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Project Summary

Installation and Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses

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Indoor radon reduction measures were tested in 40 existing houses with significantly evaluated radon concentrations in eastern Pennsylvania. In all but one, soil gas was the predominant source of the radon. The houses all had basements, sometimes with an adjoining slab-on-grade or crawl-space wing. Most of the radon mitigation techniques involved some form of active soil ventilation. In addition, three heat recovery ventilators (HRVs) were tested, and two carbon filters were tested for removing radon from well water.

The tests showed that significant radon reductions (90 - 99%) can be achieved with properly designed active soil ventilation systems. In basement houses with concrete floor slabs, suction on perimeter drain tiles can be very effective when a reasonably complete loop of drain tiles exist. Sub-slab suction (with individual suction pipes penetrating the sub-slab region) would be the next technique of choice, though it can be important that the suction pipes be carefully located when sub-slab permeability is poor. Ventilation of block wall cavities can give less predictable results. HRVs can provide moderate radon reductions (usually no greater than about 50% for reasonably sized HRVs), although their effectiveness in different parts of a house cannot always be reliably predicted. Carbon filtration can remove significant amounts of radon from water (up to 95-99%), at least over the 9-month period that they were tested in this study. The source of the carbon can be very important.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. EPA is conducting a program to develop and demonstrate cost-effective methods for reducing the concentrations of naturally occurring radon gas inside houses. This program is investigating the full range of radon reduction measures, in an effort to demonstrate suitable mitigation approaches for the full range of housing substructure types, housing design and construction methods, initial radon concentrations, and geological conditions representative of U.S. houses.

This report describes one project in the overall EPA radon mitigation program. Specifically, it describes the installation of developmental radon reduction measures in 40 existing high-radon houses located in the Reading Prong region of eastern Pennsylvania.

The 40 houses were selected to be representative of the substructure types common in that region. All of the houses have basements with concrete floor slabs, sometimes with an adjoining slab-on-grade or crawl-space wing. The foundation walls are constructed of hollow block in 30 of the houses, and poured concrete in the remaining 10. The houses were selected to have initial indoor radon concentrations of at least 740 becquerels/cubic meter (Bq/m^3)–or 20 picocuries/liter (pCi/L)–as determined by measurements by the Pennsylvania Department of Environmental Resources (PDER). One house had an initial level of 1 200 pCi/L (44,000 Bq/m^3). In all but one house, soil gas is the predominant source of the radon. Well water is the predominant source in the remaining house (with up to 11.5 MBq/m^3, or 310,000 pCi/L in the water), and is an important secondary contributor in several other houses. Extensive gamma measurements in and around the houses gave no suggestion that building materials are an important radon contributor.

Active soil ventilation approaches for radon reduction were selected for testing in most of the houses. Where soil gas is the predominant source, these approaches appear to offer the potential for achieving, at moderate cost, the very high levels of reduction needed to reach the EPA guideline of 148 Bq/m3 (4 pCi/L) in some of these houses (sometimes over 99%). Air-to-air heat exchangers (or HRVs) for increased house ventilation were tested in three houses, where the initial radon level is less severely elevated (generally where reductions no greater than 75% are required). Greater reductions with HRVs were not considered practical in view of the natural infiltration rates in these houses. Well water treatment systems were tested in two houses.

The general principle of soil ventilation is to draw or blow the soil gas away from the house before it can enter. Most commonly, fans are used: a) to draw suction on the soil around the foundation in an attempt to suck the soil gas out of the soil and to vent it away from the house: or b) to blow outdoor air into the soil, creating a "pressure bubble" underneath the house which forces the soil gas away. When fans are used to ventilate soil in either manner, the approach is referred to as *active* soil ventilation.

In this project, soil was actively ventilated in several different ways.

- Suction on drain tiles which are sometimes located beside the footings for water drainage purposes. The drain tiles can be present around the outside of the footings (exterior drain tiles), or around the inside, under the slab (interior drain tiles). If the tiles drain to sump inside the house, drain tile suction involves suction on the sump.
- Suction on the region underneath the concrete floor slab, by inserting suction pipes vertically down through the slab from inside the house.
- Suction on (or pressurization of) the network of voids inside hollow-block foundation walls. This can be accomplished either by inserting individual ventilation pipes into the void network, or by installing a baseboard duct which covers holes drilled into the block cavities.

Measurement Procedures

The performance of the radon reduction systems was determined using two types of radon measurements on the indoor air. The first type was 2 to 4 days of hourly Pylon measurements in the basement with all basement doors and windows closed, both before and after system activation ("short-term"). Sometimes measurements were also made upstairs. These measurements provided an immediate indication of the approximate percentage radon reduction, and of whether the post-mitigation concentration had been reduced below 148 Bq/m^3 (4 pCi/L). The second type involved 3-month alpha-track detector exposure during cold weather ("long term"). This measurement indicated whether the house was being reduced below 148 Bq/m^3 under cold-weather conditions, which would be expected to challenge the mitigation system performance. By comparison against any alpha-track measurements made by the PDER the previous winter, these long-term measurements could also suggest the winter-time long-term percentage reduction.

In addition to the radon measurements, various diagnostic tests were conducted before mitigation to help design the system, and after mitigation to help evaluate system performance.

Results

Table 1 summarizes the result from the 40 houses. For simplicity, only the ultimate reduction system for each house is listed. Some of the houses had more than one installation during the course of this project, and some installations were modified as the testing proceeded, as described in the report.

The radon measurements reported in Table 1 are the arithmetic averages of at least 48 hours of hourly measurements using a Pylon AB-5 semi-continous radon monitor, both before and after the mitigation system was activated. For all except House 18, the measurements were in the basement with doors and windows closed. In essentially all cases, the post-mitigation values were measured during cold weather.

Conclusions

The following conclusions are based on the results of this testing:

1. If a complete loop of perimeter drain tiles is present, suction on this loop should be one of first reduction approaches considered because: a) the tiles permit suction to be drawn effectively where it is generally needed the most, and high reductions are often achieved; b) drain tile suction is generally the least expensive active soil ventilation approach, and is the most amenable to do-it-yourself; and c) where tiles drain to a point outside the house, the entire installation is outdoors, thus offering advantages in convenience and aesthetics. Unfortunately, loops are not always complete.
2. Even where only a partial drain tile loop exists, drain tile suction can sometimes provide significant reductions and under some circumstances, might still be cost-effective to install before attempting additional measures.
3. Sub-slab suction, using pipes penetrating the sub-slab region, can be very effective in houses with either hollow-block or poured concrete foundation walls. Accordingly, it should be considered as a candidate control approach whenever significant levels of reduction are needed. If sub-slab permeability is good, one or two suction points might be sufficient, if the system is properly designed. If sub-slab permeability is not good, more suction pipes might be needed, and location of the pipes near the soil gas entry routes can become more important. In such cases, best results appear to be achieved when one or more suction points are placed near each load-bearing block wall (including interior as well as perimeter walls). The actual number and location of suction points required in a given house will depend on the nature and uniformity of sub-slab permeability, the location of major soil gas entry routes, and system design parameters

Table 1. *Summary of Results from Radon Mitigation Tests in 40 Eastern Pennsylvania Houses*

House No.	Substructure Type	Final Mitigation	Mean Radon Levels, pCi/L		Reduction, %
			Before	After	
1	*Block basement*	*Wall and sub-slab pressurization (baseboard duct)*	*161*	*5*	*97*
2	*Block basement*	*Wall and sub-slab pressurization (baseboard duct and carbon filter on well water)*	*238*	*3*	*99*
3	*Block basement*	*Wall and sub-slab suction*	*1205*	*5*	*99*
4	*Block basement*	*Sub-slab suction*	*20*	*3*	*86*
5	*Block basement*	*Wall pressurization*	*110*	*5*	*95*
6	*Block basement*	*Sub-slab suction*	*60*	*5*	*92*
7	*Block basement*	*Sub-slab and wall suction*	*402*	*4*	*99*
8	*Block basement*	*Wall suction*	*88*	*6*	*93*
9	*Block basement*	*Wall & Sub-slab pressurization (baseboard duct over French drain)*	*360*	*7*	*98*
10	*Block basement*	*Drain tile suction (exterior)*	*209*	*7*	*97*
11	*Block basement*	*Wall & sub-slab suction (baseboard duct over French drain)*	*60*	*21*	*65*
12	*Block basement*	*Drain tile suction (exterior)*	*11*	*3*	*75*
13	*Block basement*	*Drain tile suction (exterior)*	*94*	*2*	*98*
14	*Block basement*	*Wall suction*	*61*	*1*	*98*
15	*Block basement*	*Drain tile suction (exterior)*	*18*	*1*	*98*
16	*Block basement & paved crawl space*	*Wall suction*	*240*	*4*	*98*
17	*Block basement*	*HRV*[a]	*60*	*38*	*37*
18	*Block basement*	*HRV*	*2*	*1*	*50*
19	*Block Basement*	*Wall Suction*	*35*	*11*	*68*
20	*Block basement & paved crawl space*	*Sub-slab & wall suction, & suction on interior drain tiles in crawl space*	*282*	*4*	*99*
21	*Block Basement*	*Sub-slab suction*	*111*	*3*	*97*
22	*Poured concrete basement & slab on grade*	*Sub-slab suction (basement & slab)*	*34*	*9*	*74*

(Continued)

[a] *Heat recovery ventilator*

Table 1. *(Continued)*

House No.	Substructure Type	Final Mitigation	Mean Radon Levels, pCi/L		Reduction, %
			Before	After	
23	*Poured concrete basement & slab on grade*	*Sub-slab suction (basement & slab)*	*95*	*3*	*97*
24	*Poured concrete basement*	*Sub-slab suction*	*44*	*3*	*93*
25	*Poured concrete basement*	*Sub-slab suction*	*148*	*8*	*93*
26	*Block Basement*	*Drain tile suction (exterior)*	*89*	*1*	*99*
27	*Block Basement*	*Drain tile suction (exterior)*	*42*	*3*	*93*
28	*Block Basement*	*HRV*	*16*	*10*	*38*
29	*Block basement & unpaved crawl space*	*Drain tile suction (interior, sump) & crawl space liner/vent*	*47*	*2*	*96*
30	*Block Basement*	*Carbon filter on well water*	*29*	*5*	*83*
31	*Block Basement*	*Sub-Slab suction*	*485*	*4*	*99*
32	*Block Basement*	*Sub-Slab suction*	*6*	*1*	*80*
33	*Poured concrete basement*	*Sub-Slab suction*	*84*	*5*	*94*
34	*Poured concrete basement*	*Sub-Slab suction*	*696*	*5*	*99*
35	*Poured concrete basement*	*Sub-Slab suction*	*164*	*1*	*99*
36	*Poured concrete basement & slab on grade*	*Sub-slab suction (basement & slab)*	*142*	*2*	*99*
37	*Poured concrete basement & slab on grade*	*Sub-slab suction (basement only)*	*19*	*1*	*97*
38	*Block Basement*	*Sub-Slab suction*	*375*	*5*	*99*
39	*Block Basement*	*Sub-Slab suction*	*24*	*2*	*93*
40	*Poured concrete basement*	*Sub-Slab suction*	*113*	*3*	*97*

(e.g., if a hole is excavated under the slab where the pipe penetrates, in order to reduce system pressure loss). It appears that, through proper system design, sub-slab suction can be made to give high reductions even in houses with limited or poor sub-slab permeability. Diagnostic testing of the permeability before installation could aid in assessing the complexity of the sub-slab system that will be required in a given house.

4. In houses with block foundation walls, ventilation of the void network inside the walls can give high degrees of radon reduction, if major wall openings can be adequately closed and if there are no major slab-related soil gas entry routes remote from the walls, Current results suggest that a well-designed sub-slab suction system by itself might be expected to effectively treat both slab- and wall-related entry routes more often than might a wall ventilation system alone. Accordingly, in many block basement houses needing high reduction, it might be advisable to initially consider sub-slab suction rather than wall ventilation. Wall ventilation might sometimes be required in combination with sub-slab suction to reduce high radon block houses below 148 Bq/m^3 (4 pCi/L).
5. With any active soil ventilation technique, it is crucial that major openings in the slab and wall be closed, before effective suction can be drawn. Sumps should be capped even if suction on the sump is not planned. In houses with French drains that are needed to handle water drainage, the closure must retain the water drainage capabilities. Floor drains connecting to the soil should be trapped or plugged to prevent soil gas entry.
6. With any active sub-slab technique, best results have been achieved when the fan being used can maintain at least 150 Pa at the suction points with the soil gas flows encountered, typically 20 to 70 L/sec.
7. As expected, dilution appears to be a major mechanism in determining the performance of HRVs. However, other mechanisms (e.g., changes in soil gas influx) can also play a role, so that the radon reduction performance of an HRV on different floors of a given house cannot always be reliably predicted *a priori* based solely on dilution considerations. Moderate reductions (up to 80% in some parts of the house under some circumstances) can be achieved with a reasonably sized HRV in houses with typical natural infiltration rates, sometimes at the expense of lesser reductions in other parts of the house. One issue in selecting an HRV is whether it will be cost-effective relative to a comparable increase in natural ventilation without heat recovery.

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The complete report, entitled "Installation and Testing of Indoor Radon Reduction Techniques in 40 Eastern Pennsylvania Houses," (Order No. PB 88-156617/AS; Cost: $32.95, subject to change) will be available only from:

National Technical Information Service
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