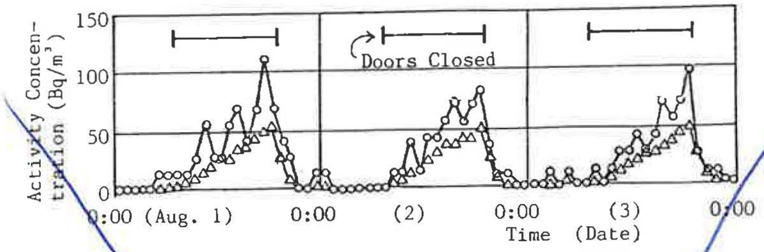

Fig. 2 Same to Fig. 1; openigs closed only during daytime (7 am - 7 pm) (continued)

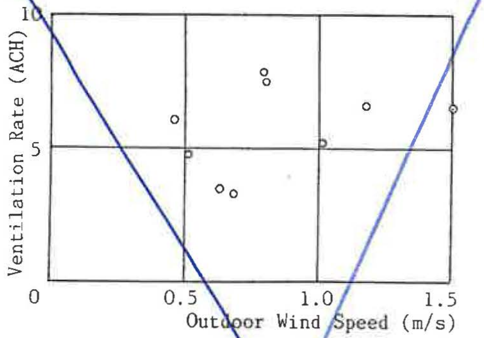

Fig. 3 Relationship between Ventilation Rates and Outdoor Wind Speeds Obtained at the Masonry.

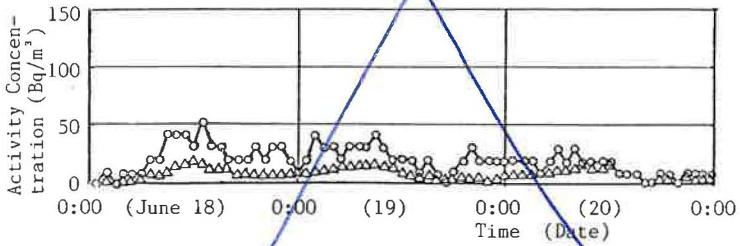

Fig. 4 Hourly Fluctuation Patterns of Indoor Concentrations of Radon and its Daughters Measured in the House "PSH"; all openings closed.

INDOOR RADON IN THREE SIMILAR TWO-STORY HOUSES WITH DIFFERENT VENTILATION SYSTEMS

Helmi Kokotti and Taisto Raunemaa
University of Kuopio, Kuopio, Finland

Abstract

The maximum concentrations (60-430 Bq/m^3) of indoor radon were observed during a drying-out period just before the tenants moved in. The house with mechanical exhaust had the highest concentrations, the house with mechanical supply and exhaust the lowest ones. During winter and spring average radon concentrations in the houses were below 100 Bq/m^3. High radon concentrations were observed in underfloor sites inside the houses. In the house with mechanical exhaust three times indoor concentration was obtained. The average air exchange rates of the dwellings varied between 0.1-0.9 times per hour. Mean radon exhalation rate for concrete was 28 Bq/m^{2}h from these results.

Introduction

Radon gas enters the house either through basement, from the pores in soil or rock driven by negative pressure, or by exhalation from building materials. In Finland building materials have not been found to cause high radon concentrations.

The aim of the study was to examine, where radon enters new houses and if there are differences between indoor radon levels due to ventilation system. The study houses were
1. built from same material (concrete)
2. located side by side on similar soil, rock and filling ground (gravel).

Materials and Methods

As an object of this study were three similar two-story new buildings, which are located side by side on a gravel hill. Solid structures of the houses are made from painted conçete elements. Each building has four two room and a kitchen (area = 40.5m^2) flats and two three room and a kitchen (area = 56.5 m^2) flats in the middle. Each dwelling has an own ventilation system: mechanical exhaust in house B, natural ventilation in house C and mechanical supply and exhaust in house D.

Concentrations of indoor radon were measured three times a year. In the fall 1985 before the tenants moved in and in the winter in the flats having maximum concentrations in the fall. In spring 1986 one dwelling in each house was investigated also for soil as a radon source. At the same time the computer controlled data collection system registered (1) the amounts of exhaust of each flat.

The radon concentrations (2) were examined by film detection technique. The packages were situated on the wall of livingroom at a height of 1.5 m. A one month collection in the fall 1985 and two month collection at other periods were carried out.

Radon exhalation from concrete in the steady state can be described (3) by the equation 1

$$E = \frac{C - C_0}{F/V} * R \; ; \; R \neq 0, \qquad (1)$$

where E is the radon exhalation rate per unit area of material (Bq/m^2h), F/V is the ratio of the radon exhaling area to the volume of the flat (1/m), R is the ventilation rate (1/h), C is radon concentration indoors (Bq/m^3) and C_0 outdoors. For C_0 an average (constant) value of 3.7 Bq/m^3 is assumed (3).

Results

Before the tenants moved in radon concentrations varied between 60-430 Bq/m^3 (Fig. 1 a.) Average levels were 250 (house B), 170 (house C) and 120 (house D) Bq/m^3 . During this drying out period the house B with mechanical exhaust system had maximum concentration of radon. It was recognized (1) that also the lowest negative pressure existed in this building.

After about two months radon concentrations were in general lower than those measured in the fall (Fig. 1 b.). It is,however, impossible to resolve the effect of seasonal variation at this stage of study. It was seen from other measurements, that tenants were more acquainted in regulating air exhange.

During spring 1986 about half of a year after the move-in average levels stayed at the same level (95 Bq/m^3) in houses B and D. In the building with natural ventilation (C) were obtained the lowest radon concentrations (mean 65 Bq/m^3). Concentrations near soil varied between 60-530 Bq/m^3 (Fig. 1 c.). The highest value of indoor air radon coincided with the highest value in the air nearmost the soil.

Air exchange rates were calculated from the exhaust amounts (Table 1). Their variation was largest in house B and smallest in house C. The values covered the range 0.1-0.9 times per hour. No evidence that the maximum ventilation rate leads to minimum radon concentration can be found in the present data. For example, in the flat having R = 0.9 1/h was obtained maximum concentration of radon (230 Bq/m^3). For comparison, the effect of an increased air exhange rate on indoor radon concentration had been studied (4) in one house during five months. Only a small effect was noticed.

From air exhange rates and from average radon concentrations over a two month period, exhalation rates for concrete were calculated (Table 2). The mean exhalation rate of radon for concrete was 28 Bq/m^2h, which is equal to the exhalation rate value 26 Bq/m^2h determined in an earlier study (3) using an F/V ratio of 1.33 1/m for apartment houses.

Table 1: The amounts of exhaust Q (m^3), standard deviation s, ventilation rate R (1/h) in houses B, C and D during spring 1986. An F/V ratio (1/m) was downstairs 1.45 (2 r + k), 1.36 (3 r + k) and upstairs 1.37 (2 r + k), 1.26 (3 r + k).

House	B mechanical exhaust	C natural exhaust	D mechanical supply and exhaust
Mean Q + s (m^3)	37.7 + 26.5	32.1 + 8.4	73.4 + 15.4
Range Q (m^3)	6.5 - 61.0	28.2 - 35.8	4.0 -101.3
s (m^3)	6.6 - 50.1	5.3 - 10.6	6.0 - 16.2
Mean s/Q (%)	79	27	72
Range s/Q (%)	22 - 111	15 - 38	6 - 343
Mean R (1/h)	0.31	0.28	0.61
Range R (1/h)	0.06 - 0.59	0.25 - 0.32	0.04 - 0.94

Table 2: The concentration and exhalation rate of radon in flats of houses B, C and D during spring 1986.

Flat	C_{Rn} (Bq/m^3)	E (Bq/m^2h)
B 11	60	23
B 12	60	16
B 13	140	31
B 14	140	43
B 15	60	3
B 16	110	10
C 17	40	7
C 19	80	14
C 21	80	17
D 23	120	3
D 24	60	35
D 25	70	24
D 26	60	29
D 27	230	147
D 28	40	18
Mean	90	28

Conclusions

The buildings in the study are located in a district, where radium concentration of soil is known to be low. A possible source of indoor air radon is then solid building materials or filling ground gravel transferred from outside the area. Radon concentration caused by building materials depends on exhalation rate and removal rate of radon gas.

The radon exhalation rate is a function of the air exchange rate. If fresh air is not brought inside with a comparable rate to exhaust, negative pressure causes accumulation of radon gas in indoor air. If the exhaust varies at the same time, accumulated indoor radon is not ventilated outdoors when exhaust is decreased. In a building with natural ventilation the air exhange is more balanced and also the rates of radon exhalation and exhaust.

When systems of air supply and exhaust are mechanical, optim between supply and removal of radon gas may be caused by balancing system. In general the mechanical air supply and exhaust system is regulated to have a small negative pressure (in house D 10 %), which is meant to prevent accumulation of humidity in constructions. If system is , however, regulated in steps, pressure difference can vary. Abrupt changing of air exchange rate may effect the rate of removal and entry of radon (4).

Acknowledgements

This research was supported by the Ministry of Environment of Finland, the National Housing Board of Finland and the City of Kuopio.

References

1. Savolainen, T., Raunemaa, T. Automatic measurement and data collection system on indoor air study at three small housing flats. Proceedings on the 4th International Conference on Indoor Air Quality and Climate. 17-21 August 1987. Berlin.

2. Mäkeläinen I. Calibration of bare LR-115 film for radon measurements in dwellings. International Seminar on Indoor Exposure to Natural Radiation and Related Risk Assesment. 3-5 October 1983. Anacapri, Italy.

3. Mustonen R. Natural radioactivity in and radon exhalation from finnish building materials. Health Physics 46:6 (1984), pp. 1195-1203.

4. Nazaroff, W.W., Feustel, H., Nero, A.V., Revzan, K.L., Grimsrud, D.T., Essling, M.A., and Toohey, R.E. Radon transport into a detached one-story house with basement. Atmospheric Environment 19:1 (1985), pp.31-46.

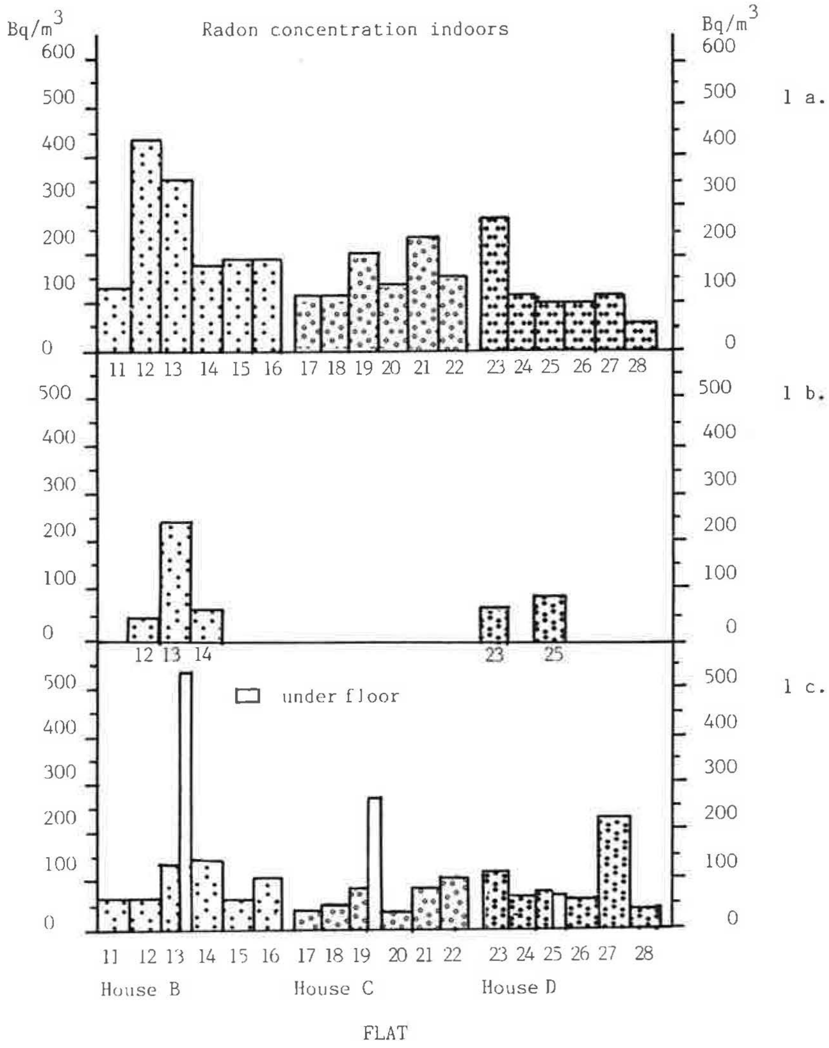

Fig. 1. The concentrations of indoor radon (Bq/m^3) in houses B, C and D
a. in the fall 9.9.-27.9.1985 before tenants moved in
b. 11.11.1985-17.1.1986 after about two months the move-in
c. in the spring 3.2.-2.4.1986