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NKB PUBLICATION <u>INDOOR CLIMATE - AIR QUALITY</u>

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NORDIC COMMITTEE ON BUILDING REGULATIONS NKB

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FOREWORD

In 1987 the Nordic Committee on Building Regulations NKB set up an indoor climate committee to provide support for the joint Nordic activity in this area. The committee drew up a five year plan of activity which was approved by the Board of NKB in November 1987. One of the tasks which received priority was to revise the section on air quality in NKB Report No 40, "Indoor Climate", published in May 1981. A working group comprising

Erik Christophersen, Denmark
Esko Tähti, Finland (to 31.12.88)
Pirjo Kimari, Finland (from 1.1.89)
Professor Eimund Skåret, Norway
Allan Wallin, Sweden
Jan Sundell, Sweden, as research officer, and
Helena Vuorelma, NKB, as secretary of the group,

was instituted to draw up a draft for this revision.

The Indoor Climate Committee of NKB has discussed the draft presented by the working group on several occasions and has recommended circulation for comment at this time. The composition of the Indoor Climate Committee is as follows:

Bengt-Göran Lindqvist, Chairman, Ministry of the Environment, Finland
Ella Blousgaard, National Building and Housing Agency, Denmark
Sigurd Hoelsbrekken, National Office of Building Technology and Administration, Norway
Professor Thomas Lindvall, Institute of Environmental Medicine, Sweden
Ove Nielsen, National Building and Housing Agency, Denmark
Ewa Rydén, National Board of Housing, Building and Planning, Sweden
Professor Eimund Skåret, Norwegian Building Research Institute, Norway
Kristina Saarela, Technical Research Centre of Finland, Finland
Helena Vuorelma, NKB, committee secretary.

The aim of the revision was to incorporate the knowledge which has become available since NKB Publication No 41 was drawn up. The working group has found that the problems experienced in buildings have several causes. Some of these causes are more obvious than others:

- Materials, fixtures and fittings, furnishings and furniture which emit pollutants of different kinds are used in buildings.

- Materials and constructions sensitive to moisture are used, while at the same time insufficient action is taken to prevent moisture loading.

- Ventilation and air conditioning installations in some cases provide insufficient outdoor air flow rates, either because they have been designed incorrectly or are not used properly, or because the supply air on its way through the installation becomes contaminated owing to the use of materials and components which emit pollutants, or because maintenance and cleaning are neglected.

- Coordination (quality assurance) in the building process is unsatisfactory with regard to the indoor climate aspects. Buildings are constructed, operated, cleaned and maintained in an unsatisfactory or incorrect manner.

The report outlines a strategy for the planning, construction, operation and maintenance of buildings. This implies that several Acts other than only building legislation are affected. The report is intended to serve as a basis for regulations/recommendations by the different regulatory authorities engaged in areas of significance for indoor climate.

The report has been edited so that each section (subject area) is introduced by an outline background text which lays down the conditions for the recommendations for regulations. The last part of each section contains examples of the way in which these can be complied with.

The proposals for regulations have been drawn up on the basis of the present state of technical and human biological knowledge. When the authorities draw up the regulations, consideration must also be given to e.g. the targets regarding the degree of exposure among the population in the country concerned and to the social, economic, cultural and political conditions.

The group has drawn on the knowledge of external experts by arranging meetings in which Nordic specialists in indoor climate have taken part, for instance a seminar on outdoor air flow rates, and meetings of experts in building physics, building materials and human biology.

Esbo, 12.6.1990.

Nordic Committee on Building Regulations NKB

1. INTRODUCTION

Since May 1981, NKB Report No 41, INDOOR CLIMATE, has served as a basis to which national regulations have conformed at different rates. Since the publication of the report, developments in mainly the area of air quality have necessitated a revision of this report.

New hygienic problems associated with the built environment have emerged at an accelerating rate. Health problems coupled with the incidence of radon, formaldehyde, mould and diffuse symptoms of an irritational type, the sick building syndrome, occur. There is also an increase in allergies and other hypersensitivity reactions which are traced back to a deterioration in indoor environments, for instance an increased incidence of irritants, house dust mites, mould, bacteria and viruses ([1]). It is difficult to estimate the scope of this problem since there have been, on the whole, few studies. A group of experts in WHO ([2]), for instance, has estimated that between 10 and 30% of new or renovated buildings are sick buildings.

A few studies which comprise a larger number of buildings are available. Investigations of offices in Denmark ([3]) and Britain ([4]) show that many factors are significant for the health problems which have been reported. Sex, psychosocial conditions, social status, work content and different forms of stress are involved in the discomfort experienced by the individual. But when account has been taken of such factors, there remain considerable differences between buildings as regards reported health problems. The building has an essential role as the cause of human discomfort.

Developments regarding building technology, building materials and energy technology have been rapid in recent decades.

From a construction process characterised by a building season (spring-summer-autumn), long building times, manual craftsmanship, small scales and "natural" materials, development has progressed to a fast, more industrialised, year round construction with new technology and synthetic materials. Work on quality assurance in construction has not kept pace with this otherwise rapid development. New technology and new materials have often gained ready acceptance since they conferred evident technical and economic advantages. There has been no prior control regarding building hygiene aspects. A similar development has taken place as regards materials for fixtures and fittings, furnishings and furniture and consumer articles. Many new types of pollutants are therefore released into the indoor air.

To this pollutant configuration must be added contaminants given off by people, cooking, tobacco smoking, open fires and by e.g. mould, bacteria and house dust mites. The Allergy Enquiry in Sweden has in addition pointed out that housekeeping and cleaning have been neglected in the society of today, and this also influences the pollution configuration indoors.

Over the same period, ventilation has been reduced as a consequence of the need for energy management and other factors ([5]). Buildings have become more airtight, with less infiltration/exfiltration as a result. Satisfactory performance of the controlled ventilation is therefore of greater importance now. Experiences gained in several sick building investigations and studies of the performance of ventilation (see e.g. [6,7]) show that many installations do not work as intended.

There is greater knowledge today of the pollution situation indoors. Principally, however, research has been of a survey character and not the kind which permits conclusions to be drawn as to which factors have significance for what regarding the incidence of ill health. At the present time it is therefore not possible other than in exceptional cases to pinpoint "guilty" substances or factors.

In the light of the uncertain state of knowledge, our philosophy is of a general nature. That is to say, what we must do is not only to avoid certain substances, factors, but generally to keep the number and intensity of pollution sources at a low level and also to secure a reasonable ventilation standard.

Hygienic conditions in a building depend not only on how the building has been constructed but also on how it is operated and maintained. In order that these aspects also should be covered, the report contains proposals which affect legislation other than conventional building legislation, for instance working environment, occupational safety, and health and safety legislation.

The report deals with the factors and proposes the requirements which have been considered essential for the health of a building. The proposals have been arrived at through an aggregate assessment of experience and scientific documentation. The text contains references to literature which is listed at the end of the report. Where no references have been available, an assessment has been made on the basis of experience.

The report examines those aspects which directly affect the quality of air indoors in premises other than industrial ones.

Additional guidelines regarding the construction of installations are given in NKB Publication No 52, Mechanical ventilation installations, Guidelines ([8]), thermal indoor climate in NKB Publication No 41, Indoor climate ([9]), and acoustic conditions in NKB Publication No 32, Guidelines for building regulations regarding acoustic conditions ([10]).

The report is set out so that each section begins with an introduction which deals with documentation and background. This is followed by recommendations for regulations and guidelines regarding the way in which these can be complied with. Proposals for requirements are formulated with the wording "shall", and guidelines with the wording "should" or merely as informational text.

For definitions, see Appendix No 1 and NKB Publication No 52, Mechanical ventilation installations, Guidelines ([8]).

2. OVERALL OBJECTIVES

Everybody (including babies, allergic and other hypersensitive persons, the sick) spend most of their lives indoors. In the home one must rest, sleep and regain one's energy. Known negative effects on health or the risk of these cannot therefore be accepted. The causative relationship between certain pollutants and their effects on health is relatively well known. For instance, WHO has for about ten substances compiled a dose-effect relationship and laid down critical threshold limits. However, the number of potentially harmful or troublesome substances indoors is much greater than this. Furthermore, little is known of interaction effects. It is therefore difficult to lay down specific quantified requirements of practical applicability for normal pollution situations indoors. Consideration of sensitive groups makes the position even more difficult.

The air indoors consists of air from the outside with pollutants from e.g. traffic, the ground and industries. On its passage through the supply air system, air may be contaminated by particles, fibres and substances from components such as filters, internal insulation and deposited dirt. When moisture is present in the system, biological growth of e.g. mould and bacteria may also take place, with contamination of the supply air. Inside the building, there is further pollution released by people and animals, and dirt from activities such as tobacco smoking, cleaning and cooking. To this must be added contaminants from open fires, building materials, fittings, fixtures, furnishings and furniture, office machinery, hobby and cleansing products, etc.

Industrial hygiene threshold limit values or fractions of these are not relevant in this context. These refer to fully healthy adult persons and 8 hours' exposure per day. In addition, they have been laid down for situations where the exposure is only to one or a few pollutants. Compared with such threshold limit values, the contents in these environments are low. On the other hand, however, the contents are often high compared with guidelines for the external environment. If the contents indoors and outdoors are compared, the situation is largely as follows:

- Particles. Contents are normally equal indoors and outdoors. In conjunction with tobacco smoking, vacuum cleaning or similar, contents are elevated indoors, often by a factor of 10 or more. Radon daughter products, and also radon, normally occur in higher, and often considerably higher, concentrations indoors than outdoors. Particles of biological origin such as viruses and bacteria, or of mould and house dust mites, occur in higher concentrations indoors than outdoors if there are internal sources. Such sources are normally present for viruses and bacteria in the form of infected persons. Indoor proliferation of mould and house dust mites is of normal occurrence.

- Inorganic gases. Contents indoors are normally somewhat lower than, or at the same level as, outdoors. Where there are open fires or tobacco smoking, the contents are higher indoors.

- Volatile organic substances. Normally, contents are 2-10 times as high indoors as outdoors. In a newly repainted or completely new building, the contents indoors are often 100 times higher.

Characterisation of the pollutant content of indoor air has so far concentrated on the pollutants and pollutant types to be found in industry or in outdoor air, or on those for which measuring methods had been developed, i.e. for total dust, inorganic gases and VOC. Most is still not clear. What VVOC, SVOC and POM contents occur? What significance do these have for the health problems encountered? As far as dust is concerned, there is generally no answer to these questions. What is relavant regarding the health of persons, total quantity, the number of particles, shape, surface, certain size fractions, what the particles consist of, their hygroscopic properties, the contaminants carried by the particles, etc?

There are very few risk estimates with regard to common complaints or symptoms such as irritation of the mucous membranes or skin, or serious diseases such as asthma as a result of airborne pollutants indoors. The same applies for other allergic or hyper-reactive diseases. There is evidence that the incidence of respiratory tract symptoms is generally affected to a large extent by the indoor climate and the airborne pollutants indoors ([1, 11, 12, 13]).

A group of experts in WHO ([14]) has discussed criteria for the evaluation of the effects of individual organic pollutants in the indoor environment. In its recommendations, the group of experts states, inter alia, that the maximum content of an individual substance shall be such as to cause an olfactory sensation in not more than 50% of persons on short term exposure to air containing the substance, for instance in a visit situation. These values refer to a "normal population" and to an "average situation".

Examples of recommended guidance values for individual substances are given in the WHO Air Quality Guidelines for Europe ([15]) which are partly reproduced in Appendix No 2. In the case of rooms which a person himself chooses to visit, such as a smoking room, higher values can be accepted. In all premises a person is at all times exposed to several substances and factors simultaneously. The knowledge is not available to carry out a weighted aggregation of such a multifactorial low dosage exposure. In the report referred to above, it is stated that "data are at present insufficient for guidelines relating to mixtures to be laid down" ([15]). The above criteria for individual substances are therefore not readily applicable. Owing to consideration of more sensitive groups such as babies, allergic or other hypersensitive persons, who may be assumed to react earlier than others, a lower percentage for a normal population must be the criterion.

Criteria for exposure of a composite nature such as e.g. the ASHRAE requirement regarding 80% acceptability ([16]) cannot be easily compared with the above criteria for individual substances. This is however the most common way in which acceptability is quoted.

The conclusion of the above is that, on the whole, knowledge is not available to lay down quantified criteria for risk assessments regarding the quality of indoor air. For a few substances guidelines have been given in the WHO document ([15]), see Appendix No 2, but for the great majority of substances and particularly for a number of substances in interaction, knowledge is insufficient. The same applies on the biological side. Threshold limit values have been proposed for bacteria ([17], 4500 cfu/m^3), mould ([18], 1000 cfu/m^3) and house dust mites ([19], 100 mites/g dust). Further investigations are however required before such threshold limit values are introduced.

Since the state of knowledge does not permit the establishment of threshold limit values based on quantified risk assessments, the following is instead recommended as an overriding regulation:

Buildings inclusive of their installations shall be planned, designed, constructed, maintained and operated so that satisfactory comfort is achieved with regard to air quality and so that danger to health does not arise when rooms are used in the way intended.

The quality of air is considered satisfactory if the great majority of visitors (80%), on entry into the room, perceive the air as acceptable (do not express displeasure), if the air does not cause irritation to skin, mucous membranes or airways, not even in persons who are somewhat more sensitive than normal, if there is no risk of sensitisation and if the risk of health effects after long term exposure is negligible. Nor must the quality of air give rise to disease.

The term "used in the way intended" implies, for instance, that smoking occurs in rooms where tobacco smoking forms part of the design conditions. There must at all times be a margin for short term pollution loads, for instance in the form of openable windows. In dwellings it shall be possible for e.g. hobbies, housekeeping, cleaning etc to be carried to the normal extent without this causing inconvenience.

In assessing buildings in operation, the experiences and complaints of people can be used in judging the "health" of the building, but other methods are also needed.

3. REQUIREMENTS FOR BUILDINGS, FITTINGS AND FIXTURES, FURNISHINGS AND FURNITURE, AND ACTIVITIES IN THE BUILDING

3.1 Planning

3.1.1 Basic conditions

Experience shows that, broadly speaking, all types of ground can be built on with good results. However, there is a greater risk of the incidence of problems if buildings are constructed on ground that is waterlogged, has a high radon content or may be contaminated, for instance as a result of earlier industrial activity ([20]). There is little risk if older construction experience is applied, such as that a building should be placed high and dry and that the ground should slope away from the house so that surface water is drained away. Moisture and mould damage as a result of damp from the ground is closely associated with lack of knowledge and defective quality assurance when ground of lesser suitability is chosen.

In view of this, the following recommendation is made for regulations:

The choice of building construction shall be made with regard to the nature of the ground so that problems connected with the indoor climate do not arise. Particular account shall be taken of damp and radon. When a building is constructed on ground contaminated by waste or industrial activity, the pollution source shall be removed or the building shall be constructed so that the pollutants cannot enter.

> The ground should be investigated with respect to local groundwater levels, pockets of water, waterbearing strata and the risk of flooding. Construction on abnormally damp ground imposes greater requirements concerning design and construction in order that moisture damage and problems with air quality may be avoided. The radon risk should also be assessed.
>
> The radon content and permeability to air of the ground imposes requirements regarding the airtightness of the building and/or a mechanical ventilation system as protection against entry of radon. The ventilation system should not operate so as to give rise to excessive negative pressures in habitable rooms.

3.1.2 The quality of outdoor air

Pollutants from the outside may be a significant risk factor. In e.g. investigations of sick buildings in the US, it has been found that intake of polluted air from the outside is a not uncommon cause of health problems ([21]).

In view of this, the following recommendation is made for regulations:

In order to secure a satisfactory indoor environment, a building shall be placed in as pure an outdoor environment as possible. The building shall be designed in view of the quality of outdoor air.

Construction near traffic routes, in town centres or near industries or similar imposes greater requirements on the placing, orientation and design of the building and the planning of its ventilation system. In such cases systems in which air is taken in directly via openings in the building shell should be avoided. It may be necessary to make a survey of the conditions and to try and evaluate future conditions. These aspects should be taken into consideration in e.g. the planning of new housing estates.

Regulations for the outdoor air exist in e.g. Finland ([22]). See also Appendix No 2 for individual guideline values according to WHO ([15]).

With regard to the siting of the outdoor air intake, see Clause 4.2.

3.2 The design of buildings

The risk of the spread of pollutants can be modified by the design and layout of the building. Open stairways or large rooms with varied activities involve the risk of the spread of pollution. The same applies, on the whole, to a mixture of polluting and nonpolluting activities in the same building.

In view of this, the following recommendation is made for regulations:

A building shall be designed with regard to the pollution which may arise. The ventilation shall be planned so that the risk of the spread of pollution in the building is kept low.

Premises in which there is a large difference in the expected degree of pollution should be separated from one another, for instance as regards both construction and ventilation. They should preferably be located in different buildings.

3.3 Construction

Moisture damage often occurs in buildings with flat roofs and with foundation slabs placed directly on the ground. Mould damage often occurs in foundation structures of the types slab laid directly on the ground with insulation on top, ground floors above crawling spaces, and basement walls with internal insulation. On flat roofs even a small leak will give rise to extensive consequential damage. For instance, problems are often encountered due to icing and cracking in climates with low temperatures and snow. The cause of these problems may be bad planning, defective construction or poor maintenance. As far as damage in general is concerned, neither designers nor others responsible for the construction process have much knowledge of building physics. See, for instance, ([23]).

Leaks from installations can give rise to extensive indirect problems such as mould growth or chemical degradation, with reduction in the quality of air as a consequence.

In view of this, the following recommendations are made for regulations:

The building structure shall be arranged so that building materials are not exposed to action such that harmful emission of pollutants to the indoor air occurs. The building structure shall be selected, constructed and maintained so that it is satisfactorily dry with respect to the materials used. The structure shall be arranged so that spread of pollution from the outside, the ground, another flat or some other separate part of the building does not occur.

Water supply, drainage and heating installations shall be planned and constructed so that the risk of consequential damage caused by leaks is prevented.

> Materials in constructions are to be selected with regard to the temperatures and moisture contents to which they will be exposed.
>
> Constructions are to be arranged so that ingress of water and moisture (driving rain, snow, moisture from the ground) cannot occur and so that moisture in materials is removed. Roofs are to be designed so that water is drained. Account should be taken of local snow and ice conditions.
>
> Thermal insulation and weathertight layers are to be arranged so that the risk of damage is prevented.
>
> Foundation structures of the type slab laid directly on the ground require great care in design and construction, for instance with regard to the placing of thermal insulation and the waterproof layers and the quality of the moisture barrier course.

Foundation structures of the type where the ground floor construction is above a crawling space are susceptible to moisture damage and should be used only on dry ground and provided with effective ventilation. The materials should be resistant to mould and rot. Timber in sole plates and wood based boards in counterfloors should be impregnated against mould and rot.

In rooms where there is a great risk of water leaks there should be either floor gulleys or the floor covering should be arranged so that any leaks can be seen. In bathrooms and similar the floor shall slope towards the floor gulley.

Pipes should be laid so that they are readily accessible for inspection and repair, and arranged so that any leaks can be seen at an early stage.

Since the pressures in different parts of a building may be different due to e.g. thermal forces, wind or the function of the ventilation system, the structure should be sufficiently airtight with regard to prevailing conditions. The same applies to points where installations penetrate elements of structure. These should be sealed with material resistant to ageing.

During construction there should be in existence a quality assurance programme which ensures that unnecessary moisture is not incorporated in the structure. Many problems can be avoided by careful handling of building materials (e.g. by ensuring that materials sensitive to moisture are always covered in the event of rain) and by continuous tests and checks of the moisture content of materials prior to their incorporation in the structure.

3.4 Building materials and surface finishes

From the point of view of air hygiene, the aim is that materials in buildings shall not impose extra requirements on ventilation. Ideally, there would then be no need to provide ventilation to remove gases emitted by building materials, fixtures and fittings, furnishings and furniture. At the present day, as a result of lack of knowledge of what materials emit and the significance of these pollutants, this is not realistic. The first step therefore is to choose materials which emit the smallest possible quantities of pollutants. Apart from their own ability to emit pollutants, surface finishes can act as storage areas for pollutants, particulates, gases and vapours from other sources. This storage effect is dependent, inter alia, on the surface area of the material. For instance, a fleecy surface has a relatively larger storage effect than a smooth one.

Uncritical use of new and hygienically untested materials, and faulty handling of materials, primarily handling that increases moisture load, is a significant cause of sick buildings. One example of this is provided by the chipboards and glued timber structures of the seventies which could emit a lot of formaldehyde, especially in conjunction with moisture. Another is screeds containing casein from the period 1977-1984 which in combination with moisture could give rise to chemical reactions that resulted in significant emission of pollutants. The moisture in this case came from damp concrete or thick courses of screed which were not given enough time to dry out before the carpets were laid. In both cases the materials were altered after the problems had been discovered. Other examples are acoustic tiles of loosely compacted mineral wool, certain paints, and adhesives. See, for instance, ([24, 25, 26, 27]).

Emissions from materials arise from (1) solvent residues, (2) remnants of raw materials (e.g. monomers), (3) reaction and decomposition products from the manufacturing process, and (4) additives. In new materials, the emissions due to the first three factors are most significant. Within one to six months, the emission decreases asymptotically to a level which is characteristic for the material and the type of emission.

Pollutants from materials can in many cases be detected by their odour. Odours in indoor air are therefore a good preliminary indicator of the quality of air in this respect. There is however considerable variation in the odour threshold of pollutants. There are substances which are harmful at levels below the odour threshold, and odour alone cannot therefore be relied upon.

Apart from radon and substances of a biological character, it is mainly the volatile organic compounds which distinguish indoor are from outdoor air. These, which often originate from building materials, fittings and fixtures, furnishings and furniture, may be grouped as follows depending on their boiling point:

* VVOC - very volatile	<0...50-100°C
* VOC - volatile	50-100...240-260°C
* SVOC - semivolatile	240-260...380-400°C
* POM - particulate	> 380°C

The more volatile a substance, the faster it is released from its source, e.g. a surface finish. The emission can be at a high level for a short time but will drop after a few weeks or months to normal level. Such emission can be accelerated by increased ventilation.

Substances with a higher boiling point, which are less volatile, are released at a slower rate. The emission lasts a long time and cannot be accelerated by ventilation. It is a characteristic of such substances that they are prone to be absorbed by other materials, especially materials of large specific surface such as textiles.

Measurements of volatile organic substances indoors have mainly concentrated on VOC. The levels of such substances are normally within the following ranges. For purposes of comparison, the concentrations of airborne dust are also given.

	VOC mg/m^3	Dust mg/m^3
Outdoor air	0.01-0.04	0.005-0.03
Dwellings	0.1 -0.4	0.01 -0.1
Offices	0.5 -0.8	0.1 -0.2
Schools, day nurseries	0.2 -0.3	

A preliminary critical scrutiny of the allergenic properties of substances contained in building materials has been made by the Danish Toxicological Centre ([28]). This is based on the substances included in the Danish Ministry of the Environment list of hazardous substances classified as R42 (may cause allergy on inhalation) or R43 (may cause allergy on skin contact) and a number of other substances which are used in building materials, although far from all. It has been possible to classify a large number of substances as presumably contact allergenic but only a few as allergenic on inhalation. It is stated in conclusion that available knowledge of allergenic properties is often unsatisfactory and that several examples of misclassification have been found. It is stated that this underlines the obligation on the part of manufacturers and importers to obtain information themselves and to evaluate the hazard attached to substances and materials. The report states that substances contained in curing systems such as isocyanates, epoxy products, acrylates and amines may be allergenic in their pure form but that after curing they seldom pose any risk of allergy. For a number of substances in general use there is no allergenic effect described in the literature, but by reasoning on the basis of analogy they may nevertheless be presumed to have an allergenic effect.

The volatility of substances plays an important part in the occurrence of the hazard. Highly volatile substances evaporate in a short time, hours or days, while substances of low volatility may take a long time, months or years, to disappear. In complex material structures such as sandwich units, foam and jointing compounds, the volatile substances may be held back and emitted over a long period. One common example of wrong use is to expose the material to a high moisture load ([1]).

In view of this, the following recommendation is made for regulations:

Building materials and surface finishes shall have the lowest possible emission properties. They shall be selected, handled, stored and used so that emission to the room air is the least possible. The material shall be able to stand up to the intended use. The material shall not contain any genotoxic or neurotoxic substances, substances which cause sensitisation or irritation of the mucous membranes, or substances harmful in any other way, which pose a health hazard when used as intended in the building.

Intended use includes e.g. cleaning.

Only materials which have low emission properties and little odour, have been tried and tested and are accompanied by a product description statement, should be used. The client should demand an internal climate related product description of the material. This description may contain data regarding the content of substances in the material, and emissions, which affect air quality and may involve health hazards or have an effect on comfort and the intended area of use. Such descriptions should be drawn up by the material manufacturer and importer.

In producing materials, the following should be complied with:

- Only known and tested raw materials should be used, and they should be selected so that they do not carry emitting substances into the material.
- The manufacturing process should be well known and its critical parameters monitored so that unreacted monomer residues are not left in the material and so that decomposition does not occur in the material during the process.
- The components of the material should be correctly selected in view of the intended use of the material, for instance damp conditions.
- Additives should be selected so that they are durable in the material and are not lost by emission.

Stone, brick, timber, gypsum and high pressure laminates are examples of materials which normally have low emission properties. Materials which may emit gases to an annoying extent over a long period should be avoided. Adhesives, fillers and jointing compounds should therefore be applied in the thinnest possible layers. Moisture sensitive materials should not be exposed to rain or snow, nor should they be incorporated in structures where moisture loading is likely. Materials must in addition be used in the intended manner and, for instance, given sufficient time to dry out before being built in. Before a building is taken into use, it is essential that the materials (e.g. surfaces painted in situ) are given sufficient time for emission to occur. Well tried materials accompanied by a product description should be used in the first place.

The surfaces of mineral fibre products should be sealed to prevent the release of fibres into the room air.

Surface finishes in a room should have the lowest possible specific area in order to prevent undesirable storage effects.

3.5 Fittings, fixtures, furnishings and furniture

Fittings, fixtures, furnishings and furniture are often just as significant a source of pollution as building materials. See also the background text to Clause 3.4.

In view of this, the following recommendation is made for regulations:

Emission into the room air by fittings, fixtures, furnishings and furniture shall be as low as possible. The materials shall stand up to the intended use. Materials shall not contain any genotoxic or neurotoxic substances, substances which cause sensitisation or irritation of the mucous membranes, or substances harmful in any other way, which pose a health hazard when used as intended in the building.

Fittings, fixtures, furnishings and furniture should be selected, handled and used so that emission to the air is the least possible. Intended use includes, for instance, resistance to cleaning.

Only materials which have little odour, have been tried and tested and are accompanied by a product description statement, should be used for fittings and fixtures, furnishings and furniture.

3.6 Processes, activities and handling

In many premises and contexts, processes, activities and handling are dominant pollution sources. One common source is tobacco smoking. In contrast to sources such as building materials, fittings and fixtures, furnishings and furniture, they are often intermittent and mobile ([29]). Measures to reduce emission to the room air are therefore to be preferred to general measures of the background ventilation type. There is also experience from industry that all polluting processes can be replaced by ones that produce less pollution, can be carried out at times and in places so that few people are affected, can be encapsulated or treated at the source by e.g. local extraction or similar. These experiences should be applied to a greater extent in the premises referred to here, for instance as regards photocopiers and laser printers. In dwellings also exposure to pollutants as a result of e.g. hobby activities should be mainly counteracted by reducing the intensity of source. Consumer, play and hobby products should therefore be controlled and marked in this respect.

In view of this, the following recommendation is made for regulations:

Processes, activities and handling shall be selected so that they have the lowest possible emission. Where processes, activities and handling which pollute the air are necessary, they should as far as possible be encapsulated, provided with local extraction, carried out in premises with separate ventilation to the external air, and limited to times when few people are exposed. Where tobacco smoking occurs special measures shall be taken to prevent the risk of passive smoking.

In view of the risk of passive smoking, tobacco smoking indoors should be limited. It is appropriate to provide special smoking rooms with separate ventilation to the external air.

Appliances which emit pollutants, such as certain photocopiers, should similarly be placed in well and separately ventilated rooms. Such appliances should be accompanied by a description containing data on the pollutants emitted and the way these should be disposed of.

In the same way as craft premises or industrial buildings, garages shall be located in spaces which are completely separated from other activity as regards ventilation. See also Clause 3.2.

3.7 Cleanability and the cleaning of buildings

Ventilation removes the airborne pollutants. Cleaning removes potential airborne pollutants from surfaces in the building.

There are many sources of such pollutants. They may be activities which emit particulates, dirt which enters the building on shoes and clothing, the people themselves, different materials and the outdoor air.

Cleaning of internal surfaces is therefore of great significance for the hygienic conditions including the quality of air in the building.

Owing to the materials used, the design and furnishings etc of a room, it is often difficult to carry out cleaning rationally. This may mean that cleaning is insufficient, but also that aggressive cleaning agents are used, agents which may themselves be emitted into the room air or may decompose surface finishes and add to the airborne pollutants.

Fitted carpets as well as textile or other materials of large specific area are often not particularly polluting as such, but they become so since it is difficult to keep them clean ([3, 30, 31]). They are important storage areas for dirt and pollutants. A relationship has for instance been demonstrated between the use of medication by allergic persons and the incidence of fitted carpets ([32]) and also between the incidence of fitted carpets and the prevalence of the sick building syndrome ([33]).

In view of this, the following recommendation is made for regulations:

Buildings shall be designed so that cleaning of surfaces in contact with supply air or room air is possible. Surfaces which are likely to become heavily soiled shall be readily accessible and easily cleanable. Surfaces and surface finishes shall be selected so that dirt is not unnecessarily concealed or accumulated.

Surfaces which collect dust or are difficult of access should be avoided. Walls and other surfaces should have a texture that does not collect dirt and dust. An endeavour should be made to keep the proportion of surfaces of high specific area as low as possible.

Internal surfaces should have a texture and colour such that dust and dirt are not concealed.

Cleaning should be carried out so often that stored dust and dirt does not result in deterioration of air quality. Cleaning should be carried out using such methods and agents that cleaning itself causes the least possible deterioration in air quality.

Cleaning should be carried out using agents provided with a product description which have been shown to be of low emission properties and nonaggressive. Vacuum cleaning should be carried out so that fine grained dust is not returned into the room air.

Radiators should be smooth and easily cleaned even along their rear faces. Electric radiators should be constructed so that heat emitting surfaces have a low temperature.

4. REQUIREMENTS FOR VENTILATION

4.1 Outdoor air flow rates

Requirements regarding air flow rates for the ventilation of buildings have varied considerably over time. After Yaglou's studies in the twenties and thirties, thinking in this area and also requirement levels were largely unchanged for a long time. It was not until the energy debate in the seventies and the increased interest in air hygiene that new knowledge regarding the need for ventilation became available. The old "truths" on which NKB Publication No 41 was based were mainly that man himself was the principal source of pollution which determined the need for air. It was also assumed that the emission of pollutants by building materials, fittings, fixtures, furniture and furnishings and similar also necessitated an air flow rate which was often lower. These separate air flow rate requirements were not added ([9]).

Today we know more about the pollution situation indoors and about the significance of different sources, and also know that the incidence of health problems due to this situation is common. Much knowledge is however still needed before health problems can be related to a certain exposure or a specific pollution source. It is only in exceptional cases that it has been possible to relate symptoms of ill health of the SBS type to the concentrations of specific air pollutants or combinations of these. There are few investigations of SBS in relation to air flow rate. During investigations of a major office complex, however, Jaakkola et al have found a significant correlation between the outdoor air flow rate and the incidence of SBS symptoms when this was less than 5 l/s,person ([34]). The conclusion was the recommendation that the air flow rate should be not less than 10 l/s,person.

In the study of Jaakkola et al and also in a large epidemiological investigation of SBS in the north of Sweden, the real air flow rates were generaly far above those specified in codes. In the latter study, the mean value for almost 600 office rooms, situated in 192 buildings, was 16.7 l/s,person ([35]). Preliminary data from this study indicate that there is no simple relationship between air flow rate and the SBS syndrome. There is however a relationship between air flow rate and individual symptoms. The incidence of certain symptoms increases at lower flow rates, while the incidence of others increases at higher flow rates.

A classical measure of air quality is the extent to which odour is perceived as acceptable by visitors directly on entry into the premises. This measure was used by Yaglou in his classical studies, and has in recent years been developed by e.g. Fanger ([36]). He has introduced new terms such as olf and decipol to measure the intensity of source and perceived air quality. An olf is equivalent to the emission of the perceived air pollutant (bioeffluents) by a standard person. A decipol is the perceived air quality due to an olf which is ventilated at 10 litres of pure air per second. He quantifies other pollution sources, e.g. building materials, fixtures and fittings, furnishings and furniture, by means of the number of standard persons (olf) which gives rise to the same dissatisfaction as the pollution source being considered. In order that the maximum number of persons dissatisfied with the perceived air quality (1.4 decipol) should be 20%, the air flow rate must be at least 7 l/s,olf. The most important finding in this line of research is that ventilation systems, fixtures and fittings, furnishings and furniture, and tobacco smoking, at least in offices and places of assembly, are sources of pollution which, from the standpoint of odour, are equivalent to, or more important than, man himself.

There is considerable variation in pollution load between buildings ([37]). According to Fanger, the pollution load from the building, fixtures and fittings, furnishings and furniture, ventilation system etc is 0.1 olf/m^2 in a "low olf" building, and 0.4 olf/m^2 in a "normal olf" building, which correspond to 0.7 and 2.8 l/s,m^2. Too little is known at present about the intensity of sources indoors, measured in olf, for the olf theory as a whole to be applied.

Measurements of the "own odour" of premises have been made to only a small extent in relation to Fanger's research. In an investigation of the odour intensity in a classroom, the research group Lindvall et al found that the odour due to persons exceeded the odour due to the premises at a CO_2 content of 800 ppm, which is equivalent to a flow rate of 10 l/s,person and approx 5 l/s,m^2 ([38]).

In a survey of pupils' degree of satisfaction with the indoor climate in 11 schools, Nielsen et al ([39]) found a large variation in degree of satisfaction between the schools. Significant explanatory variables were outdoor air flow rate per person, quantity of dust and relative humidity. These variables do not however explain the differences between schools. Each school had its own base level for satisfaction with air quality, in relation to which variations in satisfaction occur. In a study of 10 schools, Thorstensen et al found a large variation between schools as regards the frequency of complaints. She established a correlation between the content of CO_2, the perception of air quality (in decipol) and reported complaints of the SBS type ([40]).

Recent research results regarding odour thus imply that higher air flow rates are required to keep down the "own odour" from the premises and the building, inclusive of the ventilation system. With regard to odour and the emission of pollutants from dust in ventilation ducts, it has been shown ([41]) that the contribution of dust, when it is dry and properly ventilated, is negligible.

The humidity of indoor air as a ventilation criterion is a theme of current interest in the Nordic countries, due both to the frequent complaints about "dry air" and to the increasing incidence of moisture and mould damage and allergenic house dust mites (HDM). "Dry air" is a theme of current interest in geographically widely different parts of the world with greatly varying climatic conditions, i.e. the coupling to moisture content is by no means a simple one. Studies (referred to in ([41]) have also shown that the perception of "dry air" is due more often to the air being polluted or too warm than to the air being physically dry. Reinikainen et al found in a study of office workers, however, that the perception of "dry air" and SBS and dryness symptoms was lower in rooms with humidification of air than in rooms without ([43]). A lot remains to be studied, however, for instance with regard to the coupling between the humidity of air and the survival of viruses, bacteria, etc.

Simpler relationships exist between the humidity of air and the proliferation of mould and house dust mites. House dust mites thus normally constitute the design criterion. In Danish and later in Swedish dwellings, a rapid increase in the number of mites has been demonstrated. A Danish study by Korsgaard found a fortyfold rise between 1977 and 1986 and a simultaneous increase by a factor of 3-5 in allergic complaints related to this ([44]). The increased incidence has been ascribed to the fact that buildings have become "wetter" as a result of reduced ventilation. Korsgaard, among others, has shown that mites require humidity, even under winter conditions, of more than 7 g H_2O/kg of air, i.e. ca 45% RH at 21°C, for survival and increase ([45]). This is of practical significance in dwellings and possibly in day nurseries. The moisture load indoors is not sufficiently known, but there are a lot of indications that approx 0.5 ach is sufficient to keep relative humidity below this value.

Measurements in residential buildings show that air flow rates today vary appreciably with the type of dwelling and type of ventilation. It has for instance been shown in an as yet unpublished Danish investigation that detached houses with natural ventilation have an average flow rate of 0.33 ach, and those with mechanical ventilation 0.5 ach. In a similar and as yet unpublished Swedish study it has been found that the air flow rate is normally a little higher in dwellings with mechanical ventilation than in those with natural ventilation. A Finnish investigation ([46]) comprising 300 dwellings has found no significant difference in air flow rates between natural and mechanical ventilation systems. The average outdoor air flow rate (median value) was 0.5 ach, but in 50% of cases the value was below this recommended figure.

The frequent health problems, even in buildings with "standard" ventilation, a few epidemiological studies and new knowledge regarding the "own odour" of premises, all indicate that the old NKB values ought to be increased. There are however large gaps in knowledge as regards e.g. the significance of outdoor air flow rate for the incidence of different symptoms, the significance of the odour criterion for acceptability and health effects in a somewhat longer term, whether direct summation of the different outdoor air flow rate requirements is relevant, the influence of the period of operation (can a lower flow rate be accepted with respect to the load in the premises if the flow is continuous), etc. In addition, the available research results are as yet greatly limited in scope. It is not known whether they are representative for a normal stock of buildings and also for other types of properties. In view of the present state of knowledge, minimum air flow rates can be laid down only with a high degree of uncertainty.

The choice of outdoor air flow rate per person who is engaged in sedentary activities can be made on the basis of the odour criterion. For instance, the flow rate 7 l/s,person ([36]), which corresponds to 1.2 met, is obtained for the criterion of 20% dissatisfied ([47]). Higher air flow rates are required at higher levels of activity. From the standpoint of odour, an activity of 1.6 met is equivalent to 12 l/s,person, and 6 met (=gymnastics) to 77 l/s,person ([36, 47]). The outdoor air flow rate which is required with respect to other pollution sources (building materials, fixtures and fittings, furnishings and furniture, dirt, activities, etc) should reasonably be added to the air flow rate required in view of the occupancy level. There are discussions whether such an addition should be normal addition (i.e. 1 + 1 = 2) or whether it can be supposed that a hypo-addition (1 + 1 < 2) occurs. Pending further research in this field, it has been decided to apply an addition factor of 0.5 (i.e. 1 + 0.5x1 = 1.5). The value 0.5 x 0.7 $l/s,m^2$ = 0.35 $l/s,m^2$ has therefore been given as the minimum value for "clean" buildings.

In view of this, the following recommendation is made for regulations:

Rooms in which people are present other than occasionally shall be provided with an outdoor air flow rate which is sufficient to dilute and remove the pollutants normally present in the room to contents so low that at least the overriding requirements in accordance with Section 2 are complied with.

4.1.1 Choice of outdoor air flow rates

The outdoor air flow rate should be decided with respect to the required quality of indoor air, the quality of outdoor air, the type and intensity of pollution sources, ventilation and air change efficiency. When new buildings are planned, there are usually no design data available, and empirical values must therefore be used.

The empirical values given below presuppose

- that the supply air maintains good outdoor air quality,
- that air change efficiency is at least equivalent to well mixed ventilation (approx 0.5),
- that building materials, fixtures and fittings, furnishings and furniture, are low emitting,
- that there are no "special" polluting activities,
- that the supply air system is clean, and
- that the standard of cleaning in the building is satisfactory.

The outdoor air flow rate per person engaged in sedentary activities should be not less than 7 l/s,person. For higher activities greater air flow rates are required.

The additional outdoor air flow rate with respect to the release of pollutants from sources other than persons should be at least 0.35 $l/s,m^2$. A considerably higher flow rate may be required if the choice of building materials, fixtures and fittings, furnishings and furniture etc has not been properly thought through, as in many existing buildings.

For a room for a single person, of 10 m^2 area, the above implies a total outdoor air flow rate of 7 l/s,person + 10 m^2 x 0.35 $l/s,m^2$ = 10.5 l/s.

In rooms where tobacco smoking usually occurs, the outdoor air flow rate should normally be at least 20 l/s,person.

In the case of dwellings the flow rate will vary depending on the likely occupancy level and the area of the dwelling. The outdoor air flow rate per person may be somewhat lower, say 4 l/s,person. To this must be added an outdoor air flow rate with respect to the emission of pollutants from sources other than persons. This should be at least 0.35 $l/s,m^2$. The outdoor air flow rate is determined per dwelling. For a dwelling of 100 m^2 for four persons the outdoor air flow rate is therefore: 4 persons x 4 l/s,person + 100 m^2 x 0.35 $l/s,m^2$ = 51 l/s.

In design, the tolerances for air flow rate should be determined in each individual case with respect to the inaccuracy in measurement and balancing and the expected operational and maintenance conditions. With regard to tolerances, see NKB Publication No 52, Subclause 3.3.4.

4.1.2 Operation

When ventilation is turned off or when flow rate is reduced, pressure conditions in conventional systems can be substantially different from those normally aimed at. Spread of pollution can then occur from rooms with a high pollution load to those with a lower load. Supply air ducts may act as extract ducts, which may result in contamination of the ducts. When flow rates are reduced or the system is turned off, there is a higher concentration of pollutants in the room and a risk of greater "exchange" through adsorption and desorption of pollutants between different sources and surfaces in the room. This may have the result that the flow rates on full operation, which are normally sufficient, are not enough to keep contents at the required levels.

In view of this, the following recommendations are made for regulations:

When a building is not used in the intended manner, the outdoor air flow rate shall be so large that the air quality in the building when this is again put into use is not inferior to that in normal operation.

The air handling system shall be designed so that the spread of pollutants in the building, or contamination of the supply air system, does not occur during times when the building is not used.

In view of the fact that the emission of pollutants from new surface finishes, fixtures and fittings, furnishings and furniture is somewhat higher in the beginning, ventilation should normally be run at full flow rate during the first year after new construction or internal renovation. The same may be required after the installation of new fittings, fixtures, furnishings and furniture, and during cleaning.

When supply flow rates are varied, care must be taken to ensure that the installation is able to maintain the intended pressure conditions in the building so that pollutants are not spread.

4.2 The quality of outdoor air

The outdoor air admitted shall dilute the pollutants which are generated indoors and replace vitiated indoor air by "fresh" air. It is therefore essential that this outdoor air should be as clean as possible. The building should preferably be placed in as clean an environment as possible in accordance with Clause 3.1.2. Where this cannot be done, the outdoor air intake should be situated at the place in the building where the air is best in relative terms. This is normally on the roof and on the side facing the courtyard. Experience shows that outdoor air intakes are often inappropriately sited, for instance towards a street carrying heavy traffic, parking areas or similar, which causes discomfort to the users of the building.

Particulate pollutants can be effectively removed by conventional technology; this should be done so that allergenic and dirty particles are not admitted into rooms and so that the supply air installation is not contaminated.

In view of this, the following recommendation is made for regulations:

Outdoor air intakes shall be placed where the air admitted is likely to be cleanest and to have the lowest temperature in the summer, in view of the position of the building and the placing of chimneys or flues or other sources of pollution. Where this is required because the quality of outdoor air is unsatisfactory, the supply air shall be filtered to remove dust, pollen and other particulate pollutants.

In more polluted environments, for instance in town centres, the outdoor air intake shall be placed on the roof or towards an internal courtyard at a level such that pollutants from the ground are not drawn in. In supply air systems filters of not less than

Class EU 7 (F 85) should be used to filter the outdoor air. Outdoor air intakes should not be placed in the prevailing wind direction downwind from a chimney or other discharge for gas or polluted air. In siting the outdoor air intake, its distance from and height above the ground should be taken into consideration.

Vents for direct admission of outdoor air into rooms should be fitted with filters.

See also NKB Publication No 52, Subclauses 3.3.1 and 3.3.4, and ([48]).

4.3 Air flow conditions

It is impossible to prevent some spread of pollutants in rooms without extensive encapsulation and similar. Spread between rooms occurs easily, for instance when persons pass through door openings. This is however not a serious problem. Improperly adjusted installations with imbalances between the supply and extract air systems which give rise to unintended pressure conditions and flow directions, are worse and very common.

Quantified requirements regarding air change efficiency, other than that it shall be satisfactory, i.e. that it should be around or preferably over 50%, cannot be reasonably stipulated at present. There are few measurements in rooms under normal operational conditions, and the few which are available indicate that in the majority of cases this is around 50% and that there are no direct faults such as e.g. greatly elevated inlet temperatures in combination with extract terminals placed in the roof ([49, 50]). The principles should however be set out so that they may perhaps be developed in the future in a requirement context.

At the Nordic seminar "The healthy building" ([51]) the following statement was made regarding recirculated air:

"Recirculated air is not recommended in premises open to the public as a general method because of the risk of spreading gases and vapours, and in view of the experiences of faulty technology and lack of maintenance in practice. Air from "polluted" rooms, for instance smoking rooms, should not be recirculated. In existing installations recirculated air can be used, but filters and the volume of outdoor air admitted should be checked often. It is recommended that in new installations other solutions should be applied to recover heat. Recirculated air systems can be used as a method of mixing outdoor air and room air where this is a practical necessity for e.g. thermal reasons. If recirculated air is used in new buildings, special requirements must be complied with as regards balancing, regular checks on performance and cleaning of the duct system".

Conflicting results have been found in two investigations regarding the significance of the use of recirculated air for the incidence of complaints or symptoms. Jaakkola et al have found that there is not necessarily any coupling between recirculated air and complaints in offices ([52]), while Lundin in an as yet unpublished Swedish investigation has found such a coupling in a library.

Hot air heating systems have earlier been considered to demand the use of recirculated air in view of the large air flow rates required. In the new airtight and low energy buildings of today this is seldom necessary. Buildings have normally been cooled by air, which has also necessitated large air flow rates in the summer and the use of recirculated air during the cold months. Other systems for cooling which do not require such large air flow rates are being used increasingly, and this reduces the significance of recirculated air.

In view of this, the following recommendations are made for regulations:

The spread of air pollutants in the room and to other rooms shall be limited. Spread of air pollutants to other rooms where these are not normally generated shall be prevented.

Air shall be designed to flow from a room with a more stringent requirement regarding air quality to a room with a lower requirement.

Air change efficiency shall be satisfactory.

The basic principle is that pollutants should be captured as near the place of generation as possible and removed from the room as quickly as possible. In conjunction with concentrated sources of pollution which are not negligible, the concept of ventilation efficiency can be used to describe the ability of ventilation to capture and remove such pollution. This is done by relating the equilibrium concentration in the extract air to the mean concentration in room air under equilibrium conditions. The highest ventilation efficiency is achieved by providing some form of process ventilation in accordance with Clause 4.5.

If there are only diffuse and passive pollution sources such as building materials, fittings, fixtures, furnishings and furniture, or if the sources are weak and mobile, air change efficiency is a better measure. This shows how effectively air in a room is changed. It is defined as the ratio between the mean age of the air in the extract air (exchange time of the ventilation air) and twice the mean age of the air in the room. The highest efficiency, 100%, is obtained under parallel flow conditions, when air passes as a rigid body from e.g. the floor to the ceiling. Efficiency is least when there is short circuiting between supply and extract terminals. When supply and extract terminals are placed in the ceiling and the supply air is heated, there is a risk of such flow, especially if the ceiling is high and there are few sources of disturbance in the room. An air change efficiency of 50% represents "complete mixing".

In order to secure acceptable direction of flow between rooms in a building, it is necessary to ensure that pressure conditions are correct. For instance, rooms which are more polluted such as garages, smoking rooms, rooms for photocopiers, toilets and kitchens, shall be at a lower pressure than surrounding cleaner rooms. The aim in blocks of flats is to achieve neutral pressure conditions between flats.

These requirements imply that air cannot be recirculated from e.g. rooms where smoking will occur, rooms for photocopiers, or similar.

The statement from The healthy building seminar should be noted.

4.4 Processes and sanitary accommodation

Pollutants should be captured as near the source as possible. The technology for this was developed in the industrial ventilation sector long ago. In the non-industrial sector this technology regarding encapsulation and local extraction is little used and developed. See also Clause 3.6. It is likely that there will be substantial development in this area, for instance with regard to encapsulation and hoods for office equipment and also hobby activities in the home. The cooker hoods in use at present should also be subjected to further development.

Numerical values for kitchens, bathrooms and toilets are empirical and largely correspond to the recommendations in NKB Publication No 41. If flow rates are too low, moisture and mould problems easily arise.

In view of this, the following recommendation is made for regulations:

Pollution sources which are tied to a certain place and pollution sources or activities of frequent occurrence shall be provided with such process ventilation of the encapsulation, hood or local extraction type that the spread of pollutants is normally prevented.

Pollutants which are of interest from the hygienic standpoint largely follow the air streams. By controlling the flow of air, the pollutants can therefore also be controlled. As regards local extraction and encapsulation, in principle there are three types:

* Encapsulation, which means that the source of pollution is completely enclosed, for instance a fume cupboard or entire rooms such as toilets, smoking rooms or rooms for photocopiers.

* Entrainment type local extraction works by entraining the pollutants into the air stream flowing into the extraction device. Examples are weld fume extractors, vacuum cleaners, etc.

* Collection type local extraction gathers up the pollutants and then removes them. Polutants enter the extraction device under their own power. Cooker hoods are one example of this technology. They are designed so that they have sufficient volume to receive the pollutants which are often generated intermittently, and so that they have sufficient extract air flow so that the hood does not become full and "spill over". The flow rate necessary is considerably lower than in the case of the entrainment type. For instance, a large cooker hood for domestic use requires a flow rate of the order of 20 l/s while a "flat" hood which is intermediate between the two types requires flow rates of approx 100 l/s for the same function. Cooker hoods and extraction hoods are easily affected by the disturbance caused by air streams due to people moving in their vicinity or to open windows.

Sanitary accommodation such as toilets and bathrooms is provided with an extract air flow rate which is both sufficient for the room to act as a kind of encapsulation and enables the room to dry out quickly after use in order to prevent moisture and mould damage. A toilet requires an extract flow rate of not less than 10 l/s, and a bathroom not less than 15 l/s. If the bathroom has no window, it must be possible for the flow rate to be increased to not less than 30 l/s. It must be possible for such increased rate to be set for times up to at least 2 hours.

Kitchens are to be given a flow rate of not less than 20 l/s. Electric cookers with more than 2 hotplates are to be provided with a hood or local extraction with a collection efficiency of at least 85% for gaseous substances. In the case of gas cookers it is necessary in addition to the above for the collection efficiency and air flow rate to be adjusted to the need to remove combustion products.

4.5 Opening of windows

The availability of openable windows is protection against malfunction of the ventilation or heating system and a necessary extra facility for increased extraction in the event of unplanned temporary pollution loads. Bathrooms and shower rooms should also be provided with openable windows. See also Subclause 4.6.1.

In view of this, the following recommendation is made for regulations:

Every workroom and habitable room shall be provided with an openable window or windows for ventilation.

4.6 Engineering requirements for air handling installations

4.6.1 Ease of use

Jaakkola et al draw the conclusion from an investigation of a major office complex that individual control of room temperature increases satisfaction and probably reduces sick building symptoms ([53]). The same conclusion is drawn by Hedge et al from a nationwide study of building related diseases in the UK. They put forward the hypothesis that the tolerance threshold of a person to disturbances in the climate is reduced when he or she cannot modify, or control, the climate in his or her surroundings ([54]). The varying needs and tolerance thresholds of people appears to justify the introduction of a requirement that the individual should be given a large measure of control over the climate in his or her surroundings. It has however been considered that this requirement is not so well founded at present that the large additional cost which it would involve can be justified.

In view of this, the following recommendation is made for regulations:

Control devices shall be easy to reach and to understand.

The aim should be to develop systems in which the users can easily control the magnitude and direction of the air flow and the temperature of the room and the supply air. The term control device refers to all kinds of arrangements by means of which the magnitude and direction of the air flow can be controlled, i.e. it includes arrangements for opening or closing vents for the direct intake of outdoor air.

4.6.2 Space requirements

In order that inspection and maintenance should be carried out to the extent required, it is necessary that ease of access and good working spaces shall be provided.

In view of this, the following recommendation is made for regulations:

Components which require attendance and maintenance shall be sited so that they are readily accessible and replaceable, and mounted so that work can be carried out easily and safely.

For guidance reference should be made to NKB Publication No 52, Subclause 3.2.7.

4.6.3 Cleanability

Supply air installations have in some cases been shown to have considerably contaminated the outdoor air on its passage through the installation ([37, 55]). This is due to both pollutants from materials in the installation (filters, sealing compounds, oil from the production of ducts or similar) and to the dirt deposited in the installation. With regard to emissions from dry dust in ventilation ducts, see ([36]). Cleaning of extract air installations is required mainly to prevent deposits from reducing the air flow rate. It should be noted that an extract installation can at times function as a supply air installation, for instance in the event of recirculated air operation or when the ventilation system is turned off.

Rapid development with respect to system design and cleaning facilities can already be noted.

In view of this, the following recommendation is made for regulations:

It shall be possible for both supply and extract air installations to be cleaned in their entirety. Installations shall be cleaned so often that neither the magnitude of air flows nor the quality of supply air is adversely affected by deposited dirt.

For guidance reference should be made to NKB Publication No 52, Subclause 3.3.10.

4.6.4 Components and materials

Surface finishes on the inside of a supply air installation can release pollutants to the supply air in the form of both particles and fibres (internal insulation) and gases (odorous filter materials, oil from the production of ducts, etc).

In view of this, the following recommendation is made for regulations:

Components shall be made of materials which stand up to the intended use and maintenance and which do not emit pollutants such as particles or gases which may adversely affect the quality of supply air.

See NKB Publication No 52, Clause 3.3.

4.6.5 Unintended flow from extract air to supply air

Experience shows that ventilation installations are very leaky. This makes it difficult to control air flow in the building, i.e. to deliver the air to the point where it is needed.

A large number of rotary heat exchangers with or without recirculated air dampers have their fans in the wrong place, so that there is considerable recirculation of air even when the damper is closed (often up to or even above 50%)([56]). It has been shown that when fans are placed correctly, recirculation of organic gases via rotary heat exchangers may be as much as 10%.

In view of this, the following recommendation is made for regulations:

Installations shall have the required airtightness. Pressure conditions between supply and extract air installations shall be adjusted to the airtightness of these installations so that there is no unintended flow from extract air to supply air.

With regard to the airtightness of ventilation installations, see NKB Publication No 52, Subclause 3.2.3.

In conjunction with e.g. dampers for recirculated air or heat exchangers, care is to be taken that pressure conditions are such that any leakage takes place from the supply to the extract air.

4.6.6 Humidification of air

In the light of present knowledge, humidification of room air is seldom necessary unless a certain moisture content is required for production engineering reasons or e.g. in certain hospital rooms. A lot of problems associated with dryness can be remedied by humidification when humidity is less than 20% ([43, 57]).

At the Nordic seminar The healthy building ([51]), the following statement was made regarding humidification:

"From the hygienic point of view, general humidification of air is not recommended. General humidification may have side effects such as proliferation of house dust mites, legionnaire's disease, other allergies. Symptoms of "dry air" shall be mainly counteracted by methods other than humidification. Selective humidification may be required for special individuals/environments/processes. In such cases it is essential that a "safe" technology should be chosen".

See also the background text in Clause 4.1.

In view of this, the following recommendation is made for regulations:

Where humidification of air is required for special reasons, a type which does not involve the risk of microorganisms being released into the air shall be chosen.

Microorganisms multiply in still water or on surfaces which are constantly wet for long periods. See also NKB Publication No 52, Subclause 3.3.8.

The statement from The healthy building seminar should be noted.

4.6.7 Balancing, handing over

Ventilation installations shall be balanced so that the intended flow rates and tolerances are obtained.

When an installation is handed over, it shall be demonstrated that it has been constructed, and functions, in the way intended. The installation shall be handed over in a clean state ready for operation.

The design nominal air flow rates shall be specified together with the assumed reference conditions. See NKB Publication No 52, Subclause 3.2.5.

Tolerances shall be specified inclusive of inaccuracy in measurement, i.e. inclusive of the probable measurement error. This should at all times be substantially less than the permitted deviation. Reasonable tolerances for individual terminals or rooms are in the range 10 - 20%. In the case of rooms containing both supply and extract terminals, consideration shall be given in determining the tolerances to whether the room is to be at a pressure higher or lower than its surroundings.

Guidance regarding documentation, balancing and handing over is given in NKB Publication No 52.

5. DOCUMENTATION. MANAGEMENT, OPERATION AND MAINTENANCE

Experience shows that a building and its installations are often insufficiently documented with regard to aspects that are significant for the healthy state of the building. There often no documents which describe the building or its installations as they are actually constructed. Changes which are essential with regard to air quality may be made at a late stage during the construction of a building, or in conjunction with repairs or refurbishment. Changes in duct layout, change of paint, adhesive, filler or surface finishes are examples of changes which may give rise to problems. In investigating health problems in a building, work is made considerably easier if the building is well documented in all respects.

In order that air quality shall not be adversely affected, it is important that instructions should be available for the operation, maintenance and cleaning of the building and the ventilation installations, and that these should be observed. Experience shows that there are often no such instructions or they are unsatisfactory. In order that an installation may be restored to its "as built" state, it is essential that there should be documentation which sets out the way the installation was intended to function when designed.

In order that operation and maintenance should be carried out effectively, it is necessary for someone to be responsible for the function of the ventilation installation, for this work to be given a high status, and for the person concerned to be given the necessary training in the way the system works and in operational and maintenance work ([58]).

In view of this, the following recommendations are made for regulations:

The necessary drawings and descriptions shall be produced for a building and the ventilation installation. The materials used, including make and type designation, shall be documented.

Air flow rates through individual terminals or for individual rooms shall be specified together with the reference state and tolerances under the assumed internal and external loads. The same applies to the temperatures of supply air and room air. A written description of the way the installation has been designed, with the assumptions set out, shall be drawn up.

A building and the ventilation installation shall be operated, cleaned and maintained so that the quality of air is not adversely affected due to the operational, cleaning and maintenance conditions.

Instructions for the operation and maintenance of the building and the ventilation installation shall be drawn up and shall be available when the building is put into service. If possible, they shall be drawn up in cooperation with the operational and maintenance staff. The instructions for the ventilation installation shall apply only for the installation in question and shall contain all necessary information in order that satisfactory ventilation of the rooms served may be ensured.

User instructions in easily understandable language, which provide information on attendance, cleaning and maintenance, shall be affixed within easy reach of each terminal or appliance which is to be capable of regulation or cleaning by the users of the room or flat.

In addition to the documents required during the design and construction of the building, documents required during the operational stage should also be drawn up. It is important that in these the function of the installation should be described as clearly as possible. A flow chart indicating the most important functions should be produced, as well as documents which show where measuring and inspection points, cleaning doors etc are located.

A plan should also be drawn up showing how the building shall be cleaned.

There are many well developed guidelines available for the layout and contents of operational and maintenance instructions. For guidance regarding the production of operational and maintenance instructions for ventilation installations, see NKB Publication No 52, Clause 5.2.

Instructions in the appropriate Nordic language shall be displayed in the vicinity of terminals (appliances) or in some other place convenient for the users of the rooms. The instructions should be written in an easily understood language, and technical terms should be avoided.

6. QUALITY ASSURANCE, INSPECTION

The need for better quality assurance during the planning, construction and operation of a building is a theme that is common to conferences such as "Healthy Building 88" ([59]), public investigations of health problems attributable to buildings such as the Allergy Enquiry in Sweden ([1]) and the Sick Building Group in Sweden ([60]). There is unanimous demand that there should be much better follow-up and control of especially the air quality aspects at all stages.

In view of this, the following recommendations are made for regulations:

At all stages of the design, construction and operation of a building, checks shall be made that the intended quality is secured.

Buildings shall be regularly inspected with regard to the function of the ventilation and other factors which are significant for indoor climate.

The person responsible for the building is responsible for ensuring that all inspections are made.

According to the publication Climatic problems in buildings, investigation methods and remedial measures ([61]) of the Nordic Ventilation Group, investigation of building related health problems may be an appropriate method of checking the overall function of a building with respect to the internal climate. In the simplest case the check takes the form of the person responsible for the building asking the safety committee or similar whether there are any problems. If there is any doubt, the check can be extended to a questionnaire survey or a clinical investigation of the users of the building.

The quality assurance applied should be specified in advance, and this should be compared with the results of the check.

Ventilation should be checked with respect to its function in the rooms served at intervals of about 2 years. Outdoor air flow rates and extract air flow rates should be measured in the form of spot checks. If repeated inspections show that function has been maintained, inspections may be made at longer intervals.

Other factors significant for the quality of air which should be checked are e.g. the use of the rooms, the incidence of moisture and mould damage, and the standard of cleaning.

APPENDIX NO 1

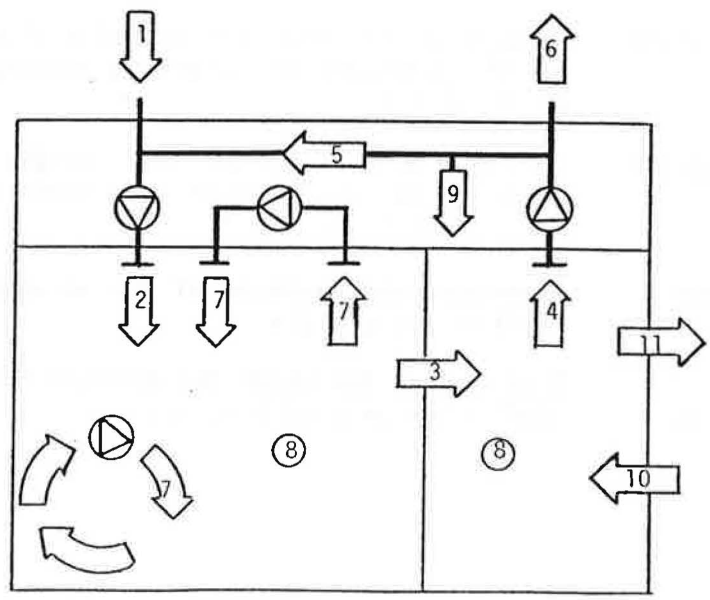
Definitions

Air pollution	Harmful or otherwise undesirable substances or organisms in air.
Air quality	This is determined by the effects on human health and other reactions, perceptions or symptoms which the concentration of water vapour and pollutants in the air gives rise to, in relation to similar effects due to pure air.
Air types	
- Outdoor air (1)	Air in the external surroundings
- Supply air (2)	Air which is supplied to a room (may consist of outside air, transferred air, recirculated air or infiltration)
- Transferred air (3)	Air which is supplied from one room to another
- Extract air (4)	Air which is removed from a room
- Recirculated air (5)	Air which is recirculated to the group of rooms from where the air has been removed
- Exhaust air (6)	Air which is discharged into the external air
- Circulated air (7)	Air which circulates inside a room or extract air from the room which is recirculated to the same room
- Inside air (8)	Air in a room
- Leakage (9)	Unintended inward or outward flow of air through leakage paths
- Infiltration (10)	Leakage of air into the building through leakage paths in the elements of structure separating it from the external air
- Exfiltration (11)	Leakage of air out of the building through leakage paths in the elements of structure separating it from the external air
Ventilation	Transport and exchange of air in order to achieve the desired air quality
Natural ventilation	Ventilation for which the driving force is temperature difference or wind pressure

Mechanical ventilation	Ventilation by means of fans or other mechanical devices

Terms relating to the effectiveness of ventilation

- Age of air	The time which has elapsed from the time the air has entered the room to the time when the air arrives at a certain point in the room or at the extract terminal
- Nominal time constant of ventilation system	Denotes the average "age" of the air molecules when they arrive at the extract terminal
- Specific air flow rate	The inverse of the nominal time constant of the system, which is the same as the ratio between the supply air flow rate in m^3/h and the volume of the room in m^3. (Previously designated the air change rate of the room).
- Air change efficiency	Shows how efficiently air in the room is changed, and is the ratio between the exchange time of the ventilation air (mean age in the extract terminal) and twice the mean age of the air in the room
- Ventilation efficiency	Shows how efficiently (quickly) a pollutant is removed from the room, and is the percentage ratio between the equilibrium concentration in the extract air and the mean concentration in the room under equilibrium conditions
- Extraction capacity	Shows how effectively, in percentage terms, a hood or similar captures released pollutants. It is the ratio between the directly captured and released quantity of pollutant
- Ventilation by opening windows	Change of air by opening windows, doors or similar which lead to the external air.



APPENDIX NO 2

Air quality guidelines for Europe [1]

3 Summary of the guidelines, pp. 20-30

[1] Air quality guidelines for Europe. World Health Organization Regional Office for Europe. WHO Regional Publications, European Series No. 23. Copenhagen 1987. 426 p.

3

Summary of the guidelines

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

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

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

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

Guideline Values based on Effects other than Cancer

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

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

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

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

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

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

Unfortunately, the situation with regard to actual environmental levels and proposed guideline values for some substances is just the opposite,

Table 1. Established guideline values and risk estimates

Substance	IARC Group classification	Risk estimate based on carcinogenic endpoint	Guideline value(s) based on: toxicological endpoint	sensory effects or annoyance reaction	ecological effects
Organic substances					
Acrylonitrile	2A	x			
Benzene	1	x			
Carbon disulfide	—		x	x	
1,2-Dichloroethane	—[a]		x		
Dichloromethane	—[a]		x		
Formaldehyde	2B		x		
Polynuclear aromatic hydrocarbons (Benzo[a]pyrene)	—[b]	x			
Styrene	3		x	x	
Tetrachloroethylene	3		x	x	
Toluene	—		x	x	
Trichloroethylene	3		x		
Vinyl chloride	1	x			
Inorganic substances					
Arsenic	1	x			
Asbestos	1	x			
Inorganic substances (contd)					
Cadmium	2B		x		
Carbon monoxide	—		x		
Chromium (VI)	1	x			
Hydrogen sulfide	—		x	x	
Lead	3		x		
Manganese	—		x		
Mercury	—		x		
Nickel	2A[c]	x			
Nitrogen dioxide	—		x		x
Ozone/photochemical oxidants	—		x		x
Radon	—	x			
Sulfur dioxide and particulate matter	—		x		x
Vanadium	—		x		

[a] Not classified, but sufficient evidence of carcinogenicity in experimental animals.

[b] Not classified, but sufficient evidence of carcinogenicity of PAH in humans in some occupational exposures (*IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, Vol. 34). Sufficient evidence of carcinogenicity for benzo[a]pyrene in animal studies. Benzo[a]pyrene is present as a component of the total content of polycyclic aromatic hydrocarbons in the environment (*IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans*, Vol. 32).

[c] Exposures from nickel refineries are classified in Group 1.

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

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

[a] Information from this table should *not* be used without reference to the rationale given in the chapters indicated.

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

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

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

[e] See Chapter 30.

Note. When air levels in the general environment are orders of magnitude lower than the guideline values, present exposures are unlikely to present a health concern. Guideline values in those cases are directed only to specific release episodes or specific indoor pollution problems.

Table 3. Guideline values for combined exposure to sulfur dioxide and particulate matter[a]

Averaging time		Sulfur dioxide	Reflectance assessment: black smoke[b]	Gravimetric assessment	
				Total suspended particulates (TSP)[c]	Thoracic particles (TP)[d]
		(µg/m³)	(µg/m³)	(µg/m³)	(µg/m³)
Short term	24 hours	125	125	120[e]	70[e]
Long term	1 year	50	50	—	—

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

[b] Nominal µg/m³ units, assessed by reflectance. Application of the black smoke value is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

[c] TSP: measurement by high volume sampler, without any size selection.

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

[e] Values to be regarded as tentative at this stage, being based on a single study (involving sulfur dioxide exposure also).

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

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

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

Substance	Detection threshold	Recognition threshold	Guideline value
Carbon disulfide in viscose emissions			20 μg/m³
Hydrogen sulfide	0.2–2.0 μg/m³	0.6–6.0 μg/m³	7 μg/m³
Styrene	70 μg/m³	210–280 μg/m³	70 μg/m³
Tetrachloroethylene	8 mg/m³	24–32 mg/m³	8 mg/m³
Toluene	1 mg/m³	10 mg/m³	1 mg/m³

Guidelines based on Carcinogenic Effects

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

Table 5. Carcinogenic risk estimates based on human studies[a]

Substance	IARC Group classification	Unit risk[b]	Site of tumour
Acrylonitrile	2A	2×10^{-5}	lung
Arsenic	1	4×10^{-3}	lung
Benzene	1	4×10^{-6}	blood (leukaemia)
Chromium (VI)	1	4×10^{-2}	lung
Nickel	2A	4×10^{-4}	lung
Polynuclear aromatic hydrocarbons (carcinogenic fraction)[c]		9×10^{-2}	lung
Vinyl chloride	1	1×10^{-6}	liver and other sites

[a] Calculated with average relative risk model.

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

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

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

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

Table 6. Risk estimates for asbestos[a]

Concentration	Range of lifetime risk estimates	
500 F*/m³ (0.0005 F/ml)	10^{-6} – 10^{-5}	(lung cancer in a population where 30% are smokers)
	10^{-5} – 10^{-4}	(mesothelioma)

[a] See Chapter 18 for an explanation of these figures.

Note. F* = fibres measured by optical methods.

Table 7. Risk estimates and recommended action level[a] for radon daughters

Exposure	Lung cancer excess lifetime risk estimate	Recommended level for remedial action in buildings
1 Bq/m³ EER	$(0.7 \times 10^{-4})-(2.1 \times 10^{-4})$	≧ 100 Bq/m³ EER (annual average)

[a] See Chapter 29 for an explanation of these figures and for further information.

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

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

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

[a] **Starr, T.B. & Buck, R.D.** The importance of delivered dose in estimating low-dose cancer risk from inhalation exposure to formaldehyde. *Fundamental and applied toxicology*, **4**: 740–753 (1984).

Table 8. Guideline values for individual substances based on effects on terrestrial vegetation

Substance	Guideline value	Averaging time	Remarks
Nitrogen dioxide	95 µg/m³ 30 µg/m³	4 hours 1 year	In the presence of SO_2 and O_3 levels which are not higher than 30 µg/m³ (arithmetic annual average) and 60 µg/m³ (average during growing season), respectively
Total nitrogen deposition	3 g/m²	1 year	Sensitive ecosystems are endangered above this level
Sulfur dioxide	30 µg/m³ 100 µg/m³	1 year 24 hours	Insufficient protection in the case of extreme climatic and topographic conditions
Ozone	200 µg/m³ 65 µg/m³ 60 µg/m³	1 hour 24 hours averaged over growing season	
Peroxyacetylnitrate	300 µg/m³ 80 µg/m³	1 hour 8 hours	

The decision on the acceptability of a certain risk should be taken by the national authorities in the context of a broader risk management process. Risk estimate figures should not be applied in isolation when regulatory decisions are being made; combined with data on exposure levels and individuals exposed, they may be a useful contribution to risk assessment. Risk assessment can then be used together with technological, economic and other considerations in the risk management process.

Guidelines based on Ecological Effects on Vegetation

Although the main objective of the air quality guidelines is the direct protection of human health, it was decided that ecological effects of air pollutants on vegetation should also be considered. The effects of air pollutants on the natural environment are of special concern when they occur at concentrations lower than those that damage human health. In such cases, air quality guidelines based only on effects on human health would allow for environmental damage that might indirectly affect human wellbeing.

It should be understood that the pollutants selected (SO_x, NO_x and ozone/photochemical oxidants) (Table 8) are only a few of a larger category of air pollutants that may adversely affect the ecosystem. Furthermore, the effects which were considered are only part of the spectrum of ecological effects. Effects on aquatic ecosystems were not evaluated, nor were effects on animals taken into account. Nevertheless, the available information indicates the importance of these pollutants and of their effects on terrestrial vegetation in the context of the European Region.

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