# RESIDENTIAL VENTILATION RATES AND INDOOR RADON DAUGHTER LEVELS

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As a result of the increasing emphasis on energy conservation, the airtightness of housing has been increased. The resulting reductions in ventilation rate have given rise to concerns over the potential deterioration of indoor air quality. This paper presents the ventilation rates which were measured in over 70 Northern Ontario residences using tracer gas techniques. In many cases, radon gas and radon daughter measurements were taken simultaneously.

Observed ventilation rates in occupied houses built in the period 1955 to 1983 ranged from 0.06 to 0.77 airchanges per hour and, in newly built unoccupied residences, as low as 0.03 airchanges per hour were measured. On average, the ventilation rate in modern electrically heated houses were one half of those in older oil heated houses.

At the lowest ventilation rates, air quality was no longer acceptable. Ventilation rates could be increased, and air quality restored, by using the heating system circulation fan to draw in outside air via a small pipe to the outside.

The ratio of radon daughters to radon gas is almost independent of ventilation, but dependent on the amount of air circulation. The latter relationship is probably caused by an increased plate-out of RaA (Po-218) with increased circulation.







## 1. Introduction

Between the years 1977 and 1983 DSMA ATCON LTD. was contracted to test houses in Elliot Lake, Ontario, and to investigate and remedy those in which elevated radon daughter concentrations were found. As part of a development program aimed at identifying the causes of high radon daughter levels, ventilation rates were measured in a number of these houses using $SF_6$ (sulphur hexafloride) tracer gas techniques. During this period and later in 1983, ventilation tests were also conducted in newly constructed houses.

A total of 170 ventilation rate measurements were conducted in 70 different residences over this period. Simultaneous radon and radon daughter levels were measured during nearly 60 of the tests. These results taken together, although not intended as a comprehensive study of house ventilation rates, constitute a collection of data from which some interesting inferences can be drawn.

## 2. Methodology

### 2.1 Ventilation Test

The whole-house ventilation rates were measured by using $SF_6$ tracer gas. This gas was chosen as it is not a normal constituent of air. It is odourless, non-toxic, and can be detected in the parts per billion range using a gas chromatograph equipped with an electron capture detector.

Evacuated tubes were injected with 2 ml of pure $SF_6$ for convenient transportation to site. Within each house being tested 2 to 4 tubes were opened, depending on house volume and number of levels, to give an initial concentration of 20-30 ppb. To ensure a uniform initial concentration throughout the house, the furnace fan (when existing) was turned on for 5 minutes, doors were left open,and the first sample not taken until an hour after release to allow thorough mixing.

Sampling was done either with a hand pump and 10 liter aluminum-polyester bags while going from room to room, or by opening evacuated test tubes in at least 2 locations in the house. Four or more samples were taken over at least a 7 hour period.

The samples were analyzed on a gas chromatograph. To avoid detector variations with time, the samples from the same house were analyzed within a few minutes of each other. $SF_6$ peak heights were plotted against time on semi-log graph paper and the ventilation rate, in air charges per hour (ach), was taken from the slope of the line going through the data. This gives the ventilation rate averaged over 7 to 8 hours.

### 2.2 Radon and Radon Daughter Concentrations

Standard grab-sampling techniques were used to measure radon and radon daughter concentrations. A sample of house air was drawn through a filter which was subsequently alpha-counted and the Working Level was calculated using the Kusnetz method. Samples of radon gas were collected with scintillation cells and the radon concentration estimated by alpha-counting.

The equilibrium fraction was calculated as the ratio of 100 WL to radon gas concentration (pCi/L).

3. Results

3.1 Ventilation Rate By Residence and Heating Type

Heating season ventilation rates in occupied houses built prior to 1976 and heated by oil fired forced air furnaces, ranged from 0.12 to 0.63 ach in detached houses, and averaged 0.28 ach (20 tests). Similar semi-detached occupied houses had ventilation rates ranging from 0.45 to 0.77 ach, averaging 0.63 ach, (5 tests). This is significantly higher than the ventilation rate for detached houses.

Heating season ventilation rates in occupied houses built after 1976 and heated by electric baseboards ranged from 0.09 to 0.67 ach in detached houses, averaging 0.16 ach (15 tests). Semi-detached houses had ventilation rates ranging from 0.04 to 0.67 ach, averaging 0.13 ach (12 tests).

On average, the ventilation rates observed in houses heated by oil fired forced air furnaces are nearly double those of more recent housing with electric baseboard heat.

Two house trailers built after 1976 had ventilation rates of 0.14 and 0.34 ach. The latter trailer had a wind turbine ventilator. These rates are similar to those observed in electric baseboard houses.

Two widely separated apartment units in a high rise built in 1979 with electric baseboard heating and corridor pressurization had ventilation rates of 0.20 and 0.21 ach in the summer. When unoccupied, and without the corridor pressurization, the apartment units had rates of 0.03 and 0.04 ach in the summer. These extremely low ventilation rates in combination with the emanation of radon and thoron gas from the aggregate in concrete floors and ceilings gave rise to high levels of radon and thoron daughters.

This points out the inherent airtightness of concrete apartment buildings, and the importance of the building ventilation system for air quality.

3.2 Occupied Versus Unoccupied Ventilation Rates

Occupation of a house increases the ventilation rate, not only due to people opening and closing doors, but also through operation of kitchen and bathroom exhaust fans and vented clothes dryers.

In the heating season, detached occupied houses heated by oil-fired furnaces had ventilation rates averaging 0.28 ach (20 tests). Similar unoccupied residences had ventilation rates ranging from 0.11 to 0.23 ach, averaging 0.16 ach (3 tests).

Occupied detached and semi-detached houses heated by electric baseboards had heating season ventilation rates ranging from 0.10 to 0.48 ach, averaging 0.19 ach (8 tests). Similar unoccupied residences had ventilation rates ranging from 0.04 to 0.67 ach, averaging 0.12 ach (19 tests). Taken together, these suggest that occupancy increases the ventilation rate by 0.1 ach.

The effect of occupation was shown conclusively when we had the opportunity to measure the same houses before and after occupation in similar weather conditions. Detached houses heated by electric forced air furnaces



had heating season ventilation rates when unoccupied ranging from 0.06 to 0.17 ach, averaging 0.09 ach (4 tests), when occupied rates ranged from 0.11 to 0.26 ach, averaging 0.18 ach (8 tests).

On average there is an increase of 0.1 ach in ventilation rate when the houses are occupied.

3.3 Date Of Construction

The residences that were built before 1976 had heating season ventilation rates ranging from 0.10 to 0.77 ach, averaging 0.27 ach (40 tests).

Residences that were built after 1976 (except those with installed ventilation systems) had heating season ventilation rates ranging from 0.04 to 0.67 ach, averaging 0.13 ach, (65 tests).

These results illustrate the size of the reduction in ventilation rate achieved in new housing. Part of this is due to the elimination of the combustion air requirement by electric heating, but part is due to better installation of air barriers in new houses. However, it is interesting to note that even the older houses built between 1958 and 1968 in Elliot Lake have ventilation rates of one half of the generally assumed figure of 0.5 ach.

3.4 Ventilation Rates During Different Seasons

Seven of the residences tested during the heating season were retested in the summer while windows were closed and exterior temperatures were higher than interior. The summer ventilation rates ranged from 0.06 to 0.21 ach, averaging 0.08 ach, compared with the heating season rates which ranged from 0.19 to 0.67 ach and averaged 0.34 ach.

Although the ventilation rate in the summer was only 25% of that in the winter, radon daughter levels were not much higher in summer than in winter, indicating that radon supply rate was also lower in the summer.

The reasons for this are that the same forces that produce ventilation flows (wind forces and the stack effect caused by temperature differences between inside and outside) also produce the soil gas flows that bring in the majority of the radon. In summer, the stack effect is often zero, and the winds are lighter. On average then, both the ventilation rate and radon supply are changed in the same proportion, and the house radon concentration remains the same.

3.5 Effect of Sub-Floor Exhaust on House Ventilation

The most common way of ensuring low levels of radon daughter levels in new residences in Elliot Lake is the installation of perforated pipe on a 2.5 m grid in coarse fill beneath the basement floor.Soil gas is drawn from this by a 100 cfm exhaust fan. By exhausting air from under the basement slab, air is forced to flow from the house to the soil through any openings in the slab, and prevents the movement of soil gas containing radon in the opposite direction.

The heating season ventilation rate of 9 electric baseboard heated houses with their sub-floor exhaust fan turned off ranged from 0.09 to 0.67 ach and averaged 0.15 ach. These same houses, with their sub-floor exhaust fan running, had heating season ventilation rates ranging from 0.18 to 0.67 ach and averaging 0.32 ach.

This increase of 0.17 ach (113%) in ventilation rates is due to the amount of air withdrawn through the floor joints. This is illustrated in two houses where the open area of basement floor perimeter crack and other penetrations had been reduced by extensive caulking. Operation of the sub-floor exhaust had no effect on the ventilation rate though it did reduce radon concentrations. From these observations it is clear that sub-floor exhaust systems can reduce the indoor radon daughter levels by reversing the house soil pressure differential, without impacting on energy conservation by increasing ventilation rate.

### 3.6 Effect of Continuous Circulation on House Ventilation

If the furnace fan is run continually, the concentrations of pollutants are decreased. Part of this is due to dilution of local sources with house air but particulates and radon daughters (which are attached to particulates) are removed by filtration and plate-out due to the increased air turbulence. The effect of circulation alone on ventilation rate is very small.

The heating season ventilation rates of 14 houses while the forced air heating system ran normally, i.e. only when heat was called for, ranged from 0.03 to 0.23 ach and averaged 0.09 ach. When the furnace fan ran continuously, the heating season ventilation rates of these same houses ranged from 0.06 to 0.29 ach and averaged 0.14 ach. This indicates that increasing air circulation in a house does not significantly affect the ventilation rate.

### 3.7 Ventilation Rates And Air Quality

Due to the concern generated about indoor air quality in newly constructed houses, 8 houses were studied where ventilation rates were controlled by continuously inducing fresh air via the heating system, using the suction provided by a continuously running furnace fan.

Without the exterior air supply, the ventilation rates in these 8 houses ranged from 0.06 to 0.27 ach and averaged 0.13 ach, typical of newly built houses during the heating season. Air quality was poor, with high humidity levels in the houses with lower ventilation rates. When fresh air was continuously induced, the ventilation rates in these houses ranged from 0.17 to 0.40 ach and averaged 0.24 ach, with generally satisfactory air quality. These results show that it is possible to achieve ventilation rates and air quality to levels observed in older forced air heated homes with this technique. The advantages of this approach, as compared to other ventilation methods are its low installation and maintainance costs.

It is noteworthy that these low ventilation rates were not obtained in super-insulated custom built homes, but in standard mass built housing. This is a clear indication of how much the airtightness of new housing has been improved.

### 3.8 Equilibrium Fraction Versus Ventilation Rates

During 57 ventilation tests, simultaneous radon and radon daughter concentration measurements were made. Equilibrium fractions (100 WL/Radon) were calculated from these data and compared with theoretical equilibrium fractions expected with ventilation as the only removal mechanism as shown in Figure 1. Our results show poor agreement with the theoretical curve, and no significant correlation with ventilation rate.



The majority (67%) of the equilibrium fraction data falls below the theoretical curve. Those points above the curve are generally associated with low concentrations with large uncertainties, and large uncertainties in the ratio.

The number of points that lie well below the theoretical curve clearly indicates that there is a removal mechanism other than ventilation. This is thought to be mainly "plate-out" of the radon daughters on surfaces such as walls and furniture, though part of the removal may be due to filtration in the air circulation systems.

## 4. Conclusions

Pre-1976 oil fired forced air heated residences were observed to have higher heating season ventilation rates, on average 0.28 airchanges per hour (ach), than post-1976 electric baseboard heated residences, which averaged 0.16 ach.

The ventilation rates in summer with windows and doors closed are about 25% of those in the heating season.

All of these ventilation rates are much lower than the 0.5 ach generally assumed as typical for housing. At the lowest values of ventilation rate, the indoor air quality is perceptibly deteriorated.

A significant fraction of the ventilation rate of a house is caused by the actions of the occupants. The average ventilation rate in modern housing increased by nearly 0.1 ach (80%) after the house was occupied by a family of five. However, this was not sufficient to compensate for the increased rates of pollutant generation by occupants, particularly humidity and cigarette smoke.

Continuous air circulation reduced concentrations of indoor pollutants (e.g. humidity, formaldehyde) by dilution into the whole house volume and radon daughter levels by increased air filtration plate-out. When this was coupled with induction of fresh air via the forced air system, acceptable indoor air quality was obtained at ventilation rates in the region of 0.25 ach. The cost of this installation is so low as to make air to air heat exchangers unattractive as a ventilation alternative.

The ratio of radon daughters to radon gas in a house is almost independent of ventilation rate. At the low ventilation rates found in houses, the major removal mechanisms are plate-out on surfaces and filtration in forced air systems.

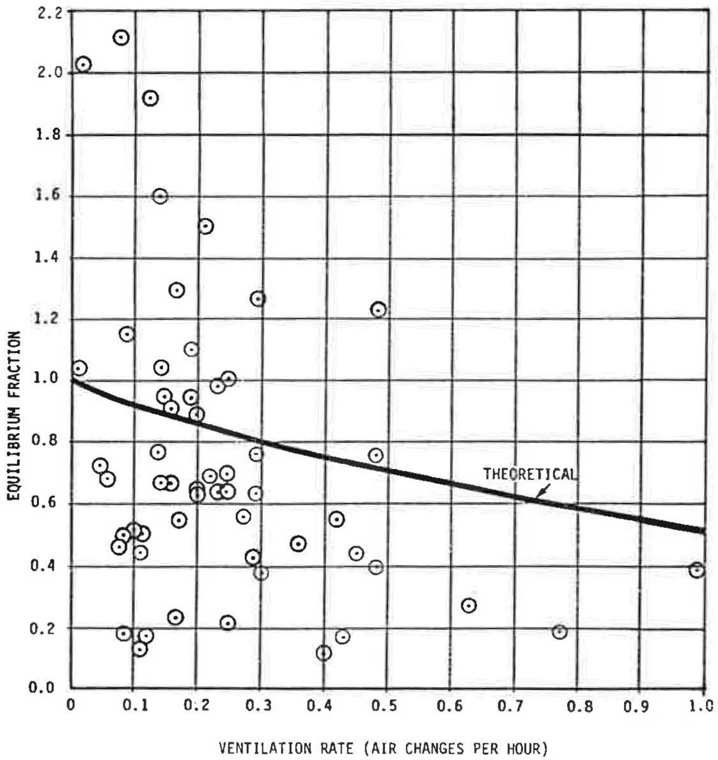


Figure 1 Equilibrium Fraction Versus Ventilation Rate



DETAILED FIELD TESTS OF RADON CONTROL TECHNIQUES IN NEW YORK STATE HOUSES

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Sixty houses with widely different construction practices and in different locations in upstate New York were monitored for integrated radon concentration. Four houses with the highest indoor air radon levels were then monitored using extensive real-time continuous instrumentation to evaluate temporary radon control techniques. Based on this experience, permanent controls were then installed and tested (using integrating monitors) in 14 houses. Among the results from real-time monitoring were insights into relationships between basement radon concentrations and basement pressure (relative to outside pressure). Of the several radon control techniques tested, whole house ventilation and basement ventilation (using air-to-air heat exchangers) were only marginally effective in reducing radon levels, while ventilation of unpaved crawl spaces and the combination of sealing below-grade openings and venting the sub-slab, provided the greatest reduction in indoor radon concentrations.

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