In figure 2 the distribution of uncertainties in the total ventilation flows in apartments is illustrated . It can be seen that no ventilation flows are estimated better than within 11.1% (technique uncertainty) and that approximately 50% of the cases have an uncertainty in the estimate that is less than 16%.

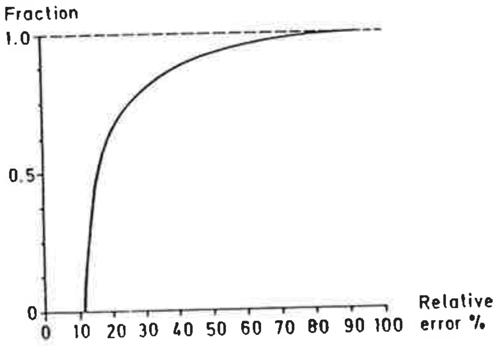

Fig. 2. Distribution function of relative uncertainties in the estimated ventilation flows in apartments. The diagram displays the fraction of cases, which has a relative standard deviation less than a given value.

CONCLUSIONS

This large-scale study of ventilation rate, required a simplified approach of experimental design, stringent laboratory routines and an uniform evaluation process. Experimental layout could not be optimised for every dwelling. In spite of this, the error analysis shows a satisfactory distribution of uncertainties. Only 10% of the cases show an uncertainty larger than 40% in the estimated ventilation flow rate, while 50% of the cases show an uncertainty less than 16%. Example of factors which helped to perform the study in a uniform way are: a pilot pre-study, a training course for the staff working in the field, and the fact that most dwelling plans were available in advance. There were a limited number of drop outs, due to contamination of samplers during use and transport. In a few cases (less than 10), the samplers were not returned to the laboratory.

The laboratory staff has followed accurate and disciplined laboratory and data filing routines. The importance of this can not be emphasised too much in such a large study.

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THE HELSINKI OFFICE ENVIRONMENT STUDY: AIR CHANGE IN MECHANICALLY VENTILATED BUILDINGS

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ABSTRACT

In this study the ventilation of office rooms of 1782 persons were measured in 33 randomly selected office buildings in Helsinki metropolitan area. Ventilation system characteristics in these buildings were also studied.

The average exhaust air flow rate was 1.2 l/s,m^2 or 17.2 l/s,occupant. The variance of air flows was found to be very high among the buildings, and among the rooms in a building. This indicates poorly balanced air flows in office buildings. Therefore, even though ventilation rates on the average comply with the Finnish building code (1), many people are exposed to either too low or too high ventilation rates.

Most office buildings in the Helsinki metropolitan have a ducted supply and exhaust system with hot water radiator heating. Air recirculation is used in about half of the buildings with mechanical supply and exhaust systems.

INTRODUCTION

This study is a part of the Helsinki Office Environment Study with a general objective to study the building related determinants of health and well-being of the office workers.

The magnitude of air change affects both the concentrations of chemical and biological indoor air pollutants and the components of thermal climate, such as air temperature and velocity, thus it is an important factor in the health and well being of the office workers (2).

The type and performance of a heating, ventilating and air conditioning (HVAC) system affect the indoor air quality of the building or ventilation zone. The symptoms and perceptions concerning health and comfort of an occupant have been attributed to the characteristics of the HVAC system (3). There is evidence that buildings with mechanical supply and exhaust, especially in connection with water-based humidification or air conditioning might present a greater risk of the symptoms connected to the sick building syndrome than naturally ventilated buildings (4)(5).

The aim of this study was to assess the magnitude and balance of mechanical air change in office buildings of Helsinki metropolitan. Also the use of air recirculation, humidification, air conditioning, the type of heating and filtering systems as well as the size and age of the buildings were studied.

METHODS

Buildings

The 34 office buildings included in this study were randomly selected from a total of 894 eligible office buildings in Helsinki Metropolitan Area Building Registry. Information on the buildings and their air handling systems was gathered by interviewing maintenance personnel and by visiting the mechanical rooms, where the air handling units were investigated. Also information available in the Building Registry was used.

Measurements

One of the buildings included in the study had a suspended ceiling and no ventilation measurements could be made. In the remaining 33 buildings, the ventilation of 1782 persons' office rooms was measured.

The ventilation in the rooms was estimated by measuring the air flow through the exhaust air outlet(s) in the room. In this paper, the term exhaust air is used to describe the air flow through the outlet(s) in each room, regardless of whether it is recirculated or exhausted from the building. This method gives a good estimate of the total air change in a room, since all mechanically ventilated buildings in Finland are designed to have negative pressure. As the number of rooms to be measured was very large, the best feasible method for measurements was to use an anemometer tube connected to a hot wire anemometer. An alternative method was applied in rooms of two buildings with an exhaust system where the exhaust air is channeled through numerous small outlets in ceiling light fixtures. In this case the design air flows were checked from the ducts by a 5-point pitot-tube method and, when matching, design values were used throughout the building.

At the same time with the ventilation measurements, the floor area of the rooms was measured. This information, and the number of persons working in the same room was used to calculate the air flow rates per floor area and per person.

RESULTS

Building characteristics

The building characteristics of the 34 mechanically ventilated buildings included in the study are displayed in Table 1. The buildings that use air recirculation are somewhat smaller and have fewer employees than other buildings with mechanical ventilation. The two buildings that have only mechanical exhaust system are larger, and older, than other mechanically ventilated buildings.

The HVAC systems used in buildings with mechanical supply and exhaust are characterized in Table 2. The buildings with air recirculation have generally more complex systems than other buildings with mechanical supply and exhaust. Air heating, induction units, mechanical cooling and fine or electrostatic filtering systems are more common in buildings that use air recirculation than in other buildings with mechanical supply and exhaust. However, heat recovery systems, other than air recirculation, are more common in buildings without air recirculation. Dual duct air distribution system was used in only one building.

Table 1. The characteristics of the buildings in the study.

Type of ventilation system	Mechanical supply and exhaust		
	Air recirculation	No air recirculation	Mechanical exhaust
N=	16	16	2
Average year of construction	1966	1954	1929
range	1871-1986	1883-1988	1905-1952
Average total volume (m^3)	25410	36614	46703
range	2982-60059	5820-92603	39468-53938
Average total floor area (m^2)	7300	10705	14543
range	901-17849	1683-28354	13401-15684
Average number of employees	120	255	366
range	16-338	15-598	334-398

Exhaust air flows

The average exhaust air flow was 1.2 l/s,m^2 or 17.2 l/s,occ , but the variance even among the rooms in a building was very large, as displayed in Figure 1. From the whole study population of 1782 persons, 1054 (59 %) worked in office rooms with exhaust air flow at or above the Finnish guideline value of 1 l/s,m^2. 1272 persons (71 %) worked in rooms with air flow at or above the guideline value of 10 l/s,occ.

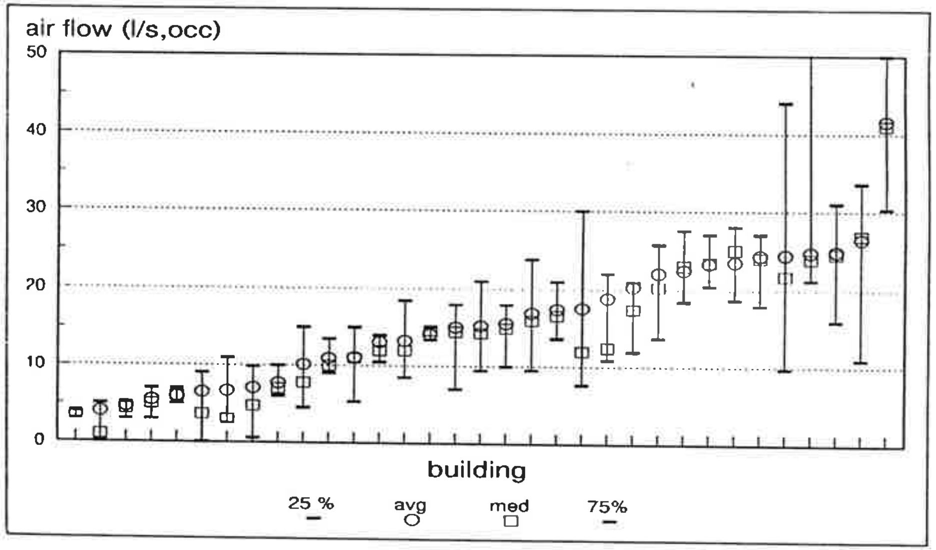

Figure 1. Distribution of ventilation rates in the offices of each building.

Table 2. The characteristics of the air handling systems of buildings with a mechanical supply and exhaust system.

		Air recirculation N	Air recirculation %	No air recirculation N	No air recirculation %
Heating system	h.w. radiators	12	75	16	100
	air heating	2	13	0	0
	induction units	2	13	0	0
Thermostatic radiator valves	whole building	8	50	8	50
	part of the building	2	13	2	13
	no	6	38	6	38
Air distribution system	ducted	12	75	14	88
	dual duct	1	6	0	0
	induction units	3	19	2	13
Heat recovery	no	12	75	7	44
	run-around coils	3	19	4	25
	regenerative	1	6	5	31
	heat wheels				
Humidification	not installed	10	63	11	69
	installed, not in use	3	19	3	19
	evaporating	1	6	2	13
	other	2	13	0	0
Mechanical cooling	no	9	56	11	69
	yes	7	44	5	31
Filter	coarse filter	2	13	6	38
	fine filter	8	50	10	63
	coarse + fine	4	25	0	0
	electrostatic	2	13	0	0

An important finding of the study was the large variation air flows in most buildings. While a majority of the buildings had an average exhaust air flow between 0.5 l/s,m² and 1.5 l/s,m², the standard deviation was more than 50 % of the average value in ten of the 33 measured buildings, which indicates very low or high air flows in some offices. When looking at the air flows per occupant, there were 17 buildings where the standard deviation was more than 50 % of the average value, which ranged from 6.0 to 27.0 l/s,occ for 85 % of the buildings.

The exhaust air flows of offices were compared in accordance with the ventilation type used in buildings. In this comparison, the buildings were classified in the same way as in the other parts of the Helsinki Office Environment Study (4). In the classification, the use of air conditioning, humidification, and air recirculation, were taken into consideration.

The highest exhaust air flows were encountered in a building which had air recirculation, air-conditioning and evaporative humidification, see Table 3. The lowest exhaust air flows were measured in buildings with mechanical exhaust only. The exhaust air flows measured were higher in the buildings with air recirculation than in similar buildings without air recirculation.

Table 3. The distribution of exhaust air flow rates of offices by ventilation system

Ventilation type	N persons	lower quartile per occupant / area l/s,occ / l/s,m²	median per occupant / area l/s,occ / l/s,m²	upper quartile per occupant / area l/s,occ / l/s,m²
Mechanical exhaust(IB)	133	0 / 0	2 / 0.14	7 / 0.38
Simple Mechanical				
no air recirc.(IIA)	169	6 / 0.35	11 / 0.75	15 / 1.11
air recirc.(IIB)	749	11 / 0.89	18 / 1.32	24 / 1.83
AC, no humidification				
no air recirc.(IIIA)	230	12 / 1.00	17 / 1.33	21 / 1.62
air recirc.(IIIB)	175	6 / 0.40	19 / 0.95	41 / 2.40
AC, steam humidification				
air recirc.(IVB)	73	11 / 0.96	14 / 1.17	22 / 1.33
AC, evaporative humidification				
no air recirc.(VA)	201	16 / 1.31	23 / 1.67	28 / 2.22
air recirc.(VB)	52	48 / 3.18	53 / 3.19	54 / 3.82

DISCUSSION

The results represent the prevailing situation of air change in office buildings in Helsinki metropolitan area, because the buildings were selected randomly from all the buildings of the designated area. The results could even be used as an estimate of the ventilation in all Finnish office buildings, since the office buildings in the metropolitan area are built to comply the same building code as all office buildings in Finland.

Mechanical supply and exhaust system is used in most office buildings and mechanical exhaust system alone is used in only a small fraction of the buildings. As some indoor air problems have been observed in buildings using a mechanical supply and exhaust system, more research should be done to find explanations behind the reasons to these problems.

While on the average small ventilation rates do not appear to be a problem in these buildings, the results indicate that the average air exchange rate in a building reflects poorly the actual ventilation rates in offices. Therefore, a room by room assessment of ventilation rates is strongly recommended, when studying the effects of ventilation. Poorly balanced ventilation will cause excessive air flows in some offices, which is not economical and also a likely cause of draft. Meanwhile people in offices with too low ventilation rates will require more ventilation, which is often accomplished by opening windows, which increases the energy consumption.

As the results of this study are examined, one must take into consideration that only the mechanical exhaust air flows were measured. Because there are leaks through open doors and openings in fenestration, some actual exchange rates may be different, especially where the measured air flows were very low or no air outlet was in the room (in which case the exhaust air flow was recorded as zero). Also, the measured air flow does not take into account the ventilation effectiveness in the room, which may affect the indoor air quality.

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ENERGY CONSUMPTION AND COST AT HIGHER VENTILATION RATES IN AN OFFICE BUILDING IN MONTRÉAL

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ABSTRACT

This paper presents the impact of higher ventilation rates on the energy consumption and cost of a large office building in Montréal, which was evaluated by computer simulation. Four configurations of the VAV system were analyzed: (i) with heat recovery from the exhaust air and the condensers, (ii) with heat recovery only from the exhaust air, (iii) with heat recovery only from the condensers, and (iv) without heat recovery. The amount of outdoor air was either kept constant or was controlled by the mixing temperature. The ventilation rate was assumed to be increased from the actual value to that recommended by the ASHRAE Standard 62-1989 or even higher. On average, the energy consumption increases at a rate of about 2.3% and the cost by 2.7% for each increment of 2.5 L/s/person of the ventilation rate, when the system uses a fixed amount of outdoor air. When the outdoor air rate is controlled by the mixing temperature and the ventilation rate is smaller than 20 L/s/person, the increase of energy consumption and cost is negligible.

INTRODUCTION

ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" specifies two alternative procedures to design and operate a ventilation system for achieving acceptable indoor air quality: (i) Ventilation Rate Procedure, and (ii) Air Quality Procedure. The first procedure prescribes the minimum outdoor air ventilation rates to be delivered by HVAC systems in commercial and residential facilities. The minimum ventilation rate for office buildings was increased from 2.5 L/s/person, as required by the previous standard, to 10 L/s/person. However, soon after its publication, ASHRAE Standard 62-1989 was contested regarding the global approach as well as the recommended values for ventilation rates. For instance, some researchers recommended higher values for the ventilation rates in office buildings of 20 or even 50 L/s/person (1).

Although most building managers are very sensitive to factors such as market conditions, public image, quality of indoor air, and tenants satisfaction, they also look at the increase in energy cost. Moreover, they ask questions about the proofs of beneficial effects of higher ventilation rates on occupants health and productivity. Some answers to their questions regarding the energy cost can be retrieved in previous publications by Eto and Meyer (2), Eto (3), Pacific Northwest Laboratory (4), and Zmeureanu and Stylianou (5), which indicated based on computer simulation that the increase of ventilation rate from 2.5 L/s/person to 10 L/s/person is expected to increase the total energy cost by 1.8% up to 12.4%, depending on factors such as: size of building, type of HVAC system, and source of energy. The evaluation of physiological and psychological effects of higher ventilation rates on people is one important factor to be investigated. However, because of the limited information regarding this