emission rates depend not only on the material but also on environment, loading and ventilation. This makes the calculation of the concentration of pollutant uncertain. The emission is strongest in the new buildings. This gives a reason to ventilate the new buildings more than the old ones.

The ventilation and air conditioning systems studied were not in general the sources of bioaerosols. The concentration of bacteria was much lower in the supply air than in room air eventhough return air was used. However, the duct system may be a source of spores when it becomes wet for example due to improper construction. This was found in two of 32 investigated detached houses with warm air heating system.

Discussion

The project started lot of research activities in the area of indoor quality and climate. Although many problems became solved lot of new questions arose. As a result from the project a better understanding of indoor air climate was achieved. A criteria for good indoor air climate was established. The results of the project had influence on the revision of Finnish building code in the area of ventilation. Numerous projects for new products have started also as a result of the project. Very important was also to find out how far the every day building industry is from the results of the research. Much higher satisfaction on indoor air climate and quality could be achieved if the all known indoor air criterias would be fullfilled. Unfortunately the practical questions in building industry seem to rise as a major obstacle for better indoor air quality and climate.

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MINIMUM VENTILATION RATES AND VENTILATION STRATEGIES

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Abstract

The ventilation of dwellings is essential for the removal of chemical contaminants, indoor pollutants as carbon dioxide, body odour, and water vapour but at the same time it effects comfort and energy consumption for space heating. The main sources of contaminants giving rise to health effects in dwellings were found to be tobacco smoke, some building materials and under certain conditions, combustion appliances. For indoor pollutants being most important within the work of International Energy Agency's Annex IX "Minimum Ventilation Rates" air exchange rates have been defined which prevent 1) damage to the health of occupants, 2) annoyance or reduction in amenity, 3) damage to the building fabric. Technical solutions which can meet the controverse requirements for good indoor air quality and energy conservation have to integrate the following aspects: 1) tight building's envelop, 2) mechanical ventilation with the possibility to adapt outdoor air supply to demand, 3) inhabitants behaviour fitting these requirements and acceptance of the technology by the inhabitants, 4) heat recovery, and 5) an important key to economical solutions: design and realization of ventilation systems of high efficiency.

1. Introduction

The earliest recommendations for ventilation rates were based on the carbon dioxide level or more or less weak definitions of a comfortable and healthy indoor air atmosphere. More than 100 years ago Pettenkofer (1) expressed his view that carbon dioxide may be a good indicator for indoor air quality. The Pettenkofer number of 0,1 % carbon dioxide content as the highest acceptable level is still applied in many national ventilation standards. Tredgold (2) recommended an air exchange of 4 cubic feet per minute and person which corresponds with 1,9 l/s per person, to prevent stuffiness. Others as e.g. Carnelly et al. (3) refferred to microorganism in the indoor environment and suggested that a concentration of 20 organisms per liter should not be exceeded for healthy conditions in schools and dwellings.

The experts cooperating in International Energy Agency's Annex IX "Minimum Ventilation Rates" tried to summarize the different approaches and the available knowledge in the fields of indoor air quality to come to a more homogenous picture. The aim was to define ventilation rates which prevent that concentration of the main pollutants will not exceed levels which may give rise to one or more of the following categories:

, damage to the health of occupants
i) annoyance or reduction in amenity
ii) damage to the building fabric.

ı the other side for economical and environmental reasons the ventilation ates should also meet energy conservation efforts in the building sector.

s pollutants of main concern have been considered: tobacco smoke, body dour, carbon dioxide, condensation and mould growth, organic substances, ndoor ionizing radiation, combustion products and particles.

t is obvious that the delution process of ventilation will not be the only easure to hold pollutants concentration within tolerable limits. For some ubstances also source alteration or substitution, air cleaning or further easures of control have to be included into strategies for energy conser- ation and good indoor air quality.

n principle two approaches have to be used in practice for specifying ven- ilation standards:

i) defining an outdoor air supply rate which by dilution or displacement lowers pollutants' concentration,

ii) defining a limiting concentration and require the building designer, owner etc. to ensure that ventilation or other measures are sufficient to control these concentrations.

Practical experience has shown and it has to be taken into account that uniformly mixed conditions of both the ventilating air and the pollutant throughout the ventilated space can not be assumed in every case. It is necessary to include into the considerations the design of the ventilation system and it's actual ventilation efficiency.

2. Indoor Pollutants and Minimum Ventilation Rates

Although tobacco smoke is one of the most frequently found indoor air pollutant, it cannot easily quantified and characterized by simple criteria. If the criterion is avoidance of any annoyance and health risk even for sensitive persons the only strategy is separating smokers from nonsmokers. If the criterion is avoidance of acute irritating effects for large public rooms and offices the ventilation rates recommended should be dependent on the number of cigaretts smoked per hour. In a statistical average between 8,3 and 19,4 l/s and per person are a sufficient outdoor air supply. An energy efficient strategy to reduce annoyance by tobacco smoke products could be demand controlled ventilation.

The investigations have shown, that carbon dioxide is a reliabel indicator for body odour. Body odour is noticed first of all by persons entering a room (visitors). An occupant adapted to a strong body odour in a room will,

when reentering after having left the space for a few minutes, perceive the same odour intensity as a visitor. For this reason it is necessary to design ventilation systems which provide body odour levels acceptable for visitors rather than for occupants. Ventilation rate and percentage of persons dissatisfied with the indoor air quality are correlated. Some standards, as e.g. ASHRAE ventilation standard or ISO thermal comfort standard, suggest 20 % dissatisfied persons as acceptable. In this case a ventilation rate of approximately 8 l/s and per person are needed to avoid annoyances. The corresponding carbon dioxide concentration is then about 0.1 %. A rational ventilation strategy is a constant minimum acceptable outdoor air supply. In rooms or buildings where occupancy varies in an unpredictable way it would be efficient to control the outdoor air supply by a carbon dioxid sensor, thus holding a constant acceptable indoor air quality.

Humidity and condensation can influence inhabitants' health as well as the building fabric if no appropriate measures, e.g. ventilation are taken. The most probable risk arising from condensation and from exposure of persons to mould infestatios are allergies. In Central European countries many cases of demage to the building fabric by moisture has been reported. Tightening the buildings resulted in lower air change rates and growing problems with damages by moisture.

An important measure is to control relative humidity by ventilation, although this represents only one factor. For German and British conditions ventilation rates of 5,6 to 11,1 l/s and person are recommended. Lower rates may apply to countries with different climatic conditions and living habits.

The use of organic substances has increesed in the last decade by building, furnishing, houehold and personal consumer products. In accordance with this development also the emittance of trace or higher amounts of e.g. volatile organic compounds may have increased.

In general up to now not much is known about the emission characteristics, indoor concentrations and health effects. The most effective measure to control these substances is to define an upper allowable concentration level or to avoid the emission of such substances. For formaldehyde e.g. the German Federal Ministry for Youth, Family and Health has established 0.1 ppm as an upper limit for indoors. The Netherlands permit only 0.02 ppm. Also if ventilation is not recommended as a prior measure to control the concentration of organics, dilution can contribute to decrease special load situatins. In common a minimum ventilation rate needed to avoid annoyance by body odour etc. should be sufficient to avoid concentration levels of organics which can not be accepted.

Also in the case of ionizing radiation e.g. by radon, most important measures are remedial actions and not defining ventilation rates. The soil subjacent to buildings is the major contribution to indoor radon. 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 emission then has to be reduced, since no realistic ventilation rate will be sufficient to dilute the radon to an acceptable concentration. For mechanical exhaust e.g. ventilation will increase the negative pressure in the building and possibly increase infiltration of radon too. To avoid or minimize radon problems balanced supply-exhaust ventilation systems are most promizing. It can be stated, that ventilation can be a good supplementary remedial tool provided that the system has been designed very carefully.

The use of ventilation as a means of combustion products control dependes much on whether the combustion appliances are unvented or vented. In the former case the outdoor air is used to dilute the combustion products, whereas in the latter it is provided for proper combustion and operation of the venting system. An effective strategy for unvented combustion applicances in terms of reducing indoor contaminant levels may be to replace them with electrical or vented combustion appliances. Where this is not possible combustion products should be locally exhausted to the outside using a mechanical exhaust hood rather than relying on whole-house ventilation.

Particle concentrations in buildings have had in last years a mayor impact on ventilation standards. In the US outdoor National Ambient Air Quality Standard 17,5 l/s and per person was established to accomodate the presence of smoking within a space in order to control the particle concentration at a level of 75 µg per m^3. 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 ventilatin for particle control. When the pollutant source and its properties are known, then these sources should be addressed explicitly. In many cases other measures than ventilation will have priority.

3. Summary

In table 1 the recommended minimum ventilation rates are summarized. The recommendations and results will be discussed in detail in the final report of International Energy Agency's Annex IX (4).

In Central Europe moisture and humidity may have priority for ventilation strategies. It is neither practicable nor good sense to emply high ventilation rates to limit the levels of contaminants which may be better controlled by other measures. Such measures, taken together with public education campaigns, could markedly improve public health and reduce the incidence of fabric damage in a short space of time. New ventilation strategies and equipment could improve standards of hygiene and comfort while increasing energy conservation.

Table 1: Recommanded ventilation rates

indoor pollutant	recommended ventilation rate	comments
moisture	5,6 to 11 l/s and person	depending on climatic conditions and habits
body odour	8 l/s per person	20 % disatisfied visitors
carbon dioxide	8 l/s per person	0,10 % carbon dioxide
	4 l/s per person	0,15 % carbon dioxide
tobacco smoke	8,3 to 19,4 l/s per person	in a statistical average
formaldehyde, organics, biocides etc.		source control

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