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Project Summary

Radon Mitigation Studies: South Central Florida Demonstration

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In this EPA radon mitigation demonstration project, 14 slab-on-grade houses in Polk County, FL, having indoor radon levels ranging from 8.7 to 103 pCi/L,* were mitigated using sub-slab depressurization (SSD) in a variety of applications. These applications were employed to evaluate optimal design criteria to be recommended as cost-effective and capable of reducing indoor radon concentrations in houses built over compacted soil fills. For all houses, obvious accessible radon entry points were sealed, and 12-20 gal. suction pits were dug into the fill material. For all but one house, multiple suction holes were necessary to reduce adequately the indoor radon concentrations. Two of the houses were mitigated with exterior horizontal suction holes drilled through the stem walls. In four of the houses, one or more of the suction pipes was located in the garage. All of the rest of the interior suction holes were located in closets or some other unobtrusive location. Except for the two houses with exterior systems, the other 12 had mitigation fans located in the attic.**

In-line centrifugal fans were used to mitigate each house, although a larger radial blower was installed overnight for experimental purposes in one house, and a vacuum cleaner was used to simulate a larger suction in another house for pressure field measurements only. Post-mitigation worst case radon concentrations in these houses generally ranged from over 1 to about 8 pCi/L. Some of these houses are still being monitored quarterly with alpha-track detectors to assess long-term mitigation effectiveness.

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

Fourteen existing slab-on-grade houses with initial indoor radon concentrations between 8.7 and 103 pCi/L in Polk County, FL, were mitigated with sub-slab depressurization (SSD) systems from December 1987 through December 1989. All of the slabs were poured on a compacted soil fill. Most of the houses were on reclaimed phosphate mining land, and the remaining ones were on undisturbed mineralized soils. These features produced a situation in which very high sub-slab radon was usually present and the compacted soil medium was resistant to evacuation of the soil gas because of its low permeability. The report summarizes the pre-existing house and soil conditions of the 14 houses, describes the design and installation of the SSD systems that were used, evaluates the systems' effectiveness, and records conclusions and recommendations for the design of successful SSD systems in houses with such low-permeability fill material.

Procedure

Candidate houses for participation the first year's study were selected from earlier surveys and measurements conducted by the Polk County Health Department (PCHD) and the Florida Department of Health and Rehabilitative Services (DHRS). The second year's houses were selected from ad-

* 1 pCi/L = 37 Bq/m³
** 1 gal. = 3.8 L

ditional measurements by PCHD or some private measurement companies and from volunteers who had heard of the project from the first year's participants. The second year's candidates were further screened by telephone (for house information) and radon measurements with charcoal canisters. A full diagnostic visit was made to the 22 candidate houses the first year, a shortened diagnostic visit was made to the 11 finalists of the second year, and a full diagnostic was performed in the six selected houses. The diagnostic testing included 1) grab and/or "sniffer" measurements of indoor and sub-slab radon concentrations, 2) "sniffer" samples to detect soil gas entry points, 3) sub-slab communication tests to measure pressure field extensions from a suction hole, 4) infiltration tests using fan doors to quantify the house leakage area, 5) house differential pressure measurements, 6) site and house gamma radiation measurements, 7) sub-slab pressure flow measurements, and 8) some soil radium measurements.

Houses were selected based primarily on homeowner willingness and cooperation, house construction features (single slabs with minimal dropped floor areas allowed), standard site and structural practices (nothing requiring solutions unique to abnormal situations), minimal indoor screening radon measurements of 8 pCi/L in the first year and 20 pCi/L in the second, and adequate access to at least three sides of the house. The houses selected were therefore chosen to be similar in essential features but to have some diversity in other features of interest. For instance, all were required to be slab-on-grade houses, but some monolithic slabs were selected to compare with the slab-in-stem-wall construction. A few houses with frame exterior walls were selected to compare with houses built with more common concrete block exterior walls. A few L-shaped houses were included to compare with rectangular ones. Houses of moderate size were selected, attempting to get a range of floor areas, but extremely small or very large houses were avoided. Houses with a range of leakage areas from relatively tight to fairly leaky were selected.

One of the early goals of the project was to develop a set of "generic" mitigation strategies for use in slab-on-grade houses and to install and evaluate such systems. In the latter phase of the project, this approach developed into identifying the engineering design criteria for planning and installing SSD systems in slab-on-grade houses built over compacted soil fills.

The mitigation systems selected varied in approach and application between the first and second years. Generally, the systems were installed in stages during the first year so that effects of the various components and steps could be studied, analyzed, and evaluated separately. In the second year's six houses, the full systems were installed with specific research questions in mind, and the systems were activated in ways to answer these specific questions.

While the houses selected for this study were fairly carefully controlled in many of their structural and construction parameters, there was enough diversity so that the mitigation systems installed represented a wide range of features common to what the commercial mitigator may encounter or need. Mitigation suction holes were drilled vertically through slabs in closets, garages, utility rooms, and other spaces. Other suction holes were oriented horizontally through stem walls from outside the house and from the garage space. One suction hole was drilled from the garage, at an angle through the garage slab/house slab interface to the house sub-slab fill material. Mitigation systems varied in degree of complexity from sealing entry points and installing one SSD suction hole to various combinations of two to nine near-perimeter and interior suction holes.

Results and Discussion

Since the purpose of this research was to demonstrate and develop procedures for reducing indoor radon concentrations in this subset of the housing stock, the ultimate description of the results will involve to some degree the measurement of the indoor radon values. Measurements of other parameters that influence either the introduction of radon into the structure or the ability of a system to retard such contamination are also relevant. This section briefly reviews some of the methods used to measure the results, a synopsis of the data collected, and an analysis of what these data mean.

Methodology

The earliest measurements made in the houses used in this study were the premitigation diagnostic measurements, which have already been mentioned. For screening purposes, indoor radon measurements by open-faced, 2-day charcoal canisters were generally used. Sub-slab communication was measured using some type of suction apparatus (vacuum cleaner or mitigation fan) evacuating a space below the slab opening, and the pressure fields were measured by a micromanometer placed at each of the various smaller test holes drilled in the slab in different directions and at different distances from the suction hole. The house differential pressures were measured with a micromanometer and various combinations of house systems (air handler, interior doors, etc.) in a range of different modes. Potential radon entry routes were tested using alpha scintillation cell "sniffers" to check wall outlets, plumbing penetrations, toilet bases, tub traps, slab seams, obvious cracks, and any other possible opening to the sub-slab space.

Pre-mitigation activity primarily consisted of indoor radon measurements. Generally, long-term alpha track detectors were deployed from the time the houses were selected until the mitigation systems were initially activated, usually from 1 to 11 months, but most typically 2. A continuous radon monitor that recorded integrated hourly counts was usually deployed for at least 2 weeks in each house before the mitigation system was activated. In the second year's houses, the house air handler was cycled between automatic and continuous modes to measure air handler effects that had been suspected from the first year's data. Sometime during the premitigation data collection, usually when the house was closed and operating as near to normal as possible, including calm, stable weather conditions, two openfaced (2-day) charcoal canisters were exposed.

The methods of initiating the mitigation process varied between the 2 years and occasionally to some extent between houses within a year. For the first six houses in the first year's study, the mitigation system was installed and activated one suction hole at a time. In the last two houses, the two suction hole systems were installed and activated without stages. In the second year's houses, the multiple suction hole mitigation systems were installed as units but then activated according to the research objectives. In three houses, the systems were activated with no pits dug under the suction holes, and then compared with the system with pits dug. In the other three houses, near-perimeter suction holes were compared with interior suction holes. Later the full systems were run at "optimum" settings in all six houses. In both year's houses, where feasible, pressure field extension was measured before the suction pits were dug and again afterwards. In all situations the indoor radon concentrations were compared to the earlier, contrasting, or pre-mitigation measurements. Generally, the comparisons were framed in terms of percent radon reduction, which usually took the form of (standard-modified)/standard x 100 where "standard" was the baseline condition (premitigation, normal operating conditions, etc.) and "modified" was the average concentration after the feature being tested was activated (suction hole activated, pit dug, air handler placed in continuous mode, etc.).

Evidence and Analysis

Generally, the pressure field extension measurements improved when suction pits were dug. Unfortunately, most of the improvement seemed to occur in the magnitude of the pressure field at fairly close test points. Although there was some increase in the measured pressure field radius, it was usually not very great. Increasing the number of suction points appeared to be the more effective way of extending the pressure field coverage.

Sealing slab openings identified as radon entry points generally improved pressure field extensions and reduced radon entry; however, in some houses the direct effects were hard to distinguish from other variations. However, in two houses, sealing tub trap areas appeared to have contributed about a 40% reduction in indoor radon concentrations, and in another, closing an open atrium produced about a 65% reduction. Based on short-term (2 weeks or longer) continuous radon monitor (CRM) results, the one single suction hole system produced from 20 to 70% reduction in indoor radon, depending on which of two sets of post-mitigation data was used for comparisons in that house. In five of the houses where two-hole systems were installed, 34-93% reductions were experienced. (The lower percent reductions occurred in the lower level houses.) In the two initially high and "difficult" houses of the first year's study, three-hole systems produced 80-90% reductions.

In the second year's houses, several additional features of the house and mitigation systems were evaluated. Generally, continuous operation of the air handling system tended to reduce indoor radon concentrations by 10- 65%. Roughly, the more a house had been "pressurized" by the air handler in the house differential pressure diagnostic test, the greater was the radon reduction effect of the air handler. This seems reasonable since five of the six air handlers were in the attic and the pressurization indicates greater return leaks than supply leaks. With the returns drawing relatively radon-free air into the system and any slight pressurization having the potential to impede some radon entry, one would expect a radon reduction. At one house with the air handler in a room closet, there was less evidence of air handler impact on radon concentrations. In a house with very little pressurization caused by the air handler, it still had a large effect on radon reduction. It was later determined that the reason for this phenomenon was that there were about as many supply leaks as return leaks; so the radon reduction could be ascribed to dilution by a leaky air handling system.

As mentioned earlier, suction pits were shown to improve pressure field extensions. More importantly, digging a suction pit in the three houses where this experiment was conducted generally reduced radon concentrations an additional 20% over those measured with no pit dug. In the three houses where the suction hole placement was compared, one showed no significant difference between interior and perimeter suction holes. However, interior suction holes produced a 14-18% reduction of indoor radon concentrations in the second and nearly 40% improvement in the third. It was thought that the different results in these three houses were probably caused by differences in the relative leakiness of their respective stem walls, with the lower effectiveness of the perimeter holes occurring in the houses with the leakier stem walls. Overall, in these last six houses, a three-suction hole system in one house produced a radon reduction of 36-62% [depending on whether the normal occupancy pattern (open-house) or the closed-house levels were used as the reference], four-hole systems in four houses produced 27-94% reductions, and a five-hole system produced a 76% reduction in the remaining house.

According to the (2 week or longer) CRM measurements, three of the first eight houses were reduced to less than the target 4 pCi/L level for indoor radon concentrations, three were between 4.6 and 5.0 pCi/L, and two were between 6.9 and 7.8 pCi/L. In the last six houses, four were below 4 pCi/L, and the other two were between 4.1 and 4.3 pCi/L. However, if the long-term (quarterly or longer) alpha track detectors (ATDs) are used, then six of the first eight houses had quarterly indoor concentrations less than 4 pCi/L, as did four of the last six houses. The annual average radon concentrations for these houses can be approximated by the averages of the four quarterly ATDs that were deployed. Two of the first year's houses averaged less than 4 pCi/L, with the other six averaging from 4.7 to 9.3 pCi/L. Three of the second year's houses averaged less than 4 pCi/L, while the other three averaged from 5.2 to 5.7 pCi/L. What is not clear in any of the higher averages is whether the owners turned off the systems during the year. It was the habit of some to turn off most or all appliances when they were out of town; so the long-term ATDs may have been exposed to higher concentrations in this manner when the houses were unoccupied.

Conclusions and Recommendations

Radon levels of slab-on-grade houses built over a compacted soil base are not always easy to mitigate, especially if the soil is a relatively strong source of radon, as in some of the reclaimed phosphate mining lands. SSD was demonstrated to work in this type of environment, but the importance of good diagnostic assessments and carefully planned and well executed installations is perhaps greater under these conditions than with slabs built over gravel fills. Based upon the results described above, several conclusions can be drawn.

Diagnostic Methods Necessary to Obtain Successful Installations

In finished slab-on-grade houses, it was often almost impossible to identify the radon entry points, but because of the nature of the sub-slab environment, neither strong pressure fields nor adequate evacuation of the radon-laden soil gas was possible. Therefore, the greater the knowledge of the source and the pathway of the radon, the greater was the probability of diverting or blocking its intrusion into the house.

The vacuum cleaner pressure field extension measurement was considered to be crucial to take before planning a SSD system. It gave the best approximation of the recommended or effective distance between suction holes, and thus, helped to indicate how many suction holes would be required. The sub-slab pressure-flow measurements indicated *a priori* the approximate flow that a SSD system would produce with a given suction, thereby assisting in planning for the optimum pipe size for use in the mitigation system.

Installation Methods Applied to Slab-on-grade Houses

While several alternative methods were attempted to extend the pressure field and to provide better coverage of the sub-slab volume under the whole slab, few worked very well. One that provided some improvement in all cases and much improvement in almost all cases was digging suction pits in the soil under the suction holes through the slabs. The optimum practical pit size was determined to be 12-20 gal.

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The use of multiple suction holes at well-chosen locations throughout the house proved to be the most successful strategy to obtain an adequate pressure field extension under most of the slab area in compacted soil fills. Generally, interior suction holes proved to be more effective at extending pressure fields and reducing indoor radon than did near-perimeter suction holes. Geometrically this observation seems reasonable if an approximately circular area of influence is assumed, and if the suction hole near an exterior wall truncates the circle, reducing the area. Another more significant feature that influenced houses in this study was that, in at least two cases, the stem walls were too permeable to air movement. This led to the fan's suction head's being lost to pulling in outdoor air through the stem wall rather than pulling as much radon-laden soil gas from under the house. At times, near-perimeter suction holes were successful, where the stem walls were less porous or where the backfill adjacent to the stem wall was less tightly compacted. For suction holes that have to be placed near stem walls, the pits should be dug toward the house interior, exposing as little of the stem wall as possible.

The SSD systems installed over tightly packed soil fills generally produced low flows through the pipes and fans. This feature allowed for using smaller pipes than would have been possible with gravel fills and higher flows. The smaller pipes produced less intrusive systems, more flexibility in system placement, greater ease of handling, and somewhat lower material costs.

Certain house features and homeowner preferences necessitated a variety of suction hole placements and applications. The report describes in greater detail the installation of horizontal suction holes through stem walls and adaptations for placing suction holes in garages. Sealing radon entry points and other openings where possible was shown to improve SSD performance. Several toilet bases and tub trap areas were sealed, and some other cracks were caulked. Generally, such actions helped in at least one or two ways. If the opening was far from a suction hole, then quite possibly localized house depressurizations could easily overwhelm the relatively slight depressurization created by the distant suction hole, and radon would enter the house. If the opening was nearer the suction hole, then a significant portion of the mitigation fan's suction could be "lost" to pulling house or outdoor air into the exhaust piping rather than radon-laden soil gas.

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The complete report, entitled "Radon Mitigation Studies: South Central Florida Demonstration," (Order No. PB93-122299/AS; Cost: $27.00; subject to change) will be available only from:
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