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Project Summary

Testing of Indoor Radon Reduction Techniques in Central Ohio Houses: Phase 2 (Winter 1988-1989)

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Developmental radon reduction techniques have been tested in nine slab-on-grade houses and four crawl-space houses near Dayton, Ohio, in Phase 2 of a two-phase project in that area. Testing in slab-on-grade houses indicated that, where a layer of aggregate was under the slab, sub-slab ventilation (SSV) with one or two suction pipes generally reduced indoor radon concentrations below 2 pCi/L* (86 to 99% reduction), even when forced-air supply ducts were under the slab. Large slabs, block foundation walls, and sub-slab ducts sometimes required additional care in SSV design (number, location of vent pipes). SSV from inside and outside the slab-on-grade house gave generally comparable performance; however, interior SSV was preferable for one large house. Increasing the number of suction pipes from one to two, and increasing fan capacity, generally appeared to improve SSV performance. Operation of SSV systems in pressure never gave better reductions than did operation in suction. Testing in crawl-space houses indicated that depressurization under a polyethylene liner over the crawl-space floor was able to reduce concentrations below 2 pCi/L in the living area (81 to 96% reduction), consistently giving better living-area reductions than did any of the crawl-space ventilation approaches. Complete coverage of the crawl-space floor with the liner, and complete sealing of the liner at seams and around the perimeter, was not always necessary. Among the crawl-space ventilation approaches, forced exhaust (a fan blowing crawl-space air outdoors) consistently gave the best performance (70 to 92% reduction); natural ventilation (opening the foundation vents) gave 46 to 83% reduction; and forced supply gave 0 to 73%. In none of the slab-on-grade or crawl-space houses did "site ventilation" provide significant indoor radon reductions.

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).

*1 pCi/L = 37 Bq/m³.

Introduction

Much of the testing to date in EPA's radon reduction program has addressed basement houses. Phase 2 of the field project in Ohio was designed to focus on the two other primary substructure types: slab on grade, and crawl space. The testing reported here supplements earlier testing carried out under Phase 1 of the Dayton project.

The objectives of Phase 2 were:

1. To demonstrate alternative radon mitigation methods, and alternative mitigation design/operating conditions, for slab-on-grade houses representing different house design/construction conditions, and

2. To demonstrate alternative methods for treating crawl-space houses.

During Phase 2, testing of radon reduction approaches was completed on five additional slab-on-grade houses in the Dayton area, bringing to nine the number of slab-on-grade houses tested during the Dayton project. (Limited testing was carried out on a tenth house.) The premitigation radon concentrations in these houses ranged between 10 and 30 pCi/L. The houses were selected to cover a range of house design/construction variables: slab size; foundation material (hollow block vs. poured concrete); presence or absence of forced-air supply ducts under the slab; and presence or absence of a sunken living room, as one example of interior obstructions that might disrupt the extension of a suction field under the slab when applying sub-slab depressurization. Much of the testing focussed on SSV as the radon reduction approach. Also tested were: continuous operation of the central furnace fan, in an effort to pressurize the sub-slab region via the forced-air supply ducts; sealing of major slab openings (i.e., the plumbing opening under the bathtub); and "site ventilation" (i.e., suction on a pipe embedded in the ground outside the house, in an effort to draw soil gas from the entire site). Two variations of SSV were tested: "exterior" SSV, with the SSV pipes penetrating horizontally into the sub-slab aggregate through the foundation wall from outdoors; and "interior" SSV, with the SSV pipes penetrating the slab vertically from indoors. All of the houses tested had a good layer of aggregate under the slab, with the underlying soil being clay.

The four crawl-space houses tested during Phase 1 of the Dayton project were the subject of further testing during Phase 2. The premitigation concentrations in the living area of these houses ranged between 5 and 17 pCi/L. Mitigation approaches tested during Phase 1 had included: natural ventilation of the crawl space (i.e., opening the foundation vents, with no fan); and forced exhaust ventilation of the crawl space (i.e., using a fan to blow crawl-space air out, depressurizing the crawl space). The approaches tested during Phase 2 were: forced supply ventilation of the crawl space (i.e., with the fan blowing outdoor air into the crawl space, possibly pressurizing it); depressurization under polyethylene sheeting laid over the unpaved crawl-space floor (sub-liner depressurization); and site ventilation. The testing of sub-liner depressurization addressed the effects of alternative degrees of coverage of the crawl-space floor by the sheeting, and alternative degrees of sealing of this liner; since placement and sealing of the liner can be difficult and labor-intensive, it is desirable to determine to what extent this effort can be reduced. In all cases, the sub-liner depressurization systems tested here involved drawing suction on a length of perforated piping laid under the liner.

Measurement Methods

The performance of the radon reduction systems was determined using two types of radon measurements on the indoor air. One involved 2-4 days of hourly measurements with a Pylon continuous radon monitor ("short-term" monitoring). This monitoring immediately indicated the approximate percentage of radon reduction. The Pylon monitoring was conducted 2-4 days before, and 2-4 days after, any changes to the system; system on/off measurements were made back-to-back, to the extent possible, to reduce temporal variations. Measurements were made in different parts of the house, as warranted, under closed-house conditions. Most of the monitoring was completed during the heating season.

The other measurement method involved alpha-track detectors (ATD's), to provide a longer-term measure of system performance. Premitigation ATD's were exposed for about 2-3 months during cold weather, just prior to installing the mitigation systems. Quarterly post-mitigation ATD measurements were conducted over 3 to 4 quarters for the Phase 1 study houses; 12-month ATD measurements are underway for the Phase 2 houses.

In addition to the radon measurements, various diagnostic tests were conducted in selected houses (e.g., sub-slab communication tests, and suction/flow measurements in mitigation system piping).

Results and Conclusions

Slab-on-Grade Houses

Based on test results in the slab-on-grade houses, the following conclusions are apparent:

1. Continuous operation of the central furnace fan was tested in four additional slab-on-grade houses under Phase 2 of the Dayton project. The conclusion regarding HVAC fan operation is unchanged from what it was after testing the first four houses during Phase 1. Specifically, continuous operation of the HVAC fan in an effort to pressurize the sub-slab region via the sub-slab supply ducts will provide no better than moderate radon reductions. Observed reductions in the eight houses ranged between 0 and 84%, compared to when the central fan was cycling normally. There was no clear correlation between the effectiveness of central fan operation and the key house variables -- size or foundation material.

2. Sub-slab ventilation -- with the SSV system operated to depressurize the sub-slab -- was very effective in all nine of the slab-on-grade houses tested, consistent with the results observed in the first four houses during Phase 1. With appropriate SSV design, radon was reduced 86 to 99% in these houses, with the SSV mitigation fan operated at full capacity. The aggregate under the slabs is likely contributing to this success.

3. Forced-air (HVAC) supply ducts under the slabs did not appear to reduce the effectiveness of sub-slab depressurization by the SSV system. Where houses with similar characteristics other than the presence of ducts could be compared, the SSV system achieved comparable reductions in houses with and without ducts.

4. Two SSV approaches were tested back-to-back in four houses: "exterior" SSV, where the system pipes penetrate the sub-slab region horizontally through the foundation wall from outdoors; and "interior" SSV, where the pipes penetrate vertically through the slab indoors. The two SSV approaches appeared to perform about equally in three of the houses; interior SSV appeared superior in the fourth. The better performance of interior SSV in the one house could not be clearly linked to any particular house characteristic (size, foundation, presence/absence of sub-slab ducts).

5. The largest house tested (240 m^2, or 2,600 ft^2) -- which had sub-slab HVAC supply ducts -- required two interior SSV pipes to reduce premitigation radon levels of 16 pCi/L to below 2 pCi/L; one pipe (at either of two locations) was insufficient to reduce levels below 4

pCi/L. Another large house (220 m^2, or 2,350 ft^2), which did not have sub-slab HVAC ducts and which had a pre-mitigation level of 24 pCi/L, achieved levels of 2-4 pCi/L with only one pipe (although a second pipe provided even greater reductions, to below 1 pCi/L). Thus, large houses may require more than one pipe, especially if ducts are under the slab. All of the other slab-on-grade houses tested, ranging from 90 to 160 m^2 (1,100 to 1,700 ft^2), achieved levels below 2 pCi/L with only one SSV pipe.

6. In the two large houses referred to in 5 above, two suction pipes were better than either one alone, and any one pipe alone was about as effective as the other pipe alone. However, in a third house where a two-pipe system was tested, one of the pipes alone gave better performance than the other one alone or than both pipes together.

7. Slab-on-grade houses having poured concrete foundations appeared to consistently achieve the better radon reductions (97 to 99% reduction at best conditions) than did houses having hollow-block foundations (usually 81 to 93% reduction at best conditions). This may have been due in part because block-foundation houses tend to be larger.

8. In slab-on-grade houses having block foundation walls and sub-slab ducts, the wall ventilation component of an exterior SSV system can sometimes be beneficial.

9. In many of the SSV installations, operating the mitigation fan at reduced capacity was sufficient to reduce indoor concentrations below 4 pCi/L; in some cases, reduced-capacity operation reduced levels below 2 pCi/L. (In most cases, reduced-capacity consisted of reducing fan power to where system flow rates were half those at full power; this point would generally be about 15% of full power.) But in most cases, operation at full capacity provided radon reductions beyond those achieved at reduced capacity.

10. Operating these SSV systems with the fan pressurizing the sub-slab region, was never as effective as operatiing them in suction, in the seven slab-on-grade houses where both pressurization and depressurization were tested. Reductions ranged from 88 to 99% in suction, and only 43 to 90% in pressure.

Crawl-Space Houses

Based on the tests in the crawl-space houses, the following conclusions are apparent:

1. In the four crawl-space houses tested, forced-supply ventilation of the crawl space reduced radon in the living area sometimes more than, and sometimes no better than, achieved by natural ventilation of the crawl space. In all cases, forced exhaust was superior to either forced supply or natural ventilation. Radon reductions in the living area ranged from 0 to 73% with forced-air supply to the crawl space; 46 to 83% with natural ventilation; and 70 to 92% with forced exhaust.

2. Sub-liner depressurization systems were able to reduce all four houses below 2 pCi/L in the living area, achieving radon reductions of 81 to 96%. Sub-liner depressurization consistently gives better living-area reductions than do any of the crawl-space ventilation approaches.

3. With sub-liner depressurization systems, complete coverage of the crawl-space floor with the plastic sheeting is not always necessary, depending upon system configuration and perhaps other variables. In two houses having a loop of perforated drain tile around the perimeter, the plastic sheeting extended out from each perimeter wall for 3 m (10 ft); the central area of the crawl space was not completely covered, with the pre-existing vapor barrier spread out to cover this central area. With the depressurization fan operating at full capacity, these systems achieved reductions of 81 to 89%, reducing living-area concentrations to about 1 pCi/L.

4. Sealing the seams between the sheets of plastic, and sealing where the liner contacts the perimeter foundation wall, can be important with sub-liner depressurization systems; the importance depends upon such variables as fan capacity. In one house -- where the plastic covered the entire floor, and where the perforated piping was in the form of two straight, parallel lengths in the interior of the crawl space -- sealing the liner at seams between plastic and around the perimeter increased living area reductions to 90% with the fan at full capacity; by comparison, with the liner completely unsealed (neither at seams nor around the perimeter), reductions were 80%. Good reductions (comparable to what had been achieved in this house with forced crawl-space exhaust, which the sub-liner system may have been simulating in this case) could be achieved with no sealing, with the fan at full capacity. In another house -- with the liner covering the entire floor, and the perforated piping forming three parallel lengths in the interior of the crawl space -- sealing the liner at seams between sheets and around the perimeter increased living-area radon reductions to 94% at reduced fan capacity; by comparison, with the liner sealed at seams but not around the perimeter, the reduction was only 20%. This dramatic effect of perimeter sealing might have resulted because of the reduced fan capacity.

5. With sub-liner depressurization, increased fan capacity appears generally to increase radon reductions, all other variables being constant. Reducing fan capacity appears to have the least impact when the liner is largely sealed. Reducing fan capacity from medium to low decreased radon reductions by 4 to 14 percentage points in two houses with fully-sealed liners. But in a house with the liner not sealed around the perimeter, reducing fan capacity from full to low decreased reduction by over 75 percentage points (from 98 to 20%). With the liner sealed, it appears that good reductions can be achieved even at reduced fan capacity.

Site Ventilation

"Site ventilation" involves drawing suction on a pipe embedded in the ground outside the house, with the intent of drawing soil gas away from the vicinity of the house, in effect treating the entire lot. If effective, this approach could be attractive, since it requires no work inside the house, and the exterior work is relatively simple. For this approach to be effective, it would be expected that the horizontal permeability of the soil would have to be relatively high, and the vertical permeability relatively low. This approach has proven to be fairly effective in some areas of Canada and Sweden where these permeability requirements are met. In most of the Dayton area houses in this project, the underlying soil is clay, and it would thus appear that these permeability requirements would not generally be met; if site ventilation were successful in Dayton, it might be expected to be fairly widely applicable. In some cases, native gravel lies under the clay; if the site ventilation pipe could penetrate into the gravel, this approach could be effective.

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On these bases, site ventilation was tested on 13 houses in this project. In all cases, a 10-cm (4-in.) diameter PVC pipe was embedded in an augered hole up to 3 m (10 ft) deep, about 2 m (7 ft) from the house. A Kanalflakt T2 fan was mounted on the above- grade end of the pipe, drawing suction at full power.

In none of the houses did the site ventilation pipes penetrate the clay layer into gravel; thus, in no case were the conditions favorable for site ventilation. And, as might be expected, reductions in the indoor radon concentrations were limited at best, varying from +65% to -48%; the average reduction, averaged over all 13 houses, was only 3%. Indoor levels appeared to increase in about as many houses as they decreased with the application of site ventilation, suggesting that the observed changes in indoor radon levels might be due in part simply to temporal variations in premitigation radon concentrations. Tests of flows and radon concentrations in the vent pipe, and tracer gas studies to evaluate gas movement through the soil toward the pipe, suggested that gas was being drawn into the vent pipe, but that it was likely largely air being drawn down from grade level; tracer testing suggested that, beyond about a meter away from the vent pipe, the influence of the vent pipe was not strong.

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The complete report, entitled "Testing of Indoor Radon Reduction Techniques in Central Ohio Houses: Phase 2 (Winter 1988-1989)," (Order No. PB 90-222 704/AS; Cost: $31.00, subject to change) will be available only from:

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