VENTILATION AND COOLING

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(Title)

Measured Air Exchange Rates at Workplaces Having Different Types of Ventilation

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1 SYNOPSIS

The aim of the study was to investigate the operation of different types of ventilation in places constructed underground and ground level; the effect of ventilation on indoor radon levels was also examined. Air exchange rates and radon concentrations were measured in underground (n=73) and ground level (n=64) workplaces. Air exchange rates, designed exhaust ventilation flows, ventilation rates per person and area were significantly higher in underground places than places constructed on the ground level. Mean of air exchange rate was significantly higher in places having only mechanical exhaust ventilation in the underground places than in the ground level places and indoor radon concentration was slightly higher in ground level, whereas in the places having mechanical exhaust and supply ventilation the mean radon concentration was almost twice higher in underground places. In general, all measures of ventilation were higher in underground places, except the ventilation rate per area against soil. This explains the radon concentration situation. The highest mean radon concentrations were found when air exchange rates were below 3 h^{-1}. Ventilation was mainly effective altough, only 30 % of originally designed ventilation flows were achieved.

2 INTRODUCTION

Finnish guidelines for ventilation are currently under reform. Old guide value for air exchange rate is 0.5 h^{-1} in dwellings /1/. The new proposal includes a range from 0.4 to 0.8 h^{-1} (table 1). These new values are mainly for dwellings, but they can also be used for offices, schools and day-care centers /2/. Good ventilation is a prerequisite for good indoor climate. When ventilation functions well and is in balance, it also prevents radon entry. In the study of Denman /3/, the improvement of the ventilation and sealing the constructions reduced the radon level up to 95 % in British hospital premises. In Belgian schools, effective ventilation together with pressurization and sealing the constructions decreased radon levels significantly (14-98 %) /4/. According to Nazaroff et al. /5/, the indoor radon concentration is expected to increase with ventilation rate if the entry mode is active and the ventilation is unbalanced. Similar findings were discovered by our group /6/ in Finnish homes, where the increase became significant when the pressure difference exceeded 5 Pa. Kim et al. /7/ have studied radon levels in 74 subway stations. They found the radon levels to vary within a wide range up to 677 Bq m^{-3} and they suggested that increasing ventilation may increase negative pressure in subway stations with mechanical ventilation. In any case, the relationship between indoor radon level and ventilation is a complex that varies considerably with the particular circumstances of a house /5/.

Table 1. The guide values for dwellings, office buildings, schools, and factories.

	Air exchange rate, h^{-1}	Airflow $l.s^{-1}$, person	$l.s^{-1}$, m^2
Dwellings(2	>0.4->0.8	5-8	0.5-1
Office buildings(2			
Offices	>0.4->0.8	8-16	1-2
Training rooms		6-12	3-6
Schools, classrooms(21	>0.4->0.8	6-12	3-6
Factories(1			
Light or middle light work		10	1.5
Garages		4	7

3 MATERIALS AND METHODS

3.1 Workplaces

Totally 137 workrooms were measured in 32 different workplaces. Radon concntrations were measured continuously in 115 workrooms and air exchange rates in 97 workrooms. The places included offices, servicing rooms, schools, and telecommunication centers. The total number of employees in these rooms was almost 400. The room volumes varied from small office rooms of 20 m^3 to large research laboratories of 17 200 m^3. Slightly more than half of workplaces (n=73) were located underground. This also includes some places which were only partly underground. For comparison the study also included workrooms in the ground level, 47 % of the places. The most common type of ventilation was mechanical exhaust and supply (n=94).

3.2 Methods

Air exchange rates (h^{-1}) were measured during working hours by the tracer gas technique and the dilution method using freon-12, or later during the study, difluorodichloromethane as the tracer gas and an infrared spectrophotometer (Miran 1A) as the analyzer. Calculated air exchange rates (h^{-1}) were calculated by dividing the designed exhaust air rate ($m^3\ h^{-1}$) by volume of the workroom. Ventilation flow rates ($m^3\ h^{-1}$) were calculated by multiplying the measured air exchange rate (h^{-1}) by volume of the workroom. Air flows were calculated by multiplying the measured air exchange rate by volume of the workroom and divided by the number of the persons ($l.s^{-1}$, p) or by the area of the workroom ($l.s^{-1}m^2$). Radon levels (Bq m^{-3}) were analyzed continuously using the Lucas cell method /8/ with a Pylon AB-5 assembly, which includes a detector, a photomultiplier and a system of data collection based on a microprocessor. The output data of the Pylon detector were processed with SP-55 software run on a PC. The flow rate of the pump was 0.4 l min^{-1}. The interval of continuous measurements was 30 minutes (averaged to one hour). Concentrations were measured during periods ranging from two hours to two weeks. Data concerning volumes, depth, working hours, number of employees, and types and operation times of ventilation were collected by questionnairies.

4 RESULTS

Measured air exchange rates distributed log-normally from 0.1 to 13.6 h^{-1} and calculated air exchange rates varied from 0.1 to 31.0 h^{-1} (figure 1). The total mean of air exchange rates in places having mechanical exhaust and combined mechanical exhaust and supply ventilation were 3.1 and 4.3 h^{-1}, respectively. The difference was not statistically significant. Air exchange rates in places having natural ventilation or mere mechanical supply ventilation were 0.1 and 0.4 h^{-1}, and 0.3 and 1.2 h^{-1}, respectively. The highest air exchange rate (13.6 h^{-1}) was measured in a workroom when the door was open to the adjacent corridor. Air exchange rate was 5.8 h^{-1} when door was closed. The calculated ventilation flow rates (calculated of designed ventilation flow) varied from 7 to 55 200 m^3h^{-1}. Calculated air flows per person were high ranging from 2 to 1179 $l.s^{-1}$,p. About 75 % of places exceeded the recommended air flows (4-16 $l.s^{-1}$). Air flows per area varied from 0.05 to 10.7 $l.s^{-1}$ which were mainly within the recommended levels (table 2). The means of measured air exchange rate, designed exhaust ventilation flow, and ventilation rates per person and area were signifigantly higher in underground places than in the places on the ground level. Mean indoor radon concentration was 42 % lower (325 Bq m^{-3}) in 90 workrooms where air exchange rate was more than the recommeded value of 0.4 h^{-1}. Workrooms having air exchange rate below 0.4 h^{-1} mean radon concentration was 559 Bq m^{-3} (n=6). Mean radon concentrations had no statistical difference between the underground and ground level places. A decreasing air exchange rate and ventilation rates per area against soil seemed to be associated with higher and more variable radon concentrations (figure 2 and 3), especially in places constructed underground or in the hillside. Ventilation rates per area against soil had no statistical difference between the depth of the buildings.

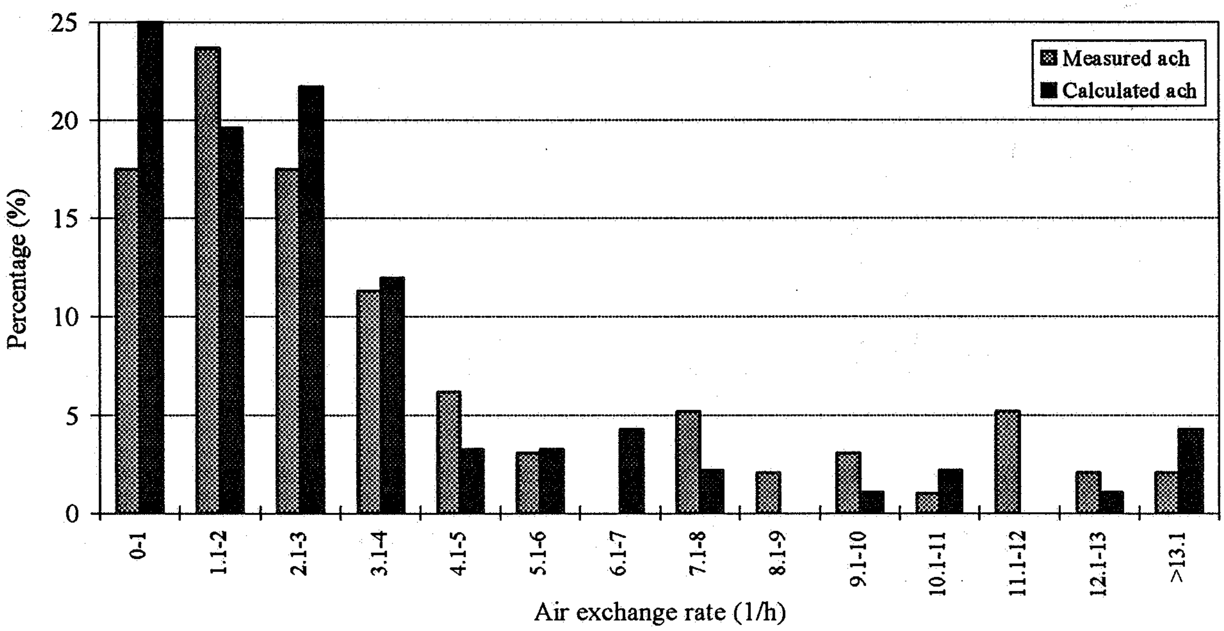

Figure 1. Distribution of the measured air exchange rates (n=97) and calculated air exchange rates (n=92).

Table 2. Measured and calculated air exchange rates (ach), ventilation flow rates, air flows per person, per area the underground (ug) and ground level (g) places and the p-values of varience analysis between underground and ground level places.

	n		Mean		Std dev		p-
	g	ug	g	ug	g	ug	values
Measured ach,(1/h)	44	53	2.9	4.7	3.1	3.7	0.0119
Calculated ach,(1/h)	46	46	2.9	4.2	4.1	5.1	0.1909
Calculated ventilation flow, (m^3/h)	41	44	279	2688	399	8692	0.0801
Designed exhaust ventilation flow, (m^3/h)	47	47	283	2054	350	3419	0.0006
Ventilation rate per area against soil	38	44	7.5	6.2	8.3	3.8	0.4310
Ventilation rate, per person (l/s,p)	39	31	33	142	56	242	0.0084
Ventilation rate, per area (l/s,m^2)	41	42	2.4	4.1	2.4	3.0	0.0038
Radon concentration (Bq/m^3)	53	62	282	329	457	509	0.6086

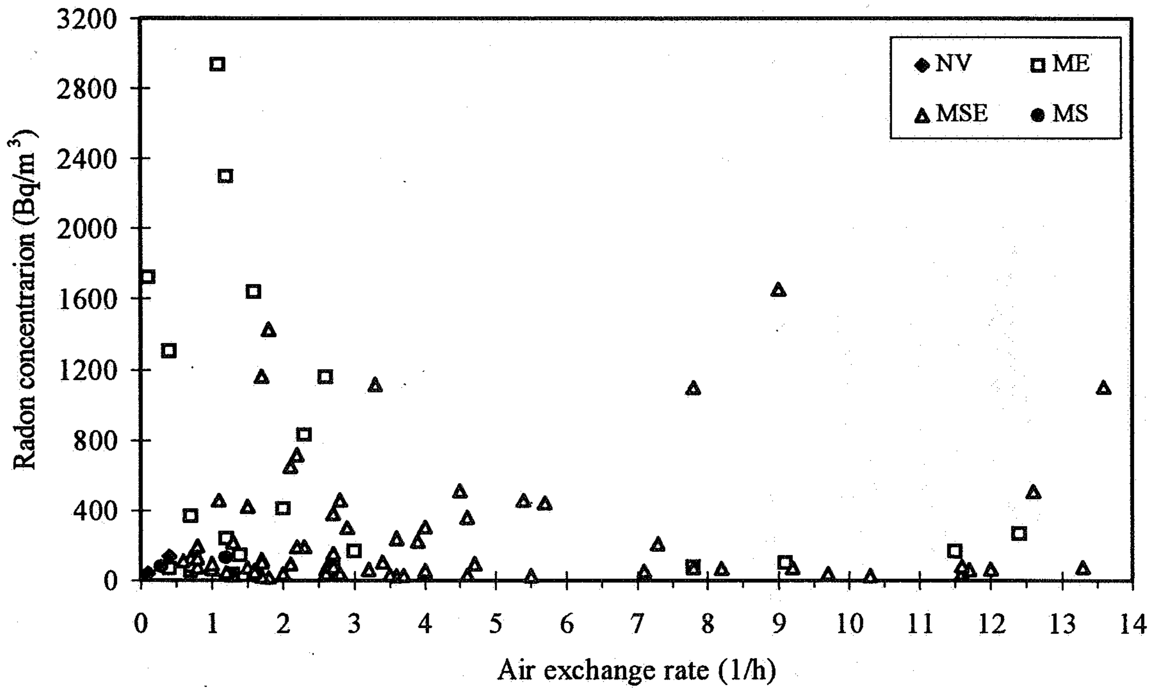

Figure 2. Radon concentrations (Bq m^{-3}) versus measured air exchange rates (h^{-1}) during working hours (n=91).

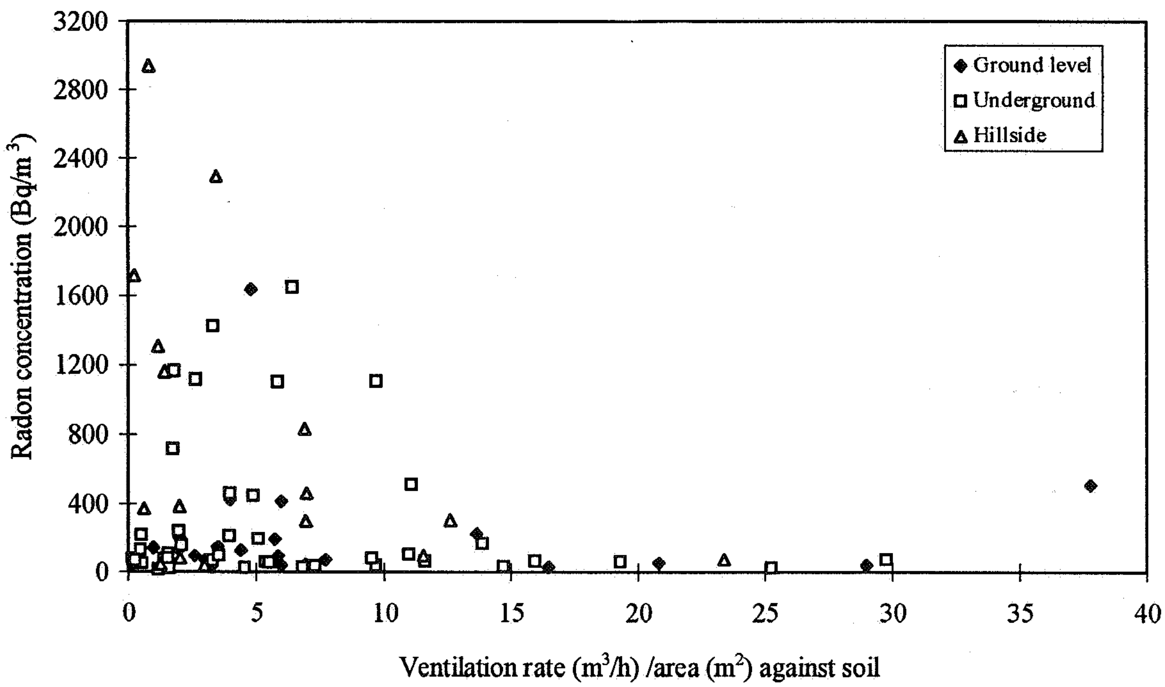

Figure 3. Radon concentretions (Bq m^{-3}) during working hours versus ventilation rate (m^3 h^{-1}) per area (m^2) against soil (n=81).

The mean air exchange rate in underground workrooms (4.7 h^{-1}) was almost twice compared to the rate in ground level (2.9 h^{-1}) workrooms. Air exchange rates were significantly different at different depths (p=0.0001), but not linearly (the linearity p=0.1523, R^2=0.015, variance analysis). The highest mean of radon concentration was measured in ground level places having mechanical exhaust ventilation. Mean air exchange rate was the lowest in these places. Air exchange rate was significantly higher in underground places having mechanical exhaust than in ground level. In places having mechanical exhaust and supply ventilation, radon concentration was significanlty higher in underground places than in ground level. The probable reason is the surrounding soil which is the main source of radon. The mean air exchange rate was at the same level in places having mechanical exhaust and supply ventilation in underground and ground level places (table 3). Ventilation was adjusted to operate during working hours with its full efficiency in 66 % of the places. During evening, nights or weekends the ventilation was not operating in 24 % of the places. Only in about 30 % of the workrooms, designed ventilation flows were achieved. Designed exhaust ventilation flows were not significantly different between the groups of underground and ground level.

Table 3. Mean of measured air exchange rates (Ach) and mean of radon concentrations (C_{Rn}) during working hours with mechanical exhaust (ME) and mechanical exhaust and supply (MSE) ventilation and the difference between them in ground level and underground workrooms.

Type of ventilation	n		Mean		Std		p-value	
	C_{Rn}	Ach	C_{Rn}	Ach	C_{Rn}	Ach	C_{Rn}	Ach
ME, ground level	15	13	644	1.4	734	0.9	0.8376	0.0070
ME, underground	9	8	572	5.7	952	5.0		
MSE, ground level	34	29	144	3.7	130	3.5	0.0345	0.2448
MSE, underground	49	43	299	4.7	408	3.5		

5 DISCUSSION

Mechanical ventilation is generally used in workplaces. Air exchange rates observed for mechanical exhaust and combined mechanical exhaust and supply ventilation were not significantly different. Measured air exchange rates varied largely during working hours. The highest air exchange rates were due to opened doors which was typical situation during workdays. Ventilation was generally in the recommended level in the underground places. More non-compliance was found in the ground level places. Ventilation rates per person were high.

Indoor radon concentrations were considerable high in some places. The highest concentrations were measured in places having only mechanical exhaust ventilation and constructed on the ground level. Some of these places were construced in the hillside, and part of their walls was against to ground. There were also places constructed in the hillside which were mainly underground and also grouped as an underground place. High radon levels were observed when the ventilation rate per area against soil was low. Effective ventilation seems to decreace indoor radon concentrations particularly in underground places and places constructed in the hillside.

Acknowledgement

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