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LONG TERM PERFORMANCE OF RADON MITIGATION SYSTEMS

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ABSTRACT
Researchers installed radon mitigation systems in 12 houses in Spokane, Washington and Coeur d'Alene, Idaho during the heating season 1985 –1986 and continued to monitor indoor radon quarterly and annually for ten years. The mitigation systems included active sub-slab ventilation, basement over-pressurization, and crawlspace isolation and ventilation. The occupants reported various operational problems with these early mitigation systems. The long-term radon measurements were essential to track the effectiveness of the mitigation systems over time. All 12 homes were visited during the second year of the study, while a second set 5 homes was visited during the fifth year to determine the cause(s) of increased radon in the homes. During these visits, the mitigation systems were inspected and measurements of system performance were made. Maintenance and modifications were performed to improve system performance in these homes.

INDEX TERMS
Radon mitigation, Sub-Slab Ventilation, Crawl Space Ventilation, Basement Over-pressurization, Long-term Radon Measurement

INTRODUCTION
A variety of approaches (described subsequently) have been used to reduce indoor radon concentrations, generally by reducing the rate of radon transport into the house from the surrounding soil. Much prior research has been described on the initial performance of these mitigation technologies, but only a few studies of long-term performance have been completed (Nitschke, et al.1988), (Scott and Robertson,1991), (Prill et al.1990). In 1985-86, we installed active mitigation systems in 12 houses (Turk et al. 1991). This paper reports the findings of a 10-year study of the performance of these systems. The resulting information will contribute to improvements in system design and installation practices.

METHODS
The follow-up radon measurements were made using alpha track detectors mailed to the occupants with detector placement and removal instructions, and data/comment cards for occupants to provide feedback on system noise, vibration, comfort issues, maintenance performed, occupant adjustment of fan switches and speed controls, crawlspace vents open or closed, and house remodeling.

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Quarterly and annual radon measurement results were immediately provided to the occupants of the homes. Occupants of those houses with indoor radon concentrations exceeding 148 Bq/m^3 were advised to take action to reduce the concentration to below 148 Bq/m^3, and were offered guidance and technical assistance.

Active Sub-slab Ventilation Systems: Seven houses were mitigated with active sub-slab ventilation systems. One house (ESP119) was mitigated with a pipe system installed from the exterior, routed under the footing and terminating under the basement slab floor. This system was operated in the conventional depressurization mode (Active Sub-Slab Depressurization or ASD). The other six houses were operated in pressurization mode (ASP) with the mitigation system fan mounted in reverse, creating a positive pressure in the pipe(s), forcing outside air beneath the slab floor. This technique was adopted in these six houses only after it was discovered that sub-slab depressurization systems were less effective in the highly air-permeable soils found in the Spokane and Rathdrum Prairie areas. ASP pipes were installed through the basement concrete slab floor into a pit filled completely with pea gravel. Screens at the outdoor intake were used to prevent, birds, rodents, insects, and debris from entering the pipes. In addition to pipes installed through the basement slab floor, house ESP111 had a second ASP system installed exterior to the house, with the pipes routed under the footing and terminating under the basement slab floor. The two ASP systems in house ESP120 were fitted with pleated filters at the pipe inlets to reduce particulate matter build-up in the pipes and on the gravel interface at the pipe outlet under the concrete slab floor.

Basement over-pressurization: Five houses were modified in the original experimental phase of the project to allow the basement zone to be pressurized relative to the surrounding soil. Four of these houses had central forced-air heating systems. An auxiliary axial fan was added to these duct systems to force main level air into the basement. These systems reduced radon concentrations in these homes at or below the target of 148 Bq/m^3 at the end of the experimental phase of the study. The fifth house, ECD027, has a dirt floor cellar used as storage. Original mitigation included adding insulation and a well-sealed membrane on the ceiling of this cellar. An axial fan was installed to create a positive pressure of 5 to 9 Pa in this zone relative to the outside using unconditioned outside air.

Crawl space Ventilation: Five of the homes were built with partial crawl spaces. During the experimental phase of the study, all crawl spaces were vented and a polyethylene membrane carefully installed on the surface of the crawl space soil as a soil gas retarder.

RESULTS

Increasing radon concentrations and system problems reported by the occupants prompted researchers to perform relatively minor modifications and maintenance to some of the systems two years after the initial experimental study was completed (Prill et al, 1990). In the basement pressurization houses, clothes dryer vent flaps were either missing, stuck open, or were being forced open by the positive pressure being created in the basements. To prevent loss of pressure, carefully weighted flaps were added to these vents. The flow rate of the basement pressurization fans was found to have decreased 20 to 25 percent in this set of homes in spite of the fact that the measured effective leakage area of these basements was unchanged. Fan speeds had been reduced or systems turned off for various reasons. Occupants in house ESP116 reported occasional back-drafting of the airtight-rated wood stove located on the main level. Providing additional combustion make-up air to the main level of the home solved the woodstove back-drafting. Mitigation resulted in radon reductions from the initial baseline of 1,665 down to 22.2 Bq/m^3.

The year-two modifications in the active sub-slab ventilation houses included minor adjustments to fan installation details to correct noise and/or vibrations (House ESP111 ASP system was turned off due to fan vibration). Filters on ASP systems had became loaded with debris resulting in decreased system air velocity and pressure. Sealants at the ASP pipe penetrations had failed resulting in air leaks and reduced system pressures. These joints were cleaned and resealed with a superior caulking product. Radon concentrations in all six of the ASP homes had exceeded the target concentration of 148 Bq/m^3 in at least one measurement period. Radon measurement results are presented in Tables 1 and 2. In houses ESP108 and ESP113 easily accessible ASP pipes were severed near the slab and a visual inspection was made. Debris carried by the outside air had built up on the gravel layer at the pipe terminus. After debris removal there was a significant increase in air velocities and a decrease in system pressures (Prill, et al.1990). It is presumed that the decrease in system performance in the other four ASP houses was a result of similar debris build-up.

A second set of modifications in the five homes with ASP systems were performed during the fifth year (1991) of the follow-up study prompted by radon concentrations in all of the ASP homes exceeding the target concentration of 148 Bq/m^3 during at least one measurement period. The inspections revealed that once again pressures in the systems had increased, and air velocities decreased, resulting from the build-up of debris at the terminus of the ASP pipes at the sub-slab gravel layer.

Clearly, removal of debris from the systems was not adequate to maintain system effectiveness, nor was frequent cleaning at the pipe/soil interface practical. Debris was removed and 22 to 44 liter pits were created in the ASP systems in five houses. Significant increases in pressure field extension by adding a 22 to 44 liter pit at the pipe terminus of active sub-slab ventilation systems in existing houses has been documented. (Prill, et al.1992). The ASP fan speeds were recorded and the pressure and air velocity were measured before and after modifications. House ESP101 ASP pressures decreased by a factor of 3 and air velocity increased by a factor of 5.5 after pits were created at two of the 3 pipes. In house ESP108 ASP pressures decreased by a factor of 1.4 and air velocity increased by a factor 43.6 after pits were created at three of the four pipes. House ESP111 ASP pressures decreased by a factor of 2.6 and air velocity increased by a factor of 5.7 after pits were created in the interior system (exterior system not accessible). House ESP113 ASP pressures decreased by a factor of 5.5 and air velocity increased by a factor of 7.2 after pits were created. House ESP120 ASP pressures decreased by a factor of 4 and air velocity increased by a factor of 21 after pits were created in one of the two systems. ASP house ECD026 was not visited (or modified) the fifth year.

Table 1. Radon concentrations (Bq/m3) in homes with active sub-slab ventilation

House ID	ESP 101	ESP 108	ESP 111	ESP 113	ESP 119	ESP 120	ECD026
Location	B, M	B, M	B, M	B, M	CS, B, M	B, M	CS, B, M
Winter-Post Mit. 85-86	74, 37	37, 37	111, 74	ND, ND	ND, 37, ND	111, 74	ND, 111, 111
Annual 4/87-4/88	629, 407	407, 296	555, 555	296, 222	37, 180, 111	740, 555	111, 111, 111
Annual 9/88 - 10/89	148, 111	148, 148	ND, ND	148, 111	37, 74, 37	ND, ND	ND, ND, ND
Annual 4/90 - 4/91	666, 333	296, 222	ND, ND	296, 296	37, 111, 37	888, 666	148, 148, 148
Annual 4/91 - 4/92	222, 111	111, 111	222, 148	37, 37	37, 111, 74	296, 185	111, 148, 148
Annual 4/92 - 4/93	111, 37	333, 185	407, 407	74, 74	37, 110, 37	111, 74	148, 185, 148
Annual 4/93 -4/94	111, 74	111, 74	925, 740	74, 74	37, 74, 74	185, 111	185, 222, 222
Annual 94 -95	148, 111	74, 74	925, 666	74, 74	37, 111, 74	185, 148	296, 296, 296
Annual 6/95 - 6/96	259,ND	74, 37	740, 703	74, ND	ND, 37, 111	666, 444	ND, 185, 185

KEY: ND: No Data Location: CS = Crawl Space; B = Basement; M = Main Level

Table 2. Radon concentrations (Bq/m^3) in homes with basement over-pressurization.

House ID	ESP 116	ECD 027	ECD 153	NCD 077	NSP 204
Location:	B, M	M	CS, B, M	CS, B, M	CS, B, M
Winter-Post Mit.85-86	ND, 74	37	ND, ND, 37	ND, ND, 74	ND, ND, 111
Annual 4/87-4/88	777, 180	180	150, 300, 260	180, 440, 220	370, 330, 180
Annual 9/88 - 10/89	ND, ND	37	ND, ND, ND	148, 259, 111	296, 296, 148
Annual 4/90 - 4/91	ND, ND	296	185, 74, 74	222, 481, 222	629, 407, 333
Annual 4/91 - 4/92	ND, ND	37	222, 111, 74	148, 592, 296	518, 407, 333
Annual 4/92- 4/93	777, 515	185	259, 198, 148	148, 518, 259	777, 629, 407
Annual 4/93 -4/94	407, 962	148	333, 185, 222	259, 444, 222	851, 703, 481
Annual 94-95	ND, ND	222	296, 148, 148	148, 444, 259	740, 592, 407
Annual 6/95 - 6/96	ND, ND	2146	296, 259, 222	ND, ND, ND	777, 592, 407

KEY: ND: No Data Location: CS = Crawl Space; B =Basement; M = Main Level

CONCLUSION AND IMPLICATIONS

The mitigation systems in this set of homes were designed and installed during the early years of radon mitigation and were experimental. It is important to note that during the experimental phase of this study the fan speeds and pressures of the mitigation systems were adjusted to control the indoor radon at just under the target of 148 Bq/m^3. These systems were thus intentionally not over-sized nor particularly robust, and hence more likely to be sensitive to occupant adjustment of fan speeds, lack of maintenance, decreased fan performance over time, and other factors. However, most mitigation strategies require some level of maintenance, and fan-powered active systems experience decreased fan performance over time and eventually fan failure.

The occupants of these homes contributed to the reduced performance of the mitigation systems by actions including: turning fans off, reducing fan speeds, defeating pressurization regimes, closing crawl-space vents, and remodeling activities. When notified of increasing radon concentrations most of the homeowners with ASD systems responded promptly to improve the performance of the mitigation systems. However, the homeowners with the basement pressurization systems did not respond, nor did the homeowner in house ESP111, in spite of offers of technical assistance from the researchers.

<u>Active Sub-Slab Ventilation:</u> After the second visit (year five) when pits were created at the ASP pipe terminus, houses ESP108 and ESP113 have remained below the target of 148 Bq/m3 annual average. System fans failed in houses ESP101 and ESP120 resulting in basement level annual average radon concentrations increasing from 111 Bq/m^3 to 259 Bq/m^3 and 111 Bq/m ^{3} to 666 Bq/m^3 respectively (fans were eventually replaced). Radon concentrations continued to increase over time in house ESP111 where the exterior ASP system was not accessible for modification.

Active sub-slab pressurization systems can be more effective than ASD systems in some buildings where construction details and/or highly permeable soil conditions exist, however this study suggests that ASP system effectiveness can be significantly reduced by the accumulation of debris deposited on the sub-slab soil/gravel. Properly designed low-flow ASP systems promise to offer highly effective and energy efficient radon control (Fisk et al.1995).

The one house in this study (ESP119) with active sub-slab depressurization (ASD) continued to remain below the target of 148 Bq/m^3 annual average for the entire duration of the study, except for one measurement. The system performance was not measured nor were modifications made, and according to data/comment cards returned by the occupant, the system fan has not been repaired nor replaced.

<u>Basement Over-Pressurization</u>: The homeowners have not reported any evidence or concerns in terms of structural problems associated with the basement pressurization systems. These systems, while very effective at reducing radon entry when designed, installed, and operated properly are easily defeated by occupants leaving basement doors open, not maintaining door seals at the basement door, turning the fan off, or changing

the balance of the supply and return systems. Three of these five homes performed poorly in terms of maintaining radon concentrations below the target of 148 Bq/m^3. Measurements of fan performance after two years found decreases in air flow rates of 20 to 25 %. Initial reports of back-drafting from the main level wood stove in house ESP116 required adding additional combustion air to that zone. Therefore the reliability and practicality of these systems must be questioned. Two of the homes, ESP116 and NCD 077, were sold during the study. The new owners/occupants were not informed by the sellers of the radon system, or follow-up study. The new occupants (year 1988) of house ESP116 were uninterested in the study and did not reliably deploy detectors, or report system and/or house operation. Subsequent radon concentrations in house ESP116 suggest that the system was either not operated or the pressure regime was defeated for reasons that are not clear. The radon concentrations in house ECD027 remained below the target of 148 Bq/m^3 except during those periods where the fan was off due to cold weather and during an extensive remodel of the home in 1995 and 1996.

With thousands of radon mitigations systems installed in homes across the U.S. over the last two decades, the findings from this small set of homes suggest additional long-term radon follow-up studies are warranted.

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