AIR QUALITY AND VENTILATION EFFICIENCY IN RESIDENTIAL AND OFFICE BUILDINGS

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Abstract

The paper presents the results from field measurements concerning the air-exchange efficiency in various buildings. Measurements were carried out with a tracer gas technique and a decay method in 15 office and residential buildings with different air distribution systems. The average air-exchange efficiency varied between 36 % and 57 % in office buildings and between 34 % and 50 % in dwellings. A short circuiting of air between supply and exhaust ducts decreased most often the average air-exchange efficiency. The nominal time constant varied between 0.2 h and 3.5 h in the tests and differed a lot from design values. Extensive measurements were made in a test room under laboratory conditions in order to find out the performance of various air distribution systems and the relation between indices used to describe the ventilation.

Introduction

The performance of a ventilation system has a great influence in the quality of indoor air and economy of ventilation. The performance of ventilation can be increased by avoiding short circuiting of fresh air between supply and exhaust ducts. The aim of this study was to obtain knowledge of the air-exchange efficiency of various ventilation systems and to clear up aspects which affect to the performance of different ventilation systems.

Experimental setup

Measurements were carried out with decay method using Freon 12 (dichlorodifluoromethane) as a tracer gas in 9 office and 16 residential buildings. The internal doors were normally open during the measurements. The homogenious starting concentration was achieved by using mixing fans during the tracer gas injection. In dwellings the greatest interest was in air-exchange efficiency, the mixing between different spaces, the differences between local mean ages of air in different locations and the impact of the closing the door of a room. In offices the main interest was in measuring the air-exchange efficiency with various ventilation patterns.

The laboratory measurements were accomplished in a test room of 53 m^3. Carbondioxide (CO_2) was used simultaniously with Freon 12 to simulate a pollutant source. A simulator for human source was used as a contaminant source. The simulator was designed to create a similar convection flow pattern as a human being. Measurements were done with both mixing and displacement ventilation systems with three nominal time constants (2,0 h, 0,9 h, 0,45 h). Temperature differences between supply and room air varied between -3 K and +3 K. The location of the pollutant simulator varied also. No heat sources were used inside the room except the normal lighting (240 W).

Results

The average air-exchange efficiency ϵ_a was measured from the exhaust duct

$$\epsilon_a = \tau_n / 2\langle\tau\rangle \qquad (1)$$

where ϵ_a = average air-exchange efficiency
τ_n = nominal time constant of air
$\langle\tau\rangle$ = the mean age of the air in the room

A constant source method was used in laboratory measurements to determine ventilation effectiveness. The average ventilation effectiveness can be calculated from the step up curve measured from the exhaust duct (3), but more reliable method is to compare concentrations in various locations during steady state conditions.

$$\langle\epsilon\rangle = \frac{C_e(\infty)-C_s}{\langle C(\infty)\rangle - C_s} \qquad (3)$$

where $\langle\epsilon\rangle$ = average ventilation effectiveness
$C_e(\infty)$ = equilibrium consentration in exhaust duct
$\langle C(\infty)\rangle$ = average equilibrium concentration in the room
C_s = constant concentration in supply air

In the laboratory tests the measured average ventilation effectiveness varied between 0,8 and 1,3 with mixing flow pattern and between 1,1 and 1,9 with displacement flow. The influence of the temperature difference between supply and room air and nominal time constant was less than 15%. The location of the human simulator affected most to the ventilation effectiveness. When the simulator was placed close to the exhaust duct the values were 20 to 40 % higher than in situation where the simulator was on the opposite side of the room. This was due the short circuiting of contaminants from the simulator to the exhaust duct.

The measured air-exchange efficiencies varied between 16 % and 56 % with mixing flow pattern and between 46 % and 72 % with displacement pattern. When the temperature difference exceeded +2 K with mixing flow pattern the air-exchange efficiency decreased significantly. No clear relation between the average air-exchange efficiency and the average ventilation effectiveness was found. The measured efficiencies from the laboratory tests are shown in figures 1a-1e (1).

In residential buildings the measured air-exchange efficiencies varied between 34 % and 50 %. The low efficiencies are due to the short circuiting between the cracks of the building envelope and extract ducts. In most cases fresh air flew directly to the WC extract register. Differences between local mean ages were normally relatively small which indicates powerful mixing of air between the rooms.

The impact of the closing the door of the room was also studied. On the average the mean age of the air when the door was closed was with natural ventilation system twice the mean age of the air when the door was open. With mechanical exhaust system the mean age of the air was even ten times higher when the door was closed. It seems that when using mechanical extract the mean age of the air in the room increases due to closing of the door more than when using natural ventilation. This is because of the different tightnesses of the buildings. With balanced ventilation systems the mean age of the air can either increase or decrease dependent on the situation (2).

The typical aspects of the airflows in residential buildings are:
- A short circuiting of air between outside door and WC extract duct
- A short circuiting of air between kitchen window cracks and kitchen extract duct
- The differences in local mean ages of the air are small if the internal doors are opened
- If the door of the room is closed the average locan mean age inside the room increases
- In a single room the differences of local mean ages are very small

In office buildings the measured air-exchange efficiencies varied between 36 % and 57 %. The efficiencies exceeding 50 % can be explained by the high velocities used for air supply and by good placement of supply and exhaust devices. Short circuiting of air between supply and exhaust ducts decreased the efficiency in most cases. The differences in local mean ages were slightly bigger in offices than in dwellings (1). The results from the measurements are shown in figures 1f-1m (1).

Conclusions

There is no clear relation between average air-exchange efficiency and average ventilation effectiveness. Therefore both indeces has to be measured in order to determine the performance of air distribution system.

The highest air-exchange efficiencies are reached when the supply and exhaust devises are located on the same wall of the room. Short circuiting can then be avoided providing that the velocity of the air in the supply jet is high enough.

Mixing of the air in offices is not always complete due to the large volumes of offices and poorly located supply and exhaust devices.

The powerful mixing in residential buildings is due to the air currents created by non-isothermal surfaces and temperature differences between rooms.

The nominal time constants differ often a lot from design values.

A summary of the air-exhange efficiency measurements is shown in table 2.

Table 2. Summary of the air-exchange efficiency measurements (1).

Type of building or room	Floorarea m^2	Number of measurements	Ventilation or air distribution system	Nominal time constant τ_n (h)	Nominal air exhange rate 1/h	Air exhange efficiency ϵ_a
Detached and semidetached houses	85 - 170	9	Natural	1.7 - 10	0.1 - 0.6	0.34 - 0.51
	210 - 300	2	Mechanical exhaust	2.0 - 3.5	0.14 - 0.50	0.38 - 0.51
	190	1	Balanced ventilation	2.2	0.31	0.44
High rise residential	43	1	Natural	3.0	0.33	0.40
	50 - 70	3	Mechanical exhaust	0.9 - 3.0	0.33 - 1.11	0.4 - 0.45
Landscape office	400 - 1500	2	Ceiling diffusers	0.3	3.3	0.50
	450	1	Window induction units	0.5	2.0	0.41
	90	1	Ceiling registers + exhaust air windows	0.3	3.33	0.50
Office	12	1	Wall registers	0.6	1.67	0.55
	50	1	Window induction units	0.6	1.67	0.52
	8 - 30	13	Mechanical exhaust with supply to hall	0.14 - 1.7	0.59 - 2.5	0.36 - 0.50
Filestorage	10	1	Ceiling diffusers	0.27	3.7	0.58
Conference room	15	1	Ceiling diffusers	0.21	4.76	0.57
Class room	65	2	Wall registers	0.37 - 0.46	2.2 - 2.7	0.48 - 0.55

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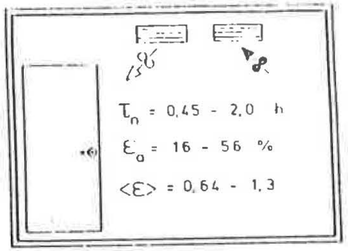
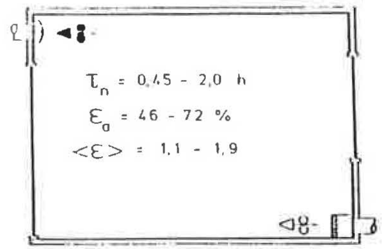
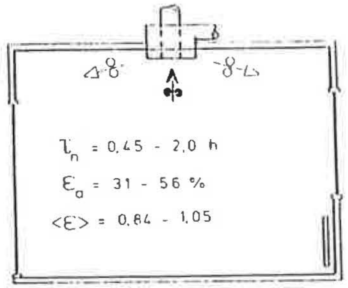


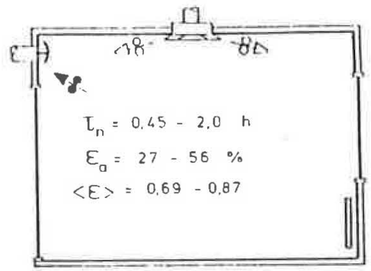
1a. Laboratory, wall registers.



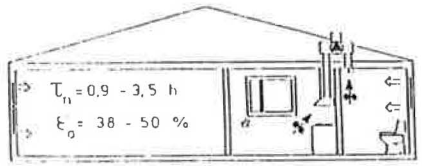
1b. Laboratory, displacement ventilation system.



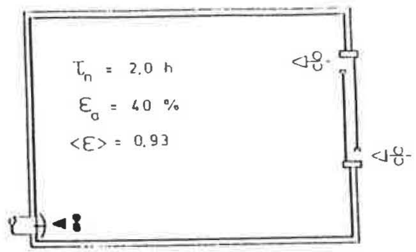
1c. Laboratory, combined sypply and exhaust.



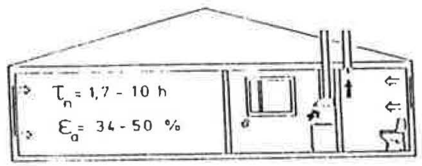
1d. Laboratory, ceiling diffuser.



1f. Residential building, mechanical exhaust.

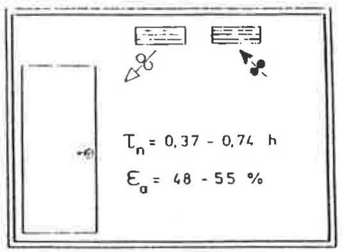


1e. Laboratory, supply trough window.

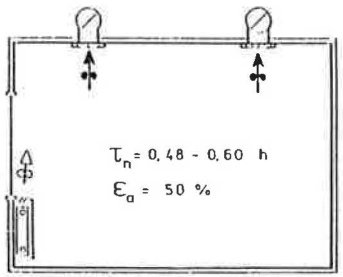


1g. Residential building, natural ventilation.

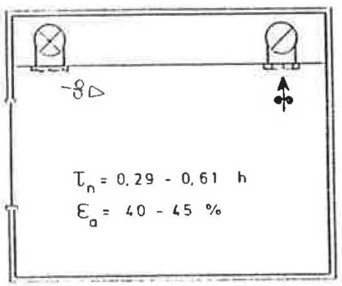
Figures 1a-1f. Results of measurements with various ventilation patterns.



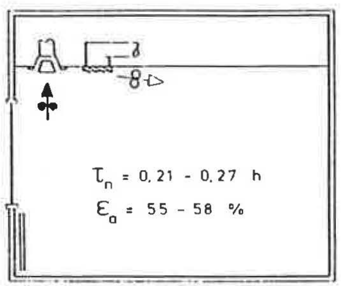
1h. Office, wall registers.



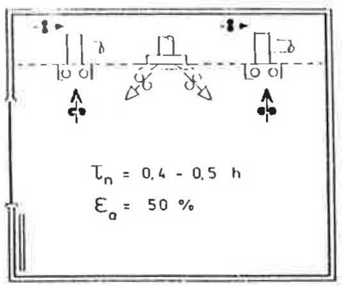
1i. Office, window induction units.



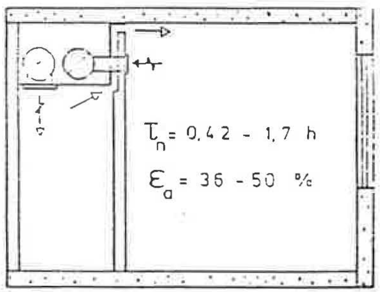
1j. Office, ceiling diffusers.



1k. Office, ceiling diffusers.



1l. Office, ceiling diffusers.



1m. Office, supply to hall.

Figures 1g-1m. Results of measurements with various ventilation patterns.

EXPERIMENTAL COMPARISON OF INDOOR CLIMATE USING VARIOUS AIR DISTRIBUTION METHODS

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Abstract

Several air distributon methods were analyzed on an experimental basis at Fläkt's Indoor Climate Center in Stockholm for the purpose of studying thermal comfort as well as air quality. The tests were conducted in a typical office module (15 m^2) during three cooling load situations: summer (45 W/m^2), spring/autumn (25 W/m^2) and winter (4 W/m^2). Climate data from the Stockholm area were used in all three cases. Test results were reported for jet-controlled air distribution with slot air diffusers, and for thermally controlled air distribution with wall-mounted as well as floor-mounted air supply devices.

Introduction

In the most common air distribution principle used to date for commercial and institutional ventilation, the air flow in the room is controlled by air jets from the supply air device. This method is designated jet-controlled air distribution. The air jets entrain ambient air, creating a steady circulating air stream with high degree of mixing air flow. This type of air flow is characterized by small pollution and temperature gradients in the room.

During the past few years, notably in the Nordic countries, a great deal of attention has been paid to an air distribution principle in which the air flow is controlled by thermal forces from heat sources in the room. The principle has therefore been designated thermally controlled air distribution. In this type of air distribution, undertempered air is supplied at low velocity and at floor level. The air is conveyed upwards to the ceiling by natural convection currents emanating from heat sources. At the ceiling, the air is exhausted. The resulting vertical temperature stratification provides a relatively stable displacement air flow in the lower part of the room, while the natural convection currents generate a mixing air flow in the upper part of the room. The relationship between the total strength of the heat source and the magnitude of the supply air flow will determine how far the mixing will penetrate down in the room and, consequently, the degree of mixing in the occupied zone. Displacement air flow is characterized by small spreading of heat and contaminants.

Thermal comfort conditions are stated in terms of temperature level, temperature gradient and air velocity, while air quality here is expressed in terms of air age and air pollution concentration. The air age indicates the rate at which room air is replaced with supply air, and thus can be considered as an indirekt measure of how quickly pollutants are removed from the room, provided that the contaminants are produced uniformly throughout the room from a homogenous source of pollution.