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"Attempts to Improve the Uncertainty in Short Term Summertime Radon Measurements by Inducing Wintertime Pressure Differentials on Basements"

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by

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Abstract

This paper summarizes efforts made to emulate wintertime radon-ventilation dynamics so that short term radon measurements can better test a mitigation effort. Past experience has shown that in heating climates, what appears to be a successful mitigation method in the summertime may be overwhelmed by negative pressures induced on the basement by wintertime stack effect and mechanical appliance operation.

Two types of efforts were made to reproduce wintertime conditions in the summer. The first was to use a window fan to induce 7 to 8 pascals of negative pressure across the building shell. The second was to increase the house temperature so that it was 30° F greater than the ambient. This would induce negative pressures by stack effect and by the furnace running.

Key Words

radon, negative pressure, diurnal cycle, radon mitigation

Introduction

In Spring of 1986 a cluster of houses with high radon concentrations were discovered in Clinton, New Jersey. In response to a request from the New Jersey Department of Environmental Protection (DEP), the Air and Energy Engineering Research Laboratory (AEERL) of the United States Environmental Protection Agency (EPA) selected this area as part of its research and demonstration program on indoor radon reduction methods. Research Triangle Institute was contracted to identify and apply radon reducing techniques to 10 of the Clinton homes. Because of the high radon levels found in these homes one of the major requirements of the project was to reduce the radon concentrations to acceptable levels during the summer when windows and doors could be kept open. With all the windows and doors open the radon levels in these buildings stayed below the Office of Radiation Program's recommended evacuation concentration. Because the project could only mitigate 10 houses and the New Jersey DEP had already found more houses with high radon levels, it was important that other affected homeowners benefit from the knowledge gained from the demonstration project before the onset of cold weather. This project has completed the first phase of radon mitigation in the 10 houses selected and is now in the second phase of long term follow-up measurements to see if the remedial methods survive winter conditions and to monitor the durability of the systems used.

Pre- and Post-Mitigation Monitoring

At the time of this project there were no established protocols or standards for making pre- and post-mitigation measurements. The only available measurement criteria were the EPA Interim Protocols for Radon and Radon Decay Product Measurements from EPA' Office of Radiation Programs and a draft copy of Protocols for Radon and Radon Decay Products Screening and Follow-up Measurements from the same office. These were used as the basis for making the measurements in the Clinton Project. The measurement criteria required that the house have all the windows and doors closed for 12 hours before the testing began and during the entire time measurements were being taken and also included a number of device specific requirements. Additionally, they were written for screening or follow-up measurements which are designed to identify problem houses or to characterize the living area concentrations on an annual basis so that they can be compared to EPA guidelines.

In trying to apply these protocols to pre- and post-mitigation measurements two problems were encountered. First, if all the windows and doors were closed on any of the 10 houses in the study, the radon concentrations promptly rose to over 200 pCi/l (picocuries per liter) which was higher than the recommended evacuation level. Second, because the high radon levels demanded immediate mitigation, measurements could not wait until winter when radon entry in the houses most likely would be greatest.

The first problem was addressed by coordinating homeowner vacations and weekend excursions with the monitoring efforts. Frequently this yielded 2 to 4 days of continuous monitoring with the building closed and an additional 2 to 4 days with the windows open. The second problem was more difficult to address and is the major thrust of this paper.

Emulating Winter Conditions

There are two possible reasons that wintertime conditions in northern climates are design conditions for radon mitigation. The first reason is that the ground is capped either by frost in the upper soil or a layer of melting snow in the subnivean soil layer. This inhibits diffusion of radon into the air from the ground surface and results in higher concentrations of radon in the soil gas1. The second reason is that combustion heating equipment (boilers, furnaces, and stoves) and a temperature induced stack effect in the house put a negative pressure on the basement. Makeup air for this suction is drawn into the basement from outside, and some fraction of it (probably 5 to 20%) is drawn in through cracks and holes in the foundation that are below grade2. This increases the entry rate of radon into the building. Figures 1 and 2 illustrate a number of sources of negative pressure on basements and the operation of the stack effect. Frequently this increased source term will far outweigh the countering effect of increased dilution air being drawn in from above grade openings in the building shell, and the net result is an increase in the radon concentrations in the building. Figure 3 [3]illustrates the relationship between inside and outside air pressure differential and radon concentration.

A related problem that should be considered concerns one of the most successful radon mitigation techniques which is to depressurize the soil that surrounds the foundation walls and floors. This amounts to sucking soil gas from much of the surrounding soil mass and diverting it directly to the outside of the building. When this is implemented, air flows from the basement through cracks and holes in the foundation to the depressurized soil mass. A smoke tracer will show air leaving the basement via openings in the concrete slab. If the suction under the concrete slab floor or behind the concrete basement walls is not strong enough (weak fan or low permeability soil) in the winter, the greater negative pressure on the basement air will reverse the airflow through the foundation penetrations. Under these conditions a smoke tracer will show soil gas entering the basement from below the concrete slab. What may be a successful summertime mitigation effort may fail under wintertime design conditions. Figure 4 [4]shows this kind of failure. The measurements were made during the fall of the year. The first five days of continuous radon decay products concentrations are with the house closed and the mitigation technique of depressurizing the sump hole turned off. On day five the mitigation fan was turned on and the levels of radon decay products dropped for five days. On the eleventh day a cold front moved in and the combination of increased stack effect and the furnace running depressurized the basement enough to draw radon bearing soil air into the basement. Radon entered at a high enough rate to overwhelm the dilution effect of the increased ventilation from above grade air leaks.

Two ways were envisioned to create the increased negative pressure of winter while monitoring in the summer. The first way was to use a window fan to induce 7-8 Pa (0.028 -0.032 in. water) across the building shell. The second was to raise the temperature of the house air to 98°F (37°C) to get a stack effect even though it was summertime. Both methods were experimented with briefly.

Method

A 20 in. (51 cm) diameter three speed window fan was placed in a living space window while radon was monitored continuously using a Pylon AB-5 and passive scintilation cells. For part of the monitoring period, the houses were closed with the fan on; part of the time, they were closed with the fan off; and part of the time the windows were open with no fan. Figures 5, 6, 7, 8 and 9 show the results of these tests.

The instruments used to make the measurements were as follows :

Continuous radon - Pylon AB-5 using a passive scintilation cell that samples by molecular diffusion through a polyurethane filter. Calibration was conducted at the beginning, middle and end of the project at the DOE, EML in Manhatten.

Integrated radon measurements - activated carbon canisters of the type developed by Andy George were used for two and four day integrated measurements. The analysis was done by counting the gamma from the short term decay products.

House tightness - Minneapolis fan doors were used to measure the tightness of the buildings and to estimate natural ventilation rates.

Air pressure differentials were measured using magnahelics, inclined manometers and micromanometers.

In the first house monitored, House C6-B (Figure 5), there were only two conditions, fan-on/house-closed and fan-off/house-open. The horizontal lines in the figure indicate the radon concentration returned from an activated carbon canister that was co-located with the continuous monitor. The length of the line reveals how long the canister was exposed. The average concentration for the first period was approximately 650 pCi/l which compares favorably with the values of 964 and 542 pCi/l measured with activated carbon in the same location by New Jersey DEP 2 months earlier (4/6-9/86 and 4/16-19/86). During our June monitoring, the outside temperature averaged about 73 °F (22.8 °C), while the average temperatures during the two DEP monitoring periods were 49 °F (9.4 °C) and 50 °F (10 °C). While the fan was on, measurements showed 7 Pa (0.028 in. water) negative pressure across the building shell. When the fan was shut off, the concentration dropped quickly to less than 10 pCi/l. The remainder of the fan-off/house-open period showed a distinctive diurnal cycle with peaks in the early part of the day and valleys in the late afternoon. Figure 6 shows this same diurnal cycle in the control house, House C2-B, that was monitored continuously during the same time period as House C6-B. The control house was operated in a closed house condition in accordance with EPA screening protocols.

The second house, House C1-A, was monitored 6/6-13/86 using the passive continuous radon monitor during three monitoring periods. The results are shown in Figure 7. The range of conditions were fan-off/house-closed, fan-on/house-closed, and fan-off/house-open. During the first period the concentration rose quickly after the windows were closed and peaked at 1300 pCi/l near 5 a.m. on 6/7 then began to drop until 11 a.m. on 6/7 when the window fan was turned on, inducing a negative pressure of 8 Pa (0.032 in. water) on the house. At this point the level of radon increased very quickly to a much higher peak of 2600 pCi/l and averaged 2075 pCi/l for this monitoring period. This compares well with New Jersey DEP (activated carbon) values of 2254 and 2141 pCi/L for the same locations on 4/7-9/86 and 4/16-19/86. At 3 p.m. on 6/9 when the fan was removed and the windows opened, the radon level in the house plummeted to a low of 60 pCi/l at 7 p.m. on 6/9 and then showed the by-now-familiar diurnal cycle seen in all the houses monitored in Clinton.

The third house, House C3-B (Figure 8), was monitored 6/16-24/86 using the passive continuous radon monitor and had three monitoring periods: fan-off/house-closed, fan-on/house-closed, and fan-off/house-open. Note that the effect of the fan induced negative pressure was dramatically different in this house than in either of the first two houses monitored. When the fan was turned on it seemed to have caused very wide excursions in the radon concentrations in the house, ranging from a low of 100 pCi/l to a maximum of 2500 pCi/l over a period of 12 hours. The average concentration during the fan-off/house-closed period was about 1375 pCi/l, compared with 1530 pCi/l measured by the New Jersey DEP (activated carbon) in the same location on 3/14-17/86. For the fan-on/house-closed period, the average was 922 pCi/l. One possible explanation for the differences seen in this house on the effects of using a fan to induce negative pressures is the relationship of the radon source to the building. In this particular house the floor was a slab on grade with heating ducts under the slab. Examining the holes in the slab from the warm air grills after the risers were removed led to the discovery that all of the soil beneath the slab had subsided leaving a 1-4 in. (2.5-10.2 cm) cavity between the bottom of the slab and the earth surface except where there were grade beams under the load bearing walls. A polyethylene vapor barrier was found in very good condition stuck to the bottom of the concrete slab. Clearly, a large surface area of exposed earth was in intimate contact with the livingspace air. When the fan was shut off and the windows opened the average concentration dropped to 200 pCi/l and the familiar diurnal cycle was seen even in the unoccupied house.

The results from the last house monitored this way, House C8-A, are shown in Figure 9. The average concentration from the continuous monitor for the fan-on/house-closed period was 425 pCi/l, compared to the New Jersey DEP measurements of 791 and 1650 pCi/l taken at the same location on 3/22-25/86 and 3/28-31/86, respectively. The average concentration for the fan-off/house-closed period was 525 pCi/l. After the fan was turned off and the windows opened the average dropped to 250 pCi/l and the diurnal cycle reasserted itself.

In one house an experiment was run by raising the temperature of the building to include stack effect negative pressures and the furnace was operated to induce combustion appliance draft. The results are shown in Figure 10. The house temperature was held at 99 °F (39 °C) for several hours during the day. Because there was not time to do this with the windows closed at no temperature differential and with the windows closed with temperature differential, the results of this test are inconclusive. It is also apparent from Figure 10 that the radon concentrations were continuing to rise when the owners arrived home and opened all the windows and doors. Negative pressures were induced by both the furnace and the temperature differential. The furnace running plus a temperature differential of 40 °F (22 °C) put about 4 Pa (0.016 in. water) negative pressure on the basement. Opening the 7 sq. ft. (0.65 sq. m.) attic hatch in the ceiling seemed to increase the negative pressure 1 or 2 Pa (0.004 to 0.008 in. water) raising it from 4 Pa to 5 or 6 Pa. Because of the difficulties in measuring small pressure differences across building shells, additional measurements are needed to validate these results. The instruments used were at their lower range and even small breezes can have impacts as large as the phenomenon that was observed.

Discussion

It is clear that a fan induced negative pressure on a house has an impact on the radon concentrations in that house. Sometimes it appears to adequately emulate wintertime entry rates in the summer and other times there is little to distinguish it from the house closed condition except larger excursions in concentration over the day. Part of the reason for this may be that radon entry depends on the resistance to soil gas entry which is affected by cracks and holes in the foundation and the pathway from the radium source into the building. Another reason may be that, although negative pressure was induced on the house conditions are still different in two ways: (1) the ground is not capped with snow or frost, and (2) a fan induces a negative pressure over the entire building shell. Typical winter conditions see the basement under the highest negative pressure and the top of the house under positive pressure because of the buoyancy of the warmed air that is driving the stack effect. See Figure 10. The difference between these two situations is that a fan will bring in about twice as much dilution air as the temperature driven stack effect for the same negative pressure put on the basement. An improvement on this might be to locate a fan where it pulls air from the basement and blows it into the upstairs of the house. The second method of running the house 40 °F (22 °C) warmer than the outside air should also overcome the problem of too much dilution air, but this approach is fraught with impracticalities of comfort and possible damage to temperature sensitive plants, furniture, or musical instruments.

Although significant problems were encountered in emulating winter time radon entry and ventilation dynamics there remains a great need to improve the quality of short term radon measurements. Possible explanations and solutions for some of these problems have been identified. Further work to try to limit the uncertainty in short term pre and post mitigation radon measurements is sorely needed.

References

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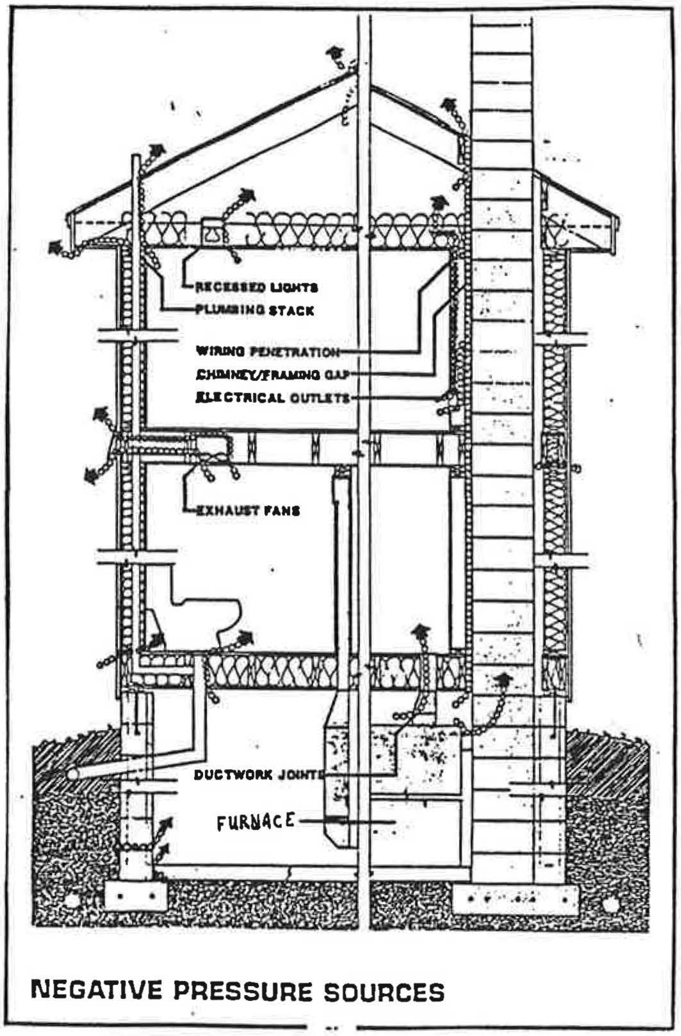

Figure I

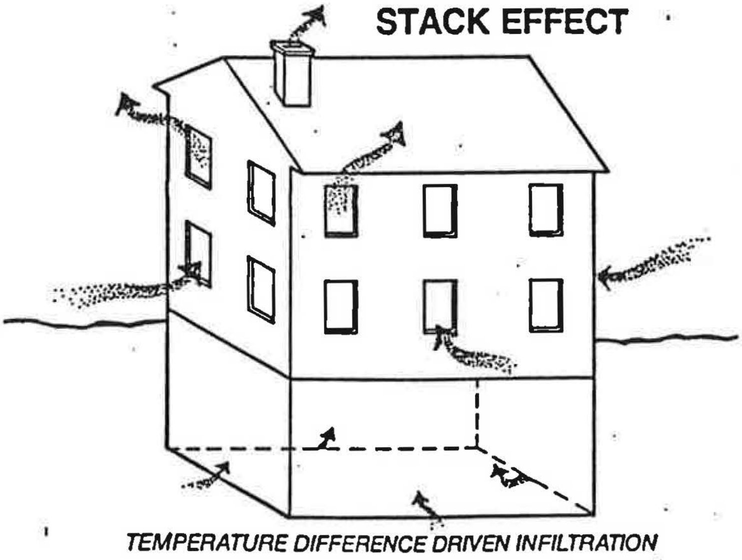

Figure II

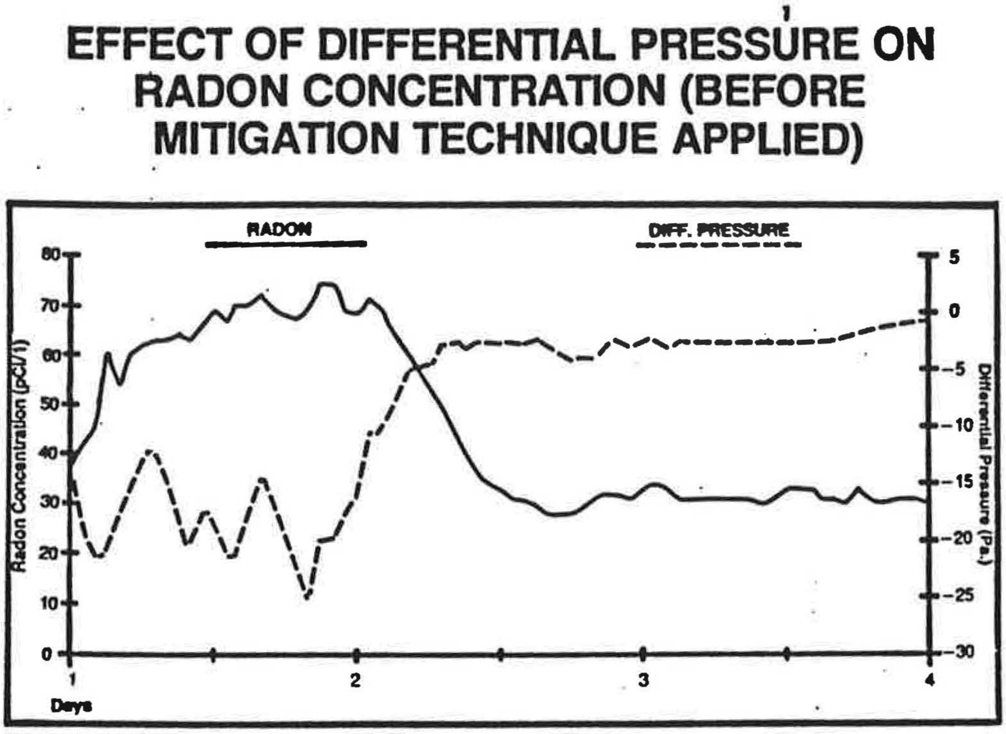

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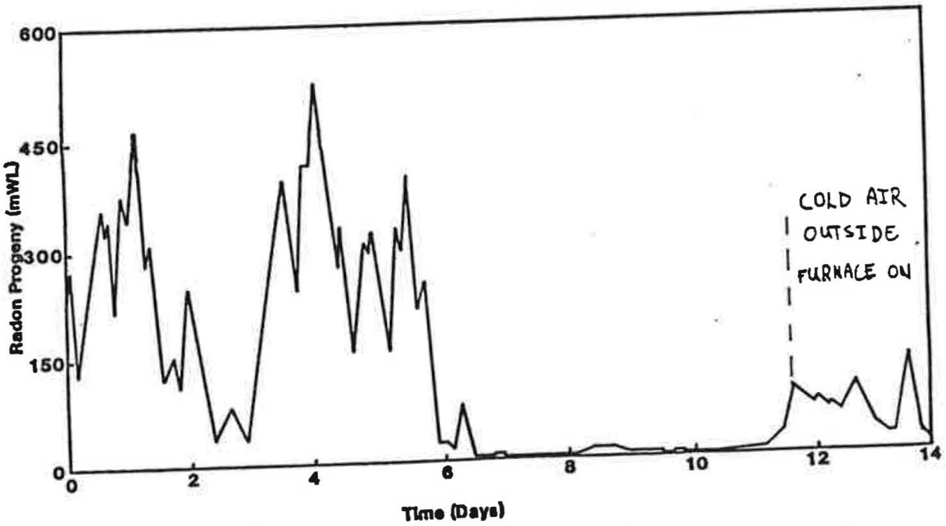
Figure III



Effect Of Sump Venting (Day 7-14) In House 21

Figure IV

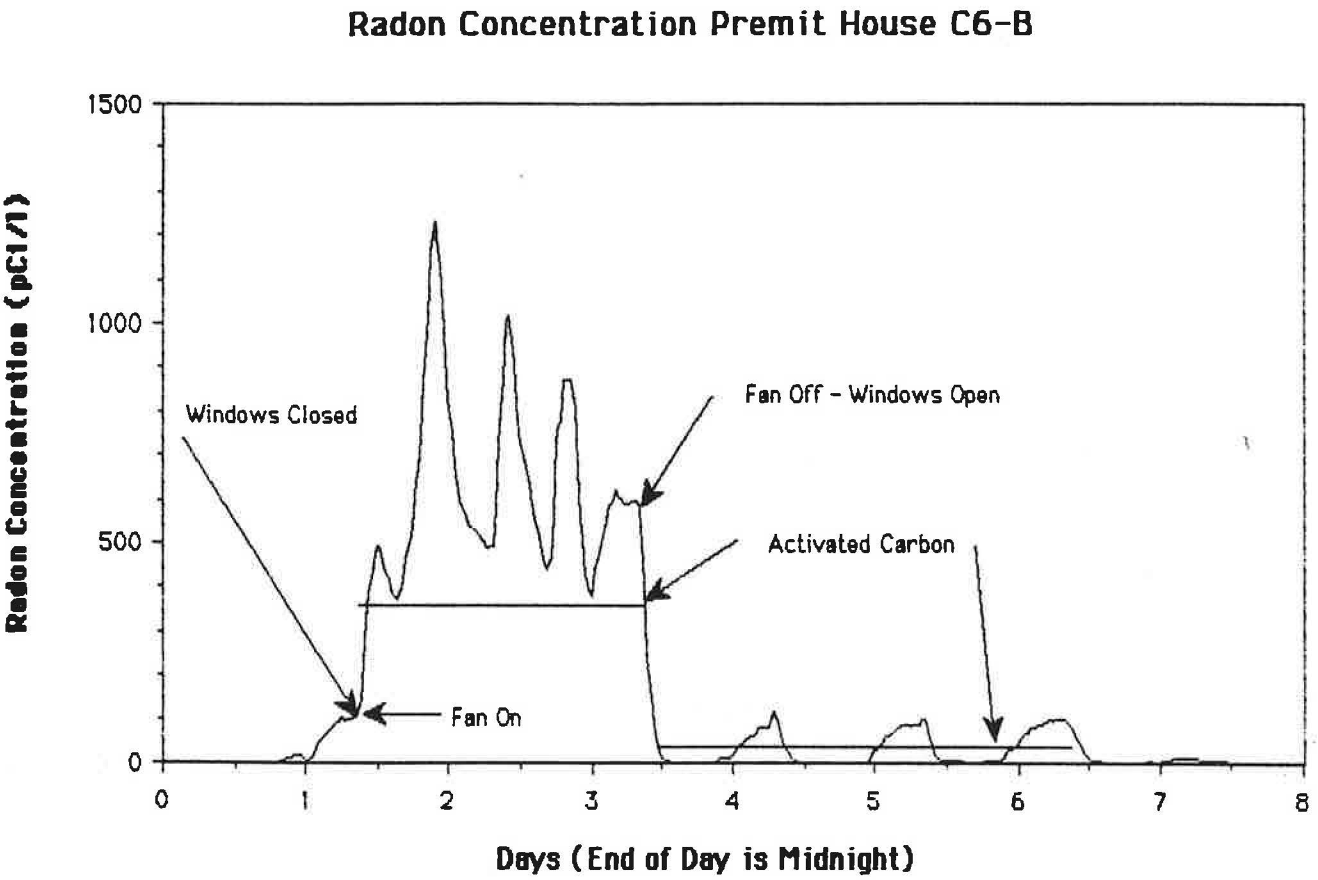

Radon Concentration Premit House C6-B
Radon Concentration (pCi/l)
1500
1000
500
0
0
1
2
3
4
5
6
7
8
Days (End of Day is Midnight)
Windows Closed
Fan On
Fan Off - Windows Open
Activated Carbon

Figure V

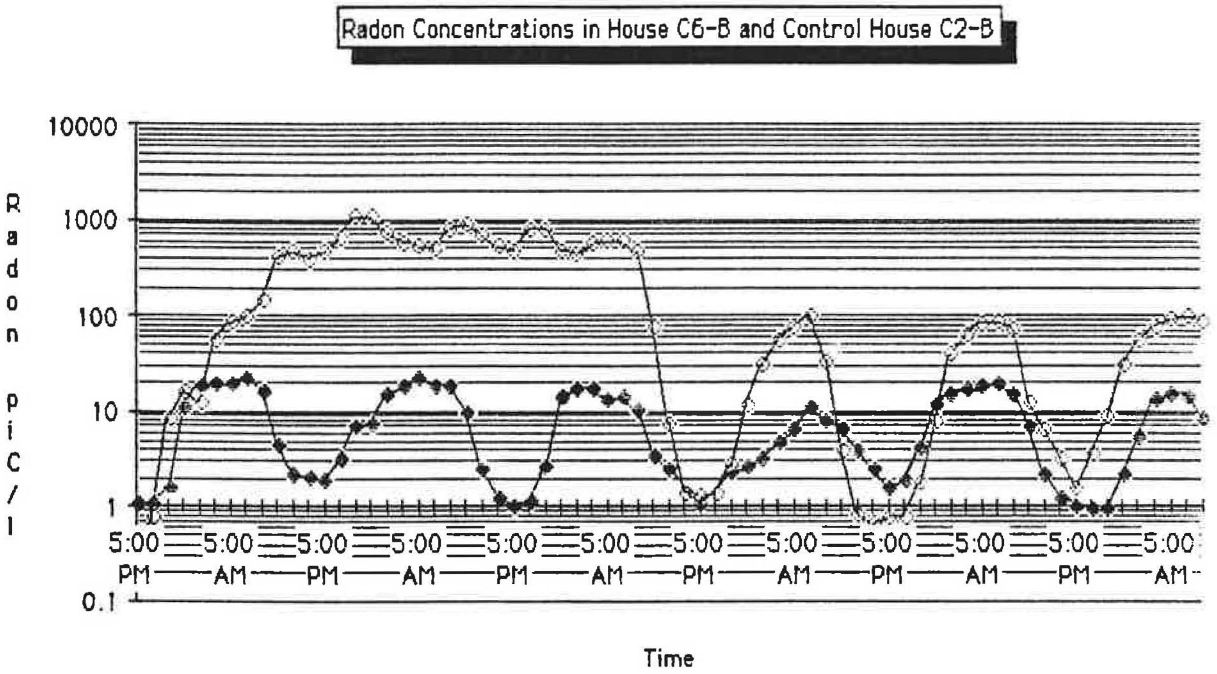

Radon Concentrations in House C6-B and Control House C2-B
10000
1000
100
10
1
0.1
Radon piC/l
5:00 PM
5:00 AM
5:00 PM
5:00 AM
5:00 PM
5:00 AM
5:00 PM
5:00 AM
5:00 PM
5:00 AM
5:00 PM
5:00 AM
Time

Figure 6

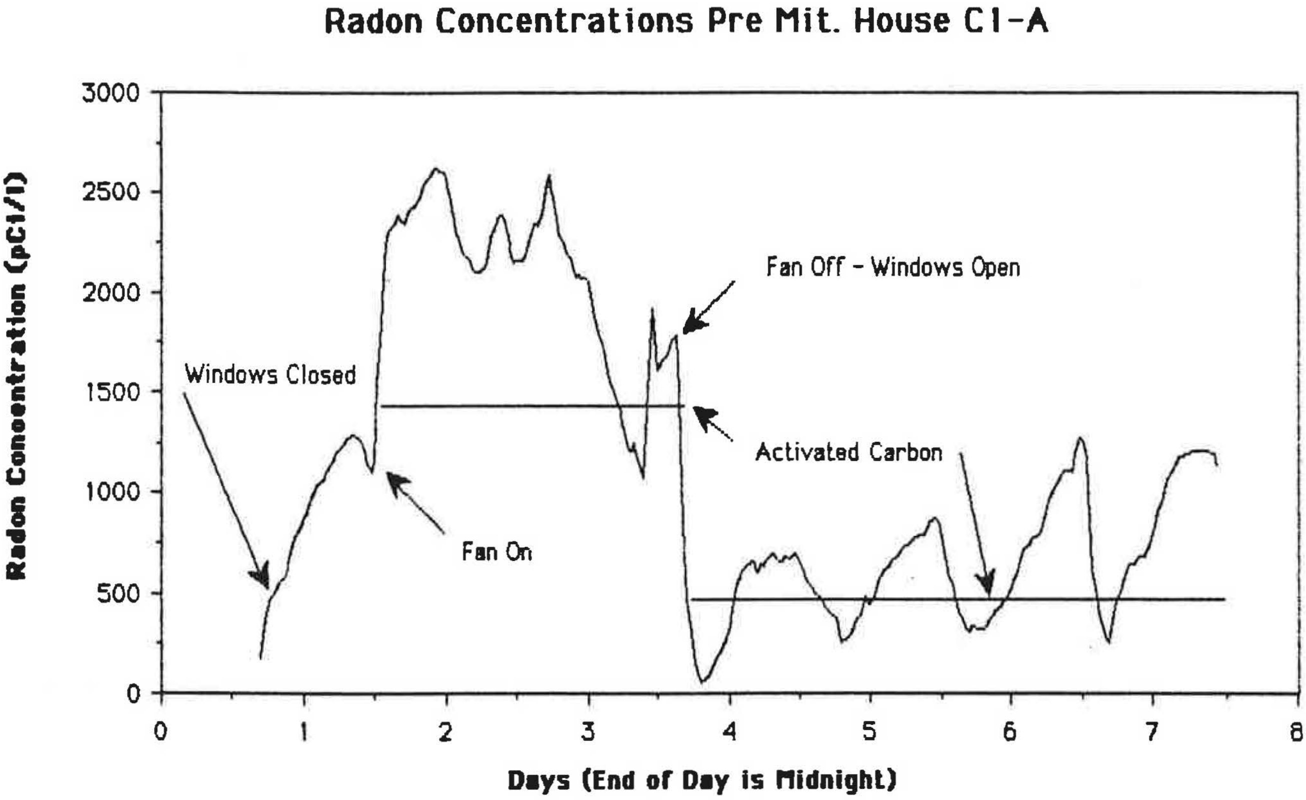

Radon Concentrations Pre Mit. House C1-A
Radon Concentration (pCi/l)
3000
2500
2000
1500
1000
500
0
Days (End of Day is Midnight)
0
1
2
3
4
5
6
7
8
Windows Closed
Fan On
Fan Off - Windows Open
Activated Carbon

Figure VII

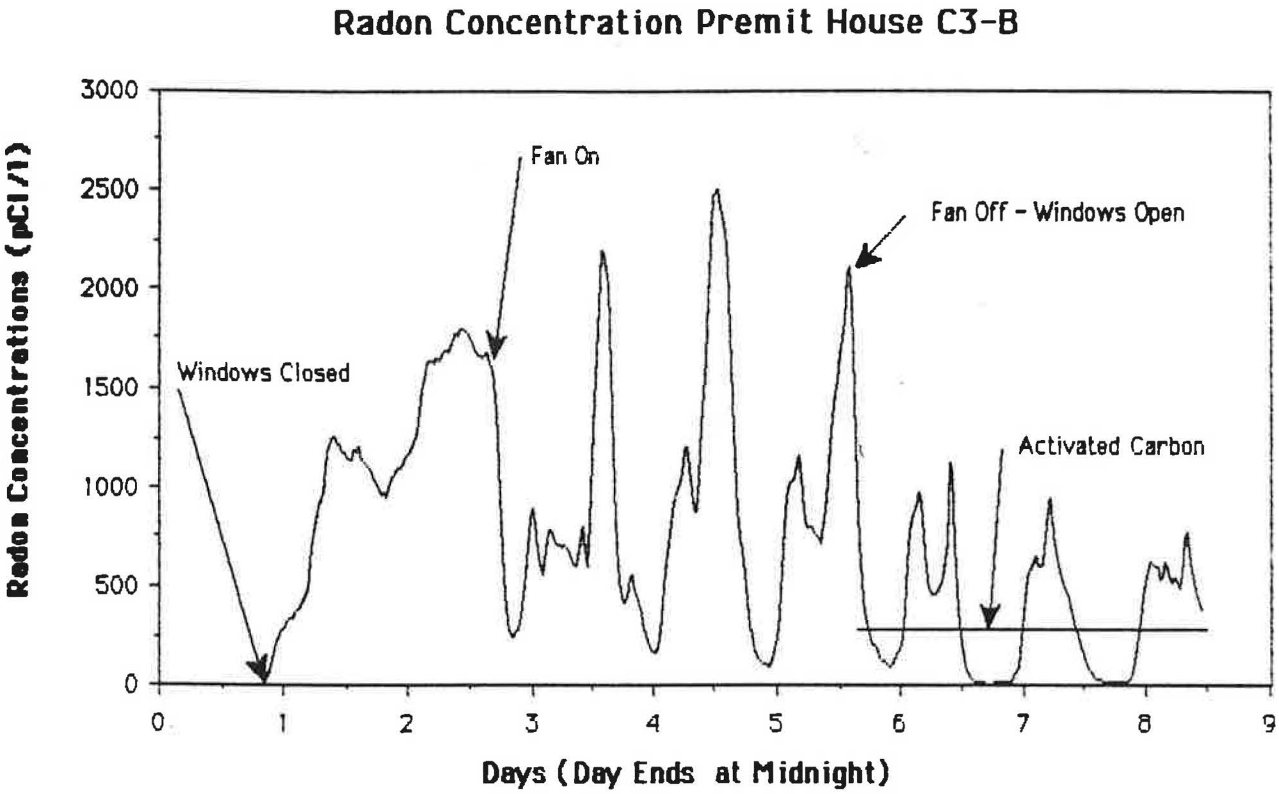
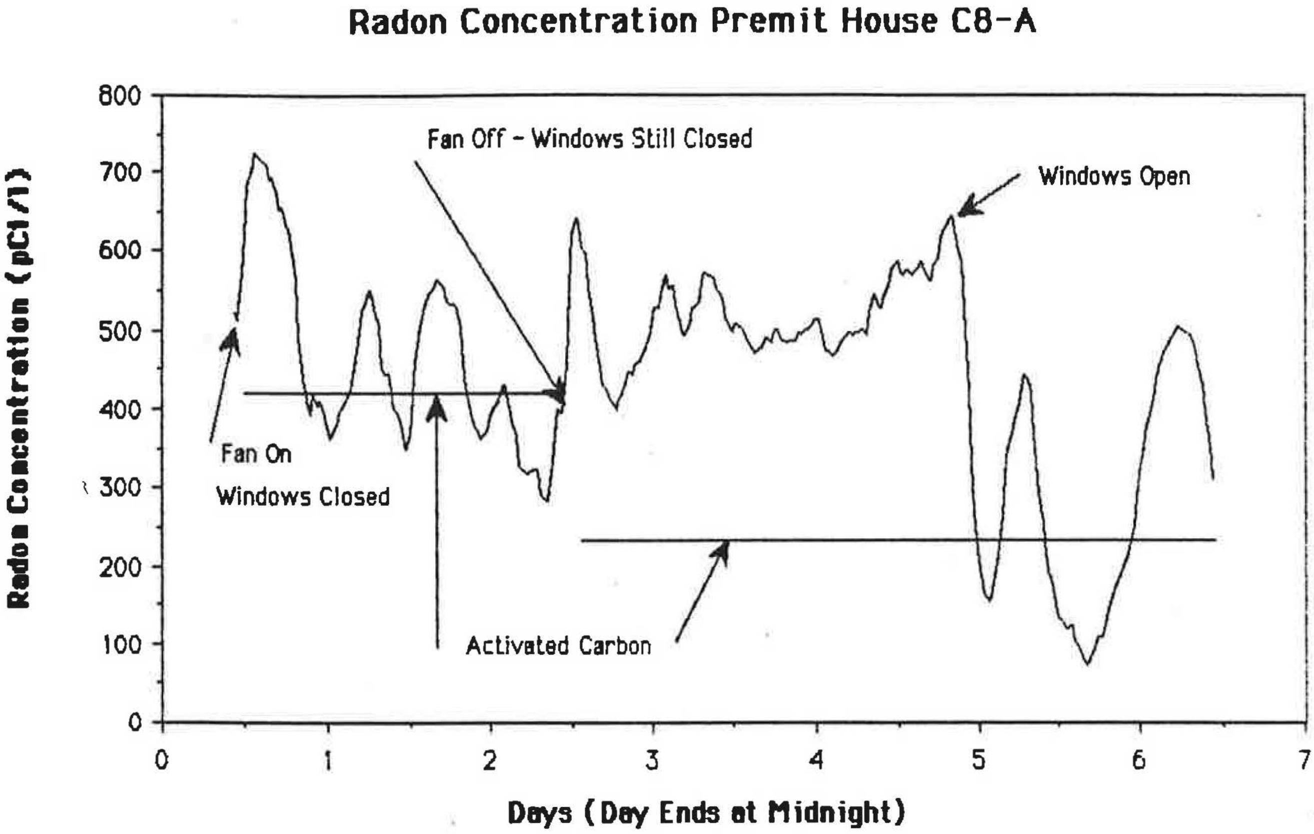

Radon Concentration Premit House C3-B
Radon Concentrations (pCi/l)
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
Days (Day Ends at Midnight)
Windows Closed
Fan On
Fan Off - Windows Open
Activated Carbon

Figure VIII



Radon Concentration Premit House C8-A

Figure IX

marsh heat on

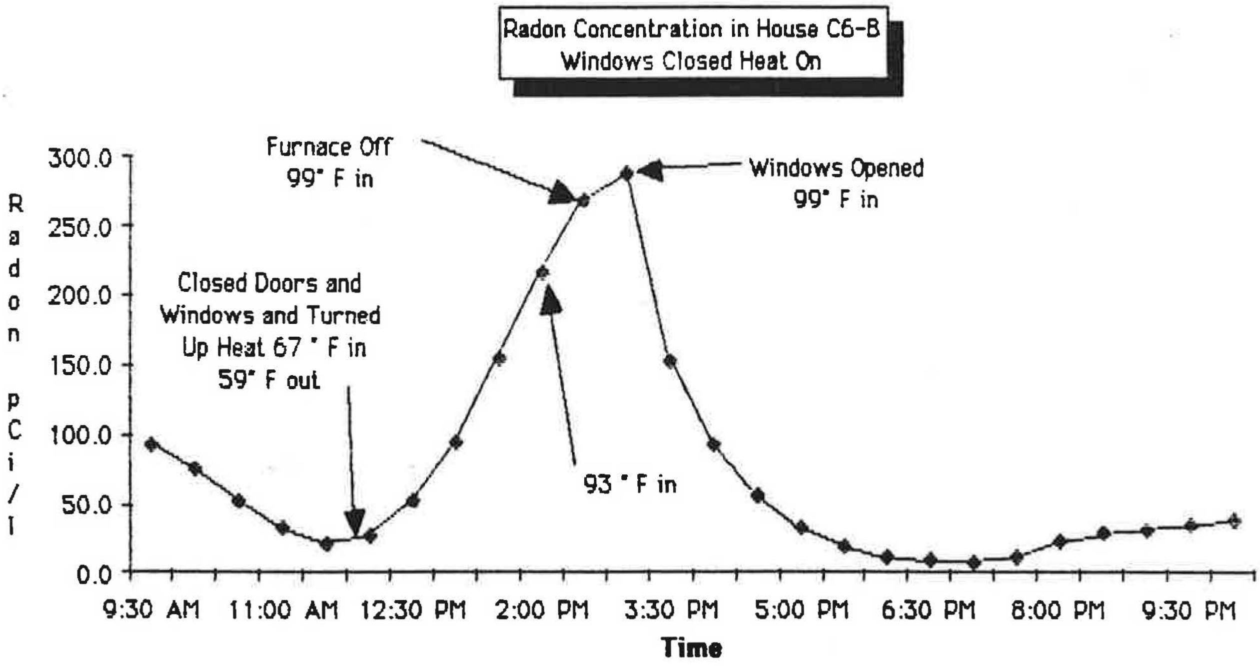


Figure X