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DETERMINATION OF AIR EXCHANGE RATES FOR DEMAND CONTROLLED VENTILATION

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SYNOPSIS

In this paper the required ventilation air flow rates in residences with different pollutant loads are considered. The calculative study was carried out by using the load data presented in the literature. The results of the study were applied in the development and dimensioning of demand controlled ventilation systems.

The first stage of calculations was to determined the required ventilation air flow rates (range) with different loads for each type of rooms separately. In the analysis of required ventilation air flow rates due to material emissions, the Monte Carlo-method was applied. The second stage of calculations was to analyse indoor air contaminant concentrations in an apartment as a whole using the required air flow rates in room spaces. The time-dependant occupant behaviour in the apartment was based on a certain assumption. Calculations with constant air flow rates ventilation were also done.

When considering different load factors; human based odours, the odours of smoking, humidity loads and contaminant emissions of materials were taken into account. The required ventilation air flow rates in different load situations were determined to guarantee good indoor air quality and humidity conditions, and to prevent health risks due to material emissions, as well.

In most calculation cases it was assumed that indoor air is fully mixed. In addition, the effect of air flows on 2-dimension contaminant field was analysed.

1 BACKGROUND

In Finland the indoor climate and ventilation of residences must fulfil the Building Code which define the satisfactory level of indoor climate in normal conditions. On the other hand the loads of ventilation are variable and therefore the ventilation air flow rates should also be adjustable by occupants.

At the moment there is no clearly recommended air flow rates for demand controlled ventilation systems. The correct required air flow at any given time or room space depends on load factors. With demand controlled ventilation it is possible to minimize energy consumption of ventilation, as well.

In this paper some typical loads and criterias as well as air flow calculations are presented. Loads and criterias are based on literature. This paper deals only with residences.

2 LOADS AND AIR FLOWS

The most important loads in residences are human based odours, odours of smoking, humidity, building and furniture materials and heat loads. The required ventilation rates were determined to guarantee good indoor air quality and humidity conditions, and to prevent health risks due to material emissions.

2.1 Human based odours

Human based odours may be handled by using carbon dioxide (CO_2) emissions and concentrations. If the percentage of dissatisfied is 20 % the CO_2 concentration is about 1000 ppm (cm^3/m^3) and required air flow is 7-8 dm^3/s per person. If there is no special requirements for odour of air, then it could be possible to use smaller air flows, e.g. 4 dm^3/s per person corresponding to the CO_2 concentration 1500 ppm.

In a case more persons than normally (e.g. visitors) occupy the room space, the air flow should be at least 8 dm^3/s per person because dispersing of odours decreases. When physical activity increases the required air flow may be 2-4 times greater compared to a condition where people are sedentary.

2.2 Odours of smoking

Odours of cigarette smoke are usually dealt with carbon monoxide (CO) concentration. Acceptable concentration is 1-2 ppm. Continuous smoking at steady-state conditions requires 100-200 dm^3/s air flow per smoker. With the typical smoking frequencies (1-4 cig/h) the needed air flow is only 20-40 dm^3/s per smoker.

2.3 Humidity loads

Too high humidity level of indoor air may cause mould growth and structural damages. According to calculations the required air exchange rate in residences should be 0.1-0.4 1/h if we use mean humidity loads. The greatest loads appear in the bathroom during shower. Required air flow is then over 50 dm^3/s. Other loads in bathroom requires only 10-30 dm^3/s air flow. In kitchen the greatest air flows, about 15-40 dm^3/s, is needed during cooking.

2.4 Materials

Almost all materials release harmful contaminants. Best known compound is formaldehyde, that is typically emitted from particle board.

To calculate the required ventilation, contaminant emissions of materials and highest accepted concentrations are needed. Both factors are very uncertain and, therefore, very difficult to used as exact initial values of calculations. One method to deal with that is to use distributions of measured emissions and calculate air flows using Monte Carlo-simulation which picks up the emissions (combinations) randomly according to the statistical probability.

Concentration limits can be estimated by the aid of limit values used at workplaces (MAC,TLV etc.). In Finland contaminant consentrations in residences must be lower than 1/10 of limit values at workplaces. Some concentration limits for residences are shown in table 1.

Emission distributions can be found out by using quite few facts about material emissions. Only the mean (or median), minimum and maximum emissions of each type of material and compound are needed. Some typical materials and emissions are shown in table 2. As an example, the normal distribution of emission is calculated in a following way:

Initial parameters

$\bar{E}$ is mean emission
E_{min} minimum emission
E_{max} maximum emission

and

RND_1 and RND_2 which are random numbers between 0...1.

To calculate the normal distribution of emission (E_i) normal deviation (S) is needed. The mean value of S is 0 and standard deviation is 1.

$$S = \sqrt{-2\ \ln(RND_1)}\ \cos(2\pi RND_2)$$

If $S < 0$ then $E_i = \bar{E} + S(\bar{E}-E_{min})/\sqrt{3}$

otherwise $E_i = \bar{E} + S(E_{max}-\bar{E})/\sqrt{3}$

where the terms $(\bar{E}-E_{min})/\sqrt{3}$ and $(E_{max}-\bar{E})/\sqrt{3}$ are approximate values of standard deviations.

Repeating calculation with different random numbers several (even hundreds) times we will get a result which is a distribution of required air flow rates.

In figure 1 the results of two cases concerning room which volume is 55 m^3 are shown. In the first case the floor (22 m^2) is covered with parquet (formaldehyde emission) and the second case with PVC-carpet (phenol emission). Other formaldehyde emitting materials are furniture (5 m^2 painted particle board) and textiles (5 m^2). Wall (55 m^2) material is painted concrete (radon emission). In the first case there is 95 % probability that 0.80 1/h air exhange rate will guarantee the good indoor air quality.

According to the calculations, the minimum air exchange rates for hole apartment should be 0.1-0.5 1/h to prevent too high contaminant concentrations.

Table 1. Concentration limits for contaminants from materials /4/,/5/.

Contaminant	Concentration limit Satisfactory air quality	Concentration limit Good air quality
Formaldehyde, $\mu g/m^3$	150	60
Phenol, $\mu g/m^3$	1900	400
Radon, Bq/m^3	200	100

Table 2. Emissions of some building materials /1/,/2/,/3/.

Contaminant Material	Emission Mean	Emission Variation
Formaldehyde	($\mu g/m^2$ h)	
Particle board	200	100-300
Painted particle board	6	0-15
Parquet	30	15-100
Textiles	15	0-65
Radon	(Bq/m^2 h)	
Concrete	27	15-30
Painted concrete	7	3-14
Phenol	($\mu g/m^2$ h)	
PVC-carpet	30	30-70

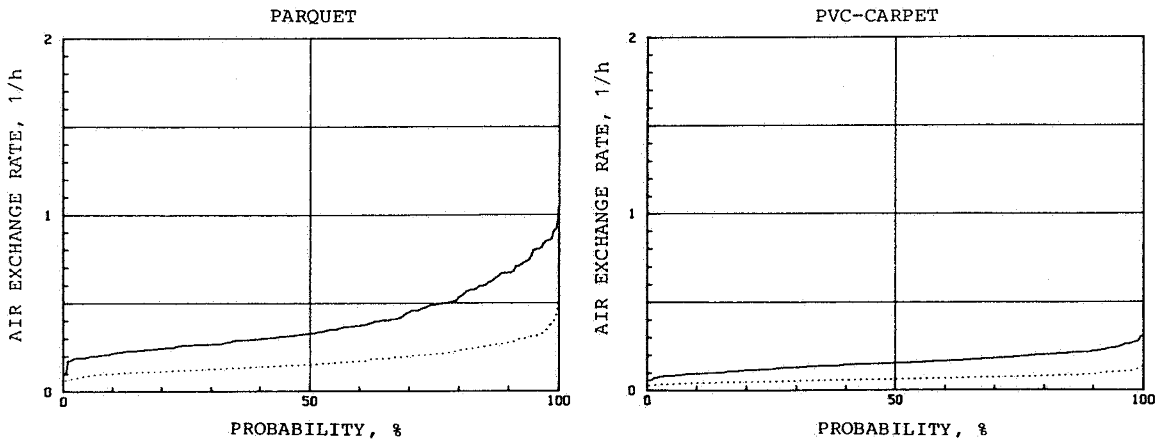

Figure 1. Distribution of required air exchange rates with two concentration limits, ____ = good, ... = satisfactory indoor air quality /5/.

4 SUMMARY

Summary of calculated air flow rates is presented in table 3.

According to the dynamic calculations of whole apartment using time-dependant occupant behaviour, the suitable air exchange rate range is about 0.4-2.0 1/h. The estimated mean air exchange rate of the day (24 h) was about 0.75 1/h. Using the air flows recommended in Finnish Building Code we will get the mean (constant) air exchange rate that is about 1.0 1/h. So the demand controlled ventilation improves the indoor air quality by decreasing the mean air exchange and energy consumption.

Table 3. Calculated air flow rates for residences /5/.

Mean air exchange rates for apartment		
- material emission loads	0.1-0.5 1/h	
- humidity loads	0.1-0.4 1/h	
- heat load (in summer)	1.0-3.0 1/h	
Air flow rates for different loads		
Sleeping rooms		
- human based odours, at night	4 dm^3/s,	person
daytime	8 dm^3/s,	person
Living-rooms		
- human based odours, normally	4-8 dm^3/s,	person
visitors	8 dm^3/s,	person
Kitchen		
- humidity loads, during use	15-40 dm^3/s	
Bathroom		
- humidity loads, during shower	50-100 dm^3/s	
bath	20-30 dm^3/s	
washed clothes drying	10-20 dm^3/s	
Sauna		
- humidity loads, during use	4 dm^3/s,	person
	(≈5-10 1/h)	
Toilet		
- removal of odours in 10 minutes	20 dm^3/s	
Wardrobe		
- material emission loads	0.5-1.5 1/h	
Smoking		
- odours of smoking	20-40 dm^3/s,	smoker

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