

The Effect of Radon Mitigation Systems on Ventilation in Buildings

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ABSTRACT

Radon mitigation can be accomplished by source removal and exclusion by sealing, local ventilation, and dilution of the radon gas. Each of these approaches can have a direct impact on heating, ventilating, and air conditioning (HVAC) operation within the building volume. Conversely, HVAC operation can also directly affect the ability of the mitigation system to function properly. Air infiltration rates and interzone flows have been measured using perfluorocarbon tracer techniques in research houses with radon problems in west central New Jersey. These tests have been augmented in two houses with constant concentration tracer gas techniques to provide further information. Using a typical basement subslab depressurization (SSD) system employing a fan to lower the pressure in the gravel aggregate under the slab, significant flow of conditioned space air is entrained into the system from the basement. This flow, in turn, can alter the pressures and flows in other areas of the building. Since subslab depressurization depends on lowering subslab pressures at least a few pascals, HVAC operation in the building that also lowers basement pressures can interfere with mitigation strategies. These various phenomena will be discussed.

INTRODUCTION

Radon mitigation employs a number of strategies to control radon concentrations in buildings. As with any indoor air quality problem, there are three basic control strategies; in order of preference, they are pollutant source control, local exhaust near the source, and dilution via ventilation once the pollutant (in this case radon) has mixed with the air in the building (ASHRAE 1981). Clearly, removing the pollution source, if possible, is the most direct and can be the least expensive solution. At the other end of the spectrum, when dilution via ventilation becomes

necessary, energy costs as well as comfort considerations interfere with mitigation. Radon concentrations are often found at levels above the EPA guideline of 4 pCi/L. Depending upon the individual state or community, 30% or more of the houses may exceed the EPA guideline. A radon concentration of 12 pCi/L means three times the ventilation rate is needed just to meet the guideline (since radon concentration is proportional to entry rate divided by ventilation rate, a tripling of the ventilation rate will cut the concentration by a factor of three). Energy associated with this amount of air removal can imply a large energy penalty unless most of the energy of space conditioning is recovered. Even with heat recovery, ventilation rates alone must be considered as a limited means to meet indoor air quality needs. For example, a calculation using a 1500 ft² house (basement excluded), a normal 0.5 air change per hour infiltration rate, assuming a 70% efficient (combustion) heating system, and a heating price of \$0.70 per therm, shows that tripling the ventilation rate would cost about \$404 per year in additional heat losses (5000 degree day region). With 70% efficient heat recovery, the cost falls to \$121 per year. In addition, once ventilation reaches the order of three times the normal rate, heat recovery is no longer able to cope with still higher ventilation demands and requires heat recovery systems that are different from existing systems, i.e., much higher air exchange rates than would be found in a residential system. Introducing high airflows to the space may also compromise occupant comfort.

MITIGATION METHODS IN USE

The gravel bed under most basement and crawl space slabs is a natural collection and easy removal site for radon gas that is mixed in the soil gas (Henschel 1987). Radon can also be emitted from water and building materials, but soil gas is a much more common source. After suitable testing for appropriate airflow communica-

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or crawl space and living space radon concentrations, averaged over each half hour; pressure differentials across the slab, outdoors to basement, and basement to upstairs; temperatures in the basement, living space, and outside; a series of weather-related measurements; and central air-handler use. Air infiltration rates, averaged over 10- to 14-day periods, were measured using perfluorocarbon tracer (PFT) techniques (Dietz et al. 1986). Each data logger was accessible 24 hours a day via a telephone modem. In addition to this fixed instrumentation package, additional diagnostic measurements using sensitive pressure meters and flowmeters were made in each house during regular visits before and after mitigation took place. Holes were drilled in critical locations and numerous air samples were taken to characterize the radon sources.

Still more sophisticated methods were used to measure air infiltration in two of the test houses. Each zone in the house was maintained at the same tracer gas target concentration by a constant concentration tracer gas (CCTG) device. The CCTG method relies upon measuring the tracer gas needed to keep each zone at the target concentration (up to 10 zones are routinely used) since the tracer gas use is directly proportional to the influx of outside air (Harje et al. 1985; Bohac et al. 1988). The concentration of tracer gas in the mitigation system exhaust pipe can also be measured, which gives a way (see below) to calculate the fraction of inside air present in the mitigation exhaust system.

RESULTS OF THE MONITORING

Looking at Figure 3 in some detail it is clear that in house 2, the control house for one seven-house group, radon is a constant problem with levels always between 5 and 30 pCi/L upstairs and in the basement. Basement air infiltration reaches maximum levels of somewhat more than one air change per hour in midwinter, and drops to half that value as the weather becomes warmer. The pressure differences from outside to basement increase during the colder months, with a smaller increase in subslab-basement pressure differential. These pressure differences enhance the flow of soil gas into the basement. Depending on the exact pressure differentials and leakage areas of the basement interfaces with the outside and the soil, this enhanced flow will either flush the basement with clean air from outside or bring in radon-rich soil gas. In the control house, the net effect is to leave radon levels about the same.

The radon entry rate can be calculated by assuming that radon behaves much the same way as the PFT gases in the house, setting the ratios of the concentration for the PFT gases and radon equal, and solving for the entry rate (Hubbard et al. 1988b). Because the PFT emission rate is essentially constant, whereas the radon entry rate may vary, errors may be introduced by equating the two. The magnitude of this error is currently being investigated. Entry rates remain fairly constant in the control house throughout the seasons displayed in Figure 3, as do the average radon concentrations.

The total basement infiltration is proportional to the outdoor-basement pressure differential, which is in turn proportional to the outdoor temperature, as shown by the similarity of the plots of these parameters in Figure 3. The radon concentration remains fairly constant over the

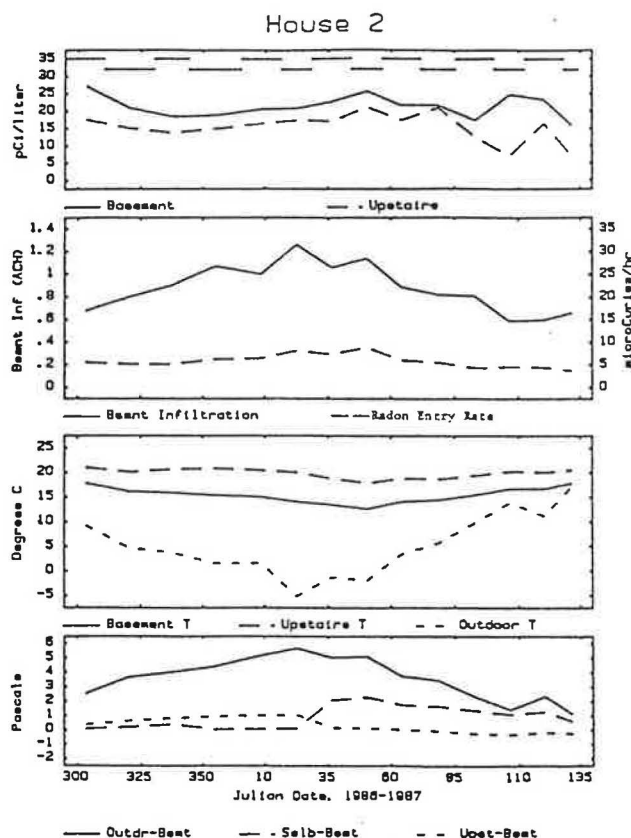


Figure 3 Data for Piedmont Study control house (house #2). The top box in the figure shows the radon concentrations in the basement and upstairs. Also, at the top of the box, the dashed lines indicate the periods over which PFT measurements were taken. The second box shows the basement air infiltration rate (solid line) and the radon source strength (broken line). The third box shows the basement, upstairs, and outdoor temperatures. The fourth box shows the difference between the outdoor/basement, subslab/basement, and upstairs/basement pressures. The greater these differences are, the greater the relative depressurization of the basement. The points from which each line is plotted are the parameter averages during the tracer gas time period. Each time period is 10 to 14 days long.

seasons, implying that the increased soil gas entry in the winter, that is part of the increased basement infiltration shown in Figure 3, is diluted in this house by an increased flow of clean air from outside (also part of the increased basement infiltration).

Radon concentrations drop sharply after mitigation using subslab depressurization (SSD). Figure 2 illustrates this point for test house 5. In this series of tests, radon concentrations were measured in the hollow block wall and beneath the floor slab as well as in the basement proper. The plotted radon levels show how quickly subslab depressurization causes the radon concentrations to fall in each of the zones measured, and that the wall responds quickly even though the fan suction, which is needed for subslab depressurization, is not applied directly to the wall but rather depends on communication through a sealed perimeter drain. The details of the perimeter drain sealing are also outlined in the figure.

Two other examples of mitigation history and the influence of other key parameters are shown in Figures 4 and

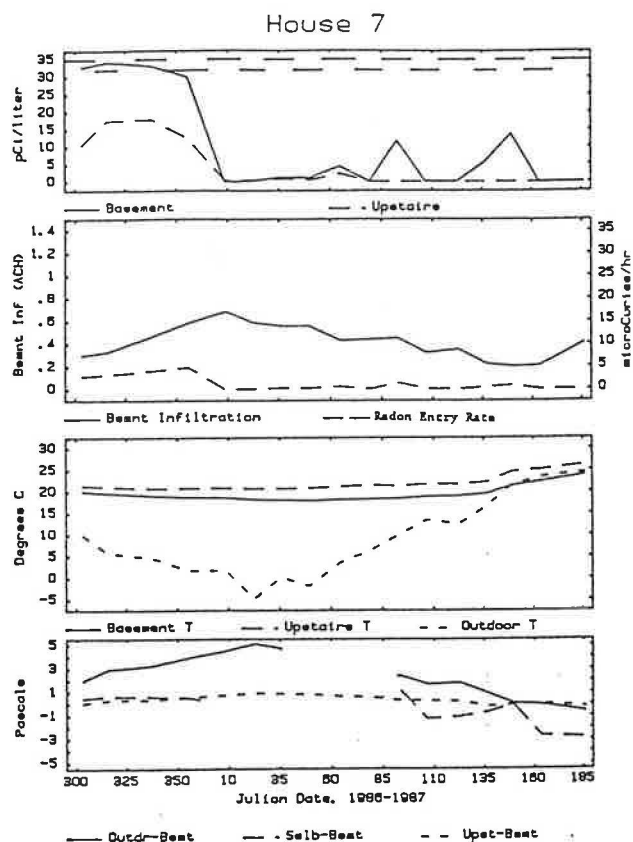


Figure 5 Piedmont Study house #7 before and after radon mitigation. The data are organized as in Figure 3.

upstairs, this effect will be greater or smaller—it will be highly dependent on the particular house.

Does the mitigation system pose any danger to the occupants by depressurizing the basement or crawl space, which often contains a combustion-type heating system? A well-designed subslab depressurization system would not cause such problems, but if perimeter drains and sumps were left unsealed, most of the exhaust air would come directly from the basement at flow rates close to the rated capacity of the fan (e.g., 100 cfm), which could pose problems. A mitigation system that exhausts air from the basement could lower the pressure in the basement enough to prevent combustion gases from exiting through a stack.

REVERSING CONDITIONS—HVAC INFLUENCES ON THE MITIGATION SYSTEM

The operation of house warm air heating systems and ducted cooling systems often results in local pressurization and depressurization of rooms (Harrje et al. 1986). This is because air supplies and returns are not balanced, i.e., they are not designed and constructed to carry equal air volumes. The general tendency is to provide adequate supplies but minimal returns, thus internal flow resistances (such as closed doors) will cause interzonal pressure differentials. In larger buildings there is often a conscientious design effort to create conditions where the building is pressurized (or depressurized) to meet certain design goals.

The residential building does not normally use these ducted systems for ventilation, although prolonged use of

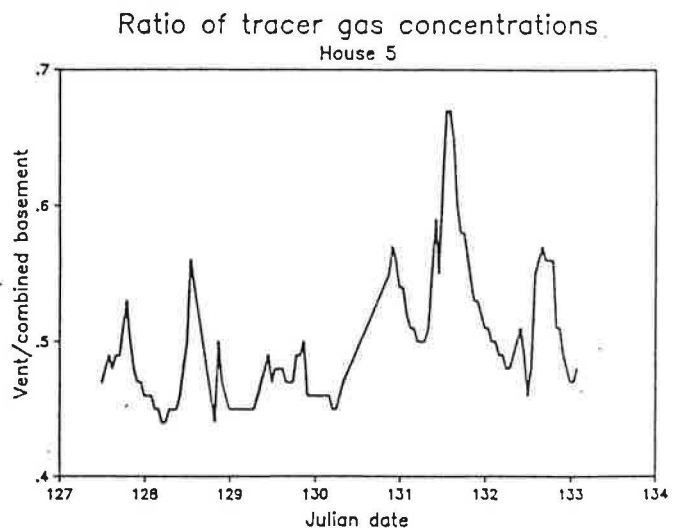


Figure 6 Ratio of tracer gas concentration in the exhaust versus house levels to determine exhaust rates of interior air-house #5.

the air handler fan will aid mixing in the various zones, redistributing any pollution loads. With inadequate returns, use of the system forces supply air to come from the vicinity of the heating or cooling unit via return-side duct leakage or openings in the fan housing. Two important events take place. Basement or crawl space radon is ingested and distributed throughout the house. Normally, basement or crawl space radon levels are twice the upstairs levels. If the air handler is operated continuously (or even for extended periods) the two zones become one with a near-uniform radon concentration. The second event is a lowering of basement and crawl space pressures, which can interfere with SSD system functioning, since the SSD system depends on maintaining a pressure difference between the basement and subslab.

Proper subslab depressurization system operation depends upon maintaining a pressure differential such that radon-laden soil gas cannot move from beneath the slab into the basement or crawl space. Reviewing Figures 4 and 5, we can see that at the point where subslab pressure is measured (other points may be more or less favorable for radon mitigation), once mitigation starts, pressure differentials are highly dependent on the way the system is adjusted, especially on the fan flow rate. Looking at house 7 (Figure 5), it is common to achieve only two pascals of pressure differential with the subslab depressurized relative to the basement. It is possible to overcome such small pressure differences during HVAC use, as discussed below.

Figure 8 points out the way in which the monitoring package and the constant concentration tracer gas system can be used to evaluate events during normal furnace and air handler operation. The data points are collected every half hour, and the plots in the first box illustrate the radon concentration upstairs (dotted line) and in the basement (solid line). The second box provides a detailed time history of the basement air infiltration. The third box depicts the fan operation (bottom line) as well as outside temperature. Box four shows that fan operation interacts with the outside-basement and subslab-basement pressure differentials.

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