4204

A COMPARISON OF RADON PROGENY WORKING LEVELS IN NEWER AND OLDER HOUSES IN WINNIPEG, CANADA

Gary Proskiw, P.Eng. Peter Piersol, P.Eng. Mark Riley

ABSTRACT

Radon progeny working levels were monitored over a one-year period in 20 new houses located in Winnipeg, Manitoba, Canada. Sixteen were constructed to the R-2000 standard for energy-efficient housing, while the remaining four were relatively conventional structures. All contained some form of mechanical ventilation system. Radon progeny working levels were found to be lower in the 20 project houses relative to those reported in a study of older, conventional houses in the same city. The geometric mean values for the R-2000, new conventional, and older conventional houses were 0.006 WL, 0.009 WL, and 0.017 WL, respectively, with the percentage of measurements exceeding the EPA guideline of 0.020 WL being 4%, 13%, and 40%, respectively. Leakier below-grade construction in the older houses was suggested as a possible explanation for the observed differences. The wide variation in observed levels for houses in the same city indicates that geographic location may not, by itself, be a reliable parameter for predicting indoor concentrations. Little correlation was observed in the 20 project houses between radon progeny working levels and independently measured total air change rates (mechanical and natural). From the perspective of establishing indoor air quality standards, air change rate was not found to be an effective mechanism for achieving radon control objectives for levels on the order of 0.020 WL.

INTRODUCTION

Radon is known to be present in all parts of Canada, although in varying concentrations. Originating in the underlying geological formations and soils, the gas can enter a house through diffusion and by airborne transport via physical discontinuities between the soil and the structure. Commonly used radon control measures include ventilation to dilute interior concentrations and source control to reduce soil gas/radon entry. The latter typically employs measures to maximize the airtightness of the below-grade and/or surface components of the structure to minimize potential infiltration sites. Other measures successfully demonstrated include sub-slab ventilation and pressurization of the basement to reduce infiltration.

Assessing the health impact of prolonged exposures to radon is difficult because the effects may not become evident for several years and may be obscured by other causes. However, it is generally accepted that exposure to radiation is harmful and, for the general public, the major exposure to radiation is reported to be inhalation of radon progeny (George 1985).

The problem of assessing the health risk has made the establishment of exposure standards difficult. At present, there are no Canadian guidelines for radon exposure in residences, although a value of 0.100 working levels (WL) has been suggested as an action level. The current U.S. Environmental Protection Agency guideline is 0.020 WL (EPA 1988). Swedish limits vary depending on the type of structure: 0.108 WL for existing dwellings, 0.054 WL for renovated buildings, and 0.019 WL for new dwellings (Swedemark and Mjones 1984).

RESEARCH PROGRAM

Project Houses

Radon progeny working levels and total air change rates were monitored in 20 detached, occupied bungalows between March 1986 and February 1987. The houses were part of the Flair Homes Energy Demo/Canadian Home Builders Association Flair Mark XIV project, located in Winnipeg, MB, Canada. All had been constructed in 1985 and 1986 by a single builder. Nineteen were located side-by-side, while the twentieth was situated approximately 1 km away.

The houses were very similar in size and layout; two floor plans were used with main floor areas of 60 m^2 and 85 m^2, respectively. Sixteen were designed to the R-2000 standard, with the remaining four constructed using relatively conventional practices. The R-2000 standard for residential construction includes requirements for building energy usage, airtightness, heating equipment, and mechanical ventilation systems.

All of the houses had cast-in-place concrete basements and floor slabs. Sixteen used interior insulation with polyethylene air/vapor barriers on the walls, stapled in place with some sealing to reduce air leakage. Four of the houses used exterior basement insulation systems with exposed concrete on the interior. Basement floor slabs were cast onto aggregate placed on undisturbed soil. Four of the slabs used 38 mm (1 1/2 in) semi-rigid glass fiber insulation between the aggregate and the concrete. These also employed passive sub-slab vents intended to generate a pressure differential across the floor slab by using wind action to induce an airflow through a roof ridge vent that was connected to the underside of the slab. All of the houses used standard basement floor drains without open sumps; however, four employed floor drain cover traps to control air infiltration. Weeping tiles were connected to the floor drains above the standard sewer trap. Domestic water was provided by mains supply.

The houses used mechanical ventilation systems ranging from intermittent, small-capacity bathroom exhaust fans to heat recovery ventilators (HRV) designed to run continuously and provide fresh air distribution to all zones of the house. Sixteen of the mechanical systems utilized multi-speed controls which permitted flow rates to be automatically or man-

---

Gary Proskiw is with UNIES Ltd., Winnipeg, MB, Canada. **Peter Piersol** is with ORTECH International, Mississauga, ON, Canada. **Mark Riley** is with Energy, Mines and Resources Canada, Ottawa, ON, Canada.

TABLE 1

Description of Project Houses

Houses	Year of Completion	Location of Basement Wall Insulation	Basement Slab Insulation	Floor Drain Cover, Passive Sub-Slab Vent	Space Heating System	Ventilation System	Envelope Operating Pressure Regime	Energy Performance Standard
1, 2	1985	Interior	No	No	Forced Air Electric Furnance	Heat Recovery Ventilator Connected to Ductwork	Balanced	R-2000
3, 4	1985	Interior	No	No	Forced Air Electric Furnance	Heat Recovery Ventilator Connected to Ductwork	Slightly Positive	R-2000
5, 6	1985	Interior	No	No	Forced Air Electric Furnance	Heat Recovery Ventilator Connected to Ductwork	Slightly Negative	R-2000
7, 8	1985	Interior	No	No	Forced Air Electric Furnance	Central Exhaust	Slightly Negative	Conventional
9, 10	1985	Interior	No	No	Forced Air Gas Furnance	Bathroom Exhaust Fan	Slightly Negative	Conventional
11, 12	1986	Exterior	Yes	Yes	Electric Baseboards & Small Capacity Heat Pump	Exhaust-Only Heat Pump Heat Recovery Ventilator	Slightly Negative	R-2000
13, 14	1986	Interior	No	Yes	Forced Air Electric Furnance	Heat Recovery Ventilator Connected to Ductwork	Slightly Negative	R-2000
15, 16	1986	Interior	No	No	Integrated Forced Air Pump Heating/ Ventilation System	Air-to-Air Electric Heat	Balanced	R-2000
17, 18	1986	Interior	No	No	Electric Baseboards	Heat Recovery Ventilator with Dedicated Supply Ductwork	Balanced	R-2000
19, 20	1986	Interior	No	No	Electric Baseboards	Heat Recovery Ventilator with Dedicated Supply Ductwork	Balanced	R-2000

TABLE 2

Radon Progeny Levels, New Winnipeg Houses

	Number of Houses	Geometric Mean (WL)	Median (WL)	Measurements >0.020 WL		Measurements >0.100 WL	
				Number	%	Number	%
R-2000 Houses							
March 1986	6	0.004	0.006	0	0%	0	0%
August 1986	14	0.007	0.006	1	7%	0	0%
October 1986	16	0.009	0.009	1	6%	0	0%
February 1987	14	0.004	0.003	0	0%	0	0%
Cumulative	50	0.006	0.007	2	4%	0	0%
Conventional Houses							
March 1986	4	0.009	0.009	0	0%	0	0%
August 1986	4	0.011	0.012	0	0%	0	0%
October 1986	4	0.010	0.015	2	50%	0	0%
February 1987	4	0.007	0.008	0	0%	0	0%
Cumulative	16	0.009	0.009	2	13%	0	0%

TABLE 3

Total Air Change Rates

	Number of Houses	Mean (ach)	Standard Deviation (ach)	Median (ach)
R-2000 Houses				
March 1986	6	0.28	0.18	0.26
October 1986	16	0.30	0.16	0.29
February 1987	15	0.43	0.13	0.45
Cumulative	37	0.35	0.16	0.36
Conventional Houses				
March 1986	4	0.16	0.05	0.14
October 1986	4	0.15	0.05	0.17
February 1987	4	0.20	0.07	0.18
Cumulative	12	0.17	0.05	0.17

ually adjusted. Ventilation rates for the R-2000 houses were established to conform to the R-2000 Home Program Design and Installation Guidelines for Ventilation Systems (1986), which require a minimum continuous mechanical ventilation rate of 0.35 ach (or possibly greater, depending on the number of rooms). Actual air change rates achieved during the monitoring program were often noticeably different due to equipment malfunction or homeowner intervention with the operation of the ventilation system.

All of the houses, including the conventional structures, were constructed with relatively tight building envelopes to minimize natural infiltration. Airtightness levels, determined in accordance with CGSB Standard 149.10-M (1986), ranged from 0.44 to 2.20 ach at 50 Pascals when measured in February 1987. A detailed description of the houses is given in Table 1.

MONITORING PROGRAM

Radon progeny working levels were measured in March 1986, August 1986, October 1986, and February 1987 with an active time-integrating, track-registering sampler that used an air pump to draw controlled amounts of air across a detecting surface. The samplers were installed in a representative location in the house basements and operated continuously for periods of approximately one week. Analysis of the exposed detector substrate was then performed.

Total air change rates were measured simultaneously during three of the four sampling periods using the capillary adsorption tube sampling (CATS) technique (Dietz and Cote 1982). This method has been found to display good agreement with the constant concentration sulphur hexafluoride technique when relatively constant total air change rates are encountered (Piersol and Mayhew 1987). Four calibrated sources, which emitted an inert perfluorocarbon tracer gas, were situated around the house on exterior walls. Two or four samplers that adsorbed the tracer were installed at central locations on each level. The amount of tracer adsorbed by the samplers was determined using gas chromatographic analysis and related to the total air change rate experienced by the house during the monitoring period.

RESULTS

Observed radon progeny working levels and total air change rate data are given in Tables 2 and 3.

DISCUSSION

Measured radon progeny working levels were generally low relative to the EPA guideline of 0.020 WL, with 4% and 13% of the measurements exceeding this level in the R-2000 and conventional houses, respectively. Seasonal variations were noted, with the highest levels recorded in the summer and fall. Geometric mean and median levels were lower in the R-2000 houses compared to the conventional structures during all four monitoring periods. A similar study of radon gas levels was performed in the same city by Yuill (1988) during the summer and fall of 1987 in which radon gas levels were measured in 70 Winnipeg houses using one-week sampling periods. These houses had been constructed between 1902 and 1980 and were representative of older, existing housing stock in the city. A summary of these results is shown in Table 4, with the radon gas levels converted to working levels using an equilibrium ratio of 0.5. One of the most striking results is that levels in the older houses were much higher than those in the 20 houses in the Flair project. The geometric mean for the older houses was 0.017 WL vs. 0.006 WL and 0.009 WL, respectively, for the R-2000 and conventional, new houses in the Flair project. Twenty-eight of the 70 older houses, or 40%, had measured levels exceeding 0.020 WL, compared with 4% and 13%, respectively, of the measurements taken in the R-2000 and conventional houses.

Although reasons for the behavioral differences between the newer and older houses need further investigation, one possible explanation is the reduced level of below-grade airtightness in the older structures. Winnipeg is located in an area of moisture-susceptible soils which can expand and contract with variations in moisture content. Foundation distress caused by differential movement of the basement is common. Older structures are particularly vulnerable because their foundations were often constructed without the structural integrity of modern foundations. The mean airtightness of the 70 older houses was reported as 6.78 ach_{50}, whereas the R-2000 and newer, conventional structures in the Flair project averaged 1.07 ach_{50} and 1.62 ach_{50}, respectively. (A difference was noted in the airtightness testing procedure between the two studies in that the 70 older houses were tested with all intentional openings unsealed. This would have resulted in elevated ach_{50} values.)

The wide variation in radon progeny levels found in these two studies for houses in the same city indicates that geographic location was not observed to be a dominant factor in determining indoor concentrations. This should be consid-

TABLE 4

Radon Progeny Levels Reported by Yuill, Older Conventional Winnipeg Houses

	Number of Houses	Geometric Mean (WL)	Median (WL)	Measurements >0.020 WL Number	%	Measurements >0.100 WL Number	%
Summer & Fall 1987	70	0.017	0.017	28	40%	0	0%

ered in attempts to map radon "hot zones" since spurious results could be produced by factors such as differences in the airtightness of below-grade components of the envelope.

The relationship between radon progeny working levels and total air change rate is classically expressed using Equation 1, which was developed on the basis of a simple mass balance on a one-compartment model and assumes perfect mixing of the indoor air:

$$Ci = Co + N/V_t \qquad (1)$$

where

Ci = indoor concentration
Co = outdoor concentration
N = net pollutant source generation rate
V_t = total air change rate

The source term, N, is assumed to be independent of the indoor concentration and air change rate. Equation 1 applies to a single structure with a constant outdoor pollutant concentration and source strength. If used to describe the behavior of a population of houses, which may or may not have similar characteristics, Equation 1 can be rewritten as:

$$Ci = Co' + N'/Vt \qquad (2)$$

The terms Co' and N' describe representative effective values of the outdoor concentration and source strength for the entire population.

Radon progeny working levels are plotted against total air change rates in Figure 1 using all measurements made during the monitoring period. This produced a correlation coefficient of 0.30. The implications of this are important. For a single house, the inverse relationship described by Equation 1 has been observed (Rector 1985), although variations in source strength can produce measurable departures from the anticipated behavior. However, Equation 2 was not found to successfully describe the behavior of a population of houses, even though they were located very close together and were of similar age. The implication is that the air change rate and hence the mechanical ventilation rate would not have been successful mechanisms to achieve radon control objectives at the range of levels encountered (typically around 0.020 WL). Other measures such as source control should be seen as the first line of defense.

The impact upon radon progeny levels of house pressurization, passive sub-slab ventilation, and floor drain cover traps will be discussed in a future paper.

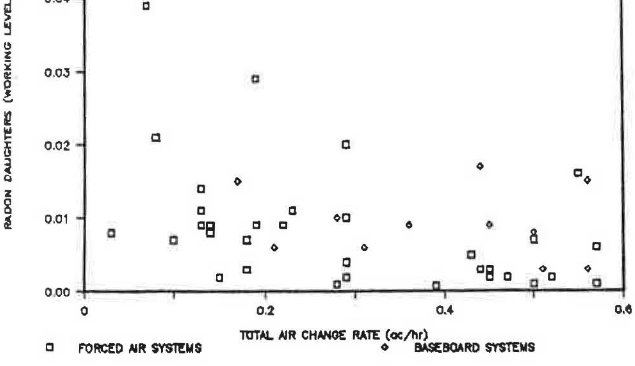

Figure 1 Radon progeny vs. total air change rate (March 1986, October 1986, January 1987)

CONCLUSIONS

Radon progeny working levels were monitored over a one-year period in 20 new, low-leakage, occupied houses equipped with mechanical ventilation systems located in Winnipeg, Canada. Levels were lower in the R-2000 energy-efficient structures than those in the conventional structures of the same age. However, levels in both the R-2000 and conventional houses were lower than those reported in a study conducted in the same city using a random sample of house types and ages. This latter group was composed largely of older, conventional structures with leakier building envelopes. Geometric mean radon progeny working levels for the R-2000, new conventional, and older conventional houses were 0.006 WL, 0.009 WL, and 0.017 WL, respectively. The percentages of measurements which exceeded the EPA guideline of 0.020 WL for the three groups were 4%, 13%, and 40%, respectively.

The wide variation in observed radon progeny levels for houses located in the same city suggests that geographic location may not, by itself, be a reliable parameter for predicting indoor concentrations.

Radon progeny working levels were compared to independently measured total air change rates and it was found that air change rate was a poor predictor of radon progeny working levels. From the perspective of establishing indoor air quality standards, total air change rate and hence mechanical ventilation rate were not observed to have been effective mechanisms for achieving radon control objectives for levels on the order of 0.020 WL.

ACKNOWLEDGMENTS

This work was conducted as part of the Flair Homes Energy Demo/Canadian Home Builders Association Flair Mark XIV Project and was supported by Energy, Mines and Resources Canada and Manitoba Energy and Mines.

REFERENCES

CGSB. 1986. Standard 149.10-M, "Determination of the airtightness of building envelopes by the fan depressurization method." Ottawa: Canadian General Standards Board.

Dietz, R.N., and Cote, E.A. 1982. "Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique." *Environment International,* Vol. 8, pp. 419–433.

Energy, Mines and Resources Canada. 1986. "R-2000 home program design and installation guidelines for ventilation systems."

EPA. 1988. *Radon reduction techniques for detached houses,* 2nd edition. Washington, DC: Environmental Protection Agency.

George, A.C. 1985. "Measurement of sources and air concentrations of radon and radon daughters in residential buildings." ASHRAE Technical Data Bulletin: *Air quality: ventilation, hazardous gas, and radon contaminants.*

Piersol, P., and Mayhew, W. 1987. "Air infiltration measurement techniques." Report prepared for the R-2000 Home Program; Energy, Mines and Resources Canada.

Rector, H.E.; Koontz, M.D.; Cade, D.R.; and Nagda, N.L. 1985. "Impact of energy conservation measures on radon progeny concentrations: a controlled study." ASHRAE Technical Data Bulletin: *Air quality: ventilation, hazardous gas, and radon contaminants.*

Swedemark, G.A., and Mjones, L. 1984. "Exposure of the Swedish population to radon daughters." *Indoor Air,* Vol. 2, *Proceedings of the International Conference (3rd) on Indoor Air Quality and Climate,* Stockholm.

Yuill and Associates Ltd. 1987. "Investigations of the indoor air quality, airtightness, and air infiltration rates of a statistically random sample of 78 houses in Winnipeg." Report prepared for Canada Mortgage and Housing Corporation.

DISCUSSION

Jeffrey C. Olcott, Envirogenics Inc., Pennington, NJ: Based on your data and the current 0.02 wl "guideline," can you comment on the feasibility of meeting the proposed U.S. EPA guideline of 0.2 to 0.7 pCi/L?

G. Proskiw, UNIES Ltd., Winnipeg, Manitoba, Canada: I believe it will be very difficult to reach on a production basis, particularly without an effective sub-slab depressurization system. The primary radon control measures used in our houses were improved below grade airtightness and mechanical ventilation, both of which were carefully constructed/installed. However, 94% and 77% of the measurements exceeded 0.2 and 0.7 pCi/L, respectively.

William A. Turner, Harriman Associates, Auburn, ME: Has any effort been made to characterize heating types—hot air vs. hot water—in the conventional homes? As one might expect, hot air systems have one-half the level of radon progeny as hot water systems due to plate-out from air movement.

Proskiw: Not yet. It will be performed once we have three years' worth of monitoring results (one year's worth of data were reported in the paper).

Carl N. Lawson, LRW Engineers, Tampa, FL: Is there any ground treatment, such as Visqueen, to keep the radon dormant?

Proskiw: No.