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MATCHED PAIR ANALYSIS OF THE INFLUENCE OF WEATHER-STRIPPING ON INDOOR RADON CONCENTRATION IN SWISS DWELLINGS

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W. Burkart, C. Wernli and H. H. Brunner
Health Physics Division
Eidgenössisches Institut für Reaktorforschung
5303 Würenlingen, Switzerland

Abstract – To quantify the inferred elevated radon concentrations in energy efficient homes caused by lower air infiltration due to air-tightness, an attempt was made to eliminate some of the more important conflicting parameters by measuring pairs of adjacent homes i.e. comparing retro-fitted or new houses with a conventional neighbouring dwelling.

Our results with passive track etching dosemeters exposed over 3 months during the winter of 1982/83 indicate that radon concentrations in the living quarters on the ground floor are increased by 107 $Bq.m^{-3}$ (2.9 $pCi.l^{-1}$) ± 50 $Bq.m^{-3}$ (1.6 $pCi.l^{-1}$) or a factor of 1.8 over the conventional home. The large absolute and relative fluctuations from pair to pair, the evident lower average radon concentrations in the cellar of the energy efficient homes and the differences in the patterns of window opening show that measurements of larger samples and an assessment of every home with air infiltration specialists is needed to separate the effect of air-tightness on the radon indoor concentration from the predominant anthropogenic, structural or geological influences.

INTRODUCTION

Indoor radon concentrations in single-family homes are influenced by many parameters in, so far, unpredictable ways. In a Swiss study during the winter of 1981-82, radon levels on the ground floor and the first floor of single-family dwellings were shown to vary between less than 0.4 and 110 $pCi.litre^{-1}$ of air[1]. Geographical patterns and dependence on elevation above ground level clearly indicate soil content of primordial nuclides and soil porosity as determining factors. However, radon emanation may show extreme variations over short distances due to long distance radon transport in the subsoil through cracks and cannot be predicted by geological charts only[2]. Recent studies[3,4] show the difficulties in relating radon indoor levels to infiltration rates alone. Therefore, to make inferences on radon concentrations in indoor air of the effect of a reduction in air infiltration in energy efficient buildings, the much larger fluctuation due to geological parameters have to be eliminated. Analysis of pairs of dwellings which are matched for some factors like subsoil and climate should provide better means to quantify comparatively small changes such as the ones expected from the lowering of ventilation rates in homes with extensive weather-stripping of windows and doors.

Tightly closing windows and doors with rubber gaskets theoretically reduce the air exchange rate in homes to values around 0.1 h^{-1} [11]. Assuming an average air exchange rate of 0.5 h^{-1} in conventional homes, the highly cost efficient energy conservation method of weather-stripping could increase radon indoor levels, which are inversely proportional to the air exchange rate for unchanged source terms, by a factor of five. However, the increase of other indoor pollutants and their influence on the opening patterns of windows, forced ventilation in kitchen and rest rooms and also less draught from the cellar in retro-fitted or new homes may counterbalance this effect. Considering the large annual dose to the general public from indoor exposure to radon[5], this question is of great importance for future energy conservation policies and building codes[6].

MATERIALS AND METHODS

In each of a total of 105 single-family homes, 3 passive radon dosemeters were placed in the cellar, the living room and a bedroom, respectively. Most of the dwellings for the matched pair analysis were selected by architects taking part in a programme sponsored by the Federal Government to reduce the heat losses of existing buildings. Since these modifications, which are undertaken on an individual basis, include mainly the installation of tightly closing windows, pairs of adjacent dwellings differing in air tightness can be formed. Only pairs having the same street address and being inhabited during the full measuring period were included. Finally, of the 243 dosemeter readings, only 72 remained for the matched pair analysis.

Dosemeters

The Karlsruhe-type passive radon dosemeters[7] were used in this study. These devices contain a polycarbonate detector which is electrochemically etched after exposure. The track counting is done automatically by a Quantimet system. For quality assurance, a set of detectors exposed to a known dose is etched and counted with each batch of field dosemeters. The internal calibration standard was checked against the radon chamber of the National Institute of Radiation Protection in Stockholm and by participation in the EC intercomparison on radon

Table 1. Average radon concentrations indoors for cellar, ground and first floor in single family dwellings in 2 geological areas of Switzerland.

Area	rubber gaskets	number of dwellings	cellar	ground floor Bq.m^{-3} radon (pCi.l^{-1} ± S.D.)	1st floor
Regional differences					
Mittelland	+ & −	49	160 (4.4± 0.9)	100 (2.6±0.5)	70 (1.9±0.3)
SE Alps	+ & −	32	1410 (38.1± 7.1)	390 (10.4±1.9)	230 (6.2±0.8
Difference		81	1250 (33.7± 7.2)	290 (7.8±2.0)	160 (4.3±0.8)
P			<<0.001	<0.001	<<0.001
Influence of weather stripping					
Mittelland	+	25	160 (4.3± 1.3)	110 (3.0±0.9)	80 (2.3±0.5)
	−	24	170 (4.6± 1.3)	80 (2.2±0.3)	50 (1.4±0.2)
Difference		49	−10 (−0.3)	30 (0.8)	30 (0.9)
P			>>0.1	>0.1	<0.1
Alps	+	9	1310 (35.5±12.7)	360 (9.8±2.1)	250 (6.6±1.3)
	−	23	1450 (39.2± 8.7)	390 (10.7±2.6)	220 (6.0±1.0)
Difference		32	−140 (3.7)	−30 (−0.9)	30 (0.6)
P			>>0.1	>>0.1	>>0.1

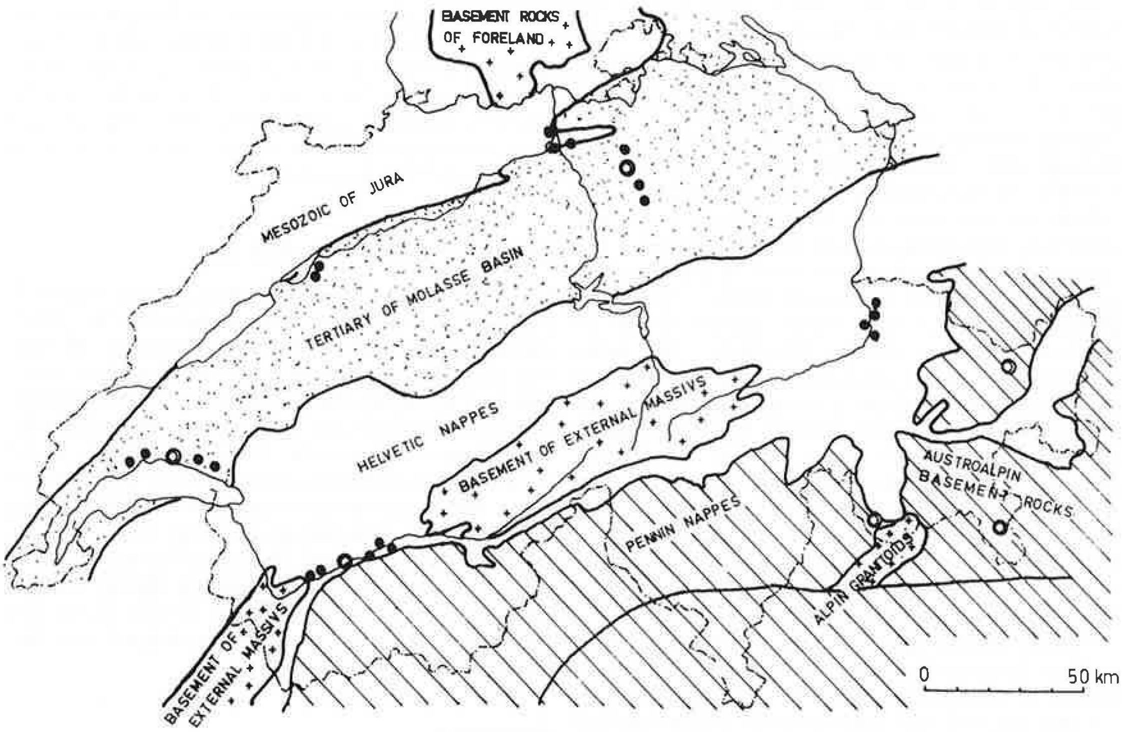

Figure 1. Locations of dwellings on a tectonic map of Switzerland. Circles denote groups of measurements; points denote single homes. Shaded and crosses: crystalline basement rocks.

dosemeters organised by the NRPB at Chilton, U.K.

RESULTS

The air exchange rate in Swiss houses is generally quite low. i.e. 0.1 to 0.6 h^{-1} for uninhabited dwellings[11], since, due to the lack of domestic fossil fuels for heating, energy conservation measures were widespread even at the time of low oil prices. In addition, building codes are defined to also meet the insulation requirements for dwellings in mountain regions with very cold climate. In some of those areas, i.e. parts of the South-eastern Swiss Alps, crystalline basement rock with relatively high uranium and thorium content reaches the surface. In the plains north of the Alps where the population centres are located, the subsoil is generally of sedimentary origin. During the winter of 1982/83 measurements were performed in the areas of the towns of Zürich and Lausanne (Mittelland) and in valleys in the South-eastern part of the canton of Graubünden (SE Alps), respectively (Figure 1). The differences between the two regions for both cellar and living quarters are highly significant (Table 1, Figure 2). The different percentages of dwellings with weather-strippings in the two subsets cannot account for this effect since the changes in indoor radon level caused by the presence of rubber gaskets in the windows and doors fall short of being statistically significant for both regions.

In an effort to explain the influence of reducing the air exchange rate, pairs of adjacent homes from both regions were pooled and the differences calculated. Despite the large fluctuations in the radon contents between different pairs, i.e. different regions, and the small sample size, Table 2 and Figure 3 indicate an increase of the average indoor radon concentration in energy efficient homes having no forced ventilation. As in the geographical study, radon concentration in the cellars of conventional homes which quite often have bare earth floors in the storage areas, are on the average higher.

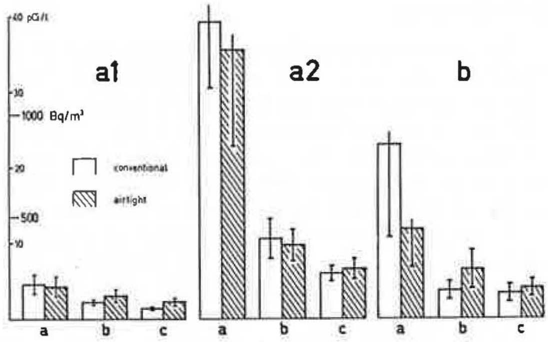

Figure 2. Indoor radon concentrations.
a) Radon indoor concentrations in the Mittelland. (al) and in crystalline basement rock areas of the Alps (a2) in dwellings with and without rubber gaskets, respectively.
b) Average radon concentrations in airtight and conventional dwellings used for the matched pair analysis.
a: cellar; b: ground floor; c: first floor; shaded: airtight homes. Bars denote the standard deviation of the mean.

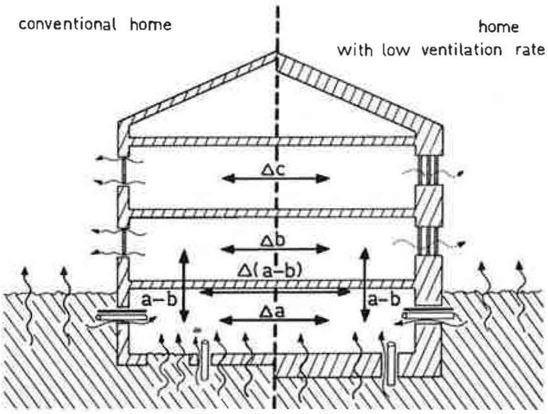

Figure 3. Differences in radon concentrations compounded for the matched pair analysis of adjacent dwellings.

Table 2. Matched pair analysis of dwellings differing in their air exchange rate. All differences are formed by subtracting the value of the conventional home from the new/retro-fitted dwelling.

	cellar	ground floor Bq.m^{-3} (pCi.l^{-1} ± S.D. of the mean)	first floor
new/retro-fitted	444 (12.0± 5.1)	244 (6.6±2.5)	152 (4.1±1.2)
conventional	858 (23.2±12.4)	137 (3.7±1.1)	126 (3.4±1.1)

	Difference	S.D.	P
Cellar (a)	−414 (−11.2)	(11.6)	0.18
ground floor (b)	107 (2.9)	(1.6)	0.06
first floor (c)	26 (0.7)	(0.9)	0.24
(b) + (c)	133 (3.6)	(2.1)	0.06
(a) − (b)	522 (−14.1)	(12.9)	0.15

DISCUSSION

The result from a small sample of pairs of dwellings matched for geological underground and local climate indicates that the theoretical increase in the indoor radon concentration due to weather-stripping is discernible after the elimination of some more important parameters influencing the radon source term. However, the relative increase of a factor of only 1.8 falls short of predicted values of around 5 derived from changes in the air exchange rates correlated with the sealing of windows and doors in uninhabited dwellings[11]. In addition to the well known counteracting influences such as anthropogenic behaviour and electric fans installed in kitchens and rest rooms[10], this study shows a lower radon emanation into the cellar of retro-fitted or new dwellings in all 3 samples. Although this effect remains to be substantiated further, the better insulation of new homes against the subsoil through massive concrete foundations and surrounding water drainage courses also back this suggestion. It will be of great importance to determine whether this effect fades with the age of the dwelling due to the formation of cracks in the basement floor and walls[8] and due to the closure of drainage spaces along the cellar walls.

Radon indoor levels in conventional and new or retro-fitted homes situated in Swiss areas with crystalline underground are considerably higher than outside the Alpine region. Since even the subsample without rubber gaskets showed a mean value for the living quarters of 296 $Bq.m^{-3}$ (8 $pCi.l^{-1}$) radon, which translates into an annual effective dose equivalent of about 900 mrem[9], the dose commitment of the population in such areas with elevated radon levels should be reduced. Several means such as forced ventilation with heat exchangers could allow both the energy need of a dwelling and the lung radiation dose to the inhabitants to be reduced[6]. The remedial cost per person-rem avoided is very low compared to the costs of limiting routine radionuclide release from nuclear power plants.

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