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IEA Annex IX
Minimum Ventilation Rates and Measures for Controlling Indoor Air Quality

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AIVC

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Annex IX Minimum Ventilation Rates

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IEA Annex IX
Minimum Ventilation Rates and Measures for Controlling Indoor Air Quality

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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *):

I Load Energy Determination of Buildings *
II Ekistics and Advanced Community Energy Systems *
III Energy Conservation in Residential Buildings *
IV Glasgow Commercial Building Monitoring *
V Air Infiltration and Ventilation Centre
VI Energy Systems and Design of Communities *
VII Local Government Energy Planning *
VIII Inhabitant Behaviour with Regard to Ventilation *
IX Minimum Ventilation Rates *
X Building HVAC Systems Simulation
XI Energy Auditing *
XII Windows and Fenestration *
XIII Energy Management in Hospitals *
XIV Condensation
XV Energy Efficiency in Schools
XVI BEMS - 1: Energy Management Procedures
XVII BEMS - 2: Evaluation and Emulation Techniques
XVIII Demand Controlled Ventilating Systems
XIX Low Slope Roof Systems

Annex IX - Minimum Ventilation Rates

From a viewpoint of energy conservation air infiltration and ventilation have to be minimized. A certain amount of fresh outside air, however, has to be supplied to a building in order to maintain healthy and comfortable conditions for the inhabitants and to avoid structural damage. The optimization of these adverse requirements will result in guidelines for minimum ventilation rates which are just large enough to meet the indispensable fresh air demand but small enough to avoid useless waste of energy. The work which has been performed under this annex is believed to be an important step towards the establishment of objective and common criteria necessary to determine minimum ventilation rates. In detail, the objectives of this task were:

- To collect background data needed for the proposal of minimum ventilation standards with regard to type and amount of activity, air quality, comfort, and moisture. Special problems should be taken into account, such as, e.g., combustion appliances inside the living area;
- To propose objective criteria for assessing and evaluating ventilation standards where sufficient knowledge is available;
- To prepare an R&D program to resolve problems inhibiting the establishment of ventilation standards.
- To quantify more closely the factors which determine the concentrations of the pollutants identified in the first phase and to determine the interrelationship between these factors.
- To establish minimum rates and all other suitable methods for ensuring that these pollutants are kept at acceptable levels.
- To summarize the information that is available about various techniques and their merits for controlling air quality and conserving energy.
- To catalogue and assess pollutant removal techniques which may be useful in solving the problems connected with maintaining acceptable air quality in buildings.

Proposals and developments to realize these recommended ventilation rates, for practical applications are subject for continuing resp. further activities.

Annex IX - Participants

Canada
Denmark
European Community (Ispra Establishment)
Federal Republic of Germany (Operating Agent)
Finland
Italy
Netherlands
Norway
Sweden
Switzerland
United Kingdom
United States of America

INTERNATIONAL ENERGY AGENCY
ENERGY CONSERVATION
IN BUILDINGS AND COMMUNITY
SYSTEMS PROGRAMME

ANNEX IX
MINIMUM VENTILATION RATES

SUMMARIZING REPORT OF WORKING PHASE I AND II
(AUGUST 1980 - NOVEMBER 1987)

by

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1. INTRODUCTION

The experts of the various countries participating in the ANNEX IX worksharing task reviewed the state of the art in the knowledge about sources, effects and control of indoor pollutants. This should serve as a basis to formulate ventilation rates in buildings which meet the requirements of energy conservation as well as the demands for an adequate indoor environment and to develop favourable ventilation and indoor air pollutant control strategies.

The results are recorded in a series of reports:

- Report 1 and Summary 1 - literature review, standards and current research
- Report 2 and Final Report Phase I - literature review to special research fields and proposal of research and development projects
- Final Report Phase I and II.

This report is basically a shortened and simplified version of the contributions to the Final Report Phase I and II intended to provide a quick overview of the topics in question also for non-experts. The discussions on the different indoor air pollutants have been structured to the following scheme:

- Source Characteristics
  - origin and special features of pollutants
- Effects of Pollutants
  - Health risks, annoyance and irritation, damage to building fabric
- Control Measures
  - limiting concentrations, source control and related measures, ventilation rates
- Ventilation Strategies
  - Conclusions and recommendations for pollutant control and its effect on ventilation

2. GENERAL CONSIDERATION

2.1 Sources of Indoor Air Pollution

For present purposes indoor air pollution can be defined as any constituent of indoor air which has a deleterious effect on the health of occupants, reduces amenity or can damage the building fabric. Such pollutants can arise from a number of sources which may conveniently be grouped into the following categories:

(a) Soil adjacent to the building
(b) Building materials
(c) Building furnishings and decorations
(d) Processes and activities taking place within the building
(e) Services to the building (e.g. water, gas)
(f) Presence of human and animal occupants
(g) Outdoor air.

2.2 The Effects of Airborne Pollutants

The effects of air pollutants may fall into one or more of the following categories:

(a) Damage to the health of occupants
(b) Annoyance or reduction in amenity.
(c) Damage to the building fabric

Taking each of these in turn

(i) Damage to the health of occupants:

Exposure to an airborne pollutant may result in an acute, short-term health response, in the long-term deterioration of health or may increase the risk of mortality, for instance from lung cancer.

Occupational health studies provide a basis for assessing effects on healthy adults, but much less information is generally available concerning exposure to low levels of airborne pollutants over a long period, particularly in relation to sensitive groups within the general population, such as the very young, the elderly and those with impaired health from other causes.

(ii) Annoyance or reduction in amenity:

Some airborne pollutants, while not directly damaging to health may give rise to minor physical irritation or possess odours which are unpleasant. These may need to be controlled to reduce the level of annoyance to an acceptable value, also in terms of the proportion of persons affected.

(iii) Damage to the building fabric:

Chemical attack to the building fabric is usually a problem with pollution of the external air, but internally generated pollutants, in particular water vapour, can also lead to fabric damage and the need for redecoration.

2.3 Control of Indoor Air Pollutants

The concentrations of pollutants in the indoor air may be controlled by a number of methods:

(a) Restriction on use or elimination of source
(b) Restriction on emission rates by source modification
(c) Direct extract of polluted air close to source
(d) Filtration or other method of air cleaning
(e) Dilution by mixing with cleaner air.

The choice of method in any given situation will depend upon a number of factors which may include:

- the chemical and physical nature of the pollutant
- the characteristics of the sources of the pollutant
- the effects of the pollutants
- the practicability of any proposed means of control
- the capital cost of control
- the running costs of any means of control, including costs related to energy consumption.

2.4 Derivation of Minimum Ventilation Rates

Dilution by unpolluted air (or at least air with a lower concentration of pollutant) is the most common method of control, and may be the only means, where pollutant sources are ill-defined, distributed or non-stationary. Examples of such pollutants are those related to occupancy.

The main steps in deriving the magnitutde of the required air supply rate are as follows:

(i) Identification of the pollutant of prime concern in the situation of interest.

(ii) Specification of a limiting, maximum acceptable indoor concentration.

(iii) Estimation of the factors, apart from dilution that determine the concentration in practice, including source strength, period of production (if the pollutant is produced on an intermittent basis), sink strengths (including absorption and chemical reaction) and concentration of the pollutant in the diluting air.

2.5 Methods for Specifying Ventilation Rates

Three approaches have been commonly used in practice for specifying ventilation standards:

(a) Define the limiting concentration of possible pollutants and require the building designer, or operator, to ensure that the ventilation is sufficient to control these concentrations. However, in practice, there are difficulties associated with implementing this approach.

(b) Define a fresh air supply rate.
The requirement is expressed as an air flow rate (for instance in units of l/s, m^3/h or cfm), usually qualified in one of the following ways:

- per unit floor area
- per unit volume - This leads to the term air changes per hour (ach).
- per person - This formulation is most appropriate when the main pollutant derives from the occupants or their activity, such as smoking.
- In addition other forms of qualification may be used for particular situations, for instance, air supply rate for combustion equipment may be specified as a flow rate per unit input (or output) rating.

(c) Specify some form of installation which is deemed to provide the required flow rate.
The most common form of this approach is to specify the dimensions of a required permanent or controllable area of opening for natural ventilation. Implicit in this approach is the understanding that an air flow rate has been determined and appropriate calculations have been carried out to obtain the required area or type of opening necessary to provide this rate, under some set of assumed conditions, by natural ventilation.

2.6 Efficient Ventilation

Ventilation requirements are generally derived using the assumption that both the ventilating air and the pollutants are uniformly mixed throughout the ventilated space. Such conditions may not occur in practice and it is necessary to take the effectiveness of any means of ventilation into account. This involves the following considerations:

(i) The average rate with which 'old' polluted air is replaced by 'new' clean air in a space, characterized by the air exchange efficiency, and

(ii) the degree to which pollutants are removed and prevented from spreading to specific areas, such as the occupied zone. This is called pollutant removal effectiveness.

3. TOBACCO SMOKE

3.1 Source Characteristics

Although tobacco smoke is one of the most frequently found indoor air pollutants, it cannot easily be characterized and quantified. It is a complex mixture of several thousand chemicals with a varying potential impact on human health. This makes measurement very difficult. In addition, with the exception of nicotine, the different tobacco smoke constituents also have sources other than tobacco smoke in indoor and outdoor environments. Today, usually CO and particulate matters are used to index the level of tobacco smoke. At present no satisfactory method exists to measure the total pollution in smoky ambient air.

A possible approach to estimating individual exposure to tobacco smoke is personal monitoring of distinct substances as e.g. nicotine. The effective intake of a distinct chemical gives a more precise picture of exposure than the knowledge of ambient concentration. However, because nicotine has a short halflife in the body, plasma levels of its metabolite, may be a better indicator of tobacco smoke exposure. The halflife of cotinine is about 16 hours and therefore suitable for general monitoring.

3.2 Effects of Pollutant

The discussion of adverse effects of sidestream tobacco smoke is limited to the non-smoking part of the population, as smokers submit voluntarily to much higher exposure and hence risk levels.

For judging the effects and risks due to passive smoking one cannot only consider the 'classical' diseases caused by smoking. Annoyance and irritation of eyes and respiratory organs should rather be taken into consideration. Irritation is primarily caused by the particle phase, while annoying odours come mostly from the gas phase of cigarette smoke.

Adverse health effects are especially severe for the risk groups of the population, namely the elderly and sick people as well as children. It has been shown that passive smoking causes irritations and pathological reactions in the respiratory system of children. Persons whose health is already impaired - such as e.g. people with asthma or hayfever - suffer much more from passive smoking, which may even lead to the acute stage of their illness.

The question whether passive smoking can cause lung cancer is still not definitively answered. It is questionable whether the problem will ever be resolved by epidemiological investigations. In Germany, the committee for the evaluation of hazardous compounds at the workplace concluded that passive smoking can cause lung cancer. However, at present a quantitative risk estimation is not possible.

Support for a carcinogenic effect of passive smoking in humans comes from mutagenicity studies. It has been demonstrated under experimental conditions that passive smoking can increase the mutagenicity of human urine to about 4 % of that of an active smoker.

3.3 Control Measures

- Limiting Concentrations

  Carbon monoxide has proved to be a useful indicator of eye irritations and annoyance due to odours. Results from field studies lead to the conclusion that an average healthy person can be exposed to an acceptable cigarette smoke level which produces a carbon monoxide concentraton of 1 to 2 ppm. Hence the countermeasures to protect passive smokers are desirable when the CO-level reaches 1 ppm and are necessary when it exceeds 2 ppm.

- Source control

  If the criteria for satisfactory air quality are avoidance of any annoyance and any health risk at all, even for the most sensitive persons, then the only strategy is to separate smokers from non-smokers. Segregation of smokers and non-smokers in the same room only prevents exposure to peak concentrations but is not very effective in reducing overall average exposure to tobacco smoke. However, mechanical ventilation systems can improve this situation by displacement ventilation.

  In small rooms (up to 50 m^3) with natural ventilation and with a relatively low air infiltration rate (0.5 airchanges per hour or less), air cleaning devices can contribute to improve air quality by lowering particle concentrations. But it has to be kept in mind that not all air pollutants can be eliminated by such devices. More details about the effectiveness of aircleaning devices are given in chapter 4.

- Ventilation Rate

  If the criterion for satisfactory air quality is the avoidance of acute irritating effects in healthy people, this can be met by ventilation strategies. In non-smoking rooms 3 to 8 l/s (12 to 30 m^3/h) fresh air per person are sufficient to maintain an acceptable air quality, depending on the carbon dioxide level. CO_2 at 1500 ppm: appr. 3 to 4 l/s (12 to 15 m^3/h) per person, CO_2 at 1000 ppm: appr. 6 to 8 l/s (20 to 30 m^3/h) per person. In rooms where smoking is allowed it has been shown that in general a three to fourfold increase in fresh air supply is sufficient to avoid acute irritating effects.

3.4 Ventilation Strategies

Minumum ventilation rates necessary to eliminate the effects of tobacco smoke in indoor air cannot easily be quantified. First of all, decisions on the risk which one is willing to accept from passive smoking, have to be taken. Depending on this, control will be achieved either by setting standards for ventilation or by administrating actions. The following suggestions are made:

- In rooms for sick persons or children, smoking should be prohibited
- In habitable rooms where non-smokers are present, smoking should be restricted. In the case of moderate smoking, acute effects can be prevented by adequate ventilation.
- In general, separate rooms or offices for smokers should be established. If this is not possible (e.g. in restaurants, large offices) - non-smoking areas should be made available.
- In large public rooms and offices the ventilation rates should be dependent on the number of cigarettes smoked per hour. This can be estimated on a statistical basis (example: 40 % of the population are smokers, each smoking an average of 1.5 cigarettes/hour; this corresponds to 0.6 cigarettes smoked per person and hour. If 50-120 m^3 fresh air per cigarette smoked are needed, the ventilation rates have to be approx. 8-20 l/s (30-70 m^3/h) per person. The lower part of this range corresponds to the avoidance of strong acute irritations, the upper part to the avoidance of annoyance due to odours, accepting 20 % dissatisfied visitors). However, once a continuous monitoring system for tobacco smoke polluted air becomes available the rate of air supply can be optimally adjusted automatically.
- In small offices and similar rooms (2-10 persons) separate rooms for smokers and non-smokers should be made available.

4. PARTICLES AND AIR CLEANING DEVICES

4.1 Source Characteristics

The discussion about particles complements chapter 3 of this report which deals with tobacco smoke. Tobacco smoke is the dominant indoor source of respirable particles and failure to recognize this fact would represent an artificial separation. Other major indoor particle sources are the outdoor ambient air, combustion sources (dominated by smoking), people and animals, and consumer aerosol products.

Examination of indoor and outdoor concentrations of elemental composition of particles showed that particles containing potassium to be from indoor sources, while particles containing sulfur, lead, bromine, and iron had predominantly outdoor sources. Particles are also carriers of organic species in the indoor environment. Characterization of these organic compounds aids both source identification and the estimation of personal exposures and possible health effects.

4.2 Effects of Pollutant

Since the main way of particle absorption is by respiration, only the particles of 0.25-10 µm can be considered 'lung-damaging' because bigger particles generally settle in the upper respiratory tract and do not reach the lung. However, analysis of health effects and the corresponding risk analysis associated with personal exposure to particles in the indoor environment is in a rudimentary stage.

A major risk assessment of non-occupational exposure to asbestos and asbestiform fibres has recently been published by the U.S. National Academy of Sciences [1]. This document, which can serve as a model for other risk assessment studies, describes the uncertainties and problems associated with the estimation of risks from non-occupational exposures. The authors estimate that the risk of developing mesothelioma from a lifetime exposure to 0.0004 fibres/cm^3 (considered to be an average concentration in a non-occupational setting) is of the order of nine in 10^6 (with a range from 0 to 350). The risk of developing lung cancer from the same lifetime exposure is six in 10^6 for non-smoking males; this rises to 64 in 10^6 for males who smoke.

Risk assessments for exposures to other particulate forms are not available. Many uncertainties exist that make it difficult to attempt such an assessment.

4.3 Control Measures

- Source Control

Source treatments assume that one has adequate information about the sources of indoor particles to effect the control procedure. In non-smoking environments this may be difficult to obtain.

Source elimination can be used in controlling sources in each of the major categories; the only exceptions are perhaps people and outdoor air. Source elimination is often a question of individual choice to be invoked only when some explicit irritant response can be linked to the source of particles. In commercial and institutional office settings it is becoming more common to restrict smoking to specific locations of the building or to ban it entirely. Modification of particulate sources also depends on personal choice. Hand pumped sprays for commercial products are likely to produce a different particle size distribution than pressurized products. If the size distribution from pumped sprays peaks for larger particles, current dosimetric models predict that the number penetrating into the lungs will be reduced.

To some extent, local ventilation can be considered source modification. An exhaust hood over a residential gas range substantially reduces the spread of combustion products from the gas range to other parts of the house.

- Air Cleaning Devices

The discussion in this section concentrates on particulate matter, hence only air cleaning devices using filter systems are considered. Devices using ultraviolet irradiation (UV), ozone (O_3) or other chemicals as antimicrobial agents or as air refresheners and ionizing systems have not been included.

A typical air cleaning device functions as follows: air is drawn in near the base, through side openings, and then passes through a system of filters before being exhausted at the top. The two parameters critical to the evaluation of such systems are:

(a) The efficiency with which the filter system eliminates the airborne contaminants.

(b) The capacity of the unit, i.e. the volume flow rate through the filter system.

a. Efficiency of Air Cleaning Devices

As suspended particles, capable of reaching the lower airways of the lung, form the most important fraction of the total particulate matter in the indoor air, the filter system should be efficient in removing this fraction. Most filters, however, become less efficient as particle size decreases. Average particle sizes in the tobacco smoke e.g. are in the order of 0.5 µm and are retained with an efficiency of only about 20 %. A higher degree of retention might be achieved with electrofilters or high efficiency absorption filters (HEPA); but devices equipped with such filters are usually much more expensive.

It is also important to note that the use of air cleaners to control particle concentrations from tobacco smoking is a well-defined procedure but will not eliminate the odours associated with tobacco smoke. Gaseous contaminants may be eliminated from the air by activated carbon filters or with other adsorbens. However it is important to note that not all gaseous contaminants are adsorbed by such filters.

b. Capacity of Air Cleaning Devices

Even the most efficient filter systems fail to improve air quality if the amount of air drawn through the filters is too small: for a 50 % reduction in air contaminants (e.g. particulate matter) the room air should be passed through the filters 3 to 5 times per hour.

In Table 4.1 the capacity of an air cleaning device necessary to reduce the level of particulate matter derived from tobacco smoke has been tabulated. In this situation the room size and the air infiltration rate are critical. It is evident that air cleaning devices are only useful in smaller rooms with a relatively low air infiltration rate. If the air exchange rate is high, as in mechanically ventilated rooms (up to about 5 air changes/hour), air cleaning devices add very little to the reduction of airborne contaminants.

Room-size [m³]	air infiltration rate = 0.5			air infiltration rate = 1.0		
	% C_o = Reduction level in particulate matter					
	60 %	40 %	25 %	60 %	40 %	25 %
25	45	90	180	90	180	360
50	90	180	360	180	360	720
100	180	360	720	360	720	1440

Table 4.1: Capacity of an air cleaning device in m³/h necessary to reduce tobacco smoke derived particulate matter as a function of room size and the desired reduction level (% C_o)

- Ventilation Rate

  In small rooms with a relatively low air infiltration rate, air cleaning devices may be an economic method to reduce airborne particulate matter from tobacco smoke. However, in other situations the most appropriate method is to increase the ventilation rate.

  Particle concentrations in buildings have had a major impact on ventilation standards. In reaction to the energy crisis, the basic standard for ventilation codes in buildings in North America, Standard 62 of the American Society of Heating, Refrigerating and Air Conditioning Engineers, was revised in 1981 as Standard 62-81 [2]. This Standard was developed using two major pollutant-ventilation guidelines. In non-smoking areas, control of CO_2 at a 2500 ppm level was considered an adequate surrogate for acceptable indoor air quality. This dictated a ventilation rate of 2.5 l/s per person (5 cfm/person) in the occupied space to control the concentration of metabolically-generated CO_2.

  In addition, it was recognized that tobacco smoking represented a major additional source of indoor contamination. Based on known particle emission data from cigarette smoking and average smoking rates of persons in buildings (one third of the occupants smoking two cigarettes per hour), an alternate ventilation value of 17.5 l/s per person (35 cfm/person) was established to accommodate the presence of smoking within a space in order to control the particle concentrations at a level of 75 $\mu g/m^3$, the outdoor National Ambient Air Quality Standard (NAAQS) established by the EPA under the Clean Air Act [3].

4.4 Ventilation Strategies

The major strength of using ventilation for pollution control, its ability to remove all pollutants with similar efficiency, is not an argument to use whole building ventilation for particle control. When the pollutant source and its properties are known, then these sources should be addressed explicitly. Smoking, a major source of respirable suspended particles in buildings, must be treated directly, not through whole-building ventilation. Source elimination, source segregation, local ventilation, and air cleaning all should be considered prior to whole building ventilation for particle control.

5. BODY ODOUR AND CARBON DIOXIDE

5.1 Source Characteristics

For setting up minimum ventilation rates human body is unique compared to other indoor pollutants. While body odour is caused by the human occupants themselves, other indoor pollutants may be avoided or decreased by proper source control. Emission of body odour will thus be related to number of persons present in a room and to their activity. Strong variations may occur depending upon hygienic standards or eating and drinking habits.

5.2 Effects of Pollutant - Carbon Dioxide as a Body Odour Index

Fanger and co-workers [4,5] have investigated body odour arising from groups of hundreds of men and women occupying two experimental auditoria. The odour intensity and acceptability were evaluated by 'visitors', drawn from a group of nearly eighty men and women, who made their judgement immediately after entering the auditoria.

The percentage of visitors dissatisfied - the fraction which considers the odour intensity as unacceptable - can be expressed as a function of the absolute carbon dioxide (CO_2) concentration, Fig. 5.1. The percentage dissatisfied increases with increasing carbon dioxide concentration, indicating that CO_2 is a usable indicator of body odour pollution.

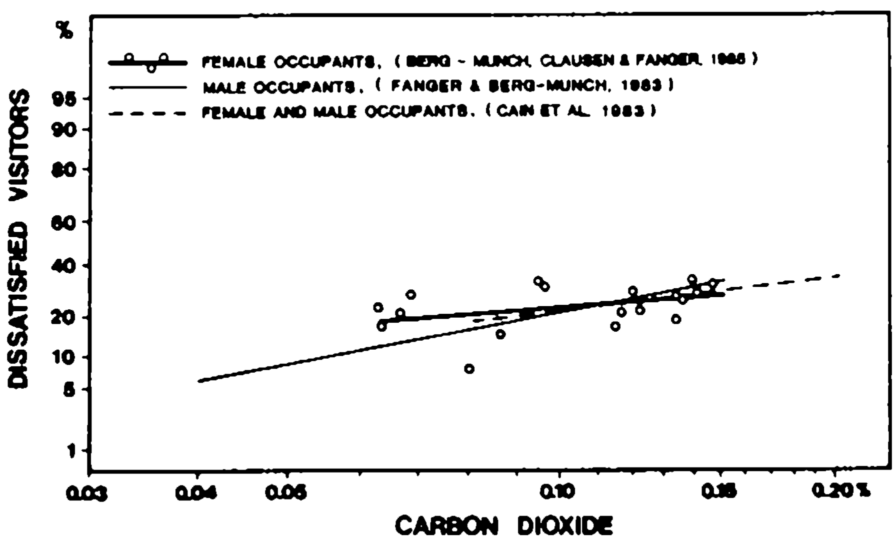

Fig. 5.1: Percentage of dissatisfied visitors as a function of the CO_2 concentration. Comparison between results for male occupants [4], female occupants [5] and a mixed group of female and male occupants [6] are shown.

It should be noted that Fig. 5.1 applies for sedentary, thermally comfortable adults who on average were bathing every 1.5 days. For other groups of people with a different hygienic standard or higher physical activity another relation may apply.

From analyzing the percentage of occupants dissatisfied with the odour level it is obvious that occupants become adapted to body odour. The degree of dissatisfaction is quite low and independent of carbon dioxide concentration for both male and females.

5.3 Control Measures

- Ventilation Rate

  It is essential to determine for whom a space is being ventilated. It is obvious that the occupants are insensitive to changes in ventilation. Body odour is noticed with full strength by persons entering a space (visitors). The sense of smell is quickly fatigued or adapted, and on that account odour which is readily noticeable or even unacceptable to a newcomer may be unnoticed by occupants who have been exposed to it for a few minutes [7].

  Corresponding to the quick adaptation of the sense of smell there occurs a rapid recovery on exposure to clean air. An occupant adapted to a strong body odour in a space will, when reentering after having left the space for a few minutes, perceive the same odour intensity as a visitor. For this reason it has been common practice to design ventilation systems which provide body odour levels acceptable for visitors rather than just for occupants.

  What proportion of visitors who are annoyed is acceptable? There is obviously no scientific answer to this question. ASHRAE Ventilation Standard [2] suggests 20 % dissatisfied as acceptable. A similar figure is used in the ISO thermal comfort standard [8]. This proportion is proposed as a reasonable basis for defining minimum air quality. In Fig. 5.2 it can be shown that 20 % dissatisfied requires a steady-state ventilation rate of 8 l/s
  (29 m^3/h) per person. This figure is suggested as the minimum ventilation rate for sedentary persons. The corresponding CO_2-concentration is approx. 0.10 % or 0.065 % above the outdoor concentration.

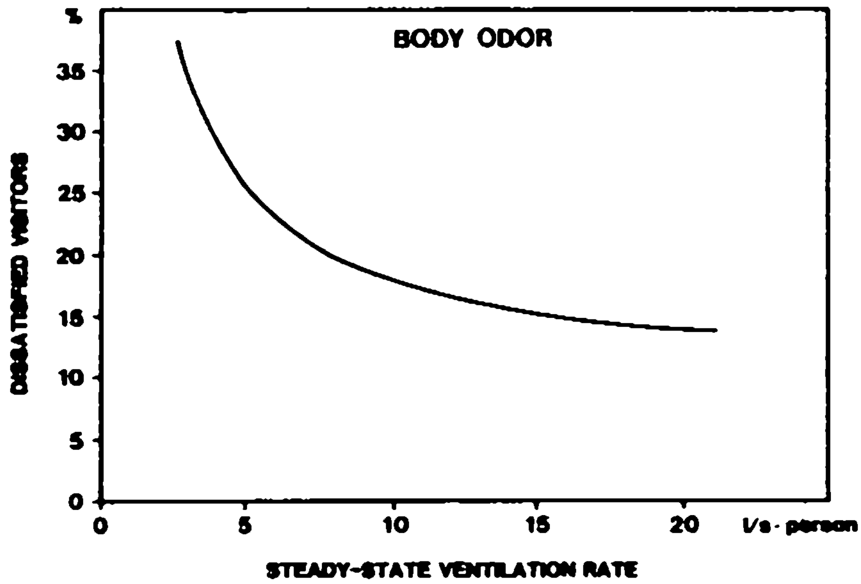

Fig. 5.2: Percentage of dissatisfied visitors as a function of calculated steady-state ventilation rate. The figure applies for a mixed group of females and males.

5.4 Ventilation Strategies

A rational ventilation strategy would be to maintain a constant minimum acceptable air quality in occupied spaces. If body odour is the dominating pollutant, carbon dioxide may be used as an index of air quality. In spaces where the occupancy is predictable during the day, the minimum ventilation may be varied according to a time schedule to maintain a constant air quality.

In spaces where the occupancy varies in an unpredictable way it may be useful to control the air quality utilizing an occupancy or carbon dioxide sensor for varying the ventilation.

6. HUMIDITY - CONDENSATION AND MOULD GROWTH

6.1 Source Characteristics

Under normal conditions the main effects of humidity on occupants and the building fabric are secondary, arising from mould growth and condensation.

The main requirements for the growth of mould fungi are:

- a source of infection
- nutrient
- water
- oxygen
- suitable temperature.

Of these water is the normal limiting factor in buildings.

The emission rate of water vapour in buildings is primarily determined by the presence and activities of occupants and by the use of unflued heating equipment. The current, generally accepted values in the United Kingdom [9] are a normal daily total of 5-10 l/day, with a maximum daily total of 10-20 l/days. Erhorn and Gertis [10] have reviewed water vapour production rates for a range of household activities, in relation to German housing. Quirouette [11] has produced a similar list for Canadian houses. Totally over 24 hours these are in broad agreement with the values reported above for the United Kingdom.

Three other sources of water vapour, which may be important in some circumstances are:

(a) Construction moisture

(b) Ground water

(c) Seasonal storage

While (a) is a temporary phenomenon, relevant to the first year of occupation of a new house, (b) and (c) are recurring, and may contribute almost as much on an average daily basis as household activities.

6.2 Effects of Pollutant

The requirements to maintain the indoor relative humidity within certain minimum and maximum levels as an important part of thermal comfort are well established and not subject to discussion in this report. The secondary effects of high levels of indoor humidity, condensation and subsequent mould growth causing possible damage to the building fabric or adverse health effects, are much more severe and will be considered for control strategies.

The most probable risk arising from exposure to heavy mould infestations is the development of allergy. Mould fungi are present at all times out of doors on dead and decaying organic matter and in the soil. Although numbers vary seasonally, spores are produced in enormous numbers and released into the surrounding. air. Typical levels outdoors in the summer are about 50.000 per m³ of air.

Recent measurements of winter spore levels inside dwellings, not infected by mould, typically show concentrations of up to 500 per m³, although large fluctuations can occur, for instance, when furniture is moved or a vacuum cleaner used. Spore concentrations within mould infested dwellings are consistently much higher, being in the range 3.000 to 7.000 per m³. Certain basic concepts should be noted in assessing the extent of health risks from moulds in buildings. Damp, poorly ventilated atmospheres are not conducive to the good health of occupants. None of the mould fungi encountered are peculiar to buildings and, as common constituents of the air, everyone is exposed to them at some stage. Any increased hazard arising from exposure to moulds in buildings must arise either from increased frequency of exposure and exposure to higher concentrations of spores than is normal.

Although spores differ greatly in allergenic potential and although there is no firm medical evidence implicating spores of building moulds in allergic disease at the concentrations in which they are believed to occur it would be unwise to regard any as entirely innocuous. Persons most at risk are the topic 10 %, the very young, the elderly and those on immuno-suppressant drugs.

6.3 Control Measures

- Limiting Concentrations

  Where mould has occurred fungicidal washes are useful for cleaning down operations and fungicidal paints may provide some protection where damp conditions are marginal.

  In order to limit the incidence of mould growth effectively, however, it is necessary to control condensation, and therefore to maintain the dewpoint temperature of the internal air below the coldest internal surface temperature of the building envelope. As part of this strategy attention has to be paid in avoiding 'cold bridges' due to defects in the building's insulation.

  The important measure therefore is to control relative humidity. Because of the variety of mould types and the consequent wide range of conditions for growth there are difficulties in defining a precise limiting value. However, experience in the United Kingdom indicates that the incidence of mould growth is very small if the relative humidity in the room is kept below a value of 70 %.

Relative humidity is determined not only by the concentration of water vapour in the air but also by air temperature.

Possible strategies for reducing the relative humidity of the indoor air are therefore as follows:

(a) Reduce moisture content of the internal air by

- minor water vapour production
- removal of water vapour by direct extract or dehumidification

(b) Increase internal air temperature by

- increase of heat input
- improvement of insulation

- Source Control

The reduction of water vapour production can generally only be attained by a change in the behaviour of the occupant.

Direct removal of water vapour at the locations of main production due to household activities can be achieved by extract ventilators in kitchen and bathrooms. Extract fans controlled by humidity tend to improve condensation risk better than those under the control of tenants.

In rooms other than kitchen or bathrooms the moisture content of internal air may be reduced by dehumidifiers. These are available in a range of sizes and water extraction capability. Most operate using a closed refrigerant heat pump cycle. Room air is passed over the cold evaporator, usually driven by a small fan, causing water vapour to condense. In general, dehumidification was found to be successful in reducing condensation problems in houses with both high internal humidity and temperature. In houses with lower temperatures dehumidifiers were found to have little effect. Although welcomed by the majority of users and perceived to alleviate condensation, noise was found to be a major drawback and to inhibit use in bedrooms.

- Ventilation Rate

Assuming average external conditions for relative humidity and air temperature during the heating period, taking estimated water vapour production rates, typical fabric transmittance and average energy consumption, the effect of average ventilation rates on relative humidity can be determined.

It is clear that adequate ventilation is a necessary but not sufficient condition to maintain internal relative humidity below 70 %, the level of heating and insulation being equally important. For this reason it is not possible to define a universally applicable ventilation rate that will ensure control over relative humidity. As a general guide, however, an air change rate lying in the range of 0.5 to 1.0 ach (air changes per hour) should provide a necessary, but not sufficient condition to maintain internal relative humidity in United Kingdom dwellings below 70 % and hence to contain mould growth.

Erhorn and Gertis [10] have carried out detailed calculations appropriate to West German conditions and derive a minimum whole house air change rate for average user behaviour in the range 0.5 to 0.8 ach. They note that this conclusion applies at each end of the heating season and that the rates may be reduced to about 2/3 in the colder months.

6.4 Ventilation Strategies

Adequate ventilation is only one factor in controlling the incidence of condensation and mould growth. However, given adequate levels of heating and thermal insulation minimum ventilation rates can be calculated. Either on the basis of maintaining relative humidity below a set level or ensuring that dewpoint temperature of the indoor air remains below that of the internal surface of any sensitive area of the building envelope. Calculations using either of both methods give comparable values for whole house ventilation rates, in the range 0.5 to 1.0 ach, for German and British conditions. Lower rates may apply to countries with different climatic conditions and living habits.

The preceding discussion and the derivation of minimum ventilation rates has been mainly based upon uniform steady state conditions. In practice many of the processes which generate water vapour within a dwelling, such as cooking, bathing or clothes washing, occur intermittently and in specific locations. This allows the possibility of locally increased ventilation, possibly using mechanical extract systems to prevent the water vapour mixing within the remainder of the dwelling. General whole house ventilation rates may then be reduced.

Reductions may also be obtained if the production rate of water vapour is reduced. This may be possible by simple alteration in the living habits of occupants, direct extraction if this is possible and the use of dehumidifiers. The latter, however, is likely to be appropriate where internal temperatures are not too low and in rooms in which the possible nuisance due to noise is tolerable.

7. INDOOR IONIZING RADIATION

7.1 Source Characteristics

The combined effect of all natural radioactivity contributes more to the total radiation burden than do all artificial sources of radiation including medical diagnostics, nuclear energy and fall out from nuclear weapon testing. The most important factor contributing to the total dose burden from natural radioactivity is radon and its short-lived decay products present in indoor air.

The relevant isotope of radon is produced in the uranium decay chain: the intermediate nuclide 222 Rn with a half-life of 3.8 days. This time is long enough to allow for a partial release from building materials and soil. The half-life is short enough to restrict transport by pure diffusion to short distances only. But once the radon has left the solid material and becomes mixed with air, convective transport over longer distances (several meters) from the soil into a building is possible.

- Radon enters a building

    - from soil, fill or capillarity layer,
    - by exhalation of a fraction of the radon which is produced by decay of radium in the building materials,
    - with drinking water, and
    - with supply air or infiltrating ambient air.

- Radon from the Soil

  In detached houses and in flats at ground level, infiltration of soil gas can act as a carrier for radon from subjacent soil, fill or the capillarity breaking layer. There are in general three requisites for excessive building infiltration of radon from the soil:

    - there must be an open connection for convective gas transport into the building,
    - there must be a driving force supporting a convective flow through the opening, i.e. a pressure gradient with negative pressure in the building relative to the soil, and
    - there must be a large enough volume of permeable soil subjacent to the building.

  Since the concentration of radon in infiltrating soil gas is very high, even a small fraction of the total untightness of a building envelope facing the soil will result in a significant increase in indoor radon concentration.

- Radon from Building Materials

  There are some examples of building materials with unusually high radium activities and correspondingly high exhalations of radon.

The most well known are mill tailings used as concrete ballast, for examples in Grand Junction, Colorado, and aerated concrete based on alum shale which was widely used in Sweden until 1975.

For practical purposes the exhalation from building materials can be regarded as constant over time. Thus the contribution from building materials to the concentration of radon in the indoor air is inversely related to the ventilation rate.

- Radon from Drinking Water

  Significant contributions to the indoor concentration of radon can be released from drinking water if this is taken from a well drilled in certain types of rock, for example granite.

7.2 Effects of Pollutant

- Emission of Alpha and Gamma radiation

  The radioactive nuclides in the decay chains of uranium and thorium emit different types of radiation, of which gamma and alpha radiation are the most important. The two types of radiation have very different properties. Gamma radiation is penetrative and made up of energetic photons. This type of radiation, emitted by nuclides in the building materials, results in a field of gamma radiation in the dwelling and an almost uniform dose to the whole body. Alpha radiation is made up of particles, i.e., nuclei of helium consisting of two neutrons and two protons. This type of radiation penetrates a few centimetres through air and only 40 to 70 micrometres through tissues. Thus this type of radiation can only reach living cells through decay of radioactive nuclides within or on the body. The health hazard derived from the resultant effective dose equivalent is generally assumed to be a factor of 20 higher than from the same energy absorbed as gamma radiation in tissues.

- Indoor Radon Concentrations

  The mean indoor equilibrium equivalent concentration (EEC) of radon has been estimated to be 15 Bq/m³ in the temperate regions of the world [12]. There are some areas where the distribution deviates significantly from this mean, some with extremely high concentrations.

  In Sweden, the combination of infiltration of radon from the soil and the use of aerated concrete based on alum shale has resulted in a mean indoor concentration of radon daughters estimated to be 53 ± 16 Bq/m³ [13]. The population exposure distribution has been estimated as:

0 Bq/m³	8.200.000 persons
100 Bq/m³	800.000 persons
200 Bq/m³	300.000 persons
400 Bq/m³	90.000 persons

Exposure to radiation is generally assumed to result in a linear increase in the probability of developing fatal cancer.

It is, however, rather a rule than an exception that estimates of exposure-risk relationships are uncertain. Nevertheless they are probably better than nothing when setting priorities in environment and health protection.

In the following the conversion factor of 0.061 m Sv/year per Bq/m³ for 80 % indoor occupancy is used in combination with the risk estimate 0.02 fatal cancers per person Sv. Effective dose equivalent figures and lifetime risk estimates for representative concentrations of radon daughters in indoor air are presented in Table 7.1.

Indoor radon daughter concentration	**mSv/year**	**lifetime risk (70 years)**
Estimated indoor mean for temperate regions 15 Bq/m³	0.9	0.1 %
Finnish, Norwegian and Swedish indoor mean, about 50 Bq/m³	3	0.4 %
Swedish action level 400 Bq/m³	24	3.4 %
Swedish action level 2000 Bq/m³, remedial action recommended within one year	120	17.0 %

Table 7.1: Effective dose equivalent and lifetime risk for representative concentrations of radon daughters (equilibrium equivalent concentrations of radon)

All risk estimates referred to in Table 7.1 are based on the so-called absolute risk concept. This concept considers only the excess radiation risk as a function of the cumulative dose or exposure. However, analysis of the increase with time of the lung cancer death rates in exposed populations suggests that a relative risk model may apply.

A working group of the World Health Organization (WHO) has evaluated radon in indoor air and concluded, in accordance with the relative risk concept, 'that estimated risk of lung cancer, attributable to inhaled radon daughter concentrations indoors, is a significant fraction of the total lung cancer risk. It is estimated that at the observed mean levels indoors, about 10 % of all lung cancer cases might be caused by radon daughters. At the high end of the concentration distribution, the risk is of the order of that caused by cigarette smoking. Reducing exposure to radon daughters is an effective approach to reducing lung cancer risks' [14].

7.3 Control Measures

- Limiting Concentrations

The setting of upper limits of accepted doses is one of three principles for radiation protection. Another principle is that a practice which causes exposure to radiation should be justified by providing a positive net benefit to mankind. The third principle discussed by ICRP (International Commission on Radiological Protection) [15] is the rule of ALARA. ALARA stands for As Low As Reasonably Achievable, economic and social factors being taken into account.

The estimation of radon daughter concentration is only part of the basis for a decision on remedial action. Other factors to be considered are the need for a reduction of the collective dose in the population, the nature of the remedial actions in question, and the attitude and willingness/ability of the inhabitants to pay for the costs. For cases where fairly simple remedial actions can be taken the ICRP suggests [15] that an action level for equilibrium equivalent radon concentration in the region of 200 Bq/m^3 (annual effective dose equivalent of about 12 mSv) might be considered. For severe and disrupting remedial action, a value several times higher might be more appropriate, the Commission says.

In Sweden, there have been regulations in force for some years which stipulate that an average concentration of 400 Bq/m^3 and more of radon daughters in the inhabited space shall be regarded as a sanitary nuisance.

- Radon from the soil

Remedial actions against infiltration of soil gas have to be focussed on

- the leakage between the soil and the interior of the building, and
- the driving force, i.e., pressure gradient sucking air through untightnesses into the building.

If the untightness where radon enters the building can be identified and sealed this can be a very cost effective remedial action.

As a general principle, infiltration of soil gas in new constructions must be prevented by designing as tight a construction as possible.

The most commonly applied way of coping with infiltration of soil gas has been to eliminate the pressure gradient between the soil and the building. This can be achieved by balancing the negative pressure caused by the stack effect by pressurizing the building. This method, however, cannot be recommended. It would have the desired effect on infiltration of soil gas but would simultaneously press warm humid indoor air into the cold parts of the walls with water vapour condensation and possibly development of mould as adverse side effects. Instead, it is recommended that the pressure gradient over the slab be changed by sucking air from the soil under the slab, thus maintaining a stronger negative pressure under the slab relative to the interior of the building.

Increased indoor ventilation is usually not an effective remedial action against infiltration of soil gas. If soil gas infiltrates the building, the resultant indoor air concentration may become extremely high. The source term emission then has to be reduced, since no realistic ventilation rate will suffice to dilute the radon to an acceptable concentration. Mechanical exhaust air ventilation of the building will increase the negative pressure in the building and possibly increase the infiltration of radon from the soil.

- Radon from Building Materials

Building materials can be regarded, by and large, as a constant source term for indoor radon. Common building materials have such low exhalation rates, less than 20 $Bq/m^2 \cdot h$, that retrofitting with a mechanical ventilation system will not be cost-effective. The most well known building material with excessive exhalation of radon is probably a type of Swedish aerated concrete with alum shale. The typical exhalation from this material is 50-200 $Bq/m^2 \cdot h$. In houses where aerated alum shale concrete is the main building material, weather stripping can result in a rise of the radon concentration up to 1000 Bq/m^3. In such situations retrofitting with a mechanical balanced ventilation system is the best remedial action.

- Air Cleaning

When air passes through a mechanical filter or an electrostatic precipitator, particlebound radon daughters, as well as the unattached fraction of the radon daughters, are removed efficiently. These filters, however, do not remove any radon from the air and thus the production of radon daughters through the decay of radon is not affected.

In conclusion, it seems that air filtration would result in only a small reduction in dose. The technique cannot be recommended as a remedial action against excessive concentrations of radon daughters except in combination with other more efficient actions. In cases of moderately enhanced concentrations of radon daughters, filtration can result in an acceptable air quality. The absolute dose reduction, however, will not be sufficient to justify the costs involved. The reduction of the radiation dose from radon daughters can nevertheless be a positive side effect when filters are installed to cope with some other indoor air quality problem.

- Identification of Problem Buildings

  A key problem is the design of screening programs for identifying buildings eligible for remedial actions. The ICRP recommends [15] that competent national authorities establish investigation levels to separate exposures that require investigation from those that do not. This procedure is meant to separate, in the least costly way, the majority of buildings with low radon concentration from the few with an elevated concentration of radon daughters above or near the action level. The ICRP recommends that not every building be subject to measurements but that characteristics such as type of building material, local geology, and ventilation principle be used in attempts to separate the small fraction of the building stock where the vast majority of buildings with radon daughter concentration above the action level can be found.

7.4 Ventilation Strategies

Common building materials used in a realistic building design and with common surface treatments give, on the average, an exhalation of radon of less than 20 $Bq/m^2 \cdot h$. With present energy costs and in a cold climate other aspects of the indoor air quality than the radon emission from building materials will set the limits for minimum recommendable ventilation rate. Ventilation rates below the generally recommended minimum rate will obviously increase the radon concentration as will the concentration of a number of other pollutants in the indoor air.

Whenever mechanical ventilation is applied in a house with suspected infiltration of radon from the soil the system should be of the balanced supply-exhaust type. Balancing the system to a neutral pressure, and regular maintenance, will be essential. Considering these demands, ventilation can be a good supplementary remedial tool, especially in cases where the building materials contribute significantly to the remaining concentration of radon.

8. COMBUSTION PRODUCTS

8.1 Source Characteristics

Whenever unvented combustion takes place indoors or venting systems attached to stoves or heaters malfunction, a wide range of combustion products can be discharged directly into the indoor atmosphere. When the externally vented heating system is properly designed, maintained and operated, combustion products that could directly affect indoor air quality do not enter the indoor environment. However, excessive negative pressures in the interior spaces caused by the operation of various exhaust appliances or faulty venting systems can result in levels of indoor air contaminants in excess of acceptable limits.

The levels of indoor contaminants produced by combustion devices depend on the emission rate and the removal rate. For vented appliances, the rate of removal depends on the effectiveness of the venting system. For unvented appliances it depends on the house air exchange rate.

8.2 Effects of Pollutant

The major pollutants associated with indoor combustion are carbon monoxide, nitrogen dioxide, organic compounds and particulates. These usually occur in low concentrations compared with carbon dioxide and water vapour which are the major combustion. Adverse health effects from exposure for indoor combustion pollutants depend upon concentrations and exposure time and range from annoyance and irritation to more severe health risks. Limiting concentrations of combustion products are e.g. given by WHO-guidelines [16] for indoor air.

8.3 Control Measures

- Source Control

  Source Removal: The obvious approach, but not necessarily the most economical, is substitution of combustion appliances by electrical appliances for heating and cooking.

  Source Modification: Combustion appliances can be modified to improve their efficiencies and thereby reduce fuel consumption and/or to reduce the emission rate of combustion products. The NO_x emission rate can be reduced by lowering the flame temperature but at the expense of increasing the CO emission rate.

  Air Treatment: There are currently no commercially available air-cleaning devices for removing gaseous combustion products such as CO, CO_2 and NO_2 from indoor air for residential application; however, airborne particulates can be removed by filtration and electrostatic precipitation.

- Ventilation Rate

The use of ventilation, whether by air infiltration or by natural or mechanical processes, as a means of air contaminant control depends much on whether the combustion appliances are unvented or vented. In the former case the ventilation air is used to dilute the combustion products, whereas in the latter it is provided for proper combustion and operation of the venting systems.

Unvented Combustion Appliances: Test results [17] with an unvented gas cooking stove indicate about a 20-percent reduction in CO and NO_2 levels when the whole-house air change rate was increased from 0.10 to 0.90 ach. Comparison with range hood experiments, however, show 60- to 80-percent reductions in the levels of CO, CO_2 and NO_2 with exhaust rates of 42 to 113 l/s, indicating that exhaust at source is much more effective than increasing the whole-house ventilation rate.

Tests [18] with a radiant-type kerosene space heater or a convective-type in a small bedroom show that WHO guidelines for indoor air for combustion products can be exceeded with unvented heaters in spaces of small volume such as bedrooms, house trailers and cabins, even with heaters that are well adjusted. Opening a window or door can reduce the pollutant levels by increasing the ventilation rate, but can result in longer burn time and, hence, exposure time.

Vented Combustion Appliances: Central furnaces require air for combustion and dilution. The combustion air is brought into the appliance at the burner, where it is mixed with the fuel, and the combustion products pass through the heat exchanger before venting. The dilution air is brought in downstream of the furnace and is used primarily to control the amount of chimney draft. The dilution air flow accounts for a much larger air requirement and heat loss than does the air actually required for combustion [19], see Table 8.1. This table summarizes the air requirements for various residential combustion appliances. The air requirements for naturally aspirated gas and oil furnaces are about 0.5 and 0.4 ach, respectively, based on an internal house volume of 500 m^3. Thus the amount of air required by heating appliances corresponds to the generally accepted amount of air supplied to the occupants of 0.5 ach. Conventional fireplaces have the highest air demand of 1.4 ach and are extremely inefficient.

Advanced furnace design such as the high-efficiency oil furnace and the induced-draft or condensing gas furnace do not need dilution air. Hence, their air requirements which range from 0.06 to 0.09 ach, are considerably lower than those of naturally aspirated furnaces.

Appliance	Air Requirement			
	Combustion	Dilution	Total	
	l/s	l/s	l/s	ach*
Conventional Oil	18	54	72	0.52
Retention Head Oil	12	54	66	0.48
High-Efficiency Oil	10	-	10	0.07
Conventional Gas	14	40	54	0.39
Induced Draft Gas	12	-	12	0.09
Condensing Gas	8	-	8	0.06
Fireplace	188	-	188	1.40
Airtight Wood Stove	5	-	5	0.03

* Based on internal volume of 500 m^3

Table 8.1: Air Demands for Residential Combustion Appliances

If the house pressure is decreased to the extent that the chimney draft of about 25 Pa is overcome, e.g. by use of extract ventilation systems, a flow reversal in a furnace chimney can occur to cause combustion products to be released inside the house. The operation of a fireplace, because of its high air requirement, has the greatest potential to cause flow reversal in the furnace chimney. On the other hand, operation of a furnace and/or exhaust appliance can result in a flow reversal in the fireplace chimney when the fireplace is burning at low fire.

8.4 Ventilation Strategies

The most effective strategy for unvented combustion appliances in terms of reducing indoor contaminant levels is to replace them with electrical or vented combustion appliances. Where this is not possible, combustion products from unvented combustion appliances such as kitchen ranges should be locally exhausted to the outside using a mechanical exhaust hood rather than relying on whole house ventilation. In general, the use of unvented combustion heaters is not recommended, and in particular in spaces of small volume, or in relatively airtight enclosures.

For vented combustion appliances, furnaces of advanced design requiring no dilution air such as condensing gas furnaces and airtight wood stoves should be used as the air requirements are considerably lower and their efficiencies are substantially higher as compared to those of conventional heating appliances. Also, in airtight houses, the operation of these furnaces, as compared to conventional furnaces, has little detrimental effect on the efficiencies of an air-to-air heat exchanger for heat recovery from the exhaust air. Fireplaces should have a separate supply of outside air and glass doors to isolate the fireplace from the house ventilation system; this increases their efficiencies and minimizes the potential for backdrafting of the furnace chimney.

Relatively airtight houses should be checked for adequacy of combustion air and chimney backdrafting. If necessary, corrective measures should be taken. These include providing adequate outside air supply and/or reducing the amount of air exhaust by various household exhaust and supplementary heating appliances.

9. SELECTED ORGANIC SUBSTANCES

9.1 Source Characteristics

A wide variety of airborne organic substances arises from materials within the building or from the building fabric itself. Other sources are related with the activities of the occupants as well as combustion and tobacco smoking. During the last ten years problems caused by indoor organic air pollutants like formaldehyde (HCHO) or wood preservatives containing pentachlorphenol (PCP) has been of major concern and the aim of intense investigations. The procedures developed and recommended for control of these pollutants will be illustrated in this chapter and can serve as an example for the treatment of other organic substances.

9.2 Effects of Pollutants

It seems appropriate to limit present considerations to health effects and nuisances resulting from longterm exposures in private homes, schools, restaurants, offices, etc. Odours from fresh paint or the exposure to a casually applied insecticide may lead to shortterm increased ventilation but will virtually not effect the fuel consumption of the house or appartment.

Concentrations of organic pollutants in the indoor air are usually well below the level of acute toxicity, but various symptoms of irritation, allergic reaction, or diffuse symptoms of sickness have frequently been observed. Often there are several contaminants present simultaneously which may pose a problem even if they are at subacute levels taken individually. Although the whole population is exposed indoors, the risk groups such as children, chronically ill, or elderly people deserve special attention. The question of severe health effects caused by indoor organic pollutants at low concentration levels, like e.g. carcinogenity in the case of exposure to formaldehyde, is still controversially discussed and not well understood.

For formaldehyde this situation is reflected by a Canadian statement from 1980 (Min. Nat. Health & Welfare) which seems still to be the best assessment of our present knowledge: 'To characterize formaldehyde as a mutagen, teratogen and carcinogen based on studies using toxic dose levels of a powerful reducing and alkalizing agent is a dubious practice. On the other hand, untoward exposure to this highly reactive chemical is certainly not advocated'.

9.3 Control Measures

- Limiting Concentrations

  To characterize the health effects of organic trace gases the concept of 'acceptable indoor concentrations' (AIC) has been introduced. For concentrations of a pollutant below AIC, the negative health effects are negligible or - if no threshold is known - at least tolerable. By increasing the ventilation rate - for a given source strength - it is always possible to dilute pollution below AIC. Values for some organic substances, as used as an example by the West German BGA (Bundesgesundheitsamt), have been taken from various sources and are listed in table 9.1.

products for indoor use: pollutants	**AIC** $[\mu g/m^3]$	**C*** $[\mu g/m^3]$	**C*/AIC**	n_{AIC} $[h^{-1}]$
particle board:	120	1360 [1]		
HCOH			11.4	22
		340 [2]	-3	6.1
FRG standard E1		≤160		
present US board		240	1.33	≤1
			2	1
wood protection:				
PCP	10	17	1.7	
coated				0.108
uncoated				0.7
γ-HCH	4	40	10	
fungicides in wall paintings:				
chlorothalonile	20	1.9	<1	-
endosulfan	6	10	1.67	0.42
TBTO	0.5	47	94	10.6 [3]
		13	26	3.67 [4]

Table 9.1: AIC-values and necessary air exchange n_{AIC} $[h^{-1}]$ for various sources calculated for a = 1 m^2/m^3

c* - concentration inside the material

1) FRG standard E2
2) Particle board coated with a formaldehyde absorbing paint
3) 25 days after painting
4) 410 days after painting

- Source Control

  To derive AIC-values for carcinogenic and other substances, which may pose a health risk at any detectable concentration, is a difficult task. Whenever possible the use of carcinogens in building materials and other indoor products should be interdicted, as has been the case in several countries with spray asbestos, uranium or arsenic based pigments, or benzene in solvents. In other cases, however, a complete ban proves impossible. For example minute traces of vinylchlorine, butadiene or acrylnitril seem to be technically unavoidable in the corresponding polymer products. If, therefore, for certain substances a complete ban proves to be impossible or impractical then the emission rate from building materials, paints, insulation materials, furniture, textiles etc. must be limited already at the production stage.

- Ventilation Rate

  Each product having a continuous indoor emission can be characterized by an air exchange rate n_{AIC} necessary to reduce pollution to an acceptable level. With n_{AIC} below 0.5 h^{-1} no problem should normally arise because basic ventilation rates required from other limiting factors should be appr. 0.5 h^{-1} or greater anyhow. For some products, like wall paints with the fungicide TBTO, the possibilities of ventilation are very limited. In the FRG particle board of emission class E1 is allowed in prefabricated houses and for the production of furniture. No problems will normally arise for loads up to 1.5 m^2/m^3, but in crowded dwellings the load from furniture alone may reach 2 m^2/m^3, and if part of this furniture were at higher temperature annoyance may be felt. PCP should usually not pose a problem - dioxine contaminations are not considered here - which agrees with the observation that very high PCP concentrations in indoor air are mostly observed after very intense application only.

9.4 Ventilation Strategies

An upper limit to ventilation rates can be derived from energy cost considerations. The lower limit of the ventilation rate is set by hygienic criteria of CO_2-concentration, body odour and humidity. The Federal Health Office of the FRG recommends 0.5-0.8 air exchanges per hour in private homes for these reasons.

Organic pollutants of the indoor air should not be a reason to specify any general ventilation rates higher than these, rather should the source of the pollutant be controlled. Product regulations therefore form a necessary and essential part of every strategy for the improvement of indoor air quality. Product regulations will limit emissions at the source and may even totally ban extremely risky substances.

10. CONCLUSIONS

The objective of the work in Annex IX was to review and, where necessary, to supplement current knowledge in order to provide a sounder basis for defining ventilation rates, designed to ensure that the concentrations of the main indoor air pollutants should not exceed levels likely to:

- damage the health of occupants;
- cause annoyance or reduction in amenity; or
- cause damage to the building fabric.

The upper limit on ventilation rates is provided by the need to conserve energy. In principle two approaches may be used to specify standards:

(i) The prescriptive approach, in which an outdoor air flow rate is stated.

(ii) The air quality approach, in which a limiting maximum pollutant concentration is defined and the building designer or user, is required to supply sufficient air to ensure that this is not exceeded.

However, dilution by fresh air is not the only method of controlling an indoor pollutant. In some cases other approach such as:

- source removal, alteration or substitution;
- direct extract ventilation; or
- air cleaning

may provide a more appropriate and efficient method of balancing the need for energy conservation and good indoor air quality.

Recommendations for adequate control measures and their effect on ventilation are briefly summarized for the individual pollutants or pollutant groups in the following:

- Tobacco smoke

  Limiting Concentrations: To avoid annoyance and irritation to an average healthy person carbon monoxide as an indicator with an upper limit of 1 to 2 ppm can serve for specifying an acceptable smoke level.

  Source Control: Smoking should be prohibited in rooms for sick persons and children. Separate rooms or offices for smokers should be established. Where this is not possible non-smoking areas should be made available.

Ventilation: In the case of moderate smoking, acute effects can be prevented by adequate ventilation. In large public rooms and offices necessary ventilation rates can be determined on a statistical basis in the range of 8-20 l/s (30-70 m^3/h) per person (corresponding to 50-120 m^3 per cigarette smoked), to avoid acute effects.

- Particles

Smoking is the main source of airborne indoor respirable particles. Particle control therefore complements the above mentioned control measures for tobacco smoke.

Air Cleaning Devices: In small rooms with a relatively low air infiltration rate, air cleaning devices can be useful to reduce airborne particles.

Ventilation: Based on particle emission data from cigarette smoking, average smoking habits and on a particle concentration limit of 75 $\mu g/m^3$ (NAAQS) a ventilation rate of 17.5 l/s (63 m^3/h) per person was established in the ASHRAE-Standard in 1981 to accommodate the presence of smoking.

- Body odour

Limiting concentration: CO_2 is an usable indicator of body odour pollution. Accepting a limit of 20 % dissatisfied persons, when entering an occupied room, this corresponds to a CO_2-concentration of 0.10 % or 0.065 % above the outdoor concentration.

Ventilation: From the limit of 0.10 % CO_2-concentration a steady-state minimum ventilation rate of 8 l/s (29 m^3/h) per person has been calculated. The limit of 0.10 % CO_2 allows for 20 % of persons dissatisfied with the odour level when entering a room. From other reasons than body odour some experts still favour a limit of 0.15 % CO_2, which is also considered in some ventilation standards. The corresponding ventilation rate of approx. 3-4 l/s (12-15 m^3/h) is given in brackets in table 9.1. In terms of body odour the lower ventilation rate is equivalent to a higher percentage than 20 % of visitors dissatisfied with the odour level.

- Humidity, condensation and mould growth

Limiting concentration: The important measure is to control relative humidity, but there are difficulties in defining a precise limiting value. However, experience indicates that the incidence of mould growth is very small if the relative humidity is kept below 70 %.

Source control: Direct removal of water vapour produced by household activities (kitchen, bathroom) can best be achieved by humidity controlled - extract fans. In houses with both high internal humidity and temperature dehumidifiers may be successfully used.

Ventilation: It is not possible to define a universally applicable ventilation rate for control of condensation and mould growth. However, given adequate levels of heating and thermal insulation, ventilation rates in the order of 0.5 to 1.0 ach should normally maintain relative humidity below 70 % and hence contain mould growth, for German and British conditions.

- Indoor ionizing radiation

  Limiting concentrations: The International Commission on Radiological Protection suggests for cases where fairly simple remedial actions can be taken an action level of appr. 200 Bq/m^3 (annual effective dose equivalent of 12 mSv). Swedish regulations regard an average concentration of 400 Bq/m^3 and more of radon daughters as a sanitary nuisance. A different principle than setting upper limits is the rule of ALARA (As low As Reasonably Achievable).

  Source control: If radon from the soil infiltrates the building no realistic ventilation rate will suffice, exhaust ventilation even aggravates the problem by increasing the negative pressure gradient. In new constructions infiltration must be prevented by building as tight as possible adjacent to the soil. If infiltration path through untightness can be identified, a very cost effective remedial action is sealing.

  Balancing the negative pressure by pressurizing the building may lead to condensation problems and is not recommended. Instead air should be sucked from the soil under the slab.

  Ventilation: If building materials with excessive radon exhalation rates, as e.g. 50-200 $Bq/m^2 \cdot h$ for Swedish aerated alum shale concrete, are present, best remedial action is balanced mechanical ventilation. Generally valid ventilation rates, however, will be determined by other factors than pollution by radon.

- Combustion products

  Limiting concentrations: Recommendations for limits of combustion products are e.g. given by WHO-guidelines for indoor air.

  Source control: The most effective strategy is replacement of unvented combustion appliances by electrical or vented ones. Where this is not possible, combustion products should be locally exhausted as e.g. for kitchen ranges.

Ventilation: Corrective measures in case of chimney backdrafting may be especially necessary for relatively airtight houses. These should include adequate supply of outside air supply and/or reducing the amount of exhaust air by various household exhaust appliances.

- Selected organic substances

  Limiting concentrations: For some organic substances, like e.g. formaldehyde, acceptable indoor concentration (AIC) limits have been established. To derive these AIC-values for all indoor organic pollutants is a difficult task, much more information is still required.

  Source control: Whenever possible the use of carcinogens in building materials and other indoor products should be interdicted. If a complete ban proves to be impossible then the emission rate of pollutants should be limited already at the production stage of these materials.

  Ventilation: Because of the large number of substances and variability in emission rates, control of organic pollutants does not provide a practical criterion for setting minimum ventilation rates. Where, in any given instance, AIC values are likely to be exceeded the uncertainties noted above would result in impracticably high ventilation rates for control and methods based upon restricting emission rates will be required.

A brief overview of general recommendations for the strategies of indoor air pollutant control are given in table 10.1. For most indoor pollutants some form of source control as e.g. by restrictions, replacements, product control or local extract ventilation - will be the primary measure. This applies to the wide variety of organic substances, combustion products and radon. Although there are no generally valid ventilation rates prescribed by these pollutants it is, however, presumed that basic air exchange through infiltration and intentional ventilation - prescribed by other factors - will provide a sufficient removal mechanism for these pollutants, if adequate source control measures have been taken.

Source control is also the preferred measure to protect the non-smokers from tobacco smoke. This can be realized by restriction of smoking or separation of smokers and non-smokers. For large offices or public rooms - with smoking allowed - adequate ventilation in the order of 8-20 l/s (30-70 m^3/h) per person should avoid accute annoyance or irritation in the case of moderate smoking.

The only two pollutants which lead to general applicable minimum ventilation rates are related to occupancy and personal activities: Body odour and humidity. To avoid annoyance to persons entering a room, a ventilation rate of 8 l/s (29 m^3/h) per person occupying the room is recommended. Whole house ventilation rates in the order of 0.5 to 1.0 air changes per hour are considered a necessary condition to avoid condensation and mould growth in most situations.

INDOOR POLLUTANT	EFFECTS	indoor concentration limit	CONTROL MEASURES source control	minimum ventilation rate	PREFERRED STRATEGY
Tobacco Smoke	annoyance, irritation, health risks	annoyance/irritation for healthy person: 1-2 ppm CO	restriction of smoking, separation non-smokers/smokers	50-120 m^3 per cigarette or 8-20 l/s per person (moderate smoking in large rooms/offices)	restriction or separation whenever possible, adequate ventilation in large public rooms or offices if smoking allowed
Particles	see above	75 $\mu g/m^3$ (NAAQS)	see above	17.5 l/s per person (based on average smoking habits)	tobacco smoke is the main source of particles, therefore strategy as above
Body Odour	annoyance	0.10 % CO_2 (0.15 % CO_2)		8.0 l/s per person (3-4 l/s per person)	ventilation variable with occupancy, if occupancy predictable variation on statistical basis
Humidity	damage to building fabric	relative humidity below 70 % is a necessary, but not sufficient condition	extract ventilation in kitchen and bathroom	appr. 0.5 to 1.0 ach	extract ventilation at main sources and minimum whole house ventilation rate
Indoor Ionizing Radiation (Radon)	health risks	200-400 Bq/m^3 as action level or rule of ALARA	sealing to the soil, avoiding negative pressure gradient	No generally valid ventilation rates	radon from soil: Sealing, avoiding negative pressure gradient Radon from building material: balanced mechanical ventilation
Combustion Products	annoyance, irritation, health risks	e.g. WHO-guidelines	replacement of unvented combustion appliances, local extract ventilation	No generally valid ventilation rates	replacement, local extraction, corrective measures for chimney backdrafting like e.g. adequate outside air supply
Selected Organic Substances	annoyance, irritation, health risks	for some substances limits have been established	restriction/interdiction of use of carcinogens, limitation of emission rates	No generally valid ventilation rates	product control: restriction/interdiction, limitation of emission rates

Table 10.1: Summary of recommended control measures and strategies for indoor pollutant control

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