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Radon Levels in Houses with Controlled Ventilation

by D.A. Figley

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Radon Levels in Houses with Controlled Ventilation, *D.A. Figley*, National Research Council of Canada, Institute for Research in Construction, Saskatoon, SK, S7N 0W9

Radon in residences has been identified as a potential health hazard to the occupants. This paper outlines the measured radon gas concentrations and ventilation rates in 25 new "low energy" houses. Radon gas concentrations were measured using Track Etch passive radon monitors and mechanically supplied ventilation rates were measured. Building envelope air leakage data and an infiltration model were used to calculate the net envelope indoor/outdoor pressure difference. Radon source strengths for each house were calculated using a simple mass balance model. The source strengths were found to vary by a factor of 10 from house to house and by a factor of 3 for an individual house.

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RADON LEVELS IN HOUSES WITH CONTROLLED VENTILATION

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NATIONAL RESEARCH COUNCIL OF CANADA
OTTAWA, CANADA

For Presentation at the 79th Annual Meeting of the
Air Pollution Control Association
Minneapolis, Minnesota June 22-27, 1986

INTRODUCTION

Recent concerns over health effects resulting from long term exposures to radon in residences have stimulated a great deal of interest in radon. Researchers[1] have measured indoor radon levels in 9999 homes in fourteen Canadian cities and found that a very broad range of concentrations should be expected. Regional variations in building materials containing radium, local geology,[2] construction techniques and ventilation system designs are interacting factors in the analysis.

From a building science approach, indoor air pollution problems require a knowledge of the pollutant sources and potential removal mechanisms. Because of the highly variable nature of radon sources, detailed design models[3] may be difficult to use. A more realistic approach may be to develop building construction details and HVAC system operation strategies that minimize radon entry. Another possible approach is the use of sub-slab ventilation.[4] This has been shown to control radon entry through the basement floor.

The degree of application of control strategies should be related to the severity of the potential radon source. In Sweden, one study has attempted to map geographical areas with various radon risk levels[5] in order to determine where various control measures may be justified.

This paper examines some of the theoretical aspects of radon entry into houses and outlines the results of radon measurements in houses with mechanical ventilation systems. The study involved monitoring the mechanically supplied and exhausted (by means of a heat recovery ventilator, HRV) ventilation air flows and the basement radon gas levels in three groups of houses located in Pinawa and Winnipeg, Manitoba.

Airtightness test data were used to relate the net air supply rate (HRV supply minus HRV exhaust) to the net building envelope pressure. The relationship between net building envelope pressure, ventilation rate and basement radon level is explored.

DESCRIPTION OF THE HOUSES

All of the houses were new, wood-frame, single-family residences with full-depth cast-in-place concrete basement walls. The floor slabs were 75-mm concrete, cast over 150 mm of gravel placed on undisturbed soil. All of the basements were insulated on the interior using wood studs with glass fibre batt insulation between the studs. A continuous 150-µm polyethylene vapor barrier was applied over the inside face of the studs and the walls were sheeted with 12-mm gypsum board (Figure 1).

The houses were grouped according to the ventilation system type and location.

The houses in Groups 1 and 3 were located in Pinawa, Manitoba and Winnipeg, Manitoba respectively, and were built by one contractor using similar construction materials and techniques. The above-grade walls were constructed using the double-stud technique.[6] Heat recovery ventilators were used to supply outside air and circulate air within the houses. The units had interlocked supply and exhaust fans with the ON/OFF operation controlled by a humidistat. The exhaust air was removed (via ductwork) from the kitchen and bathroom. The outside air was supplied into the center of the basement and allowed to migrate through the house. Floor registers were cut through the main floor to facilitate air movement between the main floor and basement. Electric baseboard heaters (convective) were used for space heating.

The houses in Group 2 were located in Pinawa, Manitoba but were built by a different contractor than the houses in Groups 1 and 3. The above-grade walls were conventional single-stud. All other construction materials and techniques were similar to those used in the Group 1 and 3 houses. Electric forced-air heating systems (20-kW input) with supply air ducts into every room and two centralized main floor return air grilles were used. Outdoor air was supplied by means of a 125-mm diameter duct connected to the return air plenum. The operation of the single-speed furnace fan (≈400 L/s) was controlled by heating demand.

Details of the houses are given in Table I.

EXPERIMENTAL METHODS

Airtightness measurements[7] were taken for all of the house envelopes. This test involved depressurizing the house with a blower door apparatus and measuring the air flow, Q(L/s), and corresponding values of the differential pressure across the building envelope, ΔP(Pa). Values for the flow coefficient, C'(L/s•Pa^n), and flow exponent, n (dimensionless), were then calculated using the expression:

$$Q = C' (\Delta P)^n \qquad (1)$$

The Group 1 and 3 houses were extremely airtight, having average induced air leakages of 0.18 and 0.28 air changes per hour (ach) @50 Pa. For the Group 2 houses, the average air leakage was 1.67 ach @50 Pa. The tests were

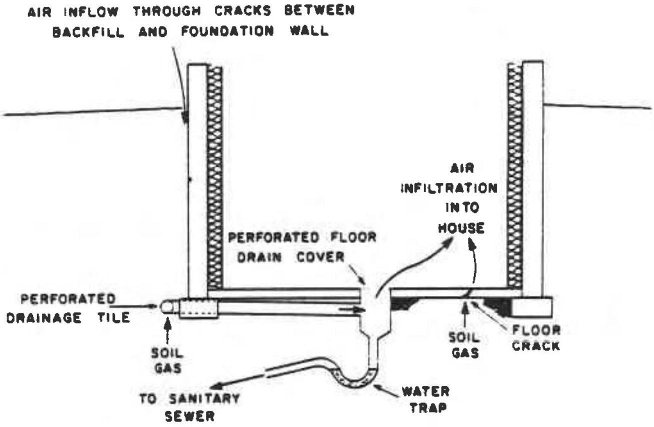

Figure 1. Typical basement construction details and potential radon entry sites

done with all the windows and doors closed and the HRV ports blocked. The floor drains were left "as is". Test data for the houses are given in Table I. In comparison, one study of 97 newer Canadian houses, tested under the same conditions,[8] found an average air leakage of 3.67 ach @50 Pa.

Elapsed time meters were installed to monitor the ON time of the interlocked HRV fans. The HRV air flow rates (supply and exhaust) and the outside air flows to the electric furnaces were measured using a heated probe anemometer traverse. At the beginning and end of the measurement period, the indoor air temperature and relative humidity were measured using an aspirating psychrometer.

Radon levels were monitored in the house basements using Terradex Type SF Miniature Track Etch Detectors.[9] The manufacturer's literature states that the calibration precision is "better than 5%"; however, the true measurement accuracy is related to the total exposure and the analysis sensitivity.[10] If the exposure is sufficiently high and the most sensitive detector analysis is performed, the systematic errors will be reduced to 5%. All the detectors were analysed at the highest sensitivity (0.2 pCi/L • month). Typically, the

Table I. General House Details

	House Code	House Volume (m^3)	Finished Floor Area excl. bsmt. (m^2)	C ($L/s \cdot Pa^n$)	n	Air Tightness (ach @50 Pa)
Group 1	2	465	91.7	1.91	0.64	0.18
	3	465	91.7	1.73	0.61	0.14
	4	465	91.7	3.84	0.55	0.26
	5	465	91.7	2.99	0.50	0.16
	7	465	91.7	1.70	0.64	0.15
	8	465	91.7	3.00	0.55	0.19
Group 2	10	452	102.8	17.19	0.63	1.61
	11	507	102.1	7.77	0.79	1.23
	12	545	110.2	13.35	0.73	1.54
	13	477	95.6	10.47	0.76	1.54
	14	545	110.2	25.83	0.62	1.96
	15	452	102.8	18.29	0.68	2.12
Group 3	17	513	92.6	6.60	0.46	0.25
	18	465	91.7	4.99	0.45	0.22
	19	455	91	6.84	0.64	0.67
	21	465	91.7	1.96	0.66	0.20
	25	465	91.7	3.27	0.59	0.25
	26	465	91.7	5.30	0.53	0.32
	27	304	59.3	5.14	0.51	0.39
	28	465	91.7	1.96	0.69	0.23
	29	465	91.7	1.66	0.63	0.15
	30	465	91.7	5.67	0.54	0.35
	31	465	91.7	3.67	0.58	0.27
	32	465	91.7	4.23	0.56	0.28
	33	465	91.7	2.36	0.67	0.24

manufacturer's estimated error for these measurements was below ±10% although in several cases, where the measured radon concentration was below 1 pCi/L, the expected error increased to approximately ±20%. A single detector was suspended approximately 0.75 metres above the basement floor near the center of each house and exposed for approximately 90 days. The results are given in Tables II, III and IV.

Outdoor temperature and wind speed data were taken from Environment Canada summaries.[11]

Three sets of measurements were conducted. The monitoring periods were December 1983 to March 1984, September to December 1984, and January to March 1985.

The total ventilation rate (V_T) for the houses was calculated as:[12]

$$V_T = \left(V_I^{\frac{1}{n}} + V_M^{\frac{1}{n}} \right)^n \qquad (2)$$

where: V_I = infiltration flow rate (L/s)
V_M = time-averaged mechanical ventilation flow rate (L/s)

Shaw's method[13] was used to calculate the infiltration rate (V_I) using the values from the fan depressurization test.

The winter values were calculated for Type 1 infiltration (temperature-driven) data using the expression:

$$V_I = 0.32\ C'\ (\Delta T)^n / 3.6 \qquad (3)$$

where: V = house volume (m^3)
ΔT = average indoor/outdoor temperature difference (°C)

The summer values were calculated assuming Type 2 infiltration (wind-driven):

$$V_I = \frac{0.76\ C'\ v^n}{3.6} \qquad (4)$$

where: v = wind speed (m/s)

For the Group 1 and 3 houses, V_M was calculated by dividing the total air flow volume through the HRV during the test (total running time multiplied by average duct air volume flow rate by the total test time. In most cases, the HRV supply (V_S) and exhaust (V_E) air flows were not balanced, so the larger of the two values was used. The difference in the air flows ($V_{NM} = V_S - V_E$) would be made up by increased infiltration or exfiltration. The value of V_M for the Group 2 houses was calculated by multiplying the furnace ON time by the outdoor air flow rate with the furnace fan ON and dividing by the total test time. The furnace ON time was approximated as the total measured furnace electrical energy consumption (kWh) divided by the rated heat output (20 kW). The air flow through a HRV or fresh air intake duct was assumed to be negligible when the fans were not operating.

The values for V_T are given in Tables II, III and IV.

Table II. Data from Test 1 (Dec. 83 - Mar. 84)

	House Code	Radon Conc. (pCi/L)	KV_T (L/s)	ΔP_N (Pa)	($\Delta P_N>0$) S_T (pCi/s)	($\Delta P_N<0$) S_T (pCi/s)
Group 1	2	6.71	16.3	14.5	107.8	-
	3	22.74	4.2	-0.9	-	114.8
	4	7.2	32.3	23.8	223.4	-
	5	6.66	8.5	-5.7	-	59.0
	7	5.58	37.5	158.3	195.9	-
	8	25.02	1.0	-4.5	-	49.5
Mean		12.32			175.7	74.4
Median		6.96			195.9	59.0
Group 2	10	3.59	13.0	-4.9	-	43.7
	11	6.22	12.7	-5.2	-	79.5
	12	4.24	16.1	-5.2	-	64.9
	13	2.33	14.2	-5.3	-	28.2
	14	2.77	19.0	-4.8	-	46.3
	15	4.37	17.1	-5.1	-	70.2
Mean		3.92				55.5
Median		3.92				55.6
Group 3	17	2.83	20.3	-6.1	-	50.4
	18	3.53	9.8	-4.3	-	33.1
	19	2.20	27.1	2.6	48.1	-
	21	8.75	18.3	-9.8	-	159.4
	25	3.04	13.4	27.5	37.0	-
	26	1.69	31.8	143.4	39.5	-
	27	2.63	10.6	-3.0	-	24.4
	28	3.37	27.7	98.7	82.9	-
	29	0.91	24.5	97.2	10.9	-
	30	6.91	26.2	7.5	174.8	-
	31	2.73	17.0	-3.3	-	40.5
	32	4.15	23.0	-9.7	-	88.0
	33	3.14	20.9	9.7	58.3	-
Mean		3.53			64.5	66.0
Median		3.04			48.1	45.5

Table III. Data from Test 2 (Sept. 84 - Dec. 84)

	House Code	Radon Conc. (pCi/L)	KV_T (L/s)	ΔP_N (Pa)	($\Delta P_N>0$) S_T (pCi/s)	($\Delta P_N<0$) S_T (pCi/s)
Group 1	2	3.08	30.9	46.1	82.7	-
	3	6.27	22.3	7.8	135.1	-
	4	6.94	8.1	0.4	59.1	-
	5	3.16	5.2	-2.3	-	16.9
	7	1.97	39.3	173.8	57.2	-
	8	5.93	6.4	0.2	40.4	-
	Mean	4.56			74.9	16.9
	Median	4.55			59.1	16.9
Group 2	10	5.6	6.8	-2.0	-	39.8
	11	6.27	5.1	-2.0	-	36.0
	12	7.95	6.9	-2.0	-	60.3
	13	2.41	5.8	-2.0	-	13.4
	14	2.07	10.4	-2.0	-	18.6
	15	9.96	8.3	-2.0	-	87.7
	Mean	5.71				42.6
	Median	5.94				37.9
Group 3	17	2.02	24.8	3.9	39.9	-
	18	2.97	10.9	-1.8	-	29.9
	19	1.07	21.0	0.4	13.0	-
	21	4.19	17.8	-6.6	-	69.7
	25	6.27	4.7	2.2	33.1	-
	26	2.2	29.3	20.4	52.0	-
	27	3.86	14.0	0.7	49.5	-
	28	4.75	22.2	75.8	99.0	-
	29	1.42	19.0	88.8	18.8	-
	30	5.05	29.4	32.8	138.5	-
	31	1.34	11.3	-1.2	-	10.8
	32	1.27	14.9	-21.4	-	12.7
	33	1.11	19.5	71.4	13.0	-
	Mean	2.89			50.8	30.8
	Median	2.20			33.1	21.3

Table IV. Data from Test 3 (Jan. 85 - Mar. 85)

	House Code	Radon Conc. (pCi/L)	KV_T (L/s)	ΔP_N (Pa)	(ΔP_N>0) S_T (pCi/s)	(ΔP_N<0) S_T (pCi/s)
Group 1	2	3.19	22.8	12.8	64.4	-
	3	-	-	-	-	-
	4	4.07	22.0	21.0	82.5	-
	5	1.63	3.3	-4.4	-	5.3
	7	-	-	-	-	-
	8	3.04	18.5	23.6	50.0	-
Mean		2.98			65.6	5.3
Median		3.12			64.4	5.3
Group 2	10	3.42	12.3	-4.9	-	39.0
	11	4.34	12.1	-5.4	-	51.2
	12	4.56	15.9	-5.2	-	69.9
	13	2.47	14.0	-5.3	-	30.0
	14	1.82	18.8	-4.8	-	26.9
	15	4.60	17.1	-5.1	-	74.3
Mean		3.54				48.6
Median		3.88				45.1
Group 3	17	3.21	19.7	4.2	57.0	-
	18	2.46	15.2	-4.3	-	32.1
	19	1.69	17.4	-2.3	-	22.3
	21	1.86	26.2	15.7	37.5	-
	25	5.93	7.5	-3.4	-	46.8
	26	2.95	26.5	8.0	67.8	-
	27	3.85	8.5	-3.6	-	30.9
	28	5.38	12.6	23.1	66.9	-
	29	1.51	22.2	55.0	23.9	-
	30	4.26	28.0	11.9	109.6	-
	31	2.07	11.7	15.1	20.5	-
	32	4.21	20.4	22.3	79.9	-
	33	0.82	22.2	76.3	7.9	-
Mean		3.09			52.3	33.0
Median		2.95			57.0	31.5

MODELLING

The radon gas concentration in a house may be described by a simple mass balance model of the form:

$$C = C_o + \frac{S_T - R}{K\ V_T} \tag{5}$$

where: C = the indoor radon gas concentration (pCi/L)
C_o = the outdoor radon gas concentration (pCi/L)
S_T = the total indoor radon source strength (pCi/s)
R = the indoor radon decay rate (pCi/s)
K = mixing factor ($K = 1$ perfect mixing)
V_T = total ventilation air flow rate (L/s)

Any energy-efficient radon control strategy should minimize the ventilation air flow heat loss by using heat recovery on the ventilation air. In addition, control methods to reduce the radon sources and increase the sinks should be incorporated.

The total indoor radon source is composed of two major components:

$$S_T = S_B + S_s \tag{6}$$

where: S_B = building source strength (pCi/s)
S_s = soil gas source strength (pCi/s)

The building source term would be composed of radon emissions from building materials containing radium 226 and the domestic water supply. Potential major building material sources could include gypsum wallboard and concrete.

The soil gas source term would result from air migrating through the surrounding soil and entering the basement via cracks and plumbing penetrations whenever the indoor pressure was lower than the exterior pressure. In particular, foundation cracks and foundation drainage systems which drain into basement floor drains may be major pathways for air to flow from the soil into the basement (Figure 1). To quantify the air flow into the basement it is first necessary to calculate the air flow inducing pressure differential acting on the basement floor. The net building envelope pressure at the basement floor, ΔP_N, can be calculated as:

$$\Delta P_N = \Delta P_M + \Delta P_{WT} + \Delta P_H \tag{7}$$

Using the airtightness test data for the houses, the mechanically induced building envelope pressure difference (ΔP_M) can be calculated by rearranging Equation 1:

$$\Delta P_M = -\left(\frac{-V_{NM}}{C'}\right)^{\frac{1}{n}} \qquad \text{when } V_{NM} < 0 \tag{8a}$$

and

$$\Delta P_M = \frac{V_{NM}}{C'}^{\frac{1}{n}} \qquad \text{when } V_{NM} > 0 \tag{8b}$$

Also acting on the building envelope are the pressures created by wind and temperature gradients. Equation 1 can be used to calculate the approximate envelope differential pressure induced by wind and thermal forces (ΔP_{WT}) by using the calculated infiltration flow rate:

$$\Delta P_{WT} = \left(- \frac{V_I}{C'} \right)^{\frac{1}{n}} \tag{9}$$

Equations 8 and 9 refer to a "whole house" pressure and are assumed to act at the neutral pressure axis of the house (approximately mid-height in the house).

For all the test conditions, the indoor air temperature exceeded the outdoor temperature, thus the resulting thermally induced negative pressure (ΔP_H) can be calculated as:[14]

$$\Delta P_H = -\rho_i g \, h(T_i - T_o)/T_o \tag{10}$$

where: ρ_i = inside air density (kg/m^3)
g = gravitational constant ($9.81 \ m/s^2$)
h = height of neutral pressure plane above the basement floor (m)
T_i = indoor air temperature (K)
T_o = outdoor temperature (K)

Positive basement pressures ($\Delta P_N > 0$) will prevent air infiltration and the corresponding transport of radon gas, thus the radon source will only be the building source strength. When the basement is under negative pressure ($\Delta P_N < 0$), air infiltration will occur and the soil gas source strength will be related to the rate of air flow.

The calculated house envelope differential pressures for some of the tests appear to be unreasonably high. Given the pressure/flow characteristics of the HRV fans, mechanically induced envelope differential pressures over 50-75 Pa could not be obtained. Thus, additional air leakage pathways not measured during the fan depressurization envelope leakage test must have existed during the normal house operation to allow the high measured air flow rates to occur. These pathways could include cracks resulting from the deterioration of weatherstripping on doors and windows.

Since the distribution of the air leakage sites cannot be determined from the air leakage test, the amount of air infiltration through the below-grade portion of the envelope (soil gas source) cannot be separated from that occurring above grade. Therefore, while the general relationship between the degree of pressurization and the basement air infiltration is known, the magnitude is not.

The radon soil gas source strength can be estimated as:

$$S_s = B \, C_s \, (V_{NM} + V_I) \qquad \text{when } \Delta P_N < 0 \tag{11a}$$

and

$$S_s = 0 \qquad \text{when } \Delta P_N > 0 \tag{11b}$$

where: B = coefficient to account for the portion of the total ventilation that entered below grade
C_s = concentration of radon in the ventilation that entered below grade (pCi/L)

Detailed measurements of the air leakage distribution for each house envelope were not made; hence, a value of B could not be determined. An alternative approach is to calculate the net soil gas source strength as:

$$S_s = D(\Delta P_N)^n \tag{12}$$

where: D = experimentally determined coefficient which accounts for the air infiltration distribution and soil gas concentration $(\frac{pCi}{s\ Pa^n})$

The total radon source strength can be written as:

$$S_T = S_B + D(\Delta P_N)^n \tag{13}$$

The primary mechanism of radon gas removal from a house (excluding dilution) is through nuclear disintegration, thus the total radon sink rate can be calculated as:[15]

$$R = 1000\ \lambda_r\ C\ V \tag{14}$$

where: λ_r = radon decay constant
= 2.11×10^{-6}/s

ANALYSIS

Measured values of C, C_o and calculated values of V_T were input into Equation 5 to solve for the values of S_T. Although the K values were not measured in this study, previous formaldehyde concentration test data[16] for these houses indicated a ratio of the K values for the Group 1 and 3 houses to the Group 2 houses of approximately 0.5. The value of K is highly dependent upon the air distribution system layout and air flow rate; however, values of between 0.6 and 1.0 are suggested for well mixed rooms.[17] Since the Group 2 houses had fully ducted supply and return air systems, a value of K = 0.8 was arbitrarily selected. Consequently, the K value for the Group 1 and 3 houses was set at 0.4. Further, errors in the estimation of the K values will affect the magnitude of the value of S_T but should not introduce significant relative errors.

For the test conditions where $\Delta P_N > 0$, the value of $S_T = S_B$. When $\Delta P_N < 0$, the individual values of S_B and S_s could not be isolated from S_T. The calculated values for S_T are given in Tables II-IV.

The frequency distributions of the source strengths for the various house groups are shown in Figures 2-4.

RESULTS

The comparison of radon source strengths enables the building scientist to evaluate indoor radon concentration data from various houses where air infiltration and ventilation, outdoor concentration, pressurization and building construction details may be confounding or interacting variables. Typically, investigators[18,19] have focused on measuring existing radon levels without consideration of these variables. This can create problems when control strategies are considered, since the design engineer cannot determine which combination of variables could be producing the radon level.

The results in Tables II-IV for houses 2, 4, 7, 17, 26, 28-30, 33 (where $\Delta P_N > 0$ for at least two tests) show that the building related source terms vary greatly between houses and with time. Typically, values for S_T for individual houses varied by a factor of 3 while values for different houses varied by more than an order of magnitude.

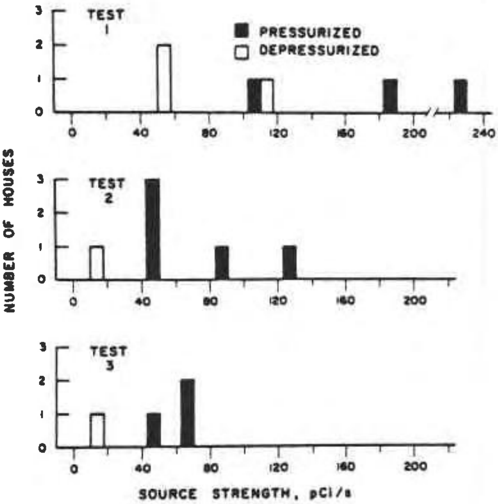

Figure 2. Frequency distribution of radon source strengths for Group 1 houses

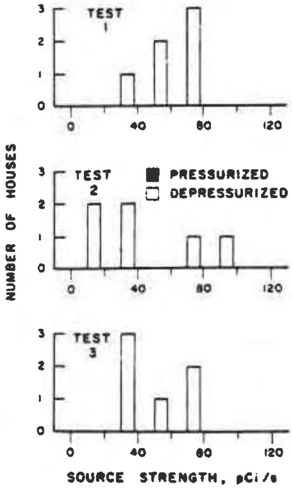

Figure 3. Frequency distribution of radon source strengths for Group 2 houses

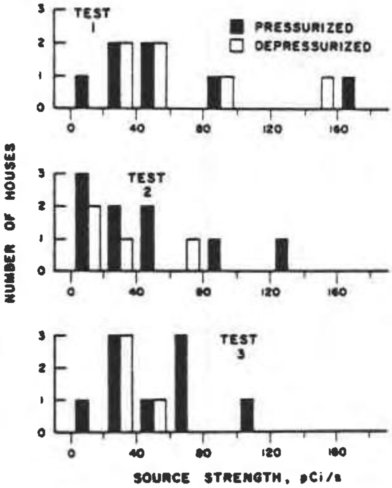

Figure 4. Frequency distribution of radon source strengths for Group 3 houses

Because of the variation of the radon source with time, it is not reasonable (for an individual house) to try to estimate a value for S_B (from the $\Delta P_N > 0$ data) and use it in Equation 13 to calculate a value for S_s (from the $\Delta P_N < 0$ data). Therefore, although the theory suggests it should exist, a relationship between the soil source and ΔP_N cannot be determined from these data. Consequently, the apparent overestimation of the magnitude of some of the calculated house pressures does not affect this analysis.

In more general terms, the house groups can be considered to fall into two broad categories; pressurized and depressurized (Figures 2-4). In all cases, the median values for S_T for the depressurized houses were lower than for the pressurized houses. This method of examining the data includes a selection bias since some houses were consistently pressurized or depressurized. A true randomized trial study would provide for a pressure status randomly allocated to each house. Therefore, some of the difference in the median values of S_T is due to the house allocation and some is due to the pressure effect.

The houses in Groups 1 and 2 were all located within 1 km of each other yet the variations in S_T between houses were very large. The pressurized Group 1 houses also had higher median values of S_T than the depressurized Group 2 houses. Since the houses in Groups 1 and 2 were of very similar construction and were located in similar sites, no explanation for the difference in the median S_T values can be proposed. The only significant difference in the houses was the type of heating and ventilating system, and the calculation of S_T should correct for KV_T.

Higher median values of S_T for the Group 1 houses as compared to the Group 3 houses are consistent with the geological siting. The Group 1 houses are located in a rural area approximately 100 km north of the Group 3 houses. This area is in the fringe of the Canadian Shield, a rocky region containing uranium bearing rock. The Group 3 houses are located in Winnipeg, a large urban center in a farming area.

Although the focus of this study has been to examine the mechanisms by which radon enters and is removed from a building, another important aspect is the magnitude of the indoor radon concentration. While building scientists require knowledge of radon sources and transport mechanisms so that control strategies can be developed and implemented, the existing indoor radon levels are of concern to health officials who must assess the risk to the exposed population. Since potential health effects are associated with long term exposures to radon, health officials must be able to make accurate exposure estimates. The wide variations in calculated radon source strengths (with time and location), coupled with the seasonal and occupant controlled variations in the ventilation rate, make estimations of long term exposure from short term measurements of the radon concentration difficult. Despite these problems, short term measurements of radon concentrations are most often used in health effect studies.

Frequency distributions of the radon gas concentrations are shown in Figures 5-7. At the present time, there are no Canadian guidelines for indoor radon levels in homes. For the purpose of this discussion, the Atomic Energy Control Board of Canada investigation level of 3 pCi/L[20] will be used. For Test 1, all of the Group 1, 67% of the Group 2 and 54% of the Group 3 houses exceeded the investigation level. A similar pattern was observed in Tests 2 and 3 (Table V), although the percentages were slightly lower. Létourneau et al.[18] had previously measured radon daughter levels in Winnipeg houses and found that 15.9% exceeded 0.02 WL. Using a value of 0.3 for an equilibrium factor,[20] 0.02 WL would correspond to a radon gas level of 7 pCi/L. Only one

Group 3 house during Test 1 exceeded 7 pCi/L. No houses in the subsequent tests exceeded 7 pCi/L. This housing group appears to have a significantly lower incidence of elevated radon levels than the previously measured Winnipeg houses. Possible explanations could be the continuous ventilation supplied by the HRV systems in the Group 3 houses as opposed to the passive ventilation in the Létourneau study. Also, the Group 3 houses had insulation and vapor barriers on the basement walls and relatively new, continuous concrete basement floor slabs. It is more likely that many of the older houses in the Létourneau study would have unfinished concrete basement walls and cracked basement floors. Winnipeg is located in an area of highly expansive clay soil and basement wall and floor cracking is a well known problem that increases with the age of the building.

CONCLUSIONS

The radon source strength can be highly variable, both with time and location. Therefore, generalized conclusions about the potential radon hazard in various geographical areas cannot be made.

The variation of the radon source strength with time can confuse the results from radon control measure studies. During the long time interval required for two consecutive Track Etch radon monitor exposures, substantial source strength variations may occur.

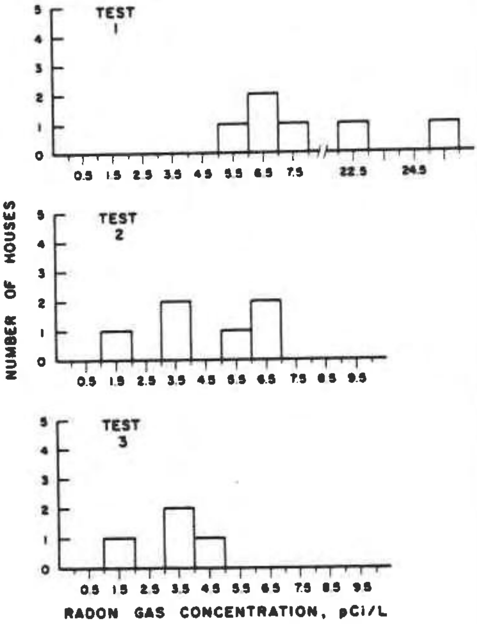

Figure 5. Frequency distribution of radon gas concentrations for Group 1 houses

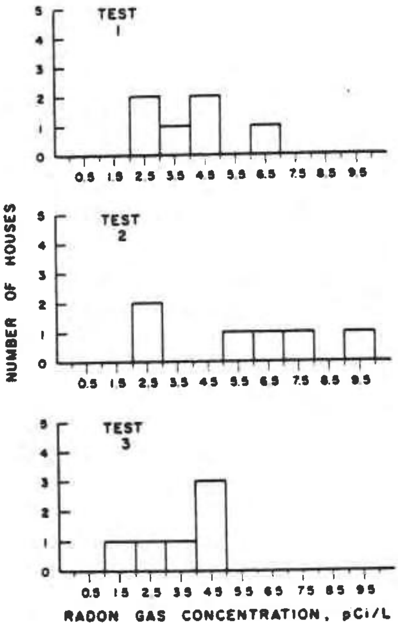

Figure 6. Frequency distribution of radon gas concentrations for Group 2 houses

The group average radon source strengths (or indoor radon concentration) of the pressurized houses were higher than those of the depressurized houses. Although the state of pressurization was not deliberately randomly allocated in the study population, no obvious selection bias is apparent. Despite the positive correlation between negative pressure and soil gas source strength indicated by the physical model, the study results showed a negative correlation.

Indoor radon concentrations over 3 pCi/L were found in many of the houses. The houses in Pinawa had higher levels than those in Winnipeg which is consistent with the geological siting.

Table V. Percentage of Houses in Each House Group with Indoor Radon Levels Exceeding 3 pCi/L

House Group	Test 1	Test 2	Test 3
Group 1	100	83	75
Group 2	67	67	67
Group 3	54	38	46

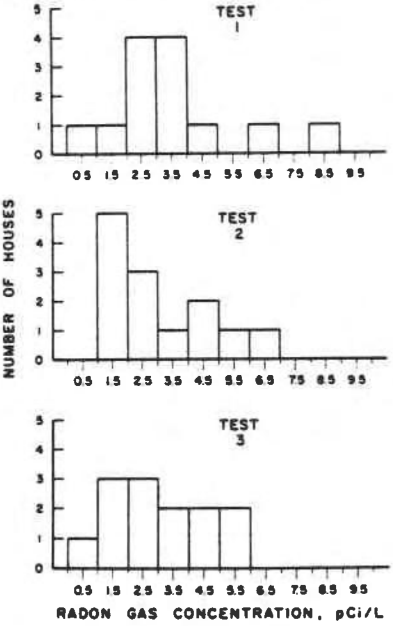

Figure 7. Frequency distribution of radon gas concentrations for Group 3 houses

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NOTE TO EDITORS