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RADON MITIGATION EFFECTS OF PASSIVE STACKS IN RESIDENTIAL NEW CONSTRUCTION

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This study involved continuously monitoring several new houses that were recently built with radon resistant features including crack sealing, porous subslab aggregate, and a stubbed-off pipe penetrating the slab for use in installing a radon mitigation system. The pipe systems were completed so that they exited from the roof, and half of the houses had radon mitigation fans installed on the pipes. Houses were continuously monitored with the pipes sealed, with the pipes open but no fans operating, and finally with the fans operating. The results show significant radon mitigation effects by the passive stack systems, in most cases, and excellent mitigation by the active systems.

INTRODUCTION

A passive stack (PS) radon mitigation system is a type of subslab depressurization (SSD) system where the source of exhaust power in the stack is buoyant air rather than an electric fan. The buoyant force is generated whenever the air in the pipe is at a higher temperature than the outdoor air. Since the major cause of radon entry into houses is thought to be pressure-driven flow of radon into the house that is primarily caused by temperature differentials, the PS has been suggested as an inexpensive, low energy solution to radon problems that automatically compensates for changes in temperature.

Several problems with PS radon mitigation have been suggested: reverse pressures from wind, pressure losses under the slab, reverse pressures during the summer, and reverse pressures due to mechanical and heating appliances. Although some mitigators report installing PS systems, there is little quantitative data on their performance. This paper reports on a study of PS in 16 new houses constructed by Ryan Homes in Maryland and Virginia. These houses had basement radon levels between 148 and 740 Bq m^{-3} before the stacks were installed. During construction, a pipe stub was imbedded in the slabs, 10 cm of clean coarse aggregate was installed beneath the slabs, and the floor-wall cracks were sealed with polyurethane caulk. In half of these houses the passive stack performance was compared to conventional fan powered SSD performance.

PASSIVE STACK THEORY

The term stack effect is commonly used to describe the pressures and flows that are generated when buoyant warm air is enclosed in a building. The ASHRAE Handbook of Fundamentals[1] contains an extensive discussion of building stack effect. In order to understand the stack effect, two terms -- column pressure and neutral pressure level -- must be defined.

Column Pressure

Column pressure is the maximum differential pressure that can be induced across any point on the building shell by an inside-outdoor temperature difference. The column pressure is proportional to the building height and the temperature difference between inside and outdoors. For example, a 25° C temperature difference and a 2.4 m building height will induce a column pressure of 0.025 cm wc across the building envelope. The column pressure is not affected by the airtightness of the building.

Neutral Pressure Level

The neutral pressure level (NPL) is the imaginary line around the enclosure where the inside-outdoor differential pressure is zero. If the top pressure is shown to be equal in magnitude to the bottom pressure, this will result in a NPL that is half way up the side of the enclosure. The NPL location and stack pressure distribution across the building envelope are determined by the building airflow resistance, including the resistance of both the building shell and any internal partitions. In houses, there are generally large openings (doors) or leaks between floors, and the internal airflow resistance is assumed to be small relative to the shell airflow resistance. Therefore, the shell openings determine the location of the NPL and the pressures across the top and bottom of the shell. Note that the NPL and the pressures on the enclosure are determined by the distribution of leaks on the enclosure surface, and not by the overall airtightness or leakiness of the enclosure. Leakier enclosures will require more heat to maintain the inside-outdoor temperature difference, but the column pressure will be independent of the airtightness. If the majority of leaks are near the top of the enclosure, then the NPL will be near the top, but the maximum pressures will be at the bottom. When top and bottom openings are equal in size, the NPL is midway up the side of the enclosure.

Effects of Sealing

Sealing leaks in the enclosure will not change the column pressure, but the NPL will be shifted if leaks near the top or bottom of the enclosure are sealed. Since radon entry may be proportional to the depressurization of the slab, sealing the upper part of the shell should be beneficial since it will reduce this depressurization, but sealing leaks in the lower part of the shell should be detrimental since it will increase the depressurization of the lower part of the enclosure. If a house could be sealed as completely as a hot air balloon, with all remaining leaks concentrated at the bottom, then there would be no stack induced depressurization on the slab that would pull radon into the house.

As a general rule for radon control, air sealing should be limited to the upper surfaces of the house in order to minimize depressurization of the slab. Since a PS system does not have much suction power, the reduction of stack effect in the building may be necessary to maximize its performance.

OBSERVATIONS/RESULTS

Passive Versus Active System Performance

In half the houses, SSD systems with fans were installed: these houses were studied to compare the performance of the PSs with the active systems. The stack was sealed for several days to approximate premitigation conditions, the stack was opened without fan operation to approximate a PS system, and finally the fan was turned on to demonstrate fan-assisted SSD performance. The resistance of the fan in the pipe was assumed to be small enough to ignore because of the small airflows in the pipes under passive conditions. House TIN had some of the highest radon levels in this study, but it was otherwise quite typical of the active houses. This house had 186 m^2 of finished floor area on two floors, and an unfinished 74 m^2 walkout basement below. The basement has poured concrete walls with the same crack sealing and stubbed off pipe described in the passive house. There was no sump and the pipe stub was connected only to a perforated pipe in the aggregate beneath the slab. The blower door measurement showed that this house was about 4 ACH (air changes per hour) at 50 Pa which is quite tight.

Winter performance

When the fan was on, the radon levels were well below 37 Bq m^{-3}, but they quickly rose to about 1110 Bq m^{-3} when the fan was turned off and the pipe was sealed. When the passive stack was simulated by opening the stack without turning on the fan, the radon levels were significantly depressed, but occasional large spikes could not be explained. Even so, the radon reduction due to the PS was about 75% (Figure 1).

Summer performance

The house was retested during warm weather in September: the radon levels during the PS test were lower than for the comparable winter levels. Since the measurements did not include a test period when the stack was sealed, it is not possible to determine the absolute mitigation performance. There were some spikes in the radon levels but not as many as the winter data showed. After this monitoring was concluded, a reexamination of the heat pump fan system showed that a construction defect had left a large hole in the return duct in the basement. The hole generated a depressurization of 0.125 Pa in the basement every time the fan came on and the basement door was closed. The September PS data may be low for this house because the mild weather did not require much heat pump operation (Figure 2).

Active versus passive

The conventional active SSD system is a very reliable solution to radon problems in new construction houses because it will overcome most of the inadequacies of PSs highlighted in this study.

Even the severe depressurization that was found in this house was negligible compared to the pressures of about 2 Pa that are commonly generated under the slab by most SSD fans. The only problem in the test houses that this excess fan power could not overcome is the lack of communication between multilevel slabs that was seen in several houses.

CONCLUSIONS

This study suggests that PS systems in new house construction can provide radon mitigation that is comparable to the performance of active systems if there are no interfering sources of house depressurization. However, the study also suggests that forced air heating systems are major sources of house depressurization due to duct leakage. Since PS systems are very sensitive to pressure imbalances in the house, they provide a sensitive tool for studying the interaction of the other systems in the house.

Duct Leakage

The pressure imbalances in houses due to duct leakage and flow imbalance were recently studied in Florida houses by Cummings[2]. That study indicated that Florida houses typically have heat pumps in the attic outside the house envelope, and that duct leakage can cause depressurization or pressurization of the entire house. Since the houses in this study had no ductwork outside the conditioned space, the leakage could only cause room to room variations in pressure rather than changes in whole house pressure. However, when the HVAC fans are in the basement, as they were for all of the houses in this study, the probability of significant pressures in the basement is quite high. All of the houses in this study had pressurization of the upstairs bedrooms when the doors were shut because of the lack of returns in the rooms. This problem does not seem to produce significant basement depressurization. It seems to be more of an energy conservation problem than a contributor to the radon problem. Cummings[2] reports a similar problem in Florida.

Adequate Ventilation

The houses in this study were found to be almost airtight. If they did not have forced air heating and cooling systems, and the pressure or leakage problems previously discussed, then they might be under-ventilated when compared to ASHRAE recommendations[3]. If the duct leakage and imbalances were corrected for reasons of energy conservation or radon mitigation, then the ventilation impact should be considered.

Limitations and Suggestions for Further Work

This study was very limited in the housing stock studied since it dealt only with heat pump houses within a limited area. Future studies might look at Florida or Minnesota houses with their different climates and HVAC systems. All of the stacks in this study were 10 cm schedule 40 PVC pipe. It would be useful to study 7.6 cm pipe since it would be simpler and cheaper to run smaller pipe through the house.

RECOMMENDATIONS TO BUILDERS

Passive stacks appear to be the most effective passive radon mitigation technique for new construction. This study suggests that the stack should be run through the warm part of the house, excellent subslab communication can be provided with 10 cm of clean coarse aggregate, and the stack pipe should be run up to the roof line. Additional guidance should include avoidance of duct leakage that depressurizes the basement and connecting stack pipes to each level of multilevel slabs. Things that can be ignored include wind caps for the stack, multiple bends in the pipe, and failures due to cooling situations.

REFERENCES

1. ASHRAE Handbook of Fundamentals, Chapter 23 Infiltration and Ventilation, Section 23.2 Driving Mechanisms, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia, 1989.

2. Personal communication with J. B. Cummings, Florida Solar Energy Center, 300 State Road 401, Cape Canaveral, Florida, Sept. 13, 1989.

3. ASHRAE Std. 62-1989, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia, 1989.

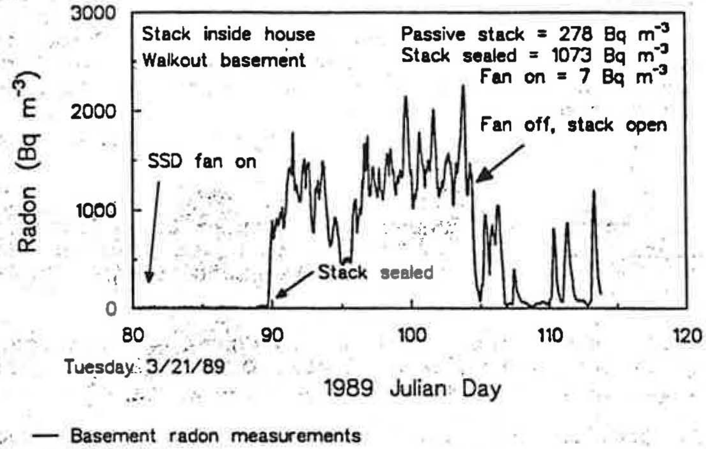

FIGURE 1 Winter Performance of Active and Passive Stack Systems

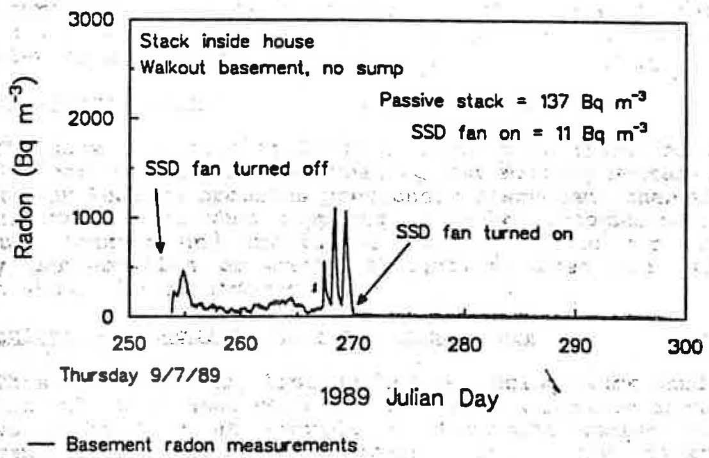

FIGURE 2 Summer Performance of Active and Passive Stack Systems