THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

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PAPER 2

IEA ANNEX IX "MINIMUM VENTILATION RATES" - SURVEY AND OUTLOOK

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SYNOPSIS

To establish guidelines for minimum ventilation rates which are sufficiently large to meet the demand for outdoor air in buildings without unnecessarily wasting energy, in Annex IX "Minimum Ventilation Rates" of the IEA Program "Energy Conservation in Buildings and Community Systems" eleven countries are co-operating. The participants had in a first step summarized existing knowledge, national standards and current and required research.

The IEA provides with the Annexes IX and V a highly suitable mechanism for coordinating the research in such diverse fields as e.g. hygiene, medicine, engineering etc. and for encouraging the necessary contributions from the various countries.

As indoor pollutants being of most importance have been identified: Carbon dioxide, tobacco smoke, formaldehyde, radon, moisture, body odour, organic vapours and gases, combustion products and particulates.

To a certain degree some of the substances which had been under investigation can be used as an indicator for acceptable air quality with respect to establish recommendable ventilation rates.

The paper gives a general view of the objectives of Annex IX, the first results and of the relation to the subject area of Annex V. It additionally gives an outlook on the future co-operation of the participating countries.

1. INTRODUCTION

From the viewpoint of energy conservation air infiltration and ventilation have to be minimized. A certain amount of outdoor air, however, has to be supplied to a building in order to maintain healthy, safe and comfortable conditions for the occupants and to avoid damage to the building fabric. The optimization of these conflicting requirements will result in guidelines for minimum ventilation rates that are sufficiently large to meet the demand for outdoor air without unnecessarily wasting energy.

The work that was and is required to define such minimum ventilation rates covers a wide range of disciplines, from hygiene and medicine on one hand to engineering and building science on the other. Therefore in 1980 the Annex IX "Minimum Ventilation Rates" within the International Energy Agency's (IEA) programme "Energy Conservation in Buildings and Community Systems" has been established in which experts in the various fields and from different countries decided to co-operate for identifying objective criteria and other background data needed to establish ventilation standards including minimum ventialion rates.

In the last years the international interest in indoor air quality (IAQ) problems has increased clearly. The reason for this increase may be that efforts to conserve energy by reducing indoor-outdoor air exchange have worsened the problem of pollutant buildup from indoor sources. On the other side many constructions materials as well as furnishing and household appliances have been shown to emit pollutants.

Considering the AIC Technical Note 12[1] it appears that about one third of r and d projects*) in the field of energy conservation in buildings refer now to air quality problems as against a few per cent some years ago. Only as an example it should be pointed out here that the latest Annex IX participant Finland has just started the extensive r and d programme "The Quality of Indoor Climate and Ventilation Requirements".

2. ANNEX IX OBJECTIVES AND PARTICIPANTS

Since January 1984 phase II of Annex IX is in progress. As reported in the AIR[2] nine countries have co-operated on a task sharing basis to complete phase I involving a review of existing knowledge, national standards and current and required research for a number of specified pollutants. A detailed report of this work is published[3]

The objectives of the phase II are:

- to quantify more closely the factors which determine the concentrations of the pollutants identified in the first phase and to determine the inter-relationships between these factors
- to establish minimum ventilation 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 measurement and sampling techniques that may be useful in solving the problems connected with maintaining acceptable air quality in buildings.

Over the next two years, the participating countries will each be conducting research to meet these objectives in relation to specific pollutants or to some more general aspect of pollution control. The pollutants under consideration include formaldehyde, tobacco smoke products, radon, moisture, body odour and carbon dioxide, and combustion products.

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*) recorded 187 projects in 23 countries

The working points within the running working programme are as follows:

(i) Emission rates and time dependence for different materials and sources and their dependence on:

- composition and processing
- installation and handling
- human behaviour
- indoor climate.

(ii) Indoor transfer and interactions:

- ad-, ab-, and desorption
- dilution
- chemical reactions and other interactions

(iii) Control

- pollution measurement, sampling and identification
- ventilation
- air cleaning and dehumification
- separation and recovery
- reduction of emission rates.

(iv) Modelling indoor pollution including economic and social factors, health aspects.

(v) Strategies for indoor air pollution control under the restraints of energy conservation.

The following countries are participants in phase II of Annex IX: Canada, Denmark, European Community, Finland, W. Germany, Italy, The Netherlands, Sweden, Switzerland, United Kingdom, United States of America.

3. CONNECTION WITH FURTHER INTERNATIONAL PROGRAMMES

There are some aspects in which the work of Annex IX and Annex V "Air Infiltration Centre" are closely related. As explained by D. Curtis[4] in the AIR, Annex IX is investigating the pollutants which affect indoor air quality with the aim of establishing acceptable concentration levels and defining corresponding minimum ventilation rates whereas Annex V is concerned with air infiltration and its effects on ventilation. There are no overlaps and to ensure that a suitable level of liaison is maintained these two Annexes are co-operating very closely by an information exchange.

To a certain extent there are connections with Annex VIII "Inhabitants Behaviour" too. Convection and, in particular, infiltration is least understood and most affected by the individual behaviour of the inhabitants. Therefore one of the main objectives[5] of Annex VIII will be:

> To determine the actual behaviour of inhabitants regarding ventilation and to correlate it to outdoor and indoor climate, and facing problems of minimum ventilation.

Germany, the Operating Agent of Annex IX, is also participant of Annex VIII and thus a suitable transfer of knowledge is ensured.

It should be noted here that Working Groups convened by the WHO Regional Office for Europe are for years active in the field of indoor pollutants and health effects. The information exchange in the last time showed that a further co-operation could be of advantage for our Annex IX work.

4. FIRST RESULTS OF THE ANNEX IX WORK

The results of the first phase can be summarized as follows:

If the generation rate of CARBON DIOXIDE is known, the quantity of outdoor air required to maintain carbon dioxide concentration below an acceptable level can be calculated. In some standards a minimum supply of outdoor air is specified based on the maximum acceptable concentration of carbon dioxide for physiological requirements. Other standards specify higher minimum outdoor air requirements to control odour and other air contaminants.

Measurements in schools showed that CO_2 was the only measured contaminant that increased significantly when outdoor air supply was reduced. The maximum CO_2 levels were found to be generally below 2500 ppm, a recommended limit in North America. In these studies, the levels of carbon dioxide and other contaminants were measured at reduced rates of mechanical supply of outdoor air. Similar measurements in an office building and eight energy efficient houses indicated CO_2 levels below 2500 ppm. From these measurements it seems that carbon dioxide is not a serious pollutant in buildings without unvented indoor combustion appliances. The level of CO_2, however, is an indicator of the amount of outdoor air supplied. More field studies are required to determine the relationship between CO_2 and other air contaminants in buildings of various occupancies.

The control of air quality based on the controlled dilution of naturally produced CO_2 appears to be satisfactory as long as there are no other contaminants that exceed their respective limits. Continual sensing of the CO_2 concentration to control the outdoor air supply can result in significant reductions in the energy required for conditioning the ventilation air. Experimental installation of CO_2-controlled outdoor supply air in a school, department store and an office building verify that substantial saving in energy can be obtained compared with conventionally controlled ventilation systems. Further studies are required to demonstrate the practicality of CO_2-controlled outdoor supply air in terms of indoor air quality, reliability and cost effectiveness.

TOBACCO SMOKE is one of the most important pollutants of indoor air. The concentrations of indoor air pollutants and their effects have been studied in various investigations in recent years. Smoke concentrations usually prevailing in smoking rooms could cause irritations of eyes and respiratory organs for a short while and could also cause annoyance. Epidemiological studies on long-term effects indicate that passive smoking may increase the susceptibility of the respiratory illnesses, especially for children and sick persons. The question of increased risk to lung cancer is not satisfactorily answered.

The irritations are caused primarily by the particle phase while annoying odours mostly come from the gas phase of smoke. The annoyance caused by smoke corresponding to carbon monoxide concentrations of 1 to 2 ppm is an acceptable level for healthy persons. Air ventilation rates should be adjusted accordingly so that this level is not exceeded in smoking rooms. For the protection of non-smokers, specially for children, sick and elderly, nonsmoking rooms should be provided so far as possible.

FORMALDEHYDE is a chemical substance widely used as a component of insulation material (Urea-Formaldehyde-Foam), and for glue specially in wood products, such as particle boards, paneling, plywood etc. It is also used on a large scale in disinfectants and household cleaning materials.

Due to the fact that formaldehyde evaporates from the above mentioned materials it becomes an unnegligible component of indoor-air.

Only in recent years gaseous formaldehyde has been incriminated to cause short/long terme irritations to the eye, nose, throat and other respiratory organs.

It has therefore become necessary to agree upon regulations concerning safe levels for formaldehyde concentrations in homes. Some European countries have suggested the maximum tolerable level to be 0,1 ppm as an indoor standard. In this connection it is indispensable to formulate regulations regarding the tolerable amount and/or emission rate of formaldehyde containing products.

The investigation on BIOCIDES started from the question if it is possible to reduce ventilation rates without creating health problems from indoor air pollution. No definite answer is possible for the present.

In order to put the problem in perspective one should know the future trend of biocide application in households. Due to the lack of statistics no extrapolations are available. We can only presume that the Chemical Industry even in the future will continue to expand with new products and we know that up to now there are few - if any - administrative regulations for these markets. If we therefore pressimistically assume an increasing trend of indoor biocide application this could certainly limit the further reductions of ventilation rates.

The RADIATION in dwellings has traditionally been regarded as part of the natural radiation, as for example the cosmic radiation and the radiation we all get from our body burden of natural potassium and thus not been subject to any international regulations. During recent years there has been discussions within different international bodies on how to deal with the part of natural radiation that is increased by technical activities. This radiation has been referred to as Technologically Enhanced Natural Radiation (TENR). These discussions, however, have not yet resulted in adoption of any international guidelines.

Sweden is the only country for the moment where the authorities has adopted nation wide guidelines for both existing buildings and future constructions.

The chapter gives an overview of the status of the present knowledge and to some selected references where more exhaustive information may be found. It also tries to give information about indoor radon in relation to other sources of radiation and its implication on public health. It presents a brief overview of the three major sources of indoor radon: building materials, soil under the building and ground water. Further the guidelines in Sweden are outlined, and the need for research and exchange of experience on measures to avoid infiltration of soilgas and epedemiological studies of possible health effects is presented.

It is important to emphasize that there is no general conflict between energy conservation and radon if infiltration rates are only slightly reduced. In untight buildings the major part of the possible reduction of infiltration rate and energy conservation can be used with a moderate increase in radon concentration. One further step to extremely low infiltration rate of course reduces the energy demand to a slightly lower level, but at the cost of a dramatic increase in radon. In a small fraction of the building stock, where the building materials show a very strong emanation of radon, a mechanical ventilation system has to be used and its net energy consumption might cause some increase in the energy consumption of these buildings. Those buildings, however, constitute a very small fraction of the building stock in any country and have little impact on the average potential for energy conservation. It is very important to notice that the highest radon concentration will be found in untight houses built on strongly radon emissing grounds on gravel and solid rocks, i.e. granite.

The assumed relation between inhalation of radon in dwellings and increased risk for lung cancer is very uncertain. The only data that can reduce this uncertainity would be results of epidemiological studies, which by statistical signification indicate a certain risk factor or an upper limit for the risk factor. Such studies are very complicated. The Radon Commission in Sweden has avaluated the possibility of such studies on exposed populations in Sweden.

The most common sources of microbial contamination of indoor air by MICROORGANISMS are the aerosol generators, air humidifiers, air ventilation units, wet surfaces and the human being. In most cases such contamination does not have any health consequences. But certain bacteria, fungi mites and their dissociation products could cause allergies or infections in respiratory organs. A higher risk does exist in the operating theaters and intensive care units of hospitals and in the sterile production of drugs.

By taking appropriate preventive measures the microbial contamination of indoor air can practically be avoided. Special care should be taken to keep the water of the spraying units used for humidifying air clean and to prevent the water condensation on wet surfaces by having a sufficient supply of air by keeping the relative humidity below about 40 %, thus the growth of dust mites in dwellings can be controlled to acceptable levels. Hospitals, pharmaceutical laboratories and food industries request an extra attention. Additional desinfection as well as a sufficient filtration of the air can be necessary. However, desinfection of air by chemicals and/or UV-radiation is e.g. not allowed by the Health Council in the Netherlands within hospitals.

The outgassing from building materials, furnishing, households and consumer products results in an air contamination by ORGANIC SUBSTANCES. From these substances especially the following have been investigated and considered: HYDROCARBONS, halogenated hydrocarbons and some other compounds as e.g. methanol, ethanol acetone and higher aldehydes and fatty acids.

Little is known of the effects upon the human organism of the compounds at concentrations observed in indoor air. For this reason, only brief references can be made to the general effects of these compounds which, however, in most cases will occur only at considerably higher concentrations.

Skin effects including eczematous contact dermatitis and skin paresthesia are common to many gaseous organic substances. In particular, water-soluble gaseous compounds will exert a general irritant action on the mucosae. A number of solvents and halogenated hydrocarbons may at high concentrations cause kidney and liver damage. Highmolecular halogenated compounds such as polychlorinated biphenyls are mostly deposited in body fat. They reduce cell growth and lessen enzyme activity. A number of polycyclic aromatic hydrocarbons have been identified as the cause of various types of cancers in animals.

Further and more detailed investigations have to show how these compounds and their effects will influece the need for air exchange and ventilation rates in non-industrial buildings.

The review of COMBUSTION PRODUCTS is principally concerned with flueless appliances as e.g. cooking ranges and ovens, small portable space heaters and water heaters.

Inadequate air supply to openflued appliances, which may include gas and oil-fired central heating and hot water boilers (furnaces), solid fuel fired boilers and open fires, may result both in incomplete combustion and the "spillage" of the flue gases. They then become partially flueless appliances, albeit with a higher total (indoor and outdoor) emission rate of combustion products since they generally have a much higher rating.

Prevention of mal-operation of open-flued appliances has been the subject of a number of studies and requirements for air supply are contained within Building Regulations, Codes of Practice and professional guides in many countries.

The report[3] covers the products of the main fuels used in buildings, including both those which result from complete combustion and those which occur when combustion is incomplete. This is followed by a brief review of health effects and then a section dealing with field studies which covers the data available on indoor concentrations found in practice and the limited number of epidemiological investigations specifically related to combustion appliances.

It has become conventional to describe the degree of vitiation in terms of the carbon dioxide. This can be misleading, because the relative quantities of water and vapour and carbon dioxide vary with fuel. The same percentage CO_2 will correspond to different oxygen concentrations for different fuels.

The HUMIDITY of ambient air varies considerably with time and location, being determined by geographical and climatic factors. In the centre of a land mass in winter, with temperatures perhaps reaching typically as low as $-40^{o}C$, moisture content my be only 0.08 g/kg dry air, whereas in the warm moist climat of a maritime region moisture content may be above 10.0 g/kg dry air. In any given locality annual variations of this magnitude are unlikely but even in the mild climate of the British Isles a ten-fold range between winter and summer is not uncommon.

In the Annex IX report[3] the factors which affect indoor humidity are discussed, followed by a brief review of the possible effects of humidity on occupants and the fabric of buildings, with particular reference in the latter case to condensation. Finally possible methods of control are considered and topics for research suggested.

Further and more detailed investigations will contribute to statements about the influence of the humidity to the need for air exchange and ventilation rates.

BODY ODOUR is the main reason for ventilation of many densely occupied spaces. It is therefore surprising that so little research has taken place in this area. The review[3] presents the principal findings of two major studies on body odour and ventilation requirements. Shortcomings of the studies are discussed and reasons for the large differences in the results obtained in the two investigations are discussed.

None of the two studies provide completely satisfying data for fixing a required ventilation rate. One used an arbitrary "moderate" mean vote of test persons on his psycho-physical scale as criterion. Another based his recommendation of 4 l/s person on 75 % acceptability of his judges. But the situation for the judges may have been a little unrealistic. After having entered their head in the sniffing box for a moment the test persons were supposed to vote whether the odour was acceptable or not. The meaning of "acceptable" may be quite different when entering a real space than for a judge under these rather artificial conditions. This may also explain the small influence of ventilation rate on acceptability in some experiments. Field validation of the observations would be essential.

The Annex IX report[3] on PARTICULATES AND FIBERS gives, beginning with some general definitions, a review of sources of indoor particulates and fibres pollution, of measurement techniques, of effects of particulate and fibres inhalation on human health and finally lists open questions and future research fields. Investigations on the effect of ventilation rate on indoor particulate and fibres pollution are needed.

The dilution of indoor air contaminants with outdoor air requires a considerable amount of energy to condition that air. The amount of outdoor air, and consequently the energy for its conditioning, can be reduced through the use of air cleaning devices for TREATMENT OF RECIRCULATED ROOM AIR.

There are commercial air cleaning devices that provide filtering to remove airborne particles, disinfection to control airborne contagion, and sorption materials to control some odour and gaseous contaminants. These devices are not used extensively because the most common control strategy, dilution, involves low capital and maintenance costs and gives a safty margin to also the many non-identified air contaminants in buildings. The concept of using air cleaning devices to permit reduction of outdoor supply air rate is relatively new. Hence, data are required on the performance of ventilation systems using such devices to control all the relevant indoor air contaminants involved.

Further, to permit the proper design of contaminant removal systems, the efficiencies of various devices must be expressed on a common basis. Standard test methods are available for evaluating particulate removal devices and are required for gaseous contaminant removal devices.

The RELATIONSHIP BETWEEN OUTDOOR AND INDOOR AIR POLLUTION depends substantially upon whether the major sources of pollutants of concern are indoor or outdoors. Major indoor pollutants are radon, formaldehyde, and combustion products principally carbon monoxide, sulfur dioxide, nitrogen dioxide and suspended particles.

In many cases radon and formaldehyde have lower concentrations outdoors than indoors, and the indoor pollutant concentrations are not significantly affected by outdoor concentrations. This is also sometimes true for some combustion pollutants, when an unvented appliance is used indoors and the outdoor pollutant levels are low. Indoor/outdoor relationship may be considered most simply in the context of a single-chamber (well-mixed) mass-balance model that utilizes first-order indoor pollutant reactivity rates and building shell pollutant penetration factors.

In considering ventilation requirements for various building types, the indoor/outdoor ratio itself is not often the parameter of interest. For indoor-generated pollutants, the ratio is often large and not relevant to ventilation requirements, which are determined directly from pollutant generation rates. For pollutants that are generated only outdoors, concentrations are generally the same or less indoors, as a result of which applicable outdoor standards could ordinarily provide suitable protection of the general public (except when outdoor air contains unusually high pollutant levels, either average or peak). When pollutants can arise from either indoor or outdoor sources to a comparable degree, the structure affects indoor concentrations in two offsetting ways of comparable importance. The structure reduces the indoor concentrations of outdoor-generated pollutants while confining indoor-generated pollutants. However, ordinarily the indoor pollutant generation rates themselves are the principle guide to ventilation requirements.

5. CONCLUDING WORDS

Annex IX is a highly suitable means for coordinating the research in the above outlined wide-ranging topics and for stimulating the necessary cooperation from participating countries. The result of this international programme will be as follows:

- A document identifying more closely the factors which determine the concentrations of the pollutants and the interrelationships between them, minimum ventilation rates and all other suitable methods for acceptable air quality levels, further a document summarizing information about ventilation techniques for controlling air quality and conserving energy, and a document cataloging and assessing measurement and sampling techniques.

- A final report integrating the results of this task and containing recommendations for such additional research activities as may be appropriate.

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