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EXHAUST VENTILATION AND RADON INDUCTION IN A SUBARCTIC CLIMATE

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ABSTRACT

This paper is based on research experience in radon transport. Radon in homes is a serious health concern in the Tanana Valley region of Interior Alaska. The authors have much research experience in this area and are keenly interested in radon transport and dynamics for this climatic zone.

The source of radon for Interior Alaska is primarily uplands metamorphic schist bedrock, which can allow radon induction pathways to basements. In addition, housing is becoming more health conscious and ventilation is becoming a standard anticipated element in building envelopes. This research focuses on an opportunity to discover how radon might be inducted in two houses recently built with exhaust-only ventilation systems. The houses were also found to have worrisome radon levels. These were made available to us for research and the result is reported herein.

The results show that indeed radon can be inducted by exhaust-only ventilation systems, as can carbon monoxide from an attached garage. However the results are complex and not intuitive. This experience adds to our sense that understanding radon transport requires a great deal of scrutiny and rigorous understanding of building science and pressure differentials in a house to fully comprehend and make sense of the results we see in research.

1. INTRODUCTION

Because we aspire to maintain the climate of the tropical savanna in our modern residential housing, it is essential that we control the flows of heat, air, and moisture into and out of those homes. Experience with residential buildings in the great natural laboratory of Interior Alaska has led the authors to fully appreciate the functional relationship of these three aspects of indoor comfort and health, and the consequent need to achieve good air tightness in the building envelope. This airtightness allows for control of air leakage, which is otherwise (and commonly in the past) uncontrolled.

Our research experience is also focused on radon transport, as that is a serious concern in the Tanana Valley of Interior Alaska. The authors have done much of the in-depth research and investigation of radon transport and dynamics for this climatic zone. Radon transport into residences is pressure driven. Since air leakage is also pressure driven, paying attention to the radon transport phenomena in our research houses can often lead to unexpected insights, and an understanding of the pressure dynamics of houses. Since radon is also a serious indoor air pollutant, we routinely monitor it during our research investigations. See figure 1 for building science conceptual graphic. We have also noted that humidity is a good indicator of air leakage, and therefore could also indicate the possibility of a radon prone house. Figure 2 shows some measurements of air leakage plotted against winter and summer humidity levels indoors.

The source of radon in Interior Alaska is primarily uplands metamorphic schist bedrock, highly fractured and often near the surface, so that it is intercepted during basement construction (i.e., at less than two meters (~8 feet) depth). This can allow radon induction pathways to the basement if that basement is not airtight. Uranium is present in this schist at about twice the average concentration for soils in general (~2 ppm, Paul Metz, personal communication 1992) and is the source of the soil radon for this geologic formation, which surrounds Fairbanks.

Other building science issues strongly affecting these concerns must be mentioned. They are the need for ventilation in residential buildings as airtightness is increased, and the consequent concerns about pressure dynamics and backdrafting of appliances, which normally exhaust combustion products with minimal stack draft pressure differentials. Of obvious concern is carbon monoxide. In our research we measure it as a routine matter, and report some important observations about it in this paper. Carbon dioxide, not typically a health concern, is useful as a surrogate for inferring the presence of other pollutants, as well as a good indicator of air leakage rates when employed as a tracer in dilution/decay tests. We continue its use in this work as in past efforts (Johnson, et al 2001). An additional research opportunity was afforded us when we became aware of a problem radon situation in two homes in the Fairbanks area, which had been built with exhaust-only ventilation systems. One of these also had an attached garage. This home was intensively monitored for carbon monoxide concerns, pressure differentials across the building envelope, as well as radon level during 2001.

2. FIELD METHODS AND DATA ACQUISITION

Over a three-year period from 1998-2000, our team gathered data on dozens of homes, but concentrated particularly on eight homes, to which we had superior access. Extensive data on carbon monoxide (CO), Carbon dioxide (C_{O2}), relative humidity (RH), and temperature (T, indoor and outdoor ambient) were gathered. In the eight focus homes, we collected data seasonally using TSI Q Traks, data acquisition devices which measure and record data on CO, C_{O2}, RH, and T. TSI Q Trak devices use IR adsorption to measure C_{O2}, electro-chemical detection for CO, thin film capacitive sensors for RH, and thermistors for T. For the three-year data acquisition the houses measured had volumes ranging from 102 m_3(3600 ft_3) to 908 m_3 (32,000 ft_3) and the number of occupants ranged from 2 to 4. Five had hydronic baseboard heating (HBH) and the rest had forced air systems. Five houses had attached garages.

For this study the data from blower door air leakage tests is used to determine the air leakage rates at 50 Pa, for eight of the houses. The blower door tests were done using the Energy Conservatory's blower door system. These were compared to winter and summer average percentages of relative humidity to determine the correlation between air leakage and RH, and also compared to indoor radon concentration for five of the houses which had radon mitigation systems, to determine the measurable affect of leakage on radon induction.

A new research opportunity became available to us when it was discovered that two homes had recently been built which had exhaust-only ventilation systems. These houses also had worrisome radon levels. One of these homes was made available to us. It had an attached single car garage. Since this home provided significant additional data and insight for this study, it is described in detail. This home was professionally constructed of a wood frame, on a concrete block foundation. The floor of the daylight basement is concrete and heated with an in-slab heating system via a hydronic, oil-fired heating system located in the garage. House floor area is 130 m_2(1400 ft_2) and the volume is 340 m_3(12000 ft_3). The ventilation system operated on a cycle at high and low rates of flow. The high volume rate is 132 l/s (280cfm), and the low is 94 l/s (200 cfm), as measured by hot wire anemometer at the exhaust vent on two separate occasions. Four passive "Fresh 80" vents are used to provide intake air. Two are mounted in the basement level in each bedroom about 2.1 m (7 feet) off the floor, and two more are on the first floor level 2.4 m (8 feet) off the floor in the kitchen/dining room. Occupants are two adults and two dogs. One vehicle was parked in the garage and left on a very regular schedule each weekday.

The following equipment was deployed in this home between 1/21/01 and 3/25/01:

- 2 Q Traks, one on each floor
- Sun Nuclear Radon Monitor recording 8 hr average concentrations
- Hobo temperature loggers, recording outdoor, main floor, and basement temperature at one-hour intervals
- Hobo state logger recording the ON/OFF times of the exhaust ventilator
- Hobo voltage logger/Modus Dp meter recording instantaneous pressures across the building envelope at 15-minute intervals.

3. RESULTS AND DISCUSSION

Figure 2 is a plot of percent relative humidity in five homes for winter and in three homes for summer, as a function of their respective air leakage (ACH @ 50 Pa). This was a fundamental question to which we sought an answer in this work. For building science insight it is useful to know just how strong the correlation is between air leakage and resultant relative humidity indoors. The results for our work are disappointing. The correlation is weak, and only one of the houses was able to maintain a winter relative humidity above 30%. It also was NOT the house with the least air leakage although it was one of the tightest houses measured. The ranges of airtightness for all houses measured was from 2.39 to 8.75 ACH@ 50 Pa. The house with the lowest air leakage rate differed from the house capable of maintaining the highest relative humidity, in that it is a three-story house. Clearly this can have a substantial effect during winter, and likely explains the disparity between leakage and relative humidity found in the two cases. There is a general trend toward lower humidity with increasing air leakage, but it is not dramatic for the eight houses we measured. Figure 3 shows the relationship between house air leakage (again expressed as ACH@ 50 Pa) and the radon concentration for five houses, which had radon problems. Again the relationship is weak but a trend for greater leakage leading to higher radon concentration is present.

<u>The Goldstream House: A Case Of Exhaust-Only Ventilation</u>

The next several figures and data sets are from the Goldstream house (as we call it) with exhaust-only ventilation. The first question to which we sought an answer is, "To what degree does the ventilation system depressurize the house?" Figure 4 shows clearly the depressurization is consistently 7 Pa above the non-ventilating condition. This also indicates that there is always about 2 Pa depressurization on the building envelope, presumably from natural stack effect. The fan operation causes an additional 7 Pa depressurization, so the net negative pressure moving air into the house is 9 Pa during fan operation. This difference tracks steadily throughout the record. The data points are 15-minute intervals.

Figure 5 is a plot of carbon monoxide data for the Goldstream house, averaged over two months, with data taken at five-minute intervals. This enabled us to answer our second question about the effect of exhaust-only ventilation: "How does the ventilation operation effect pollutant movement from the attached garage?" The plot clearly shows the consistent induced flow of carbon monoxide from the garage during the two ventilation fan cycles, which occur immediately after the car is removed from the garage regularly each morning at 6:30 AM. This data is strikingly similar to another study of a similar nature done by Freeman (2000) in Anchorage, Alaska. Freeman looked at the transport of carbon monoxide from attached garages in twelve houses, which had a mixture of both forced air and hydronic heating systems, but no ventilation systems. On some occasions Freeman found that exposure levels of carbon monoxide reached 115% of the EPA recommended eight-hour exposure average of 9 ppm. However in most cases, the immediate levels of carbon monoxide measured in the garage, and the subsequent exposure levels in the houses in the Freeman study are dramatically higher than the two month average and subsequent exposure measured in the Goldstream House. This is unexpected, but indicates that the depressurization, is definitely causing carbon monoxide to enter the house after the cold start of the stored automobile. The resulting level of carbon monoxide in the Goldstream house is not as high as in many of the houses Freeman measured. It appears that induction of carbon monoxide from the attached garage doesn't necessarily get worse with a depressurizing ventilation system. It consistently occurs, but it may be that dilution of make up air from other leakage in the building shell may help moderate the concentration of the resulting carbon monoxide in the Goldstream house. Another important factor may be return air duct leakage in the garage of several of the Anchorage houses, which could accelerate the movement and increase the concentration of CO in the houses that are forced-air heated. Freeman (2000) notes as one of his conclusions, that "CO transfers were particularly high where furnace ductwork of forced-air heating systems was located in the garage." Freeman (2000) infers the possibility of leakage in the return ducts but did not investigate this in his study.

Radon Induction And Exhaust-Only Ventilation

Next we examine figures 6 and 7. Figure 6 shows the 8-hour averages of radon concentration for an entire year. A striking feature of the plot is the near-disappearance of radon induction during much of the summer for the Goldstream house. This confirms other measurements and experience in Interior Alaska regarding summer radon levels (Schmid et al 1999). For reasons that are not entirely understood, the source strength and transport of radon seems to greatly decline in summer. But the pressure differential over the building shell, the opening of windows for ventilation, the absence of frozen soil at the ground surface, and lower soil gas pressure all probably play a role. During the winter however, the radon levels fluctuate greatly, reaching nearly 100 picoCuries per liter in early October, then dropping to a fluctuating level between 50 and 10 picoCuries per liter through most of the winter, rising briefly to over 120 picoCuries per liter again in February. After this brief peak the level drops to the 10-40 picoCurie range again until the summer thaw occurs in late May, and the radon level diminishes to below 4 picoCuries. All this is quite confounding, and more research is necessary to explain the fluctuations. Certainly they are not all due to the induction of radon by the exhaust ventilation system.

Figure 7 allows us to speculate on the effect of the ventilation system. It shows what happens to the radon level in the Goldstream house when the system is turned off for five days (the last five days plotted on figure 7). Clearly the radon level goes up steadily, nearly doubling in the five days it is turned off. Although counterintuitive, it nonetheless appears that radon induction is reduced by the ventilation fan. One hypothesis is that just as in the case of dilution of the induced CO from the garage, the net effect of the exhaust ventilation may also be dilution of the radon. This could be explained more credibly if we knew what the air leakage above grade is for the Goldstream house. A test of the air exchange in the Goldstream house was done (10/22/00, outside temp -4 C, 25F, gusty wind) and was determined to be 2.7 ACH at 50 Pa. Air leakage could certainly cause some dilution at this rate, but much depends on the distribution of that leakage. This was not determined during the blower door test.

A cursory balance of airflows from make-up air inlet vents (Fresh 80, 2001) compared to the exhaust volume of the fan is instructive. The Goldstream house has four Fresh 80 inlet vents. Each is assumed to be operating at a differential pressure (Dp) of 9 Pa during exhaust ventilation. At this Dp, each vent has a rated airflow capacity of 4.7-5.1 l/s (10-12 cfm) (Fresh 80 Literature). Four vents could optimistically provide only 19.2-20 l/s (40-48 cfm), yet the fan is exhausting at minimum (by our measurement) 94 l/s (200 cfm). The unaccounted difference of 70.5 l/s (150 cfm) must therefore be coming from air leakage (induced infiltration) into the house. Clearly this could dilute indoor pollutants, as it is likely all outdoor air. The measured difference in ventilation rate in the basement of this house between the on and off condition of the ventilator was a factor of 2. When the ventilator was on, the rate was 0.6 ACH hour, and with the ventilator off, it was 0.3 ACH.

4. CONCLUSIONS, INFERENCES, AND SUGGESTIONS FOR FURTHER RESEARCH

A. Although a weak correlation exists between air leakage measured with blower door technology and the ability to maintain healthy indoor relative humidity levels in winter (>30%), the levels of airtightness in the houses in this study were not high enough to consistently maintain healthy relative humidities. Further research on a group of homes with air leakage rates between 1.5 and 2.5 ACH@ 50 Pa would clarify the range of airtightness which is needed for humidity control. It may also be crucial where the majority of the air leakage in a house is with respect to the neutral pressure plane. A large amount of leakage at the ceiling of a house may be more problematic for induction of pollutants than leakage at ground level, and its effects may be significantly different.

B. House air leakage is also weakly correlated with radon induction. The house with the highest leakage rate also had by far the highest radon induction rate, but other houses with more modest leakage had very modest radon induction rates. The correlation is always positive however, with higher leakage rates yielding higher radon induction.

C. An exhaust–only ventilation system induces a consistent negative pressure of about 7 Pa above the natural pressure gradient, and consistently inducts carbon monoxide from an attached garage after cold auto starts, if no air sealing or blockage of the air flow is in place.

D. Radon levels in the Goldstream house fluctuate greatly when the exhaust ventilation system is in operation. When it is shut down the radon levels in the house rise to nearly double the average radon level when the ventilation system is operating. It is not possible to adequately explain this without knowing the air leakage distribution of the Goldstream house.

E. Radon levels consistently drop during the summer months in Alaska, as several recent studies have confirmed. Real Estate transactions unfortunately often occur during the summer, with accompanying demands for radon tests. Clearly the results of summer radon tests should not be considered valid. The winter levels of radon can be orders of magnitude higher.

F. Inferring the rate of make-up airflow from the design vents (Fresh 80) for the Goldstream house, it is clear that 75% of the make-up air is outside air brought in through induction by the ventilation system. This amount of air is .75 ACH hour, and could account for dilution of indoor air pollutants noted in the study.

Authors' note: Much of this paper was presented at the "6th Nordic Building Physics Symposium" in Trondheim, Norway , at the National Technical University of Norway, June 17-19, 2002.

5. REFERENCES

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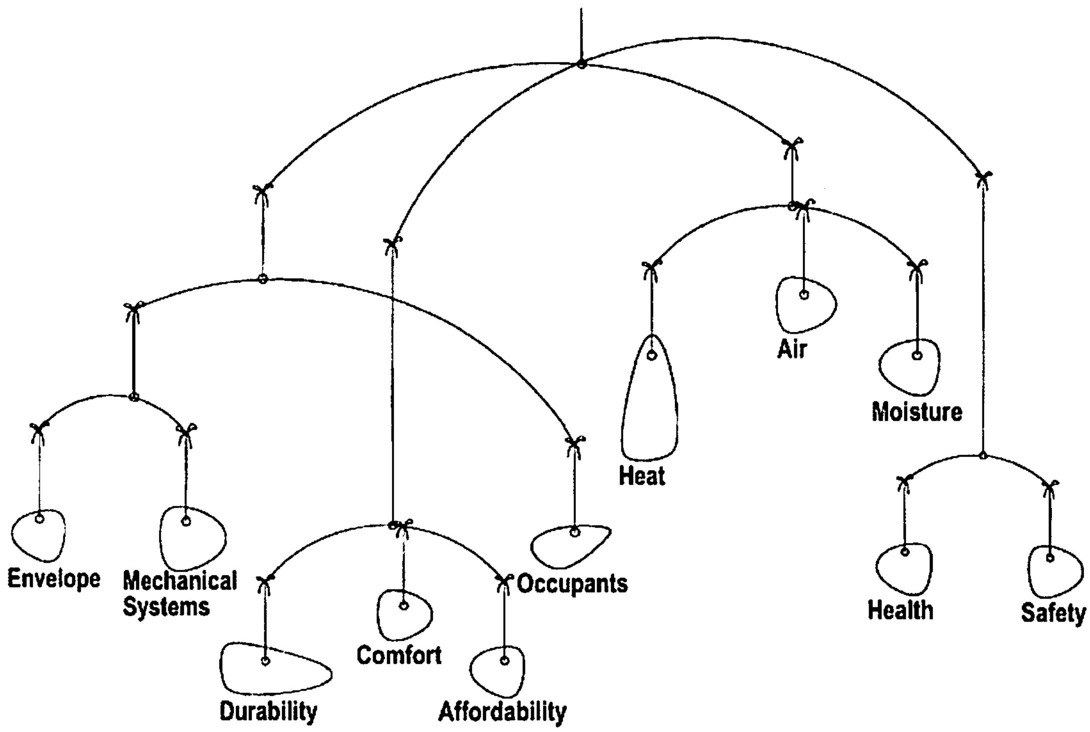

Figure 1: A building, in order to function in healthy balance, is a design problem of some complexity. Controlling the movement of air, moisture, and heat is a primary building physics problem.

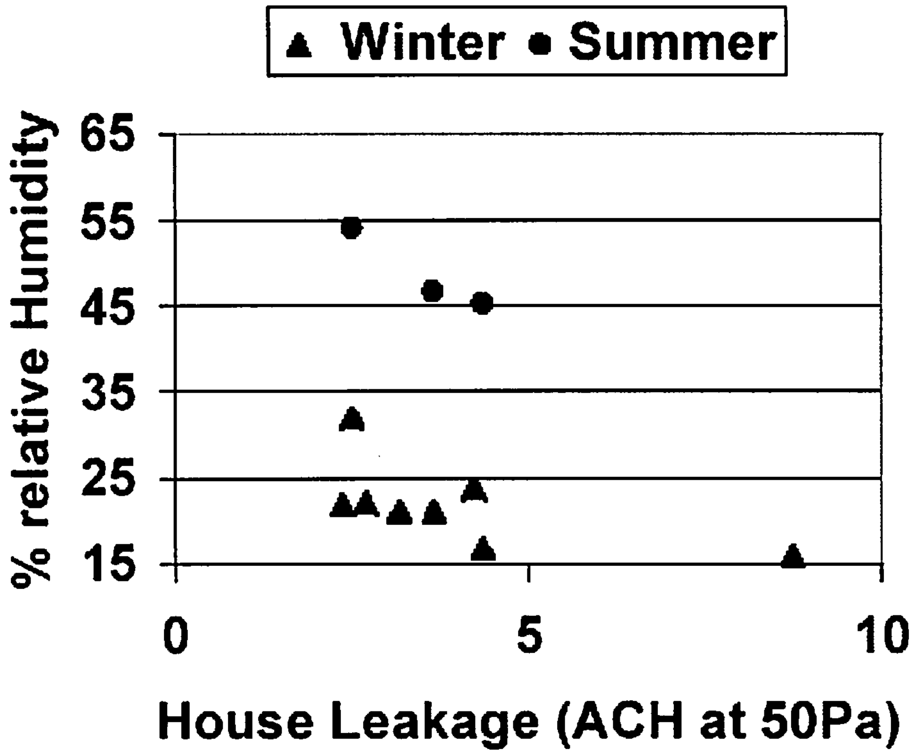

Figure 2: House relative humidity, both summer and winter, as a function of as a function of air leakage, in air changes per hour.

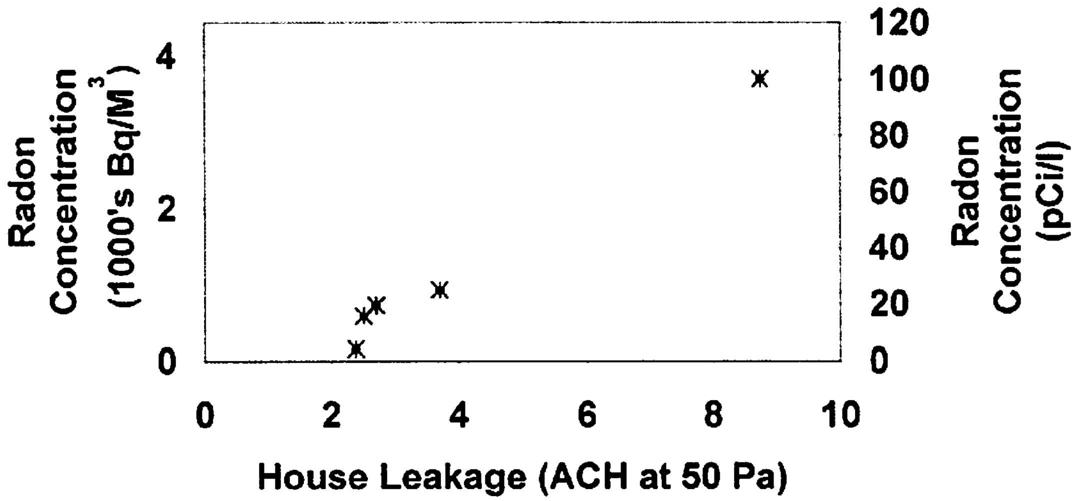

Figure 3: House air leakage versus winter radon concentration.

Figure 4: Differential pressure across building envelope for Goldstream house, with ventilator on, and with it off.

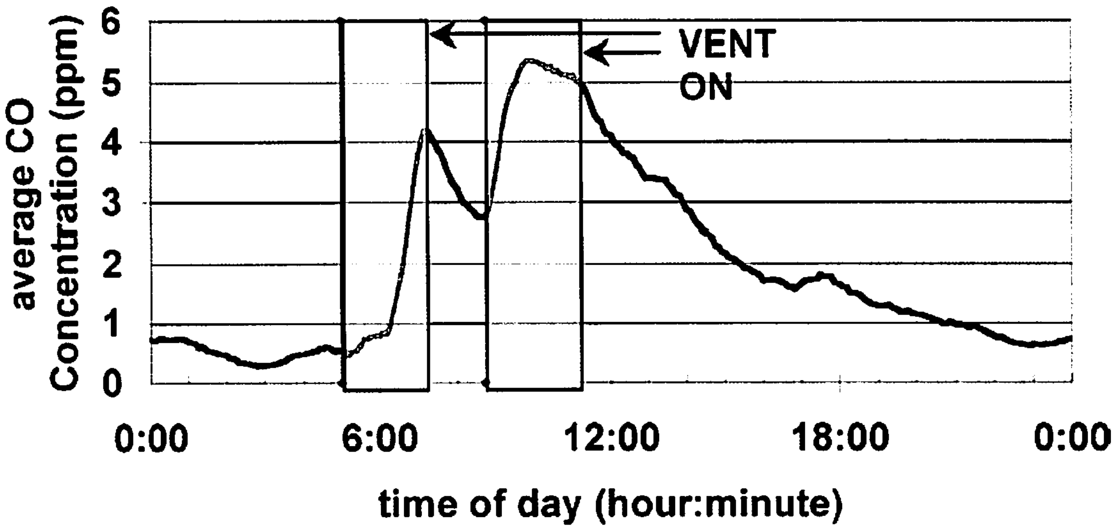

Figure 5: A plot of average carbon monoxide concentration vs. time of day for Goldstream house with attached garage.

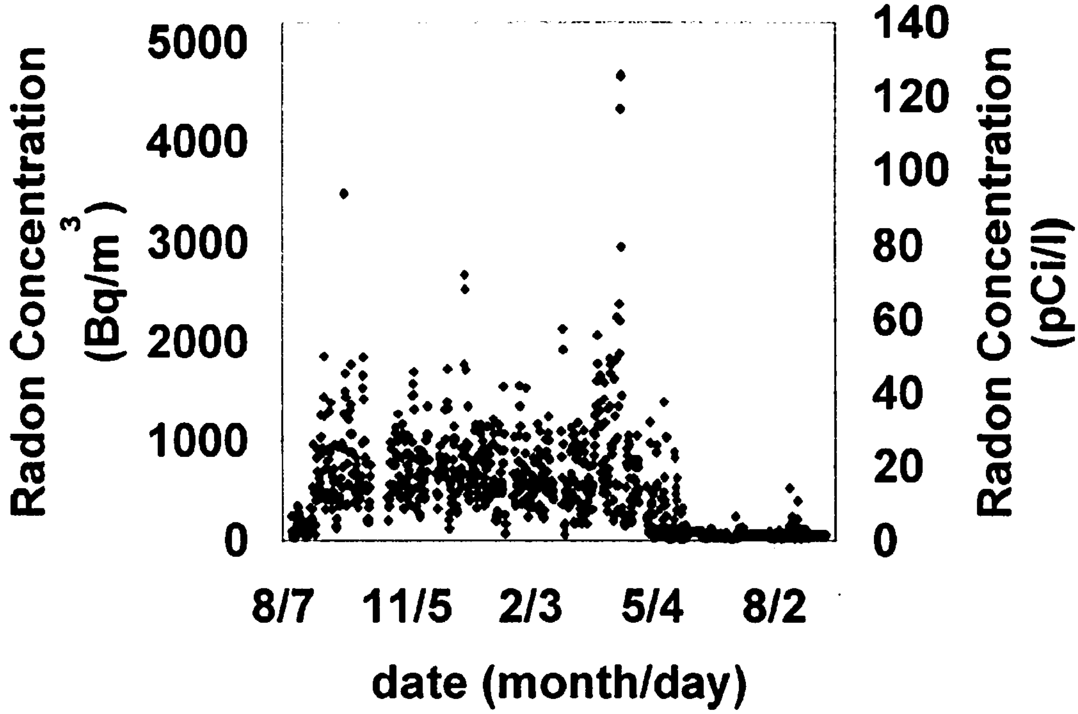

Figure 6: A plot of seasonal variability of radon concentration, Goldstream house, from August 7, 2000, through August 2, 2001.

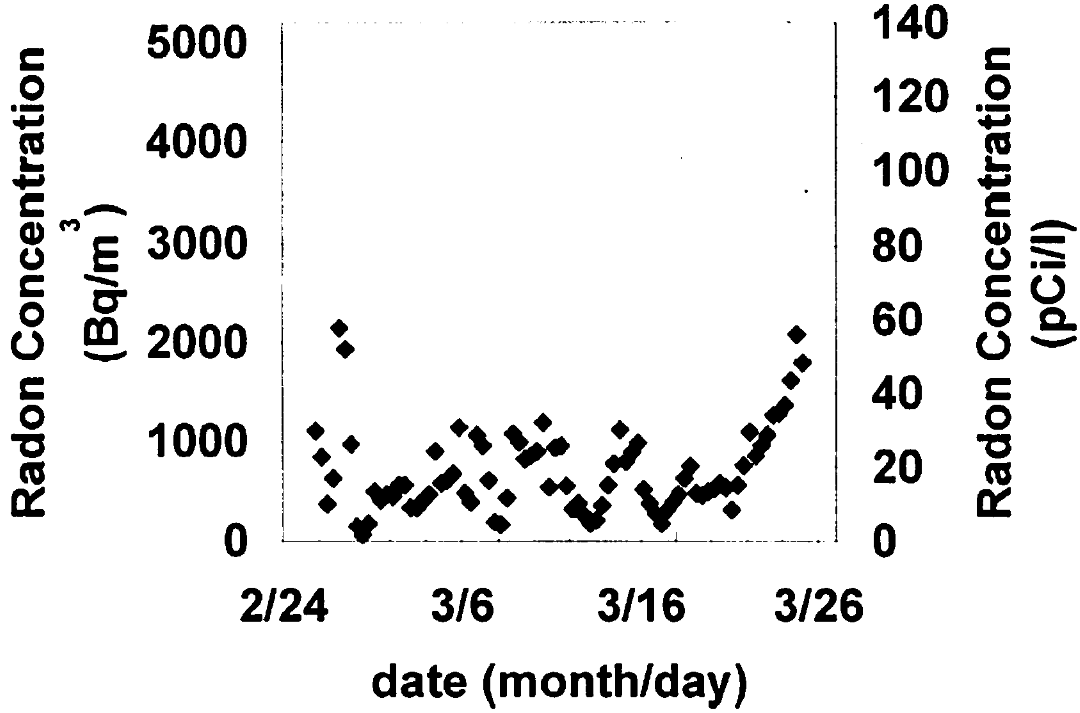

Figure 7: A plot of radon concentration versus time for the Goldstream house. During the last week of this measurement period, the ventilation system was turned off, and the result was a steady increase in radon concentration.