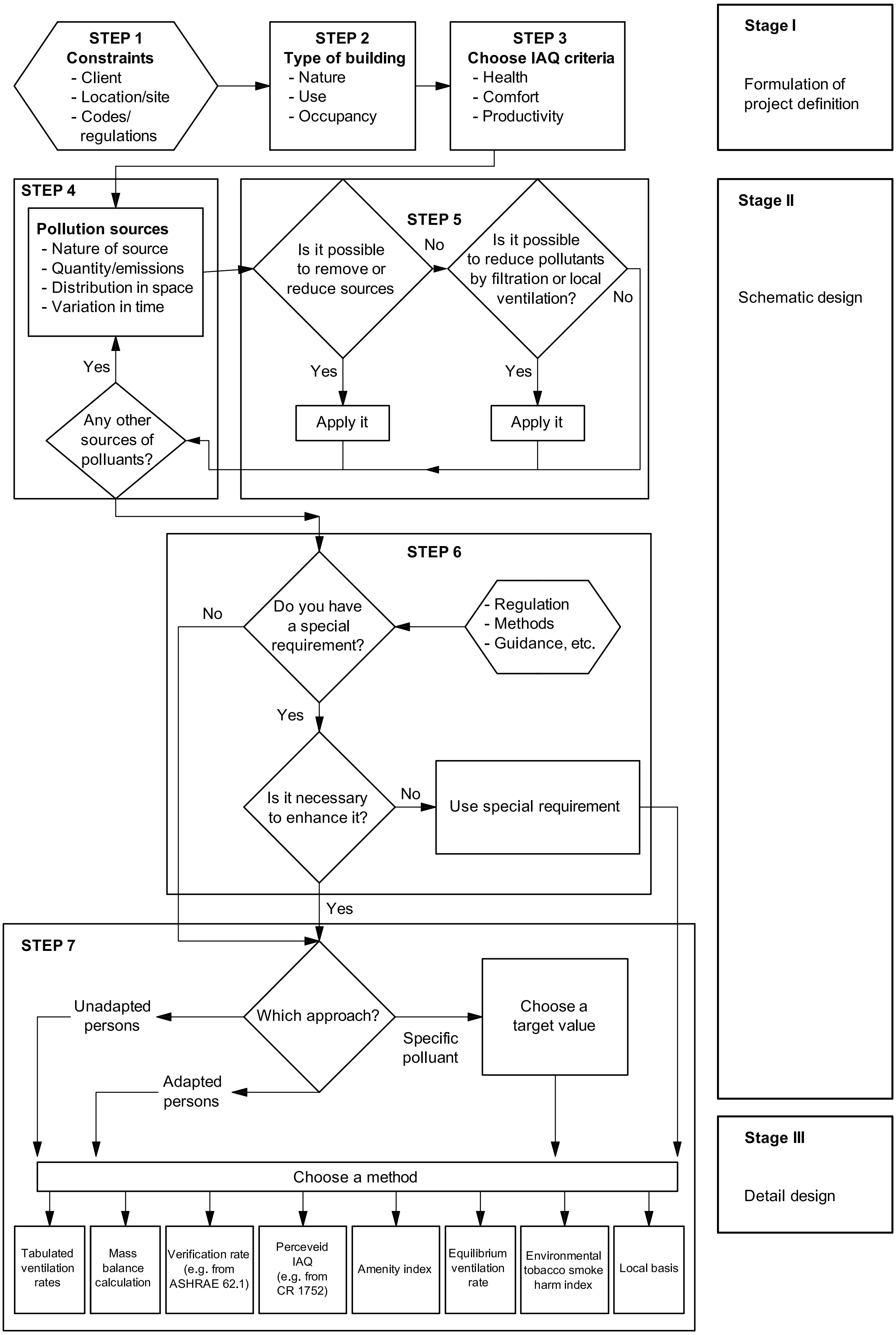

Figure 1 — Summary of design process for defining IAQ

7.2.1.2 Regulations, local requirements or policy

Designers may be required to take into account the regulations or local requirements in relation to, for example, indoor or outdoor emission of pollutants, energy consumption, local design methods, basic ventilation rate, etc.

7.2.1.3 Outdoor air quality

The quality of the outdoor air where the building is located can have a significant impact on the amount of ventilation air required. If local data on the air surrounding the building are available, they shall be used. In some cases, it can be possible to select air intake locations to optimize the quality of the ventilation air; see EN 13779:2004 [45], Annex A.2 for guidance). Typical pollutants measured in outdoor air include carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, pollens and particulates.

In addition to the outdoor air quality, an observational survey of the building location and its immediate surroundings shall be conducted during hours when the building is expected to be normally occupied. The intent of the survey shall be to identify any contaminants from local sources that can be inadvertently introduced through ventilation air or other parts of the building structure.

7.2.2 Constraints due to the nature and use of the building

7.2.2.1 Existing or new construction

When an HVAC system is designed for a new building, there are relatively few physical limitations that restrict the design of an optimum system. In an existing building however, the building structure, electrical services, piping layout and ductwork can limit the design of the new system. The occupants of the building and their activities can also restrict new construction activities. The designer shall identify and document all limitations that are expected in an existing building. If such limitations are likely to have a negative impact on the IAQ, these issues shall be discussed and the appropriate action agreed with the building owner.

7.2.2.2 Flexibility

Often, buildings are built on a speculative basis without knowing the exact application or use of the facility. In such cases, the designer should try to identify general categories of expected use and design a system that is flexible enough to accommodate most of the likely applications. All assumptions and limitations of the system design shall be documented and acknowledged by the building owner. It is recommended that the impact on IAQ be re-evaluated once the building use has been identified.

7.2.2.3 Type of building materials

The building materials and the integrity of the building architecture can contribute to the quality of indoor air. Some materials can absorb air pollutants under certain conditions and release them under different conditions. Generally, non-porous materials absorb fewer pollutants than porous materials. If practicable, materials with emission data should be identified and low-polluting materials used for building fabric and furnishings. See also Annex C.

7.2.2.4 Building hygiene activities

A high degree of cleanliness shall always be maintained in a building since poorly cleaned furnishings can themselves have an adverse effect on IAQ. Removal of pollutants through regular and judicious cleaning activities can have a positive effect on the IAQ. Hygiene-related activities (from vacuuming and shampooing to pest control) can have either a beneficial or a detrimental effect on IAQ, depending on how they are undertaken. Such activities can occur for a short period but may affect the IAQ for a longer time after the activity has ceased. The frequency of such activities can be minimized by selecting materials that require less frequent cleaning. Judicial use of cleaning chemicals should also be encouraged in order to minimize exposure to these chemicals. The design shall consider increasing the ventilation rate (by opening windows or through a mechanical system) during cleaning.

7.2.2.5 Airtightness and pressure differentials

The building structure design shall be such as to minimize the introduction of pollutants due to infiltration from outside the structure. Pressure differentials between various zones within the building should be controlled so as to minimize unwanted movement of pollutants between zones. This requires consideration of airtightness between zones in addition to the motive forces for air movement.

NOTE ISO 9972 specifies a method to measure airtightness of buildings.

7.2.2.6 Ventilation types

There are primarily three types of ventilation: natural ventilation, mechanical ventilation and hybrid (mixed-mode) ventilation. Natural ventilation uses natural forces (wind and the stack effect) to achieve the required air movement. Mechanical ventilation uses mechanically driven devices such as fans. In both cases, the aim in relation to IAQ is to achieve planned movement of air between indoors and outdoors, or from one area of the building to another, in order to dilute and lower pollutant concentrations to acceptable levels. Hybrid systems use a combination of natural and mechanical ventilation to achieve the same result, ventilation air movement being maintained by different forces such as the outdoor climate changes during the year.

7.2.2.7 Window operability

Windows can generally be designed to be operable with easy access to the controls or, at the other extreme, they can be designed to be inoperable. The selection of window type should be dependent on the type of ventilation system that is specified. If a mechanical system or advanced natural ventilation system is designed that does not depend on an open window for proper ventilation, window opening may be restricted (but ideally not prevented because inoperable windows can cause negative psychological effects on some occupants). When operable windows are opened in such a building, the pressure relationships in the building can be disrupted and the ventilation system can become less effective.

7.2.2.8 Air cleaning

Adequate air cleaning shall always be considered as an integral part of a good HVAC system. Filters serve to reduce intake or recirculation of particles (and sometimes gases and vapours) and keep the building and the HVAC system cleaner. Regular maintenance of filters and their supports is required to minimize growth of micro-organisms or generation of unwanted chemicals. See also Annex E.

7.2.2.9 Use or occupancy type

Pollution levels in a building are directly influenced by the type of activities that occur in the building. For instance, office buildings are affected by the emissions from office furniture, office materials and equipment such as copiers and printers. Restaurants are affected by the humidity and odours generated by cooking. Designers shall always understand the intended use of the building in as much detail as practicable before embarking on the design.

7.2.2.10 Number of people

Humans generate organic bioeffluents, CO_2 and water vapour as a result of normal metabolism. The level of bioeffluents generated by individuals varies as a function of the activity levels as well as the ages of the individuals. The number of people in a given area (occupant density) shall also be considered when designing a building. Variable occupancy shall be given adequate consideration in determining ventilation rates and the capacity to vary them during the day in each zone of the building.

7.2.2.11 Smoking policy

Tobacco smoking deserves special consideration when designing buildings for acceptable IAQ. From a health perspective, no scientific body has established a safe level of exposure to ETS. The association between exposure to ETS and an increased risk of serious and fatal illnesses in adults and children is well established.

No realistic combination of ventilation and filtration provides a reasonably safe environment where smoking is permitted; see Reference [44].

Significant and additional ventilation and filtration can assist in providing a more comfortable environment (fewer odours, fewer irritants) where smoking is permitted although the nuisance is not completely eliminated.

Air shall not be recirculated, or otherwise allowed to move, from a smoking area into a non-smoking area. Air-pressure management techniques should also be used when needed to achieve this objective.

7.2.2.12 HVAC operation and maintenance — Quality and quantity

When designing an HVAC system, consideration shall be given to the quality and quantity of operation and maintenance that is required for the system and the availability of qualified technical personnel. The system shall be designed, for example, such that there is adequate access to components that require maintenance on a regular basis (e.g. filters) or occasionally (e.g. ducts).

7.3 Determination of the basis of the IAQ target level

7.3.1 General

The principal design criteria for IAQ are

— health (including identifiable illness and the occurrence of non-specific symptoms): see 7.3.2,

— comfort (or perceived IAQ, or “acceptability”): see 7.3.3,

— human performance (for learning, work, sports performance, etc.): see 7.3.4.

As stated in Clause 6, the designer shall agree with the client to use one or more of these as the criterion or criteria, and document the choice. In some contexts, design criteria can be related to the quality of the environment for animals, plants or objects (e.g. in museums), but these are outside the scope of this International Standard. The design criteria, therefore, take into account aspects of human response and the design targets (see Annex B) are sometimes expressed directly in relation to human response (e.g. percent dissatisfied). Even when design criteria are expressed in terms of targets for pollutant levels or ventilation rates, the basis for the levels selected is human response.

A clear understanding of the criteria is critical in the following stages:

a) selecting a method of defining targets (e.g. a method of calculating pollutant emissions or the required ventilation rate);

b) setting targets (e.g. a particular ventilation rate or pollutant concentration).

These stages are covered in Annex B. At this stage, it can be noted that the approach can differ depending on the degree of control that individual building occupants have over the sources of pollution and the ventilation rate. In particular, control shall depend on whether or not natural ventilation is employed. Where control is in the hands of the building’s engineer or other maintenance personnel, there is a responsibility to define the targeted ventilation rate, and to instigate operational procedures to ensure that it is, in practice, achieved. Where control is in the hands of the individual occupant, the building shall still be designed so that it is able to deliver the required ventilation at a given point in time, but the control processes can be less well defined: the users have become part of the control system and can, therefore, regulate operation to achieve their own requirements.

NOTE Implicitly then, the greater the risk that users are unable to use their own judgement to protect their health and comfort, the greater the requirement for the ventilation rate to be controlled by other means.

EXAMPLE If there is a health risk from a pollutant that is not perceived before it does harm, then the occupants should not be placed at risk by requiring them to control the ventilation. In most buildings, this concern does not apply, and it is rather the outdoor climate and building configuration that define whether centrally controlled mechanical ventilation is a necessity.

7.3.2 Health

The constitution of the World Health Organization defines good health as "...a state of complete physical, mental and social well-being, not merely the absence of disease and infirmity". This means that comfort can be perceived as an aspect of health; this definition is accepted but, for the sake of clarity, comfort is considered separately in this International Standard.

NOTE 1 Air pollution targets and standards have been established for many years, but primarily in relation to the outdoor environment and industrial workplaces rather than non-industrial workplaces. Usually, the criterion has been health, either the risk of illness or the prevalence of specified symptoms. A number of illnesses are known to be related to indoor air pollution and they can cause serious health effects, including death; fortunately, they are also relatively uncommon. For example, legionnaires' disease is a well-known and potentially fatal disease. Other examples include asthma and long-term outcomes such as cancer.

On industrial premises, workers are typically exposed to one or a few chemicals at a time. In offices and similar non-industrial workplaces, exposure to any individual pollutant is typically much lower than in industry. Loss of life or serious diseases are, therefore, not normally the limiting considerations. Instead, the exposure is characterized by a wide spectrum of compounds at low concentrations, derived from building materials, furniture, office equipment, human metabolism, environmental tobacco smoke and outdoor air. Owing to the multitude of pollutants and uncertainties about their interactions, the target should be much lower concentrations of individual pollutants. This applies also to kindergartens, nursing homes and similar spaces, where people can spend a longer time than at the workplace, or where the occupants include more susceptible persons, e.g. children, the elderly and people suffering from any form of hypersensitivity to pollutants. However, the short- and long-term effects of multiple low-level exposures are not well understood.

NOTE 2 A dominant health consideration has been a range of acute non-specific symptoms that people report when they are in buildings and that become less severe or disappear when they leave the building (e.g. irritation or dryness of the eyes, nose, throat and skin; headaches; lethargy; lack of concentration). These symptoms have been found to be far more prevalent in some buildings than in others, a phenomenon that has come to be known as the sick building syndrome (SBS). The evidence is that a substantial number of people in many buildings are affected by SBS. The symptoms can become quite severe and lead to reduced productivity or increased absenteeism. More information on the subject can be found in Reference [21]. Air-conditioned buildings are generally associated with a higher prevalence of SBS and this difference can probably largely be attributed to failures in design, operation or maintenance. SBS can also occur in buildings with natural ventilation.

SBS is not entirely due to indoor air pollution, but minimizing pollutant concentrations is an important part of risk management. However, care should be taken not to introduce or increase other risk factors in the process (e.g. high temperature, low humidity, microbial contamination of surfaces or restricted occupant control over the indoor climate).

In the case of pollutants that exert their effect via the immune system (e.g. allergic reactions), a possible outcome is to become sensitized with continued exposure so that the same concentration of a pollutant has a greater effect. Sensitization is also possible when a substance has an irritant or toxic effect.

7.3.3 Comfort

7.3.3.1 Using comfort in design

In a different category from non-specific symptoms, there are commonly complaints about the indoor environment itself (e.g. it is too hot, the odour level is too high, the humidity or the air velocity is too high or too low, and a range of other complaints about the environment) rather than about the perceptions of the person's own health. Hence, humans judge the acceptability of air quality based on a feeling of comfort.

This sense of comfort is based on information collected by several sensory organs, including the nose, throat, eyes and skin, as well as internal regulatory organs, principally the hypothalamus. These parts of the body are sensitive to temperature, humidity and a wide range of pollutants in the air. It is the combined response of all these senses that determines whether the air is perceived as fresh and pleasant or stale, stuffy and irritating. There are two senses that are primarily responsible for perceiving the chemical content of the air:

— olfactory sensory receptors, which are situated in the nasal cavity and are sensitive to several hundred thousand odorants;

— general chemical sensory (trigeminal) receptors, which are situated all over the mucous membranes in the nose and the eyes and are sensitive to a similarly large number of irritants in the air.

In contrast to procedures for setting pollutant limits, ventilation rates in non-industrial workplaces have generally been set according to criteria of comfort or “acceptability”. This offers the option of using a people's perception of the indoor environment to determine what percentage of people are dissatisfied by a certain level of pollution. This approach has been used with reasonable success for many years in the case of physical aspects of the environment such as temperature and lighting. It is more difficult to apply in the case of indoor pollution because of the many different chemicals involved and the fact that some harmful air pollutants might not be sensed at all (for example carbon monoxide or radon). Also, the sensory effects of pollutants are not linked with their toxicity in a simple, quantitative way. Therefore, perceived air quality based on comfort is not a complete measure of IAQ. Yet, it is also true that when poor perceived IAQ in a building is improved by removing pollution sources and increasing ventilation, the risk of adverse health effects is normally also reduced.

Even for those pollutants that can be detected by their odour or irritation effects, there is the issue of who should be the judge of what is acceptable. Yet, in those cases when irritation is a health issue, it should be addressed. For comfort issues, one option is to use all the occupants or a random sample of them. Another option is to use a panel of people to go to a building and assess the quality of the air. The panel can be untrained (i.e. uncalibrated but representative, sometimes called “naïve”) or trained to respond according to consistent criteria. A common method is for an untrained impartial panel to enter a space and give a judgement of IAQ within 15 s; this represents the response of visitors to the space (unadapted).

7.3.3.2 Adapted and unadapted comfort criteria

Humans generate organic bioeffluents, CO_2 and water vapour as by-products of normal metabolism. Some adaptation to bioeffluents takes place during occupancy, while little, if any, adaptation occurs for some other pollutants, especially if they have an irritation effect (e.g. tobacco smoke and many pollutants from building materials). Hence, for basic ventilation to control odour from bioeffluents, adapted people (occupants) require about one third of the rate required by unadapted people (“visitors”). For some pollutants, no adaptation can be assumed.

NOTE There are two kinds of adaptation to odour. Over periods of about 3 min, people become less sensitive to any odours present. Over much longer periods (weeks or months), people can come to accept an odour as normal and harmless and, therefore, become less aware of (or concerned about) it. Conversely, over a period of minutes or hours, the discomfort from exposure to pollutants can increase. Over a longer period, adaptation is possible but this can be largely behavioural (e.g. by ceasing to wear contact lenses, thus reducing eye discomfort).

7.3.4 Productivity

To date, productivity and staff efficiency have not been used as a direct basis for standards, but the principal problem has been with defining and measuring productivity. Nevertheless, productivity is a key element in the motivation to improve IAQ in the workplace since it is generally assumed that healthy, comfortable staff is also a productive staff. To use work performance (e.g. speed and accuracy) as a criterion is feasible in some settings, for example where people are doing repetitive, routine tasks, but in other cases it is much more difficult to assess whether performance has been improved or reduced by a certain level of indoor pollution. For some types of work, it can be some years after a piece of work was performed before its usefulness can be established.

NOTE In developed countries, a doubling or halving of energy use can be offset by productivity changes of less than 1 %. The actual impact of IAQ improvement on productivity is difficult to state and, of course, it depends on the starting condition and type of improvement. However, some studies have shown the impact of productivity improvements in the 0 % to 9 % (measured task efficiency) range with modest investment in IAQ improvement measures. Consequently, the possible productivity effect of IAQ improvement measures are worth consideration.

Designers have the option of specifying a higher IAQ than the minimum where there is evidence that this would enhance productivity. Designers should consider this option and agree with the client whether productivity should be considered in the design.

7.3.5 Criteria in practice — IAQ is not the only problem

Whatever criteria are chosen, it is necessary to ensure that pollutant concentration levels are held to acceptable levels.

NOTE 1 This still requires extensive research because of the vast number of pollutants and the difficulty in establishing their effects. In the meantime, there is still an imperative to minimize indoor pollution now and not wait for the research to be completed.

NOTE 2 A serious technical challenge in setting standards for IAQ is the fact that IAQ interacts with other factors to cause occupant complaints. The same human responses can result from IAQ problems and from failings that are quite distinct from IAQ. This is certainly the case for SBS. The list of suggested causes for SBS is very long indeed and, while many focus on IAQ and ventilation rates, there does seem to be some contribution from a wide range of other factors in the environment (particularly temperature, humidity, draught, lighting, noise, surface pollution and personal control over the environment). Almost certainly, no single factor can account for SBS. In all probability there is a different combination of causes in different buildings.

Interactions occur at a range of levels.

— The building: The design, construction and location of a building and its services and furnishings influence IAQ in a variety of ways, from the site microclimate through shell design (e.g. depth of space) to the building services and fitting-out.

— The indoor environment: The effects of the building are generally mediated by the indoor environment.

— The organization: Organizations that occupy and operate buildings can contribute to IAQ complaints, for example via the quality of building and workforce management.

— The individual: Reported experience of IAQ problems varies from one person to another within buildings for a number of reasons that include personal control over the environment, constitutional factors, behaviour and individual mental and physical health.

In addition, continuous actions shall be taken, starting from the original brief, specification and design of a building through the construction, installation and commissioning to the maintenance and operation of the building as required in Clause 6.

Finally, IAQ shall be considered together with the energy implications of the choices we make. Energy is part of a global crisis, not just because of dwindling resources but because of problems such as CO_2 emissions and global warming. In the 1970s energy crisis, energy was the dominant consideration and ventilation rates were cut dramatically in many countries, increasing the risk of IAQ problems. It would be wrong now to consider only IAQ and forget energy.

Hence, the designer needs to take into account a range of factors other than pollutant concentrations if complaints about problems attributed to poor IAQ are to be minimized. The appropriate guidelines and standards shall be followed in making these considerations.

Annex A
(informative)

Sources and control of indoor air pollution

A.1 Introduction

There are many pollution sources in buildings and, collectively, they emit biological contaminants and hundreds or thousands of different chemicals, but at low rates. Pollution sources in a building include the occupants and their activities. Furthermore, materials in the building, including furnishings, carpets, cleaning chemicals, etc., can contribute significantly to the pollution of the air. Some materials pollute a lot, some a little, but they can all contribute to the deterioration of the IAQ. The pollution sources provide a pollution load on the air in the space. This load can be expressed as a chemical pollution load, as a sensory pollution load and as a biological pollution load.

The chemical load may be expressed as the emission of individual chemicals from the sources. The source strength of a material may be expressed as the emission rate (or emission factor) of individual chemicals in $\mu g \cdot s^{-1}$ or $\mu g \cdot m^{-2} \cdot s^{-1}$). The chemical pollution load of each individual chemical in the air in the space can then be estimated by addition of the source strengths and expressed in $\mu g \cdot s^{-1}$.

Although several emissions databases are being developed, information is not always available on the emission rates from materials or equipment used in buildings. In addition, it is sometimes impractical to account for the source strength of each of the chemicals occurring in indoor air. But in some cases, where an individual chemical is suspected of being a critical pollutant because of its toxic potential, an estimate of the pollution load of that particular chemical in a space can be practicable. Even without complete information, it can be practicable to incorporate some measure of pollutant emissions into the criteria for selection of materials and equipment. Further information is given in Annex D.

The sensory pollution load in the air is caused by those pollution sources having an impact on the perceived air quality. The load is often expressed by a sensory unit, the olf. The sensory load in the air can, according to some studies, be estimated by adding the loads in the air in a space, usually from the occupants and the building (including furniture and equipment). The limits of additivity have not been fully defined. Data on the sensory load from occupants of different age and activity and from a range of buildings with high and low pollution loads are available.

A.2 Pollutant sources

A.2.1 Building, materials and equipment

The building, the materials used and the equipment used within the building are all sources of pollutants. This is the case not just when they are new, but also when they are used, refurbished or cleaned, and as they get older.

Sources include

- the building structure and material; see Annex D,
- the furniture and soft furnishings,
- building services equipment, e.g. filters, dust or odour sources in ducts; see Annex F,
- computer equipment, photocopying machines, etc.

A.2.2 Occupants and processes

The occupants and the processes taking place in the building represent another set of pollutant sources. These include

- body odour, skin cells, cosmetics,
- food, drink, smoking, toilets,
- printing, photocopying, use of other equipment, paper storage, cleaning,
- other processes, e.g. combustion processes, chemicals specific to the activities in the building,
- biological contaminants such as bacteria, viruses, fungi, moulds, spores, dust mites, pollen, human and pet dander, etc.

A.2.3 External environment

The external environment can be a source of pollutants, with sources including air, soil and water. For example, heavy traffic, industrial processes, mining, contaminated land or sources of allergenic material in the locality can all have a significant impact on the IAQ. Information on acceptability of outside air is given in WHO guidelines; see Annex C. Many national or local authorities also set limits for the outdoor air, which the designer should consider when specifying the need for air cleaning.

Pollutants can be classified as particles or gases.

a) Particles

The size of particles is often indicated as an aerodynamic diameter. Particles in the atmosphere vary in size from less than 0,01 µm up to objects the size of leaves and insects. Studies of atmospheric particles show that their size distribution is often bimodal, i.e. the particles are made up of two separate fractions, one fine and one coarse. Coarse particles, about 2,5 µm and larger, consist of natural dust from the effect of wind, erosion, plants, volcanoes, etc. The finer fraction, made up of particles smaller than 2,5 µm, originates primarily from human activity in the form of combustion products, vehicle emissions and other processes. The total distribution and concentration of atmospheric dust varies greatly, depending on the place, season, time of day, etc.

The atmospheric dust is composed of inert particles and viable and non-viable biological particles (e.g. fungal spores, bacteria and viruses). Most allergens are particles containing proteins (from furry animals, pollens, mites, etc.). All proteins are different but they are about the same in size and react with the same type of biological mechanism. There are theories that exposure to pollution from pollens can increase the allergic reaction to them. The allergens are normally connected to larger particles.

b) Gases

Industry, vehicles, heating appliances and power generation sites emit gases (e.g. sulfur dioxide, ozone, radon, nitrogen oxide, carbon monoxide and VOCs).

This document assumes that the outdoor air is generally acceptable for health and comfort for the purpose of dilution ventilation. Where it has been established that the outdoor air is not acceptable, pre-treatment of the outdoor air can be needed; otherwise the IAQ can also fail to reach an acceptable level.

A.3 Choice of methods of control

A.3.1 Available methods

There are many ways to reduce pollution in the indoor air. Ventilation is often regarded as convenient because it can be seen as addressing all pollutants of indoor origin at the same time. However, it is not always the best solution. The choice of one approach against another depends on a number of factors, including the nature of the pollutant itself, its source characteristics, the effect of the pollution on people and the relative practicability and economics (initial costs and operating costs). Thus, knowledge of pollutants and methods of control affect not only the execution of a method of control but also the choice.

The following measures, in sequential order of preference, should be adopted to eliminate or reduce the exposure of occupants to airborne contaminants in buildings.

a) Source control; see A.3.2

— Eliminate the sources of the contaminant(s).

— Substitute with sources that produce less harmful or less malodorous contaminants.

— Modify the sources to reduce emission rate of contaminants(s).

— Institute local pollutant management; see Clause A.4.

— Segregate occupants from potential sources of contaminants.

— Improve local ventilation, e.g. by local exhaust (if source of contamination is local).

— Use air cleaning to reduce local pollutants.

b) Ventilation; see Clause A.5

— Improve ventilation effectiveness, for example by choice of system type: mixing versus displacement.

— Use appropriate overall ventilation rate.

— Use appropriate air cleaning.

— Require personal protection.

These measures are not mutually exclusive and some combination is usually necessary. Adequate ventilation is always required, whatever other approaches are also used.

A.3.2 Source control

A.3.2.1 Elimination

Elimination of a source means taking a source away altogether because it is not needed in the building. This can mean, for example, moving storage of source material or processes to another location or restricting certain activities (e.g. smoking, using correction fluids). In some cases, even eating and drinking can come to represent a significant source and can be restricted, at least in time if not in space.

A.3.2.2 Substitution

If the source of pollution is necessarily present in the building in some form, then consideration can be given to using materials or equipment that emit pollutants at a lower rate. The following are examples of possible approaches.

— Low-emission materials should be selected for actual use during its entire life for the basic structure, the furnishings, building services and materials used in cleaning the building.

— All new buildings should be designed to minimize unacceptable odour as far as reasonably practicable and economically viable.

— It is also important to reduce pollution sources within ventilation or air-conditioning systems, including the entrainment of outdoor pollution into air intake; see Annex F.

— Regular cleaning and maintenance of systems and furnishings are also very important factors in reducing odours.

A.3.2.3 Modification

Even if a source is inherently a high emitter, it is sometimes practicable to modify it to reduce emissions. For example, materials emission rates vary over time and with temperature and humidity. So positioning materials in buildings (and ventilating spaces at a high rate) in advance of occupancy can reduce emission rates when the building is later occupied.

In principle, this process can be enhanced by heating the building to a temperature higher than normal, a process sometimes referred to as “bake-out”. In practice, this is difficult to do without the adsorption and re-emission of pollutants and without the high temperature damaging building components or contents.

A.4 Local pollutant management

A.4.1 Segregation

This involves separating the occupants from sources of pollutants. For example, in terms of the processes within an office, paper storage can be in a separate area from workers, or there can be a separate area for printers and photocopiers and designated smoking areas. Where such an approach is taken, special attention should be given to ventilation and airtightness where the pollution sources are located. Additional ventilation measures are generally required in such areas.

A degree of segregation can be achieved without a complete physical barrier by increasing the distance between source and occupants or by using an air curtain.

A.4.2 Local exhaust

Local exhaust close to pollutant sources, e.g. a photocopier or an area where chemicals are used, can reduce the requirement for total ventilation of the building. Air curtains can sometimes improve exhaust efficiency.

A.4.3 Local air cleaning

Local air cleaning (particle/gaseous filtration) can be used to clean pollutants generated in a localized area; see Annex E.

A.5 Dilution

A.5.1 Overall ventilation rate

Ventilation of one kind or another is the most common approach to reducing levels of pollution in buildings. The usual strategy is simply to introduce outdoor air (assumed to be fresh air) at a rate calculated to be necessary to dilute the pollution in the building. The principles are quite simple: identify the pollutants that are present, determine their effects on human beings and calculate what concentrations should be allowed. The sources in the building, the production rate and the target concentration levels are then used to calculate the required fresh air supply rate. In practice, the designer rarely has all the required information and it is necessary to make some estimations or assumptions. Additional dilution might not be an appropriate control strategy for some biological contaminants.

Where recirculated air is used, care should be taken that spaces served by common recirculation systems are of similar occupancies, unless the recirculated air is acceptably treated. Where air is recirculated or transferred from a space where smoking is not prohibited to another space, both spaces are to be treated as spaces where smoking is allowed and ventilation rates calculated accordingly.

A.5.2 Ventilation effectiveness

The air quality might 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; see Annex G.

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 has a value of 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.

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 can be calculated by numerical simulation or measured experimentally.

A.5.3 Air cleaning

Cleaning of the air delivered to a space reduces the pollutant concentration in the space. Recirculation and ventilation airstreams may be cleaned and they may be cleaned separately and/or after they have been combined. Where there is a risk of exhaust air being re-entrained into the ventilation air, cleaning the exhaust air can also improve IAQ. Normally, this should not arise because the locations of exhaust and intake openings should be located to avoid re-entrainment, although cleaning of the exhaust air can still be required if the outdoor environment around the exhaust would otherwise be adversely affected.

Air cleaners (“filters”) are of two types: particulate air cleaners and gas-phase air cleaners.

Different standards have differing recommendations about the minimum efficiencies of filters, but they generally agree that there should be two stages of filtration of outdoor air (pre-filter and main filter). For more details, see Annex E.

Annex B
(informative)

Methods of expressing IAQ

B.1 Methods of expressing IAQ

IAQ may be expressed in terms of the health risk to the occupants or/and the occupants' expression of acceptability, based on their perception of the IAQ.

— In terms of health, the pollutant concentration levels when compared to acceptable levels as established by approved authorities provides an expression of IAQ. Some regulations also impose minimum concentration or airflow rates for hygiene.

— In terms of acceptability, the percentage of people who perceive that the air is unacceptable (percent dissatisfied) is an expression of the quality of air from a comfort point of view. This criterion may be based on either unadapted or adapted people.

Either of these methods can be used to design a system. The designer shall use the methodology in Clause 6 before using a method in a design and should apply only a single methodology throughout a project. A designer can use more than one method to cross-check the conclusions; however, it is critical that he be consistent in applying the appropriate methods. Tables B.1 and B.2 summarize the different methods that permit the calculations and the criteria that are taken into account. Both tables allow the designer first to decide which factors to take into account and then to select a method of expressing IAQ that covers all or most of the selected factors.

In Table B.1, the column headings start with the general type of method and then show which documents (standards, etc.) include a method of that type.

In Table B.2, the column headings start with the document and then show which general types of method are available in that document. There is a spare column in which the designer can enter information on alternative documents (e.g. a national standard or a future revision of a standard).

The headings in Table B.1 are expanded in Clauses B.2, B.3 and B.4 following the same logical structure.

Table B.1 — Factors taken into account in different methods of expressing IAQ

Factors taken into account			Basis of standard/guidance																			
			Ventilation rate								Target concentration								Health risk			
			Health				Comfort (PAQ)				Health				Comfort (PAQ)							
			AS 1668.2	ASHRAE 62.1	EN 13779	CR 1752	EN 13779	CR 1752	ASHRAE 62.1	AS 1668.2	ASHRAE 62.1	EN 13779	CR 1752	AS 1668.2	EN 13779 [a]	ASHRAE 62.1	CR 1752	AS 1668.2	AS 1668 [b]			
Approach to multiple pollutants	Independent/none		X				X			X	X	X	X	X	X	X	X	X	X			
	Partial addition						X															
	Add			X		X		X	X													
Comfort assumption	Adapted								X	X								X				
	Unadapted						X	X		X					X			X				
Health basis	Short-term (< 1 day)		X								X			X								
	Long-term (> 1 day)		X								X			X					X			
Population	Children		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
	Working-age adult		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
	Elderly		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
	People with health-related sensitivity (e.g. asthma)																					
Emission sources	People	per square metre	X	X			X	X	X	X				X	X			X				
		number	X	X			X	X	X	X				X				X	X			
	Smoking						X	X		X								X	X			
	Materials/equipment		X	X	X	X	X	X	X	X				X				X				
	Effect of temperature/ RH/air flow									X								X				

Table B.1 (*continued*)

Factors taken into account		Basis of standard/guidance																			
		Ventilation rate								Target concentration								Health risk			
		Health				Comfort (PAQ)				Health				Comfort (PAQ)							
		AS 1668.2	ASHRAE 62.1	EN 13779	CR 1752	EN 13779	CR 1752	ASHRAE 62.1	AS 1668.2	ASHRAE 62.1	EN 13779	CR 1752	AS 1668.2	EN 13779 [a]	ASHRAE 62.1	CR 1752	AS 1668.2	AS 1668 [b]			
Ventilation	Rate	X	X	X	X	X	X	X	X				X	X			X	X			
	Recirculation	X	X	X	X	X	X	X	X				X	X			X	X			
	Effectiveness	X	X	X	X	X	X	X	X				X	X			X	X			
	Air movement between zones	X						X	X				X				X				
Modifying mechanism	Air cleaning	X						X	X	X			X		X		X	X			
	Sink effects													X							
Outdoor air	Concentrations	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Zone	Multi-zone	X	X			X	X	X	X				X	X			X				
	By zone	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Variation	Complete day	X	X			X	X	X	X				X				X	X			
	Shorter periods	X	X					X	X				X				X				
	Occupancy	X	X					X	X				X				X	X			
Output (ventilation requirement)	Default table	X	X	X	X	X	X	X	X				X				X				
	Calculation for each case	X							X	X	X	X	X	X	X	X	X	X			
	More than one target level					X	X		X					X			X	X			

[a] For CO_2.

[b] For the environmental tobacco smoke harm index (ETSHI).

Table B.2 — Factors taken into account in different documents that offer methods of expressing IAQ

Factors taken into account		ASHRAE 62.1				AS 1668.2				CR 1752				EN 13779				….			
		VRP [a]	IAQP [b]	……		Prescriptive	Engineering	Natural ventilation	ETSHI	Rate	IAQ			Ventilation rate	CO_2	PAQ	Mass balance				
Procedure	Ventilation rate	X				X	X	X	X					X		X					
	Target concentration		X			X	X		X						X	X	X				
	Health risk								X												
Criterion	Health	X	X			X	X	X	X												
	Comfort	X	X			X	X	X						X	X	X					
Approach to multiple pollutants	Independent/none					X	X	X	X						X		X				
	Partial addition					X	X							X							
	Add	X														X					
Comfort assumption	Adapted	X				X	X														
	Unadapted	X				X	X							X	X	X					
Health basis	Short-term (< 1 day [c])	X	X			X	X	X													
	Long-term (> 1 day [c])	X	X			X	X	X	X												
Population	Children		X			X	X	X													
	Working-age adult	X	X			X	X	X	X					X	X	X					
	Elderly		X			X	X	X													
	People with health-related sensitivity (e.g. asthma)		X			X	X	X													

Table B.2 (*continued*)

Factors taken into account			ASHRAE 62.1				AS 1668.2				CR 1752				EN 13779				….			
			VRP [a]	**IAQP** [b]	**……**		**Prescriptive**	**Engineering**	**Natural ventilation**	**ETSHI**	**Rate**	**IAQ**			**Ventilation rate**	**CO_2**	**PAQ**	**Mass balance**				
Emission sources	People	per square metre	X				X	X	X	X					X	X	X					
		per cubic metre																				
	Smoking						X	X	X	X												
	Materials/equipment		X				X	X	X													
	Effect of temperature/ RH/air flow						X	X														
Ventilation	Rate		X				X	X	X	X					X	X	X	X				
	Recirculation		X				X	X		X					X	X		X				
	Effectiveness		X				X	X							X	X	X	X				
	Air movement between zones						X	X	X													
Modifying mechanism	Air cleaning		X	X				X		X												
	Sink effects																					
Outdoor air	Concentrations		X	X			X	X							X	X	X	X				
Zone	Whole building		X				X	X	X						X	X	X	X				
	By zone		X				X	X	X	X					X	X	X	X				
Variation	Complete day		X				X	X	X	X					X	X	X	X				
	Shorter periods						X	X								X		X				
	Occupancy						X	X	X	X												
Output	Default table								X						X		X					
	Calculation for each case						X	X	X	X						X		X				
	More than one target level							X		X					X	X	X					

[a] Ventilation rate procedure.

[b] indoor air quality procedure.

[c] 1 day is a standard working day up to 8 h of exposure.

B.2 Methods based on ventilation rate

B.2.1 Ventilation for health

At present, there are no standards that offer ventilation rates based only on protection of health. However, methods based on comfort, as described in B.2.2, are generally also held to protect health under most circumstances. Where health is of primary concern, a target concentration (see Clause B.3) or health risk approach (see Clause B.4) should be used.

B.2.2 Ventilation for comfort

B.2.2.1 Introduction

In the various standards, there are several approaches to determining the appropriate ventilation rate for comfort. These are described below and cross-referenced to specific standards and guidance where appropriate.

B.2.2.2 Tabulated ventilation rates

Acceptable air quality is achieved by providing ventilation air of a specified quality and quantity into the occupied space. Prescriptive methodologies are available in which a specific amount of ventilation air is recommended in order to dilute the pollutant levels to acceptable concentrations. Tables are provided for specifying the amount of ventilation air required for various types of occupancies. Ventilation may be specified "per person" or "per unit area" or "per unit volume" or in "air changes per hour".

— When based on the number of persons, the amount of ventilation air required is specified as a unit per person. Therefore, the number of occupants expected in the occupied zone shall be determined in order to calculate the total ventilation air for the building as described in Clause 6. This approach assumes either that the occupants are the only pollutant source or that pollutant emission from other sources is proportional to the number of occupants, e.g. there is a fixed floor area per occupant.

— When based on floor area, the ventilation air required is specified as a unit per square metre. Therefore the total area in the building shall be determined in order to calculate the total ventilation air for the building as described in Clause 6. This approach assumes that all pollutant emissions are proportional to floor area. The implication is either that people are not normally present or that there is a fixed number of people per unit area.

It is also possible to specify both a rate per person and an additional rate per unit area. This allows both people and other sources to be taken into account on the most logical, simple basis.

This method implicitly assumes a certain level of indoor pollution sources, air cleaning and a known level of outdoor pollutant concentrations, as well as ventilation effectiveness. This approach is, therefore, subject to potentially large inaccuracies if applied in circumstances that differ significantly from those from which the specified rates were derived. It is most suitable for use within countries or restricted climatic regions, in specified building types and with consistent building practice. Within these limitations, it can short-cut many of the complications of specifying ventilation rates.

B.2.2.3 Ventilation rate for acceptable IAQ — ASHRAE 62.1 [2]

A ventilation rate calculation method is intended to provide air quality levels that satisfy a substantial majority of adapted persons (occupants) in spaces that are properly designed, maintained and operated and that are being used for their intended purpose. For each ventilation system, this method prescribes minimum supply air rates for each space served by the system as well as an overall system outdoor air rate.

B.2.2.4 Perceived air quality method — CR 1752 [4]

Humans judge the acceptability of air quality based partly on a feeling of comfort that comes from information collected by their sensory organs. It is important to realize that this perception is not directly linked with health effects.

This method is available to designers to be able to classify a building or occupancy types into three categories, i.e. A, B and C, of air quality perceived by unadapted visitors. The “A” category building is designated at a higher quality level than “B” and “C”; thus the “A” category building is ventilated at a higher rate (for any given rate of indoor pollutant emission) than the other two. An easy-to-read table can be referenced to determine the ventilation rate for each type of occupancy.

B.2.2.5 Amenity index — AS 1668.2 [3]

Some standards allow for the achievement of different levels of ventilation amenity, represented by the calculation of a dilution index for various types of enclosures and different contaminant levels. Higher values represent a higher ventilation amenity. Procedures allow the designer to calculate a dilution index for various enclosures and calculate the ventilation and air cleaning parameters necessary to achieve pre-selected conditions.

B.2.2.6 Equilibrium ventilation rate — AS 1668.2 [3]

The equilibrium ventilation rate procedure is a prescriptive procedure that can be used to determine the minimum flow rate required for a system. Depending on the activity level in an occupied space, the table provides guidance on the amount of ventilation air required. Different values are recommended depending on whether the system applies to a single-zone or to a multiple-zone building. Recommended values change depending on the room temperature.

B.3 Target concentration value

B.3.1 Mass balance approach

B.3.1.1 Basis of approach

This contaminant concentration level procedure provides a methodology to calculate the ventilation rate required to meet a specified concentration level for a specific pollutant. In such procedures, it is necessary to identify the most critical pollutant (chemical or group of chemicals) and to estimate the pollution load of those chemicals in the space. Furthermore, a guideline value from a recognized body or body having jurisdiction, as appropriate, should be available for that pollutant.

B.3.1.2 Steady-state calculation of mass balance

The ventilation rate, q_{V}, expressed in cubic metres per second, required for diluting a pollutant in steady-state condition is calculated from Equation (B.1):

$$q_{\text{V}} = \frac{G_h}{C_{h,\text{i}} - C_{h,\text{o}}} \times \frac{1}{\varepsilon_{\text{V}}} \tag{B.1}$$

where

G_h is the emission rate of a chemical, h, expressed in milligrams per second;

$C_{h,\text{i}}$ is the guideline concentration value of a chemical, h, expressed in milligrams per cubic metre;

$C_{h,\text{o}}$ is the outdoor concentration of a chemical, h, at air intake (or supply), expressed in milligrams per cubic metre;

ε_v is the ventilation effectiveness.

The concentrations $C_{h,\text{i}}$ and $C_{h,\text{o}}$ may also be expressed on a volume-per-volume basis.

NOTE Microlitres per litre is equivalent to volume parts per million (ppm), a deprecated unit.

In this case, the chemical pollution load, G_h, is expressed as litres per second and the equation has the form given in Equation (B.2):

$$q_\text{v} = \frac{G_h \times 10^6}{C_{h,\text{i}} - C_{h,\text{o}}} \times \frac{1}{\varepsilon_\text{v}} \quad \text{(B.2)}$$

In cases where there are several pollutants, it can be necessary to check all relevant pollutants in order to determine the most critical one.

B.3.1.3 Non-steady state conditions

Equation (B.1) is valid for a steady-state situation (default situation) with a long-lasting, constant emission. When the emission period is short, the stationary equilibrium-concentration might not be achieved or the airflow can be reduced for a given maximum concentration level. The time-dependence of the concentration level in the room is given by Equation (B.3), assuming that the supply air rate is equal to the extract air rate:

$$C_h(z) - C_{h,\text{o}} = C_h(0) + \frac{G_h}{q_\text{v}} \left(1 - e^{-\frac{q_\text{v}}{V_\text{r}} \cdot t} \right) \quad \text{(B.3)}$$

where

G_h is the emission rate of a chemical, h, expressed in milligrams per second;

$C_h(z)$ is the guideline concentration value of a chemical, h, expressed in milligrams per cubic metre, at time z;

$C_{h,\text{o}}$ is the outdoor concentration of a chemical, h, at air intake (or supply), expressed in milligrams per cubic metre;

V_r is the volume of air in the room, expressed in cubic metres;

t is the time, expressed in seconds;

q_v is the air flow, expressed in cubic metres per second.

B.3.2 Target values for health

Exposure to pollutants in the air can constitute a certain health risk. Adverse health effects can be comprised of short-term effects or long-term adverse effects like cancer. To limit the health risk to a low level, maximum permissible concentrations and corresponding exposure times for individual chemicals are available. National authorities have determined occupational exposure limits [e.g. threshold limit values (TLV) in the USA] in industrial environments where workers are exposed to a few known chemicals. Some countries use a certain fraction of TLV to be applied as a limit value for non-industrial premises; alternatively, a fraction of the lethal dose for 50 % of a given animal population, LD_{50}, may be used.

If the production rates of specific pollutants of concern are known and target values are available, analytical procedures exist to calculate the ventilation rate required to achieve a contaminant concentration level acceptable from a health point of view. Annex C provides recommended guideline values for common pollutants found in indoor and outdoor air, derived from the World Health Organization (WHO) air quality guidelines. WHO guidelines are not recognized standards, but represent the best scientific judgement at the time at which they are written. Many national authorities also set concentration limits for workplaces but these tend to relate to industrial settings in which there is a risk of high concentrations of one or a few pollutants arising from industrial processes. For broader application, in environments with multiple pollutants at relatively low concentrations, the WHO guidelines are generally to be preferred. Designers should consult these guidelines, together with any applicable national regulations, in order to determine the rationale on which the tabulated values are based.

B.3.3 Target values for comfort

Human occupants produce CO_2, water vapour and contaminants, including particulate matter, biological aerosols and VOCs. The target concentration for comfort is based on CO_2 as an indicator of human bioeffluents.

This method assumes implicitly a certain level of indoor pollution sources, air cleaning and a known level of outdoor pollutant concentrations, as well as ventilation effectiveness. This approach is, therefore, subject to potentially large inaccuracies if applied in circumstances that differ significantly from those from which the specified rates were derived. It is most suitable for use within countries or restricted climatic regions, in specified building types and with consistent building practice. Within these limitations, it can short-cut many of the complications of specifying ventilation rates.

CO_2 is a good indicator for the emission of human bioeffluents. Classification by the CO_2 level is well established for occupied rooms, where smoking is not allowed and pollution is caused mainly by human metabolism. Equation (B.2) may be used to calculate the necessary airflow rate depending on the chosen CO_2 level.

EN 13779 [45] gives the following four levels (from most to least acceptable) of typical specifications for the total CO_2 concentrations, which are caused mainly by people, in rooms above outdoor levels:

a) $<$ 400 µl/l[1];

b) 400 µl/l to 60 µl/l;

c) 600 µl/ to 1,000 µl/l;

d) $>$ 1,000 µl/l.

ASHRAE 62.1:2007 [2], Appendix C, provides a rationale for the minimum physiological requirements for respiration air based on CO_2 concentration. For example, for sedentary persons, it calculates a CO_2 level of approximately 700 µl/l above the outdoor level.

NOTE CO_2 is a good indicator in spaces where the occupation density is high (e.g. schools, auditoria), but can be insufficient in some cases (hygiene rooms, smoking zones) and in the presence of other pollutants.

B.4 Health risk method

AS 1668.2 [3] is the only standard that takes this approach at present with the “environmental tobacco smoke harm index (ETSHI)”. The ETSHI is an expression of an index accounting for a significant part of the mortality risk associated with a specified exposure to environmental tobacco smoke in an environment that is ventilated and is either fitted or not fitted with devices for removal of some ETS components that contribute to the risk.

1) The units “µl/l” are equivalent to volume parts per million (ppm), a deprecated unit.

Annex C
(informative)

Examples of WHO air quality guidelines

The values given in Table C.1 are based on the exposure to single airborne chemicals through inhalation alone. They do not take account of additive, synergistic or antagonistic effects (except for the combined exposure to sulfur dioxide and particulate matter) or exposure through routes other than inhalation. The basis for derivation is different for each chemical; hence, they cannot be compared with each other within an overall hierarchy of exposure effects. The WHO guidelines provide information on typical sources, occurrence in air, typical concentrations reported, routes of exposure, metabolic processes, proven and suspected health effects and an evaluation of human health risks for each chemical.

For particulate matter, a guideline figure is not provided, although there are local or regional guidelines for outdoor air pollution in many areas. These guidelines should not be applied directly to the indoor air, since the composition of indoor particles is different and, therefore, the same health effects should not be expected. However, outdoor air quality and the related guidelines can be used in decisions about the approach taken to cleaning intake air.

Table C.1 — WHO guideline values for individual substances (Reference [6])

Substance	Averaging time	Guideline value concentration in air $\mu g \cdot m^{-3}$	Notes (from Reference [6])
Arsenic	Lifetime	—	Estimated 1 500 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$
Benzene	Lifetime	—	Estimated 6 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$
1,3-butadiene	No value in WHO	—	
Cadmium	Annual	0,005 [a]	
Carbon monoxide	15 min	100 000 [b]	
	30 min	60 000 [b]	
	1 h	300 000 [c]	
	8 h (running)	100 000 [c]	
Chromium(VI)	Lifetime	—	Estimated 40 000 deaths from cancer in population of 1 million through lifetime exposure of 1 $\mu g \cdot m^{-3}$
1,2-dichloroethane	24 h	700	
Dichloromethane-(methyl chloride)	24 h	3 000	
	1 week	450	
Formaldehyde	30 min	100	
Hydrogen sulfide^{-3}[d)]	24 h	150	
Lead	1 year	0,5	

Table C.1 (*continued*)

Substance	Averaging time	Guideline value concentration in air µg·m^{-3}	Notes (from Reference [6])
Man-made vitreous fibres – refractory ceramic fibres (MMVF – RC)	Lifetime	—	Estimated 40 000 deaths from cancer in population of 1 million through lifetime exposure of 1 µg·m^{-3}
Manganese	1 year	0,15	
Mercury	1 year	1	
Nickel	Lifetime	—	Estimated 380 deaths from cancer in population of 1 million through lifetime exposure of 1 µg·m^{-3}
Nitrogen dioxide	1 h	200	
	1 year	40	
Ozone	8 h	120	
PM_{10} (particulate matter < 10 µg·m^{-3} diameter)	No values in WHO	—	
Radon	Lifetime	—	Estimated 30 to 60 deaths from cancer in population of 1 million through lifetime exposure of 1 Bq·m^{-3}
Styrene	1 week	260	
Sulfur dioxide	10 min	500	
	24 h	125	
	1 year	50	
Tetrachloroethylene	24 h	250	
Toluene	1 week	260	
Trichloroethylene	Lifetime	—	Estimated 4,3 deaths from cancer in population of 10 million through lifetime exposure of 1 m^{-3}

[a] The guideline value is based on the prevention of a further increase of cadmium in agricultural soils, which is likely to increase the dietary intake.

[b] Not re-evaluated for the second edition of the guidelines.

[c] Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 h.

Annex D
(informative)

Emissions from building materials

D.1 Measurement of emissions from materials by chamber methods

In 1993, CEN began work on the preparation of a European standard for measuring VOC emissions from new building materials. The main driving force for the work was the requirement for comparable measurements to demonstrate whether products met the requirements for Hygiene, Health and Environment (Essential Requirement No. 3) under the Construction Products Directive.

The harmonized standards being developed by CEN (the European Standard Committees), e.g. CEN/TC 134 for floor coverings, CEN/TC 193 for flooring installation materials (adhesives, primers and smoothing compounds), CEN/TC 38 for timber and timber treatment products and CEN/TC 139 for paints and varnishes, have to provide both the consumers and sellers with a legal basis to certify the product in relation to health and safety and environment issues, as well as provide a harmonized basis for comparison of product properties for building applications.

Equally important was the development of national and industry-based material labelling schemes based on VOC emission. The work undertaken within the European Collaborative Action provided the technical basis for ISO 16000-6 [40], ISO 16000-9 [41], ISO 16000-10 [42] and ISO 16000-11 [43].

ECA COST Project 613 (1989) published a guideline for the determination of the steady-state formaldehyde emission. This guideline is based principally on tests in a large (walk-in) chamber, although data from small-scale chambers ($\leqslant 1\ m^{-3}$) are also included.

CEN/TC 112 is responsible for preparing the European standards for testing the formaldehyde emission from wood-panel products. Their work is adopted in ISO 12460 (all parts) [7]. It is based on establishing a steady-state formaldehyde concentration due to the release of formaldehyde from the panel product contained in a chamber over a 28 day period.

D.2 Labelling and certification schemes for low-emission products

Product labelling, based on health, safety and durability, can be a valuable tool to assist designers, specifiers and other consumers in the selection of products. Certification can be a good marketing tool for the industry to demonstrate the quality of products and provide a harmonized basis for comparison of quality for materials to be used in building applications. ISO 16000-6 [40], ISO 16000-9 [41], ISO 16000-10 [42] and ISO 16000-11 [43] provide a means for testing VOC emission from materials and, therefore, the basis for certification of a product. However, an agreed, harmonized classification of products based on emission rates is required to demonstrate compliance with the Essential Requirement No. 3 of the European Construction Products Directive. As of the publication date of this document, no European product standard includes recommended limits for VOC emissions. However, a number of labelling schemes and guidelines were operating in Europe.

The European Commission published a report in 1997 about the evaluation of VOC emissions from solid flooring materials with respect to their potential effects on human health and comfort when the material is used in buildings. It also provides a strategy for setting up labelling schemes for assessing chemical emissions from flooring products. Although the report focuses on flooring materials, the principles for evaluating VOC emissions can also be applied to other building products.

VOC emissions from carpets have been a major issue in the USA. This was brought to the fore by sickness complaints after the installation of carpet in the US Environment Protection Agency headquarters (Reference [24]). This led to petitioning to require testing of VOC emissions from carpets and to limit the emission of 4-phenylcyclohexene, which was formed from the Diels-Alder reaction between styrene and butadiene monomers. A US “Carpet Dialogue” was constituted to form a voluntary labelling scheme (http://www.carpet-rug.com) with the aim of reducing VOC emissions from carpets. Also, the carpet industry is required to periodically test the emission of TVOC from products as part of quality-control procedures and to provide consumers with comparative information on the TVOC emission. The State of California regulations concerning VOC emissions from paints and varnishes and the State of Washington’s East Campus Plus Program were designed to address air-quality problems in office buildings. These specify that all materials used in the construction of new office buildings, including furnishing and finishing, comply with requirements for emissions of formaldehyde, TVOC and particulates.

In Europe, a number of labelling schemes have been introduced to control VOC emissions from building materials. A summary of the requirements of these labelling schemes for flooring products and for paints and coating products is provided in Tables D.1 and D.2.

D.3 Emissions databases

Building materials and products are major sources of VOC emissions in indoor environments. The results of emission tests have been reported in many studies, and databases have been developed to allow building professionals and others to extract data about product emission characteristics.

A database[2)] of indoor air pollution sources called SOPHIE (Sources of Pollution for a Healthy and Comfortable Indoor Environment) was developed under a collaborative project supported by the JOULE programme of the European Commission. This database covers three types of VOC emission source: building materials, furnishings and HVAC components. The main features of the database include the characteristics of the building and furnishing materials and some HVAC components; chemical emission rates; sensory effects (odour and mucous irritation ratings); toxicology of the chemicals; and an evaluation of the impact on pollution loads in the indoor environment based on a “model room” of 17,4 m^3 and a 0,5 h^{-1} air change rate. The expected VOC concentration in the room for a selected material is calculated, providing an evaluation of the perceived IAQ for the occupant. The emission rate data are based only on measurements taken 3 days and 28 days after exposure in the test chamber. Materials were tested using small-scale (volume on the order of litres) chambers as well as the standard-sized chambers (1 m^3, 0,125 m^3) or by emission cells (e.g. 35 ml). The protocol for testing of the materials is largely as given in accordance with ISO 16000-6 [40], ISO 16000-9 [41], ISO 16000-10 [42] and ISO 16000-11 [43].

SOPHIE allows emission data to be entered and search engines to be used for interpreting these data (chemical and sensory irritation rating) and toxicological information on the emission sources. It is also an evaluation tool, which allows the indoor pollution impact of building and furnishing materials to be compared, ranked and assessed. Prediction of indoor concentrations of VOCs can be made for a selected material or HVAC component and for a given ventilation rate.

Several research organizations in Europe and in America have developed emissions databases for their own use and for access by consumers and building designers. For example, an emissions database has been developed at BRE (http://www.bre.co.uk/), based on the analysis of VOC emissions from a variety of building materials collected on site during construction of an office building [36]. This database contains emission rate data for the major chemicals and describes the products, including where they are installed in the building. Emission data can be used in the BREEZE model of air movement and ventilation [37] to predict concentrations of pollutants in an indoor environment.

The Danish Society of Indoor Climate has developed a database that tests and labels building products according to their impact on IAQ (http://www.danskbyggeri.dk/). VTT in Finland has also developed a database [38].

A “Source Ranking Database” program has been developed in the USA by the US Environment Protection Agency (US EPA), Indoor Air Source Characterization Project, to provide a mechanism for building designers

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2) The listed databases are examples of suitable products available commercially. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of these products.

to select the least environmentally harmful materials. The VOC emission rates of materials, product formulation, sizes of exposed populations and the quantitative toxicity data as well as the toxic effects of the VOCs are included in the database.

The US EPA has also made available on the internet a “Multi-Chamber Concentration and Exposure Model” (MCCEM) (http://www.epa.gov/) for users to estimate average and peak indoor air concentrations of chemicals released from products or materials in houses, apartments, townhouses or other residences. The model can also be used to assess other indoor environments, e.g. schools and offices, if the user can supply the necessary input data. The model can evaluate a person's inhalation exposure of VOCs and calculate the single-day doses, chronic average daily doses or lifetime average daily doses.

Table D.1 — European labelling schemes for low-emission flooring products

<table>
<tr><th>Labelling schemes</th><th colspan="4">Classification requirements/Description</th></tr>
<tr><td>Danish voluntary labelling scheme</td><td colspan="4">Requires evaluation of the VOC emission rates and odour and irritation thresholds of the flooring materials in an environmental chamber or cell, with results scaled to a 17 m^3 modelled room.</td></tr>
<tr><td>Finnish M1 label for finishing materials

http://www.rts.fi/</td><td colspan="4">Requires measurements of TVOC ($< 200\ \mu g \cdot m^{-2} \cdot h^{-1}$), carcinogens ($< 5\ \mu g \cdot m^{-2} \cdot h^{-1}$), formaldehyde ($< 50\ \mu g \cdot m^{-2} \cdot h^{-1}$), ammonia ($< 30\ \mu g \cdot m^{-2} \cdot h^{-1}$) and odour dissatisfaction (15 %) after 28 days of exposure in an environmental chamber.</td></tr>
<tr><td>GuT, Environmental Quality Mark for Carpets

http://www.gut-ev.org/</td><td colspan="4">Regulates emissions of CFCs, pesticides, carcinogens (recognized, proven or suspected, e.g. benzene, butadiene, vinylchloride, vinylacetate and formaldehyde), which shall not be detected in product; and limits emission of toluene ($50\ \mu g \cdot m^{-3}$), styrene ($5\ \mu g \cdot m^{-3}$), 4-vinylcyclohexene ($2\ \mu g \cdot m^{-3}$), 4-phenylcyclohexene ($20\ \mu g \cdot m^{-3}$), TVOC ($30\ \mu g \cdot m^{-3}$), total aromatic hydrocarbons ($150\ \mu g \cdot m^{-3}$), and odours, tested in a standard environmental chamber. Dyes or auxiliary substances shall not contain heavy metals, such as lead, cadmium, mercury or chromium(VI).</td></tr>
<tr><td rowspan="6">GEV EMICODE Labelling System for adhesives, primers and smoothing compounds

http://www.emicode.com/</td><td colspan="4">The product is analysed for carcinogenic compounds after 24 h of exposure in an environmental chamber. The substances are classified as a recognized (C1), a proven (C2) or a suspected (C3) carcinogen according to European Directives or German legislation.

The following carcinogenic compounds are currently restricted:
C1: acrylamide, acrylonitrile, benzene, 1,4-dioxane;
C2: acetaldehyde and formaldehyde;
C3: vinylacetate.

EMICODE sets the following limits:
C1 substances: $< 2\ \mu g \cdot m^{-3}$,
C2 substances: $< 10\ \mu g \cdot m^{-3}$;
C3 substances: $< 50\ \mu g \cdot m^{-3}$.

TVOC and the principal VOCs (above $20\ \mu g \cdot m^{-3}$) are also quantified, after 10 days of exposure. The following three categories of product are used, based on TVOC emission rates.</td></tr>
<tr><th rowspan="2">Product</th><th colspan="3">TVOC emission rates by product category
$\mu g \cdot m^{-3}$</th></tr>
<tr><td>EC 1</td><td>EC 2</td><td>EC 3</td></tr>
<tr><td>Primers</td><td>< 100</td><td>100 to 300</td><td>> 300</td></tr>
<tr><td>Levelling compounds</td><td>< 200</td><td>200 to 600</td><td>> 600</td></tr>
<tr><td>Flooring adhesives</td><td>< 500</td><td>500 to 1 500</td><td>> 1 500</td></tr>
</table>

Table D.1 (*continued*)

<table>
<tr><th>Labelling schemes</th><th colspan="3">Classification requirements/Description</th></tr>
<tr><td>Swedish standard for floorings
GBR/SP Trade standards GBR 1992.</td><td colspan="3">Requires measurement and declaration of TVOC emission rates after 4 weeks and 26 weeks of exposure of the flooring materials in an emission cell, and the 10 principal individual VOCs.</td></tr>
<tr><td>Nordic Swan Ecolabelling Programme</td><td colspan="3">The scheme prohibits the presence in the product of carcinogens, halogenated VOCs, organic tin compounds, phthalates, polybrominated diphenyl ethers and also substances that are mutagenic or harmful to the human reproductive system. Heavy metals are also not allowed. Emission of formaldehyde from the finished product shall be less than 0,1 $mg \cdot m^{-3}$ in the chamber air. The procedures used in the Danish and Finnish schemes also apply in the Nordic Swan Ecolabelling Programme. Both the environmental chamber and emission cell tests can be used.</td></tr>
<tr><td rowspan="7">German Blue Angel Ecolabelling Scheme
RAL-UZ 38
RAL-UZ 76
RAL-UZ 430</td><td colspan="3">This labelling scheme covers flooring materials, furniture and wall panels. Auxiliary materials, such as adhesives and coating materials, are also included in the scheme. The scheme provides labelling to cover the whole life-cycle of the products. The scheme controls emissions of formaldehyde, TVOC, halogenated organic compounds and toxic substances that are carcinogenic, mutagenic and/or teratogenic. Standard environmental chamber tests are required for the certification of VOC emissions from the products. The following are the emission requirements for large surface products used in building.</td></tr>
<tr><th rowspan="2">Compound</th><th colspan="2">Emission requirements
$\mu g \cdot m^{-3}$</th></tr>
<tr><th>1 day</th><th>28 day</th></tr>
<tr><td>Formaldehyde</td><td>—</td><td>62</td></tr>
<tr><td>TVOC (50 °C to 250 °C)</td><td>—</td><td>300</td></tr>
<tr><td>Total VOCs (> 250 °C)</td><td>—</td><td>100</td></tr>
<tr><td>Toxic substances</td><td>< 1</td><td>1</td></tr>
</table>

Table D.2 — European labelling schemes for control of VOC emissions from coatings

Labelling schemes	Requirements/Description
Danish voluntary labelling scheme	See Table D.1 for requirements.
Finnish M1 label for finishing materials http://www.rts.fi/	See Table D.1 for requirements.
EU Ecolabel Scheme http://www.ecosite.co.uk/ B & Q and British Coating Federation Scheme	Provides criteria for paints, varnishes and cleaning products for indoor uses. The quantity of VOCs and volatile aromatic hydrocarbons (VAHs) are included in restrictions. The limits for Class I and Class II paints and varnishes are similar to those required by B & Q and the British Coatings Federation schemes. The "Ecolabel" criteria limit the use of paints and varnishes that contain toxic, highly toxic, carcinogenic, mutagenic or teratogenic substances classified under the European Directives 79/831/EEC and 83/4367/EEC, and also substances that are mandated a warning label by Directives 88/379/EEC. The VOCs included in this restriction are benzene, methanol, acetonitrile, 1,1,1-trichloroethane, xylenes, toluene, turpentine, ethylbenzene, butanol, 2-ethoxyethylacetate and formaldehyde. a) Paint category 1 (for walls and ceiling): — The VOC content shall not be greater than 30 $g \cdot l^{-1}$ (and in warm and dry climate $\leqslant$ 60 $g \cdot l^{-1}$). — The VAHs shall not be greater than 0,5 % of the product mass. b) Paint category 1 (for use on other surfaces): — The VOC content shall be less than or equal to 250 $g \cdot l^{-1}$. — The VAHs shall be less than or equal to 5 % of the product mass.
German Federal Environment Agency, Blue Angel Scheme	This scheme requires that the paints and varnishes not contain mutagenic or carcinogenic substances. The maximum allowed levels are as follows: — VOC content 10 % by mass for water-soluble paints and 15 % by mass for oil-based paints; — toxic VOC content $\leqslant$ 0,5 % by mass for water-soluble paints and $\leqslant$ 5 % by mass for oil-based paints. The product should not contain any heavy metals, such as lead, cadmium or chromium. Chamber tests of low-emission paints that had qualified for the Blue Angel Label showed that, after 48 h of paint application, the emission of the solvent VOCs was reduced to below the detection range of the analysis. The scheme also has restrictions on the production and uses of dyes that contain more than 1 % 2-naphthylamine, 1 % 4-nitrodiphenyl and $\leqslant$ 1 % chlorinated solvents, such as carbon tetrachloride, tetrachloroethanes and pentachloroethanes.
The Danish Technological Institute "Paint favourable to IAQ"	The factors included for consideration are IAQ and working environment, paint application characteristics, and coating performance. Emission rates of VOCs and odour are the properties to be assessed as well as drying time, adhesion and paint mass application. Three categories of paints are provided. This classification scheme is supported by a Nordic group of industries and institutes. Products are characterized as follows: — "Amongst the very best paints": paints that produce a VOC concentration less than 5 $\mu g \cdot m^{-3}$ within 2 weeks to 4 weeks after paint application; — "Acceptable": paints that do not emit any substances that are carcinogenic or have a toxic effect or cause mucous membrane irritation to the eye or the respiratory system; — "Poor-quality paints": paints that do not meet the criteria for acceptable paints.

A complex database of VOC emission from building materials has been developed in Canada by the National Research Council Institute for Research in Construction. In this emissions database, empirical models are used to represent the measured VOC emissions from the building materials tested in small environmental chambers over time. The database is managed by a computer program called “MEDB-IAQ”, which is a materials emissions database and IAQ simulation program. The program allows the user to browse, interrogate and generate reports on the emission data. It also has a single-zone simulation model for users to estimate the impact of selected materials on the VOC concentration in a building.

Annex E
(informative)

Air cleaning devices

E.1 Needs of air filtration for better indoor air quality

Filtration of outdoor or recirculation air reduces the level of pollutants in the air. The basic technology is to pass air through a filter, which retains the pollutant, and then to distribute the filtered air in the vicinity of the people in the building. There is a wide range of filter types performing this duty. Some filters remove only particulate matter while others, for example carbon filters, reduce the concentration of gaseous pollutants, including odours. Maintenance and replacement of filters is essential for their continued effectiveness and to avoid generating and re-entraining pollutants from the embedded pollutants in the filter element.

Filtration is necessary to reduce an undesirably high concentration of contaminants in the ventilation system to acceptable levels. Deposited pollutants can provide a potential breeding ground for micro-organisms and increase the likelihood of emitting pollutants during the operating life of the system. Studies have shown that a filter is required for the supply air system.

When the correct air filters are installed and frequently replaced, they contribute to better IAQ by the following:

— keeping the system cleaner from deposited contaminants, which means that the designed airflow is maintained and temperature and humidity are kept within specifications; a clean system, operating with the designed airflow, improves the removal of indoor contaminants generated by humans, building materials and equipment;

— maintaining the efficiency of equipment, allowing fans, heating and cooling equipment to work properly;

— reducing the entry, deposit and growth of micro-organisms in the system, which reduces the concentration of non-viable disease-causing airborne agents;

— reducing the concentration of microbiological pollutants (fungi, bacteria, viruses, etc.) in indoor air; however, it is necessary to recognize that few diseases are primarily spread by airborne agents;

— reducing outdoor and indoor contaminants in the air stream to acceptable levels; outdoor contaminants can be removed easily before entering the system;

— making air visually clean (remove or control pollutants, like tobacco smoke, that are visible);

— reducing the concentration of pollens, etc. in indoor air, thus making the air less objectionable to asthma and hay-fever sufferers;

— reducing the requirement for the cleaning of the rooms;

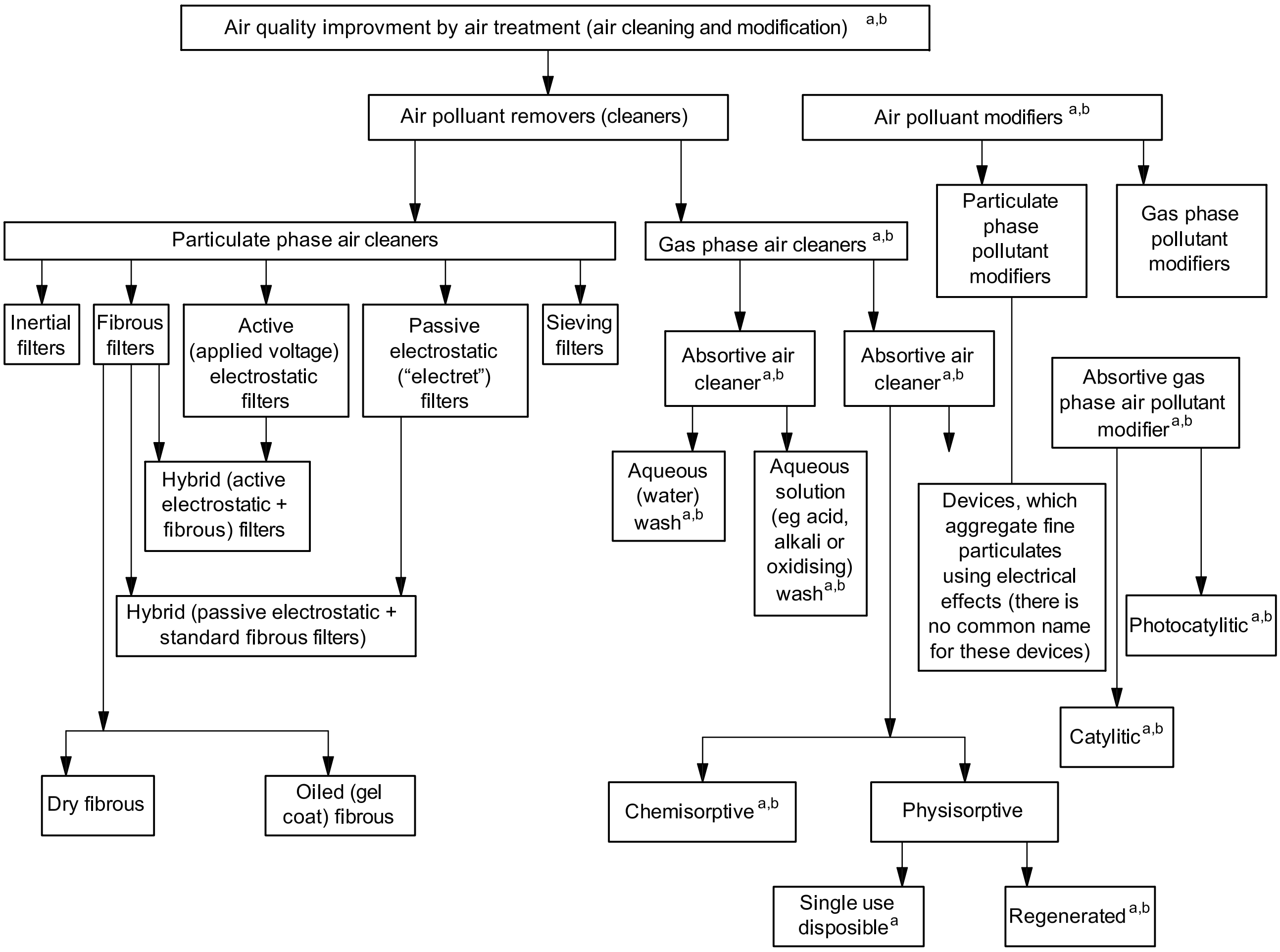
— reducing the build-up of dust in electronic equipment (e.g. personal computers) in rooms.

Filters are used primarily for cleaning supply air in air-conditioning systems and also to remove indoor emissions from the return air system.

A wide variety of filter types for the removal of particulates is available on the market. Particulate air cleaning is a well-developed technology with well-defined product specifications and standards.

Adsorption and chemisorption filters, such as activated carbon, photocatalytic filters, potassium-permanganate-impregnated media and zeolites, are available for removal of gas-phase contamination (e.g. to control odours).

At the time of publication of this International Standard, gas-phase air filtration for commercial HVAC applications is not supported by well-defined generic product specifications and standards (standards are now being developed). Test specifications for removal of specific pollutants are available; however, it is necessary to rely on proprietary test/rating methods for HVAC application of gas-phase air filters. Each method should be carefully evaluated before it is specified or otherwise relied upon.



a May humidify.

b May dehumidify.

Figure E.1 — Types of air cleaners

E.2 Particulate filters for HVAC applications

E.2.1 Types of filter

E.2.1.1 Active electrostatic filters act to ionize or electrically charge the particulates and then the charged particulates are attracted to, and collected on, charged plates. These filters feature high-efficiency removal with low pressure drop, necessary high-voltage electrical apparatus, and particular maintenance requirements.

WARNING — There is the possibility that excess ozone can be generated if these filters malfunction.

E.2.1.2 Passive electrostatic fibre filters have a “permanent” electrical charge that is put onto the fibres when the filters are manufactured; otherwise, these filters are much like normal fibre filters. These filters feature very high efficiency when clean, diminishing efficiency as they load up, until they reach a minimum efficiency, and, thereafter, increasing efficiency with higher pressure drops as they become more contaminated. The electrostatic charge is exhausted or masked by the dirt loading in the early stage of the filter’s life.

E.2.1.3 Normal fibre filters are mats of fibrous material with the following characteristics.

— The fibre thickness, fibre orientation, matt thickness, etc. of each filter is chosen by the filter manufacturer to give particular results.

— Sometimes the fibres are covered with an “oil” or “gel” to improve particle adhesion.

— As fibrous filters get dirtier, they get more efficient; particulates have more surfaces to attach to, i.e. the fibres and the dirt that have already been collected.

— Humidity can affect filter efficiency but this effect is seldom documented.

E.2.2 Efficiency

Particulate air filters for HVAC applications are divided into two categories:

a) Coarse filters

Coarse filters are efficient for large particles, some pollens and insects in order to protect the installation itself. They are used as a single-stage filter or as a pre-filter for the protection of fine filters. These filters are designed to remove the coarse particles from medium to high concentrations of atmospheric particulate contamination. The efficiency of these filters is low on small atmospheric air particles. Typical filters are flat media pads, panel filters and coarse bag filters. In Europe, these filters are classified G1 to G4, as given in Table E.1, after ISO 21220 [8]. In the USA, these filters are classified MERV1 to MERV8, as given in Table E.2, after ASHRAE 52.2:2000.

Table E.1 — Classification of air filters after ISO 21220 [8]

Class	Final pressure crop Pa	Average arrestance of synthetic dust A_m %	Average efficiency of 0,4 µm particles E_m %
G1	250	$50 \leqslant A_m < 65$	
G2	250	$65 \leqslant A_m < 80$	
G3	250	$80 \leqslant A_m < 90$	
G4	250	$90 \leqslant A_m$	
F4 [a]			$20 \leqslant E_m < 40$
F5	450		$40 \leqslant E_m < 60$
F6	450		$60 \leqslant E_m < 80$
F7	450		$80 \leqslant E_m < 90$
F8	450		$90 \leqslant E_m < 95$
F9	450		$95 \leqslant E_m$

NOTE The characteristics of atmospheric dust vary widely in comparison with those of the synthetic loading dust used in the tests. Because of this, the test results do not provide a basis for predicting either operational performance or life. Loss of media charge or shedding of particles or fibres can also adversely affect efficiency; see Annexes A and B.

[a] AS 1668.2 [3] adopts this method of classifying air filters, however, and an additional class is added: F4 with $20 \leqslant E_m < 40$.

Table E.2 — Classification of air filters after ASHRAE 52.2:2000

Group number	MERV	Average efficiency in size range %			Arrestance[a] %	Final pressure Pa
		0,30 µm to 1,0 µm	1,0 µm to 3,0 µm	3,0 µm to 10 µm		
1	1	—	—	$E_3 < 20$	$A_{avg} < 65$	75
	2	—	—	$E_3 < 20$	$65 \leqslant A_{avg} < 70$	75
	3	—	—	$E_3 < 20$	$70 \leqslant A_{avg} < 75$	75
	4	—	—	$E_3 < 20$	$75 \leqslant A_{avg}$	75
2	5	—	—	$20 \leqslant E_3 < 35$	—	150
	6	—	—	$35 \leqslant E_3 < 50$	—	150
	7	—	—	$50 \leqslant E_3 < 70$	—	150
	8	—	—	$70 \leqslant E_3$	—	150
3	9	—	$E_2 < 50$	$85 \leqslant E_3$	—	250
	10	—	$50 \leqslant E_2 < 65$	$85 \leqslant E_3$	—	250
	11	—	$65 \leqslant E_2 < 80$	$85 \leqslant E_3$	—	250
	12	—	$80 \leqslant E_2$	$90 \leqslant E_3$	—	250
4	13	$E_1 < 75$	$90 \leqslant E_2$	$90 \leqslant E_3$	—	350
	14	$75 \leqslant E_1 < 85$	$90 \leqslant E_2$	$90 \leqslant E_3$	—	350
	15	$85 \leqslant E_1 < 95$	$90 \leqslant E_2$	$90 \leqslant E_3$	—	350
	16	$90 \leqslant E_1$	$90 \leqslant E_2$	$90 \leqslant E_3$	—	350

[a] From ASHRAE 52.1:1992.

b) Fine filters

These filters are efficient against a wide range of atmospheric air particles. Fine filters are efficient against both atmospheric particulate matter and aerosols that are composed mainly (on a particle-number-weighted basis) of particles smaller than 1 µm.

Typical filters are compact filters and bag filters. In Europe, these filters are classified F5 to F9 after EN 779:2002, Table E.1. In the USA, these filters are classified MERV9 to MERV16 after ASHRAE 52.2:2000, Table E.2.

c) Combination coarse/fine air filters

High-efficiency particulate air filters (HEPA) and ultra-low penetration air filters (ULPA) are not commonly used in general ventilation and, therefore, are not dealt with in this annex.

E.3 Gas-phase filters

Gaseous contaminants can be removed by various air-cleaning processes. This process employs physical adsorption, which is a reversible process or a combined physical/chemical reaction. Chemisorption is an irreversible process.

Gaseous pollutant-modifying devices are catalytic and photocatalytic ventilation air pollutant modifiers. Both devices are forms of adsorption devices in which some gaseous molecules are dissociatively adsorbed onto a rare metal or titanium dioxide surface with, in the case of photocatalytic devices, the assistance of added energy in the form of light quanta, usually with an ultra-violet frequency. In dissociative adsorption, the intermolecular bonds are broken and subunits of the molecules become separate entities on the adsorbent surface. These entities can, then, separately desorb into the airstream or they can combine (to form new molecules or to reform the original molecules) and then desorb into the airstream. It is claimed that UV photocatalytic air-pollutant-modifying devices are useful for converting VOC pollutants into less objectionable compounds.

Gaseous pollutants are removed from the air by gas-phase filters or gas-phase air cleaners (GPAC). There are two types of GPACs: wet (absorptive) and dry. A wet GPAC is usually an air washer. A dry GPAC is usually a sorptive device (physisorptive or chemisorptive). In both cases, the primary mechanism is adsorption, i.e. the capture of gaseous pollutant molecules onto the surfaces of GPAC material. Activated carbon is the most commonly used material to remove organic substances from air. The special feature of activated carbon is that it has a very large surface area as a result of the size distribution of the “pores” in the filter. This large surface allows it, in general, to remove pollutants from air by adsorption. If the temperature of the gases adsorbed on a surface is increased (i.e. the molecules have more energy and move about or vibrate more vigorously on the surface), then they can escape from the surface. This is desorption. Desorption can also result from a change of gas pressure.

The development of filter designs and chemical adsorption materials has led to the design of gas-phase filters for general ventilation systems meeting demands for high flows and low pressure loss. In polluted urban environments, the requirement for the removal of gaseous contaminants in supply air has increased. EN 13779 [45] recommends gas-phase filtration for polluted outdoor environments and when good IAQ is required.

E.4 Design guidelines for filtration

There is a wide variety of national practice. The designer may decide the level of filtration he wants, either to protect the equipment (i.e. from dust) or to increase IAQ by the usage of a fine filter (bag filter or equivalent).

a) EUROVENT Rec 06-1999 [16] indicates that supply air may be filtered in two steps to protect the fine filter, i.e. bag filter or equivalent, if there is one. Otherwise, one filter is enough.

Table E.3 — Correspondence of filters with the desired level of practice

Level of practice	Protection of equipment	Increased IAQ
Very good	F7/MERV 13	F7/MERV 13 + F9/MERV 15
Good	F6/MERV 11	F5/MERV 9 + F8/MERV 14
Acceptable	G4/MERV 7	G4/MERV 11 + F7/MERV 13

If there is only one filtration step, the minimum requirement is F5/MERV 9 quality.

In any case, efficiency should not decrease below specified limits in real life. Fresh air as well as recirculated (return) air has to be treated in the same manner.

A large amount of VOCs is borne by particles. For effective removal, gas-phase filters can be justified in an urban environment. It is necessary to protect these filters by fine filters of a quality F6/MERV 11 or better.

b) Extract air from kitchens should always be cleaned in a first step with a special filter for grease that can be changed and cleaned easily.

c) Filters should generally not be installed directly behind the fan outlet or across places where the flow distribution over the filter area is not uniform.

d) When selecting a filter, it is necessary to give great care to parameters other than efficiency, i.e. filter class, such as the following:

— initial pressure drop;

— final pressure drop recommended by the manufacturer or available in the HVAC system; see EN 13053;

— dust-holding capacity.

It is necessary that the initial pressure drop of the filter be as low as possible to minimize energy consumption. The dust-holding capacity of the filter is a good indicator of its lifetime when the appropriate filter is applied.

e) Great care is required regarding the design and positioning of the air intake to avoid drawing in local pollutants (from exhausts) and to avoid ingestion of rain or snow through the filter.

f) As indicated in Clause 6, the efficiency of particulate filters shall be designed to achieve the required levels of cleanliness under all conditions when the system is running (i.e. variations of performances as well as pressure drop shall be taken into account).

g) When sizing/dimensioning the system (fans, filters, allowing access, etc.), the designer shall take into account the necessity to replace filters.

Information shall be given to the owner about the maintenance that is required.

— Filters shall be replaced when their pressure drop reaches the specified final pressure drop or when the hygienic limit of use is reached, whichever comes first. Any instructions for the use of the specific filter under the conditions where it is installed should be observed.

— For hygienic reasons, it can be necessary (in some environments) to replace the filters after the main pollen and spore season in the autumn. If requirements are stringent, it can also be necessary to change the filters in the spring after the heating season to eliminate odorous combustion products.

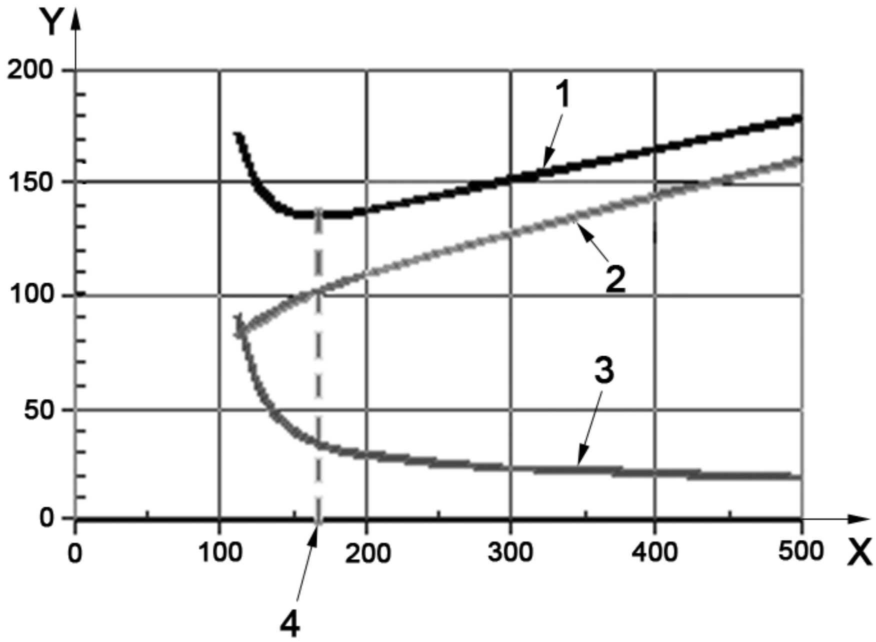
— Filters should be replaced carefully, using personal protective equipment, to prevent the escape of trapped impurities and to prevent new filters from being contaminated before they are fitted.

The risk of microbial growth on filters is always present, but generally kept low if correct design, installation, and maintenance procedures are followed. To minimize the risk of microbial growth, the ventilation system should be designed to keep the relative humidity below 75 % at the filter banks under all seasonal atmospheric conditions. Air filters should be kept as dry as possible. Air filters get wet when supplied with foggy outdoor air. High-efficiency filters are capable of retaining water particles that can saturate the filter. The adverse effects include microbial growth, odour emission, corrosion, penetration of moisture into the air handling system and, in some conditions, freezing of the filter. These effects should be taken seriously because of the growing tendency to use 100 % outdoor air to supply air handling systems.

Leaks in a filter section significantly decrease the filtration efficiency. Therefore, it is important to comply with the requirements for airtightness and bypass leakage as given in EN 1886.

E.5 Life-cycle costing (LCC)

Life-cycle cost analyses have become an important instrument for reducing costs and the environmental impact of filters. In Europe, work is being intensively carried out to develop guidelines or requirements for life-cycle cost calculations. Ventilation systems often account for the lion's share of a building's energy consumption and the pressure loss in air filters can account for a large part of the ventilation system's total pressure loss. More and more users are requiring LCC calculations when purchasing filtration systems and components. For filters, EUROVENT Rec 10-1999 [17] contains guidelines for calculating the costs of a filter during its entire service life; see Figure E.2.



Key

X final pressure, expressed in pascals
Y cost, expressed in euros per year
1 total
2 energy
3 filter
4 minimum cost

Conditions: F7 filter; flow rate, 1 m^3/s; energy cost, 0,05 euro/kWh; operating time, 8 760 h/year.

Figure E.2 — Example of impact of final pressure on LCC for a specific filter

E.6 Test standards

Different air filter test methods exist according to the type of filter, as given in Table E.4.

Table E.4 — Test methods for different filter types

Type of filter	Test method reference
Particulate – coarse filter	EN 779:2002 or ASHRAE 52.1:1992 or ASHRAE 52.2: 2000
Particulate – fine filter	EN 779:2002 or ASHRAE 52.2: 2000
In situ test	EUROVENT 4/10
Portable air cleaner	ANSI-AHAM AC-1:2006
Gas-phase air cleaning	Different methods are currently being developed

Annex F
(informative)

HVAC equipment as a source of pollution

F.1 General

In order to achieve good IAQ, HVAC equipment should be correctly designed, installed and operated. Main sources of pollution in a ventilation system vary depending on its construction, use and standard of maintenance. This annex provides some rules to limit the pollution risk, including odours, particulate matter and microbiological contamination in the installations. Regular cleaning or replacement of components is critical and should be clearly specified and communicated to the operation and maintenance personnel.

F.2 Air intake

The air-inlet location is critical to ensure the best inlet condition; it should be as far as practicable (feasible) from pollution sources, e.g. car exhaust gases, air exhausts, fumes from combustion appliances and cooling tower discharges.

The goal is that intakes for outdoor air be located and arranged so that under all conditions of normal operations

a) contamination from pollution sources does not reduce the quality of outdoor air entering the intake to a level significantly below that of outdoor air in the locality, except where outdoor air entering the intake is treated to achieve the same effect,

b) the effects of wind, adjacent structures and other factors do not cause the flow rate of outdoor air to be reduced below the minimum requirements.

Examples of recommendations are given in EN 13779:2004 [45], A.2.4, or in ASHRAE 62.1 [2].

F.3 Air handling unit and its components or fans

Requirements and guidance concerning hygienic aspects in air handling units are given in EN 13053 [9] and EUROVENT Rec 14-2000 [19]. This clause, together with Clauses F.4 and F.5, summarize some of the essential issues.

Filters shall be dimensioned and correctly installed as described in Annex E. Studies have shown that as filters age, odour emissions from them increase. Design shall, therefore, allow easy access for regular maintenance so that filters can be changed without difficulty. Recent studies indicate that odours due to new filters depend on the materials used in their construction.

When humidifiers are required, fresh water should be used and the hygienic recommendations from the manufacturer followed. Humidifiers should be emptied and dried when not in use and cleaned regularly under any circumstances. Desalinizing or demineralizing agents or devices, when used, should not negatively affect the IAQ.

Cooling coils should not allow condensed or stagnant water to remain in the fins and/or drip tray. The trap system for the condensate seal shall not be emptied during the winter months, otherwise odours can drift back into the ducts.

Heat exchangers can allow air leakage and the associated air recirculation, which shall be investigated.

F.4 Ductwork

Oil residues are generally considered to dominate the sensory pollution in new ductwork. The oil layer, although thin and invisible, emits odours and dissatisfaction has been correlated to the specific surface mass. Generally recommended values are around 50 mg·m^{-2}. In addition, some ductwork sealants and rubber parts can create odours.

Dampers by their function of balancing the system do have an important effect on IAQ. During the design, dampers should be correctly situated in all main take-offs from the main duct to the rooms and the system should be correctly balanced when handing over as well as after duct cleaning and maintenance.

The accumulation of dust and debris in the ductworks during construction should be avoided, by appropriate storage and eventually cap-sealing, to limit hygienic risk. Ducts should be kept clean for correct operation. EN 12097 [5] gives guidance on how to design the ductwork system taking into account the requirements for maintenance, including cleaning.

F.5 Cooling towers

To prevent *Legionella* growth in cooling-tower circuits, a water-treatment system with biocides should be used to prevent corrosion and scaling in the system. Drift eliminators and heat-transfer surfaces should be cleaned regularly. It is essential to position fresh air inlets far away from cooling-tower air discharges, with due consideration being paid to prevailing wind direction and adjacent structures. Further guidance is given in EUROVENT Rec 9/5-2002 [20].

Annex G
(informative)

Ventilation effectiveness

The air quality might not be the same throughout a ventilated space. What is of concern to the occupants is the air quality in the breathing zone. Such a lack of homogeneity of the air quality in a space has an impact on the ventilation requirement. This is expressed by the ventilation effectiveness, ε_v, representing the contaminant removal effectiveness, as given in Equation (G.1):

$$\varepsilon_v = \frac{C_e - C_s}{C_i - C_s} \tag{G.1}$$

where

C_e is the pollution concentration in the exhaust air;

C_s is the pollution concentration in the supply air;

C_i is the pollution concentration in the breathing zone.

The ventilation effectiveness depends on the air distribution and the location of the pollution sources in the space. It can, therefore, have different values for different pollutants. If there is complete mixing of air and pollutants, the ventilation effectiveness is 1. If the air quality in the breathing zone is better than in the exhaust, the ventilation effectiveness is higher than 1 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 inferior than in the exhaust air, the ventilation effectiveness is lower than 1 and more ventilation is required.

Ventilation effectiveness is a function of the location and the 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. Examples of ventilation effectiveness are given in Table G.1 for different ventilation principles.

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.

The values in Table G.1 consider the impact of air distribution and supply air temperature 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. If the effectiveness of a given displacement ventilation system is unknown, an effectiveness of 1 can be assumed.

Table G.1 — Examples of ventilation effectiveness in the breathing zone of spaces ventilated in different ways

Ventilation arrangement	Temperature difference between supply air and room air K	Ventilation effectiveness ε_v
Mixing; high-level supply and exhaust	< 0	0,9 to 1,0
	0 to 2	0,9
	2 to 5	0,8
	> 5	0,4 to 0,7
Mixing; high-level supply, low-level exhaust	< -5	0,9
	-5 to 0	0,9 to 1,0
	> 0	1,0
Displacement	< 0	1,2 to 1,4
	0 to 2	0,7 to 0,9
	> 2	0,2 to 0,7

ASHRAE 62.1:2007 [2] also gives some default values of ventilation effectiveness; see Table G.2. This value, designated the “zone air distribution effectiveness”, E_z, is calculated per zone and then, after summing all zones airflows, an overall system ventilation efficiency, E_v, is applied to calculate the total outdoor air intake flow. The zone air distribution effectiveness is defined as “a measure of how effectively the zone air distribution uses its supply air to maintain acceptable IAQ in the breathing zone” and the system ventilation efficiency is “the ratio of the outdoor air intake to the total zone primary airflow for all the zones served by the air handler”.

NOTE Table G.2 cannot be used directly to calculate ventilation rates. Refer to the ventilation rate procedure in ASHRAE 62.1 [2] for applying these factors to the specific designs that are being considered.

Table G.2 — Default values of the zone air distribution effectiveness after ASHRAE 62.1:2007 [2]

System design and operating condition	Zone air distribution effectiveness [f] E_z
Ceiling [a] supply of cool air [b]	1,0
Ceiling supply of warm air [c] and floor return	1,0
Ceiling supply of warm air at least 8 °C (15 °F) above space temperature and ceiling return	0,8
Ceiling supply of warm air less than 8 °C (15 °F) above space temperature and ceiling return, provided that the 0,8 m/s (150 ft/min) supply air jet reaches to within 1,4 m (4,5 ft) of floor level NOTE For lower-velocity supply air $\varepsilon_v = 0{,}8$.	1,0
Floor supply of cool air and ceiling return, provided that the 0,8 m/s (150 ft/min) supply jet reaches at least 1,4 m (4,5 ft) above the floor NOTE Most underfloor air distribution systems comply with this provision	1,0
Floor supply [d] of cool air and ceiling return, provided that the low-velocity displacement ventilation achieves unidirectional flow and thermal stratification	1,2
Floor supply of warm air and floor return	1,0
Floor supply of warm air and ceiling return	0,7
Make-up supply [e] drawn in on the opposite side of the room from the exhaust and/or return	0,8
Make-up supply drawn in near the exhaust and/or return location	0,5

NOTE Table G.2 cannot be used directly to calculate ventilation rates. Refer to the ventilation rate procedure in ASHRAE 62.1 [2] for applying these factors to the specific designs that are being considered.

[a] Ceiling includes any point above the breathing zone.

[b] Cool air is air cooler than space temperature.

[c] Warm air is air warmer than space temperature.

[d] Floor includes any point below the breathing zone.

[e] Make-up supply is the air that enters an enclosure or an air-handling system in a controlled manner, but not by direct mechanical means (passive air inlet).

[f] As an alternative to using the above values, ε_v may be regarded as equal to air change effectiveness determined in accordance with ASHRAE 129 for all air distribution configurations except unidirectional flow.

To calculate the overall system ventilation efficiency, E_v, the maximum of all zone primary outdoor air fractions, designated Z_p for each zone, is calculated; see Table G.3. This fraction is equal for each zone to the outdoor airflow coming into this zone divided per the total airflow to the zone. For a system, called a once-through system, that uses 100 % outdoor air and no recirculated air to spaces served by the system, E_v is equal to 1.

Table G.3 — Default values for the ventilation system efficiency

Outdoor air fraction Max. Z_p [a]	**Ventilation system efficiency** E_v
$\leqslant$ 0,25	0,90
$\leqslant$ 0,35	0,80
$\leqslant$ 0,45	0,70
$\leqslant$ 0,55	0,60
$>$ 0,55	[b]

NOTE Table G.3 cannot be used directly to calculate ventilation rates. Refer to the ventilation rate procedure in ASHRAE 62.1 [2] for applying these factors to the specific designs that are being considered.

[a] The values of E_v in this table are based on a 0,15 average outdoor air fraction for the system (i.e. the ratio of the uncorrected indoor air intake to the total zone primary airflow for all the zones served by the air handler). For systems with higher values of the average outdoor air fraction, this table can result in unrealistically low values of E_v and the use of ASHRAE 62.1:2007 [2], Appendix A, can yield more realistic results.

[b] See ASHRAE 62.1:2007 [2], Appendix A.

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