May, 1981

Minimum Ventilation Rates - Biological Demands

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Annex IX: 'Minimum Ventilation Rates'
This report also appears as a report to International Energy Agency

Contents

Note

This report covers mainly experiences of ventilation problems in Sweden.

1. A REVIEW OF THE LITTERATURE

1.1 Introduction

Indoor air quality is related directly to the amount and quality of outdoor air supplied, by controlled or uncontrolled ventilation, and to pollution generated indoors. Calculations indicate that we spend about 70 % of our time indoors. New materials, new methods, changing subjective values and human behaviour are just some of the factors which necessitate further research work in this sector.

Among air pollutants which are emitted indoors are odours from humans and animals, tobacco smoke, oxides of nitrogen, carbon dioxide, carbon monoxide, formaldehyde, hydrocarbons and particulate matter. Ionizing radiation from radon and radon decay products is a problem in buildings made of certain materials. Other problems are dust, dust mites and mildew spores, which can give rise to allergic reactions.

Indoor air pollution is generated by building materials, furniture, humans, animals, clothes etc. Further interaction between other climatic parameters and air pollution can result in problems of which very little is known. Indoor air is often also polluted by a large number of activities and processes: e.g. increased use of chemicals etc. for cleaning, insect sprays, use in hobbies etc.

It is not possible simply to take the threshold limit values for working environments and transfer them to indoor residential environments. Both exposure periods and individuals exposed differ widely. Allowance for allergic persons and others with particular sensitivity makes the problem even more difficult. Taken together, these factors mean that margins of safety must be considerably higher in residential buildings than in working buildings. Nevertheless, there is little knowledge on the subject.

In order to comply with specified threshold limit values, ventilation systems are often dimensioned on the dilution principle. The necessary rate of air change is determined so that an acceptable air quality should be maintained in occupied zones. It is difficult to arrive at optimally dimensioned flows due to inadequate knowledge of source levels and safety margins.

A somewhat suspect development is the increasing number of systems which are based on local extraction with recirculation of indoor air. Particulate matter in such systems can be removed by filtration, but the gas phase often remains uncleaned. Such systems can be useful as a complement to other systems, but should be used with care and awareness of their limitations and effects.

Increasing energy consciousness in recent years has tended to lead to a reduction in air change frequency in the built environment. With unchanged source levels, this results in a deterioration of air quality. This tendency is particularly noticeable in the residential sector. Individual single-family houses built in recent years have air change rates which are sometimes as low as 0.1 - 0.4 air changes/hour, i.e. well below the requirements of the 1975 Swedish Building Regulations. At the same time, greater use has been made of plastic and synthetic building materials instead of wood and stone, with resulting changes in emissions to the indoor air. The effects of this development on public health, particularly in the longer term, are as yet largely unknown. An indication of the seriousness of the problem is given by the fact that, in many cases, the CO_2 concentration in residential buildings equals or exceeds the threshold limit value for workplaces. Values exceeding this limit have been recorded in modern bedrooms as a result of occupation for several hours with the door closed.

The following pages are an analysis of information largely obtained from two recent reports on ventilation and health protection in buildings (Beckman et al., 1981; Löfgren, 1981).

1.2 Mildew

Mould fungi grow saprophytically on organic substances, e.g. wood and indoor dust, and as parasites on plants and animals. Most moulds and mildews release airborne spores which are distributed by wind and air currents. The concentration of spores in the air varies widely, and is dependent on the environment.

Depending on the local growth and climatic conditions, spore concentrations can vary considerably between adjacent areas and at different times. The concentration of spores is also dependent on geographical location. In Sweden, and in other countries with similar climates, the concentrations of spores are greatest between July and October. In general, the indoor spore concentration tends to follow the outdoor concentration in terms of both quality and type of spore (Holmberg and Kallings, 1980).

Air humidifiers, air conditioners and wall-to-wall carpets can affect the types of spores to be found, and can also provide a suitable environment for their growth. Floor dust contains different types of mould from those which are encountered in circulating indoor air. There are about 10–15 different types of mould which dominate as allergens in the Nordic environment. However, particular and more uncommon types of mould may also dominate as allergens if the local growth conditions are right (ibid).

Serious mould and mildew damage has been found in Swedish buildings since the beginning of the 1970s. The number of buildings showing signs of attack seems to be increasing continuously, and is estimated to amount at present to about 3 000. It is known that the mildew problem is due primarily to increased humidity levels and poor ventilation, which in turn result from new building methods and energy conservation. New types of building materials and methods of handling them are further causes of trouble. Drying times for sawn and planed timber are becoming shorter and shorter, with the result that there is a growing risk of the incorporation into buildings of timber which has not been dried sufficiently to ensure a sufficiently low moisture ratio at the time of moving into the house. Careless or unsuitable storage on the building site can result in the moisture ratio increasing between the time of delivery and when the timber is used. When coupled with other moisture loads, e.g. condensation or moisture on walls or ceilings, excessive moisture ratio in the wood can result in mould. Mould causes damage to the building, and is expensive to eliminate. It usually gives rise to a most unpleasant smell which permeates textiles (e.g. clothes), plastics, skin and hair. The smell is very difficult to get rid of, and often causes psycho-social problems.

Mould spores are a natural part of our environment. In buildings which have been attacked, they have found the right conditions for growing and forming hypha, which release further spores. Mould fungi can produce biologically active substances (toxins). It is not known whether spores, too, contain toxins.

Mould spores can cause allergic alveolitis. This is an allergic inflammation of the lungs which causes muscle pain, nausea, high temperature and shivering. The symptoms often disappear without treatment if exposure is terminated, but often return on renewed exposure. Repeated attacks can result in chronic illness, but it seems likely that a hereditary disposition to the illness is necessary. The number of cases of allergic alveolitis diagnosed and caused by mould seems to have been increasing in recent years, which could indicate that an investigation into a possible link between the illness and mildew in buildings is merited.

At least 10 % of all asthmatics are oversensitive to mould. About 175 000 persons in Sweden suffer from asthma (Wirsin and Bodin, 1980). Of those persons who are regularly exposed to large quantities of mould spores, about 10-15 % develop allergic alveolitis (Holmberg and Kallings, 1980). There is a greater frequency in connection with exposure to chemical substances which damage lung tissue. Alveolitis then arises due to subsequent inhalation of mould spores, with the result that the proportion of persons developing allergic alveolitis is increasing.

1.3 Other biological factors

Air humidifiers and ventilation systems can assist in creating the right conditions for the growth of micro-organisms. This can cause high concentrations of micro-organisms in indoor air, particularly if ventilation performance is poor, and can result in long periods of human exposure. These risks should be considered when checking existing installations and in the development of new methods and equipment.

Sewage treatment plants are often enclosed. Ventilation discharge from these buildings can contain infectious organisms in high concentrations which are capable of entering other buildings through ventilation systems. The possible effects of such discharges have not been determined.

Legionnaire´s disease and Sauna taker´s disease can be spread through ventilation systems. There are strong suspicions of links between buildings or their ventilation systems and several epidemics of legionnaire´s disease One of the common factors in relation to an outbreak in Sweden in 1979, in about 60 persons were taken ill, was a department store.

Dust mites can give rise to hypersensitive reactions such as asthma and allergic rhinitis. According to a Danish investigation (Korsgaard, 1979), 1 % of the Danish population suffers from allergic problems caused by dust mites. Dust mites were found in 87 % of 75 randomly selected Danish dwellings. The highest concentrations were found in dust from mattresses and in dwellings with a relative humidity above 40 %.

1.4 Radon

All human life is exposed to a certain level of ionizing radiation from natural radiation sources. We have also created a number of artificial sources, e.g. radiography equipment. All ionizing radiation increases the risk of mutations, and thereby also of cancer.

The substances which have the greatest significance for radiation in buildings are radium-226 and its decay products (radon and its decay products). These elements decay, emitting energy in the form of ionizing radiation (alpha, beta and gamma radiation). When this radiation encounters body tissues, it gives up its energy to them. Alpha and gamma radiation are of particular interest in this context.

Alpha radiation is easily stopped, and cannot penetrate the skin. Radon decay products, however, are particulate, and can be inhaled and fasten in the mucus layers of the bronchial tract. They emit alpha radiation in decaying, which can then damage cells in the bronchial traet and cause lung cancer.

Gamma radiation can easily penetrate body tissues, and can contribute to the formation of various types of cancer and can also cause damage to genes. However, gamma radiation probably represents less of a health risk in Swedish buildings than does alpha radiation.

Our knowledge of the dose/effect relationship between radon and lung cancer is very poor, i.e. it is difficult to quantify the risk of developing lung cancer when exposed to different radiation doses. This is complicated by the fact that there is inadequate knowledge of radon levels in the Swedish building stock, and so also of the radiation doses to which the population is exposed.

Epidemiological investigations of mine workers, exposed to high levels of airborne radon decay products in their work, indicate that radon can contribute to the occurrence of lung and bronchial cancer, and that the risk is higher for smokers than for non-smokers. However, the air in mines cannot be compared with the air in residential buildings. No epidemiological investigations have been carried out with the object of determining the relationship between radon in buildings and lung cancer.

Risk assessments are based instead on mathematical model calculations. The use of a model immediately introduces an element of uncertainty into the calculations. It is also particularly difficult to estimate the radiati dose to which a given person has been ecposed, even if the radon concentration in the air is known. It is therefore necessary to make further assumpt when assessing the risk, which increases the uncertainty. Several estimates of the relationship between radon decay product concentrations in the air and the absorbed radiation dose have been published. Depending on the mathematical model used, and on the assumptions made, the highest and lowest values reached in these reports vary by a factor of about 50 (Swedish Expert Committee on Safety and the Environment, 1978).

In 1978, the National Institute of Radiation Protection estimated the radiation dose to which the Swedish population is exposed due to radon in residential buildings. Starting from this figure, and from various specified relationships between radon exposure and lung cancer, it was estimated that between 200 and 1000 cases of lung cancer are induced annually as a result of exposure to radon in residential buildings. People living in houses built of shale-based lightweight concrete with high radium content run a five times greater risk of contracting lung cancer than those living in an 'average' Swedish house.

There has been a considerable increase in R & D work since high radon contents were detected in the indoor air of a number of Swedish residential buildings during the autumn of 1978 (Swedish Expert Committee on Radon, 1979).

1.5 Light air ions

Light air ions are formed when a charged atom molecule, e.g. oxygen or nitrogen, acquires further energy. An ion-dipole reaction then causes uncharged molecules to attach themselves as a shell round the charged molecule (cluster formation), forming a light air ion. The structure of these ions is not exactly known at present (Backman, 1979). The energy which is necessary for the formation of light air ions can be supplied in the form of ionizing radiation (e.g. from radon), by friction (e.g. in sandstorms), when large drops of water are broken up in waterfalls, by nuclear weapon explosions, by corona discharges, or by combustion.

Clean air over land normally contains about (1.5-4) x 10^9 light air ions per m^3. There are somewhat more positive ions than negative ions, in a proportion of 1.2:1. In polluted air, the number of light air ions is somewhat less, and the proportion of positive ions increases. This is due to the fact that light air ions react with pollutants and from medium and heavy air ions, and also to the fact that negative light air ions are more mobile than positive ions and so tend to attach themselves to pollutants to a greater extent.

The natural process which has most effect on ion formation indoors is the decay of radon and radon decay products. Light air ions can be discharged in air conditioning equipment, on electrostatically charged surfaces, through contact with clothes or skin on an electrostatically charged person or through contact with air pollutants.

Naturally ventilated buildings generally exhibit wide variations in the concentration of light air ions, largely due to the effects of radioactivity (ionizing radiation) in the foundations and building materials. The concentration of light air ions is generally lower in air-conditioned buildings, and the proportion of positive to negative ions is higher, than in the surrounding outdoor air.

Research into the subject shows that light air ions can have biological effects. However, it is not clear whether they are capable of affecting health.

1.6 Chemical factors

Pollutants in the air around us consist of a very large number of substances, which makes it difficult to relate demonstrated effects to any one, or even a few, substances in the air (Johansson, 1978). Further, knowledge of the functional relationships between specific air pollutants and defined effects is often inadequate. This is further complicated by the fact that different pollutants can produce different effects in combination, as illustrated by the combined effects of asbestos exposure and smoking, sulphur dioxide and soot particles or formaldehyde and aerosol of salt. Another problem area is the long-term effects (possibly including cancer) of polyaromatic hydrocarbons, nitrosamines etc.

The relationship between indoor and outdoor air pollution levels has been studied in a series of investigations of the indoor concentrations of sulphur dioxide and carbon monoxide in relation to the outdoor levels. A considerably lower SO_2 level has been recorded indoors than outdoors (Ubisch, 1970).

Similar work has subsequently been carried out with respect to other gaseous organic substances. Investigations have revealed higher levels of air pollution indoors than outdoors in newly-built childrens' day nurseries, probably due to the emission of solvents (alcohols and terpenes) from building materials and fittings (Johansson, Pettersson and Rehn, 1978, 1979).

Similar findings have also been reported from Denmark and USA. With the need to conserve energy, this has focussed interest on permitted levels of pollution for residential and general premises. It may well be necessary to introduce product control and/or approval of building materials and fittings having potential air polluting properties and intended for use in low-energy buildings.

A substance of current interest is formaldehyde (Pettersson and Rehn, 1977). When high formaldehyde levels were first found in new residential buildings, the National Swedish Environment Protection Board studied the health risks associated with formaldehyde and prepared a proposal for limiting values for residential buildings which has subsequently been used as a basis for the proposal for advice and code of practice on the subject by the National Board of Health and Welfare.

In properly draughtproofed buildings, it is not possible to obtain sufficient ventilation solely through natural ventilation powered by the difference in density between the colder outdoor air and warmer indoor air. It has not been possible to maintain the specified minimum value of 0.5 air changes/h in individual single-family houses. This air change rate has been difficult to achieve in modern airtight houses, even with the addition of a kitchen fan. The problem has not been completely investigated, but it seems that occupants of houses with inadequate ventilation tend to be aware of it through odours, condensation on windows, mildew, increased irritation of mucous membranes etc. (Berglund, 1979: Berglund and Lindvall, 1979). The facts show that co-ordinated action is required when energy conservation work is undertaken, in order to ensure that all aspects and effects are considered.

Based on experience of the problems which have arisen in individual single-family houses, it is likely that balanced ventilation will become a standard requirement in future. It would be beneficial if complete ventilation systems, including heat exchangers, could receive type approval.

The low energy flows which will be all that will be necessary in future buildings could well lead to an increased use of air as the heat transport medium. Development in Finland is tending to confirm this, as trends there indicate a considerable increase in favour of such systems. It should be pointed out in this context that there is a risk of establishment of large stagnation zones when using warm air supply systems.

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2. EXISTING STANDARDS

2.1 Materials

The 1980 Swedish Building Regulation specify certain general hygienic requirements for buildings which affect the indoor air quality. The Product Control Act (SFS 1973:329) lays down requirements relating to substances and goods which involve health and enviromental risks. Specific rules which affect the building at present are concerned with substances intended to be used against mould and decay. The use of cadmium will be banned from July 1982. There are also restrictions, primarily in the interests of those working with the substances, on the use of such materials as asbestos, epoxy products, reinforced ester plastics, isocyanates, quartz sand for floating floors, mineral wool and PCB.

The Building Regulations state explicitly that the formaldehyde content of chipboard and plywood must not exceed a maximum fo 0.040 % by weight. The measurement method is also specified (the perforator method), as are the methods of manufacture and site inspection to be used.

The Building Regulations also specify the maximum permissible radiation from radioactive substances, the requirements for protection against dirt deposits and discolouration and against the spread of gas and odour.

2.2 Airtightness

In the interests of energy conservation, heated buildings must be airtight: for example, detached houses must not leak more than three air changes/h at a pressure difference of 50 Pa, while apartment buildings with three or more storeys must not leak more than one air change/h.

2.3 Air quality

The Building Regulations give detailed requirements on air flow, approved air quality and air change rates. Ventilation in residential buildings must be sufficient to ensure a continuous air change rate of at least 0.35 l/s, m^2 of residential area for an apartment as a whole. The annual indoor average value of radon decay product level must not exceed 70 Bq/m^3. Natural draught ventilation is approved for single-family houses, although the specified minimum air change rate cannot be achieved in all weather conditions. Mechanical ventilation must be employed in all other residential buildings. This is carefully specified for various areas in a dwelling, as for other types of premises (e.g. medical centres, hospitals, garages etc.).

When rebuilding existing structures, ventilation must be provided so that the mean annual value of radon decay product levels does not exceed 200 Bq/m^3 in any room.

Minimum exhaust air flow rates are specified for kitchens, bathrooms, lavatories, utility rooms etc.

2.4 Energy conservation

The Building Regulations specify that air conditioning and other equipment must be designed and installed so that heating or cooling is provided, distributed and used in accordance with good energy management practice. This means that, for instance, it must be possible to reduce the supply of outdoor air when the building, or part of it, is not in use. It must be possible to adjust and control the system. Under certain conditions (e.g. where there is a heat energy difference of more that 50 MWh/year during the heating season), air conditioning equipment must be provided with heat recovery equipment from the exhaust air.

3. CURRENT RESEARCH

3.1 List of proposed research, development and pilot trails

1. Survey and assessment, in the existing built environment, of:

   a) The number of climate control systems, particularly ventilation.

   b) The uses to which premises are put, and users' behaviour as a result of climatic influences.

   c) The frequency of symtoms and discomfort etc. in users, related to the indoor climate.

2. Development of new ventilation principles. Examples:

   a) New methods of balanced ventilation in air-tight buildings.

b) Development of new ventilation equipment for low-energy air treatment, applicable also to individual rooms.

c) Development of new air cleaning methods.

3. Development of new methods of measurement and appraisal fo climatic effects on persons, including:

   a) Comfort levels.

   b) Effects on behaviour.

   c) "Early warning" systems.

   d) Indicators (chemical/physical, biological tests).

4. Medical/environmental hygiene measurements of air pollution levels indoors and around buildings, with emphasis on:

   a) Risk analysis, risk assessment, threshold limit value philosophies.

   b) Biologically relevant exposure descriptions.

   c) Effect appraisals in relation to human adaptability and to groups whose sensitivities, needs and reactions determine quantification of threshold limit values.

   d) Biological follow-up of the effects of design solutions.

5. Feasibility of ventilation - by - demand, starting from:

   a) System loading in terms of occupants, activities or processes.

   b) Ability of the users to affect the ventilation themselves.

   c) Requirements of the building (e.g. for control of humidity levels).

6. Analyses of entire occupied enviroments within the framework of energy management, for example:

   a) Investigations of noise and vibration from ventilation systems.

   b) Interaction between various climatic factors and the air conditioning system.

7. Environmental hygiene/health effects of specific energy management measures, involving both existing and new buildings. Examples are:

   a) Ecological buildings.

   b) Heat recovery and air recirculation systems.

c) Alternative combustion systems (e.g. stoves etc.) for space heating.

8. Guarding against unforeseen circumstances, including planned solutions for:

   a) Increased ventilation in special premises due to, say, the presence of radon, mildew or smoke.

   b) Feasibility of modifying the ventilation in premises used by particularly sensitive persons with lower tolerance levels, e.g. asthmatics.

   c) Survival measures in crisis situations, e.g. failure of the electricity supply or acute fuel shortage.

   d) Consequence analyses of future changes in life styles of importance for the utilization of buildings.

9. Development of methods of testing for performance and environmental hygiene/health inspection of the ventilation of buildings, including not only methods of measurement but also the organisational structure. Tests, measurements etc. can concern:

   a) Foreign substances.

   b) Materials.

   c) Components.

   d) Systems.

   e) The whole environment.