OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden, 17-20 September, 1996

(Title) Comparison of Indoor Levels of Radon Between Workplaces and Homes Located nearby in Different Parts of Finland

(Authors) Pirjo Korhonen, Helmi Kokotti and Pentti Kalliokoski

(Affiliation) Department of Environmental Sciences, University of Kuopio, Finland

SYNOPSIS

The aim of this study was to compare the radon levels at workplaces and in homes located nearby. Homes (number of 57) and partly or fully underground workrooms (number of 55) have been studied at the four workplaces in southern Finland and one workplace in northern Finland. Radon concentrations both at workplaces and in homes seemed to be at the same level in the same district. The mean radon concentration in workrooms was 406 $Bq.m^{-3}$, and in homes concentration was 398 $Bq.m^{-3}$. At the workplaces having mere exhaust ventilation the mean radon concentration was higher (arithmetic mean of 677 $Bq.m^{-3}$, n=14), than the places having mechanical exhaust and supply ventilation (arithmetic mean of 207 $Bq.m^{-3}$, n=33). In an average the naturally ventilated workplaces (n=8) had the lowest level of indoor radon (arithmetic mean of 133 $Bq.m^{-3}$). The highest radon level, both in the workrooms (2937 $Bq.m^{-3}$) and in the homes (3080 $Bq.m^{-3}$), was found in the northern Finland. The high values of indoor radon might be partly explained by the hill-construction of buildings without sealed constructions against soil, and partly by depressurisation caused by mechanical exhaust ventilation.

INTRODUCTION

Radon is a radioactive noble gas, which is the decay product of radium. Radon enters a building mainly from soil below the building. Radon could also be exhaled from tap water or building materials. In addition, indoor radon concentration depends on meteorological factors, subgrade structures, air exchange rates and pressure conditions. Effective mechanical ventilation reduces indoor radon concentration, if the constructions of the buildings have been properly sealed and the underpressure is not increased /1, 2/. Houses having crawlspace usually have lower radon levels than slab-on-grade constructed houses. Variation in both outdoor temperature and wind induce the subterranean air-flows in the esker, which was observed to result in winter/summer radon concentration ratios of 3-30, in esker top areas, whereas in slope areas with amplified summer concentrations, the ratio is typically 0.1-0.5. Typical values in flat areas are 1.5-2. /2/. In the Chinese study at underground workplaces the radon concentrations increased from 13.6 $Bq.m^{-3}$ to 119.0 $Bq.m^{-3}$, with the underground depth of 5 meters to 35 meters, respectively /3/. In Finland the radon levels in homes have been studied by the Finnish Centre for Radiation and

Nuclear Safety (STUK). The overall radon level in flats and in single-family houses was 82 Bq.m^{-3} and 145 Bq.m^{-3}, respectively /4/. Radon levels at workplaces have been studied by STUK and the radon levels at partly or fully underground workplaces have been studied by our group. The concentrations have been found to vary a lot in different parts of Finland. The mean concentrations during working hours have been 90 Bq.m^{-3} in central Finland and 300 Bq.m^{-3} in southern Finland /5/.

MATERIAL AND METHODS

The workplaces in this study were located in southern Finland in four different districts (places A-D) and one place in northern Finland (place E). The total number of measured workplaces was 55 and number of the homes was 57 (table 1.). Most of the workrooms had mechanical supply and exhaust (n=33) and the rest had either mere mechanical exhaust (n=14) or natural ventilation (n=8) (table 1.). All the homes had natural ventilation and a ground level foundation.

Table 1. The number of workrooms with different types of ventilation, different types of foundations and number of the homes in each places.

	Workplaces							Homes
	Types of ventilation			Types of foundation				
	MSE	ME	NV	U	G	H	N	N
Place A	7	-	1	7	1	-	8	4
Place B	9	1		3	6	1	10	11
Place C	6	5	7	3	15	-	18	1
Place D	6	1	-	5	2	-	7	1
Place E	5	7	-	-	1	11	12	40
Number of places	33	14	8	18	25	12	55	57

MSE mechanical supply and exhaust
ME mechanical exhaust
NV natural ventilation
U underground workroom
G ground level workroom
H hill-constructed workroom
N number of workrooms or homes

Radon levels were analysed continuously near the workers' breathing zone by using the Lucas cell method /6/ 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 air was 0.4 l/min. The interval of continuous measurements was 30 minutes (averaged to one hour). Concentrations were measured during periods ranging from few hours to several days. The integrated long-term radon levels at workplaces and homes were determined by alpha track etch films and analysed by STUK /7/. At workplaces alpha films revealed the average radon level during one month. This integrated radon concentration also included the radon levels at nights and weekends, when the ventilation was not usually operating at full capacity. In homes alpha films revealed the average radon level during two months. The pressure differences across the wall, either separating or external, were monitored by an electronic manometer together with a datataker. The pressure differences were measured continuously averaging every 30 minute to one hour. During daytime working hours, air exchange rates were measured by the tracer gas technique and by the dilution method using nitrous oxide as the tracer gas and an infrared spectrophotometer, Miran 1A, as the analyser.

RESULTS

The continuously measured and integrated radon levels varied from 27 to 2937 Bq.m^{-3} (arithmetic mean of 352 Bq.m^{-3}, n=40) and from 20 to 405 Bq.m^{-3} (arithmetic mean of 205 Bq.m^{-3}, n=20) at the workplaces, respectively. The integrated radon levels varied from 20 to 3080 Bq.m^{-3} (arithmetic mean of 398 Bq.m^{-3}, n=57) in homes (figure 1. and table 2.). The arithmetic mean of the air exchange rates in the underground workrooms or workrooms on the ground level were 3.1 h^{-1} (n=35) and the arithmetic mean of pressure difference was -5.6 Pa (n=11) (table 2). The highest average value, 658 Bq.m^{-3}, when comparing the different types of ventilation, was found from the places having mere mechanical exhaust (table 3.). The mechanical exhaust causing underpressure (tables 2. and 3, place E) elevated the radon level. The underground location of the workroom did not seem to increase the radon concentration (fig. 2. and table 4.).

The radon concentrations in the place A were quite low (table 2.), although 7 of those places were underground (table 1.). This may be due to effective ventilation in the underground workrooms (7 h^{-1}) (table 2.). The highest radon concentration, measured both with continuous and integrated methods, existed in the workroom located ground level. This workroom had only natural ventilation (tables 3. and 4.). Also the integrated radon level in the home was at the same level than the level in ground level workroom, but higher than the levels in the underground workrooms (figure 1. and table 4.).

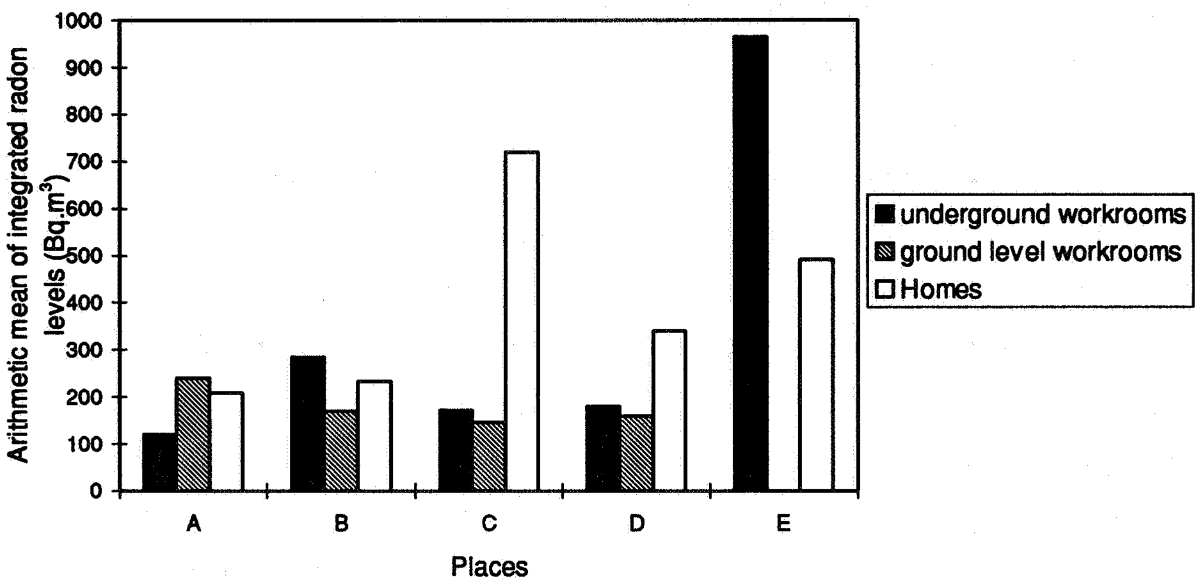

Figure1. The arithmetic means of integrated radon concentrations (Bq.m^{-3}) on the ground level and underground workrooms and homes in each places.

Table 2. The arithmetic mean, the range and the number (#) of the continuous and integrated radon concentrations (C_{Rn}, Bq.m^{-3}), air exchange rates (h^{-1}) and pressure differences (Pa) in the workrooms and integrated radon concentrations in the homes.

Places	Workplaces				Homes
	Continuous C_{Rn} (Bq.m^{-3})	Integrated C_{Rn} (Bq.m^{-3})	Air exchange rates (h^{-1})	Pressure differences (Pa)	Integrated C_{Rn} (Bq.m^{-3})
Place A	68 (27-174, 8)	120 (70-240, 5)	7.0 (0.4-12.0, 7)	-1.3 (-3.7-1.2, 4)	208 (20-400, 4)
Place B	288 (48-653, 6)	285 (160-450, 4)	2.6 (2.0-4.0, 5)	-	233 (60-460, 11)
Place C	134 (36-349, 9)	172 (20-370, 9)	1.3 (0.1-3.2, 6)	-5.1 (1)	720 (1)
Place D	306 (41-1163, 5)	243 (160-200, 2)	2.8 (1.3-4.7, 5)	0.6 (0.3-0.8, 2)	340 (1)
Place E	965 (56-2937, 12)	-	1.6 (0.4-2.7, 12)	-10.4 (-19.3--2.8, 5)	491 (20-3080, 40)(*
Average	352 (27-2937, 40)	205 (20-450, 20)	3.1 (0.1-12.0, 35)	-5.6 (-19.3-0.8, 11)	398 (20-3080, 57)

(* the measurements have been done by STUK

In the place B the integrated radon levels were at the same level both at workrooms and at homes (table 2.). The highest radon concentration was at the workroom having mere mechanical exhaust (table 3.). In this district the continuously measured radon levels were higher on the ground level rooms than underground, and integrated levels were lower (table 4.). In the place C the integrated radon concentration in the home was 720 $Bq.m^{-3}$, which is the highest radon concentration in this district (tables 2. and 3.). With the same type of ventilation, natural ventilation, radon levels in workrooms were lower than the level in the home (table 3.). The ventilation in these workrooms was not so effective, which might cause elevated indoor radon levels. In this place integrated and continuously measured radon concentrations were at the same level on the ground level rooms (table 4.). In the place D the highest continuously measured radon concentration was 1163 $Bq.m^{-3}$. This workroom located underground and had mechanical exhaust and supply ventilation (tables 2., 3. and 4.). The circulation of the exhaust and supply air were used which may have increased the radon level. The home that located little further from the ground level workrooms had higher radon concentration than the workrooms (tables 3. and 4.). The highest radon concentrations were observed in place E, both in the workrooms (arithmetic mean of 965 $Bq.m^{-3}$) and in the homes (arithmetic mean of 491 $Bq.m^{-3}$). Also these workrooms were depressurized (down to -20 Pa) and the air exchange rates were quite low (0.4-2.8 h^{-1}, n=12) (table 2.). The workrooms, except one, and homes were located on the slope of the esker. All these buildings, where former workrooms locate, had one wall against the ground (table 4.) and most of them had mere mechanical exhaust (table 3.).

Table 3. Continuous and integrated radon levels (C_{Rn}, $Bq.m^{-3}$) and numbers (N) of workplaces and homes with the different types of ventilation.

	Arithmetic mean of radon concentration ($Bq.m^{3}$) (N)			
	MSE	ME	NV	Homes, NV
Place A, continuous / integrated	53 (7) / 90 (4)	- / -	- / 174 (1)	208 (4)
Place B, continuous / integrated	260 (5) / 285 (4)	426 (1) /	- /-	233 (11)
Place C, continuous / integrated	184 (5) / 175 (2)	75 (2) / 230 (3)	71 (2) / 136 (5)	720 (1)
Place D, continuous / integrated	306 (6) / 200 (1)	- /160 (1)	- / -	340 (1)
Place E, continuous / integrated	252 (5) / -	1474 (7) / -	- / -	491 (40)
Total average	211 (28) / 188 (11)	658 (10) / 195 (4)	71 (2) / 155 (6)	361 (57)

MSE mechanical supply and exhaust ME mechanical exhaust NV natural ventilation

Table 4. The continuous and integrated radon levels (Bq.m^{-3}) and numbers (N) of different types of foundation in workrooms in each places.

	Arithmetic mean of radon concentration (Bq.m^{-3}) (N)		
	underground	hillside	ground level
Place A, continuous / integrated	53 (7) / 90 (4)	- / -	174 (1) / 240 (1)
Place B, continuous / integrated	59 (1) / 400 (1)	48 (1) / -	405 (4) / 170 (2)
Place C, continuous / integrated	68 (1) / 275 (2)	- / -	142 (7) / 146 (8)
Place D, continuous / integrated	372 (4) / 180 (1)	- / -	41 (1) / 160 (1)
Place E, continuous / integrated	- / -	1041 (11) /-	126 (1) / -

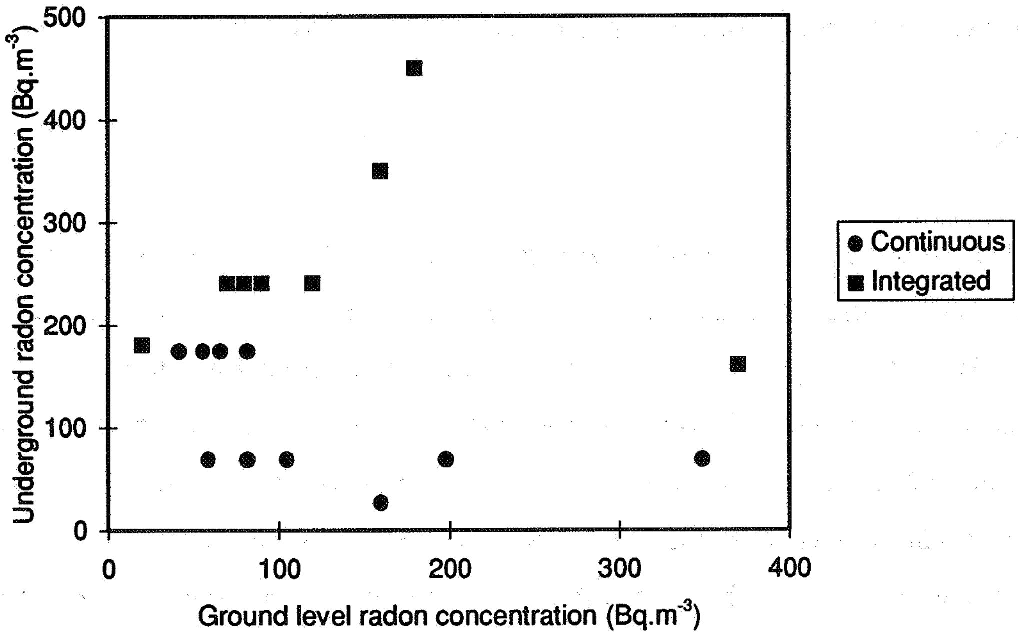

Figure 2. The radon levels (Bq.m^{-3}) measured by continuous and integrated methods in underground and ground level workrooms.

In the place A continuous and integrated measurements have been done at the same time in 5 of the workrooms. The radon concentrations seemed to be at the same level with both used methods (figure 3.).

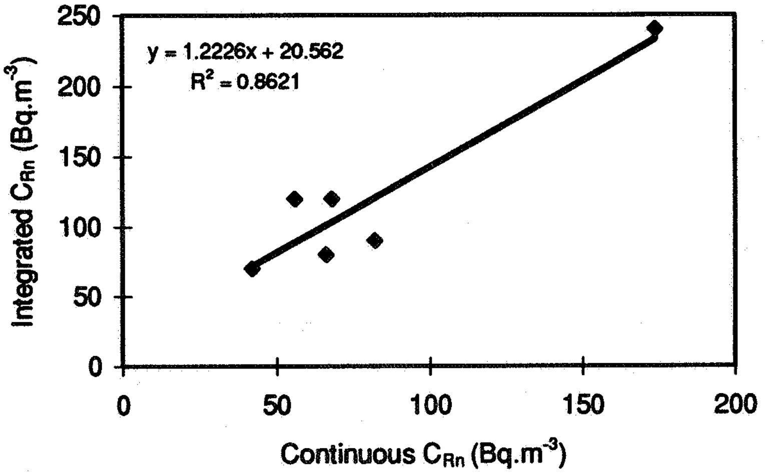

Figure 3. Comparison of the continuous and integrated methods of radon measurements.

CONCLUSIONS

The radon levels were highest on the hillside area in northern Finland where the hill-constructed workrooms had mere mechanical exhaust. The possible explanation to the high radon concentration could be that the parts of the walls of these buildings were constructed against the soil, which made radon entry possible. Also the high underpressure due to mechanical exhaust increased radon entry from soil. Also the homes on the hillside area had highest radon levels, when compared to other homes. Generally, the radon levels at workplaces and in homes were observed to be at the same level in the same district. The underground location of workrooms did not rise the indoor radon levels at all the places. Some places had even lower radon level in underground workrooms than the ground level workrooms. This was possibly caused by effective dilution by mechanical supply and exhaust ventilation at underground workrooms.

Acknowledgements

The authors would like to thank MSc Juha Anttila, MSc Kai Tornikoski and MSc Eija Riihimäki for their skilled assistance during measurements. This research is supported by Foundation of Occupational Health of Finnish Ministry of Finance.

REFERENCES

1. KOKOTTI, H.

'Dependence of Radon Level on Ventilation Systems in Residences''

Kuopio University Publications C. Natural and Environmental Sciences 32. University of Kuopio, 1995

2. ARVELA, H.

'Residential Radon in Finland: Sources, Variation, Modelling and Dose Comparisons''

STUK-A124, Finnish Centre for Radiation and Nuclear Safety, 1995

3. DENG W., JIANG R. AND LIU Y.

'Radon Study in Underground Buildings in Chongqoing, China''

Proceedings of the 6th Int. Conference on Indoor Air Quality and Climate, Helsinki, Finland, Vol 4, 1993, pp449-452.

4. ARVELA, H., Mäkeläinen I. and Castrén O.

'Sampling research of Radon in Residences in Finland (Otantatutkimus asuntojen radonista Suomessa''(in Finnish)

STUK-A108, Finnish Centre for Radiation and Nuclear Safety, 1993

5. KORHONEN P., KOKOTTI H. AND KALLIOKOSKI P.

'The Effect of Ventilation and Pressure Differences on Concentrations of Radon at Workplaces''

Proceedings of 16th AIVC Conference, Implementing the Results of Ventilation Research. Palm Springs, USA, 19-22.9.1995, Vol 1, pp105-113

6. LUCAS, H.

"Improved Low Level Alpha Scintillation Counter for Radon"

Rev. Sci. Instr, 28, 1957; pp680-683.

7. MÄKELAINEN, I.

"Experiences with Track Etch Detectors for Radon Measurements"

Nuclear Tracks, 12, 1986; pp717-720.