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Project Summary

Design and Testing of Sub-Slab Depressurization for Radon Mitigation in North Florida Houses: Part I - Performance and Durability

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A demonstration/research project was conducted to evaluate sub-slab depressurization (SSD) techniques for radon mitigation in North-central Florida where the housing stock is primarily slab-on-grade and the sub-slab medium typically consists of native soil and sand. Objectives included developing and testing the use of a soil depressurization computer model as a design tool, optimization of SSD design for North Florida houses, and observation of the performance and durability of the installed systems.

Between May 1989 and August 1990, SSD systems were designed and installed in nine houses--seven with simple rectangular floor plans and two with more complex L-shaped designs. Installations included a single-suction-point system in one house and two-suction-point/single-fan systems in eight houses. The installation in one of the larger L-shaped houses consisted of a single-suction-point system in addition to a two-suction-point/single-fan system. All systems used small diameter, nominal 50-mm (2-in.) piping.

All houses were equipped with continuous radon monitors and integrating radon monitors were also deployed. All houses were visited on a regular schedule for measurements and observations.

The mitigation successfully reduced indoor radon concentrations originally on the order of 10 to 30 pCi/L to post-mitigation values of <4 pCi/L in all nine houses. Levels were reduced to values on the order of 2 pCi/L or less in three houses.

Installation experiences demonstrated the importance of avoiding "short-circuit" air flow leakage near suction points, providing drainage for moisture that condenses in the system during cooler weather (even in Florida), and sealing around discharge ducts at roof penetrations to prevent re-entry of exhausted sub-slab gases.

System manipulations indicated that a single suction point was sufficient on two houses with 160 to 170 m^2 (1700 to 1800 ft^2) slabs, but that passive ventilation is not likely to be effective for this type of sub-slab medium.

During the limited time available for durability observations (3 to 18 months), the systems retained effectiveness in maintaining reduced indoor radon concentrations, no fans failed, and no structural effects were observed.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, 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).

Background

This work was conducted in North Florida because of the presence of elevated indoor radon[1] levels and the need to investigate mitigation techniques successful for the housing stock and conditions represented.

In late 1986, results from a statewide indoor radon survey identified two focal areas of elevated indoor radon in Florida: one in the Bone Valley phosphate mining region of West Central Florida (Polk, Hillsborough, and surrounding counties); and the other in the North Florida Hawthorn formation region--with the greatest affected populations in the Gainesville-Ocala area (Alachua and Marion counties). Several other studies have confirmed the presence of indoor radon levels ranging from <1 to about 200 pCi/L in this area.

In Florida, the housing stock is primarily of slab-on-grade construction with several variations of floor-wall joining. There is a small percentage of crawl-space and slab/crawl-space combination houses (both open and enclosed crawl spaces), and there are very few houses with basements.

The U.S. Environmental Protection Agency (EPA) has suggested that soil depressurization is the most successful method of limiting indoor radon; thus sub-slab depressurization (SSD) appeared to be a promising mitigation method for Florida houses. However, at the time this project was initiated, most mitigation experience in the U.S. had been with basement houses. Furthermore, the sub-slab materials commonly used in Florida construction consist of native soil and sand. These would be expected to have lower air permeabilities than the coarse gravels commonly used under basement slabs in regions of the U.S. where SSD has been highly successful. This suggested that more complex and more robust systems might be required to successfully control radon in construction typical of Florida.

Radon mitigation demonstration work in Florida was begun with the 1987 initiation of the EPA-sponsored *Florida Radon Mitigation Project - Phase* I in Central Florida (Polk county). In late 1987, EPA also sponsored a University of Florida (UF) project to identify elevated radon houses that might serve as candidates for a parallel North Florida mitigation project. During the 1987-88 winter, screening measurements (charcoal collector method) were made in nearly 400 Gainesville and Ocala vicinity slab-on-grade houses in neighborhoods designated on the basis of geological potential for elevated radon. In these screening measurements on this selected group of houses, about 70% of the indoor radon concentrations exceeded 4 pCi/L and about 20% of the total exceeded 20 pCi/L.

The North Florida effort continued with the August 1988 initiation of the research and demonstration project, *Florida Radon Mitigation Project Phase II - North Florida*.

Objectives

This project had a demonstration objective and a series of research objectives. The *demonstration objective* was to demonstrate mitigation methods that are effective for the substrate and construction type characteristic of the North Florida region. Initial emphasis was on sub-slab depressurization (SSD). The project had three *research objectives:*

1. Develop tools for design of SSD systems. This includes testing the use of a soil depressurization computer model[2].
2. Optimize SSD design for North Florida houses.
3. Observe the short- and long-term performance and durability of the installed SSD system in this environment

This project involved the following work areas:

1. Select and characterize a candidate pool of houses.
2. Mitigate a subset of these houses --select houses, design mitigation systems, and install mitigation systems.
3. Monitor:
   - 3a. Collect baseline data prior to mitigation.
   - 3b. Monitor initial post-mitigation performance.
   - 3c. Conduct special studies on installed systems for the purpose of system optimization.
   - 3d. Evaluate durability of installed systems--continue monitoring and observations for the duration of the project.

Diagnostic Methods

From the data obtained in a house identification study, 12 elevated radon houses were selected as potential candidates for the mitigation demonstration. These houses were visited, and the EPA diagnostic measurements were performed. These diagnostic observations included descriptive information, sub-slab measurements, radon measurements, and house dynamics observations.

Sub-slab measurements included determination of soil gas radon by “sniff” and “grab” sampling, sub-slab communication testing, calculation of effective permeability, and sampling of the sub-slab material. Indoor radon measurements included short-term measurements of concentrations in the living space and also measurements of radon in the building shell. House dynamics measurements included indoor/outdoor and indoor/sub-slab pressure differential measurements under various conditions and blower door pressurization/depressurization tests.

Mitigation System Design and Installation

The design procedures are described in the Part II report. Briefly, potential suction points were located on the basis of accessible, unobtrusive locations--usually in interior closets. The UF soil depressurization computer model was then used as a design tool. For an initial set of five houses selected for mitigation in 1989, the model was used to simulate pressure fields under proposed designs. Suction system pressures and flows were predicted by superimposing the sub-slab “system curve” on the respective fan performance curves of candidate fans. For each house, the number of suction points, their locations, and the fan size were selected from the combination giving a pressure field coverage believed to be adequate to overcome inflow of radon-bearing soil gas. Subsequently, the computer model was used to develop soil depressurization system guidelines for the Florida radon-resistant building code. For a second set (four houses) selected for mitigation in 1990, system designs were specified using the evolving code guidelines.

To save cost, reduce space requirements, and facilitate installation, nominal 50-mm (2-in.) polyvinyl chloride (PVC) piping was specified for the major runs of the SSD systems rather than the nominal 100-mm (4-in.) piping reported in the literature for previous mitigation projects. It was anticipated that, because of the low flows associated with the low permeability Florida sub-slab medium, flow-related pressure losses in the smaller piping would not be large enough to compromise the effectiveness of the system.

[1] The terms “radon” and “Rn” are used to designate the radon isotope, radon-222; and “radium” is used to designate radium-226.

[2] Further development and testing of a computer model previously developed at UF for simulating sub-slab pressures and flows during the operation of soil depressurization systems was authorized. The work, which included expanding the model, developing it as an SSD design tool, and validation, is presented in Part II of this report.

At each suction point, sub-slab fill and/or soil was removed to form a roughly hemispherical pit, approximately 0.5 to 0.9 m (20 to 36 in.) in diameter. Nominal 100-mm (4-in.) PVC piping with a cleanout branch to serve as an access port was installed through the slabs. The remainder of the suction system consisted of nominal 50-mm (2-in.) PVC piping. Suction piping was run vertically from the pit to the attic. Fans were located in the attic. For the systems with two suction points, lateral piping was run from the vertical risers to a tee located under the suction fan. For the single-suction-point systems, the vertical piping was run directly up to the fan.

Systems were installed by the research team. Electrical hookup was provided by licensed electrical contractors.

Monitoring

Approach, Parameters, and Measurements

At each house, monitoring was conducted during three time periods: 1) the baseline data collection period, 2) the system installation and tuning period, and 3) the post-installation performance/durability monitoring period. Data collection consisted of a combination of 1) continuous multi-parameter data acquisition (in a subset of four houses), 2) continuous radon monitoring, 3) integrated radon monitoring, and 4) point measurements and observations in conjunction with site visits.

The continuous recording data-acquisition systems which were installed in the subset of four houses (referred to as "instrumented houses") consisted of data loggers with sensors for pressure differential (outdoor vs. indoor and sub-slab vs. indoor), indoor radon, temperature (indoor and outdoor), rainfall, and wind speed and direction. Data were sampled every 30 seconds and summed or averaged, and hourly sums or averages were stored in memory.

Indoor radon was monitored continuously in all houses, either as part of the data logging system (hourly averages) in the instrumented houses or by a stand-alone continuous radon monitor (4-hour averages) in the other houses. Integrating radon monitors (electret ionization chambers) were also used.

During site visits to the houses, pressures and flows were measured in the suction lines near the suction point, and "sniff" and "grab" sample measurements were made of radon concentrations in the sub-slab and/or exhaust air. Qualitative observations were made of the system and house condition.

Baseline Measurements

Baseline data collection was targeted for at least a month-long period prior to installation of the SSD system. Measurements included indoor radon concentration by integrating detectors, indoor radon concentration by continuous monitoring, pressure differentials (in some instrumented houses), and weather data (in some instrumented houses).

Post-Installation Performance/ Durability Monitoring

Following installation and tuning of the mitigation system, continuous data acquisition systems (instrumented houses) or continuous radon monitors (non-instrumented houses) were operated, integrating radon monitors were deployed, and periodic house visits were performed.

Post-installation monitoring was conducted according to the following general three-stage schedule:

- *Stage 1 Monitoring* (in service <6 months)--Continuous and/or integrating indoor radon monitoring was performed and houses were visited bi-weekly to observe system operation, measure pressures and flows, and service radon monitoring equipment.
- *Stage 2 Monitoring* (in service 6 to 12 months)--Houses without data loggers were visited monthly. For houses with data loggers, data acquisition was continued, data were reviewed, and visits were performed as necessary.
- *Stage 3 Monitoring* (in service >12 months)--As a longer-term follow-up, visits were conducted approximately every 6 months to inspect the systems, measure pressures and flows, and deploy radon monitors for a week-long measurement.

Performance and durability were evaluated in terms of:

- *System Performance and Interaction with the Sub-slab Medium*--System pressures and flows, noise and vibration, and requirements for adjustments and maintenance.
- *Condition of the Sub-slab Environment*--Effective permeability calculated from pressures and flows, and exhaust air and/or sub-slab radon concentrations.
- *Effectiveness*--Indoor radon concentrations.
- *Structural Effects*--Observations for evidence of subsidence, heaving, cracking, separation of joints, etc.

In addition, responses were made to homeowner questions or homeowner-identified problems.

Results and Discussion

House Characterization

Diagnostics were performed on 12 Gainesville and Ocala vicinity slab-on-grade houses during the last week of November 1988.

Installation of Demonstration SSD Mitigation Systems

SSD systems were installed in nine houses: six in Gainesville and three in Ocala (Table 1). House floor plans include seven rectangular and two more complex, L-shaped designs. The installations include one house with a single-suction-point system, seven with two-suction-point/single-fan systems, and a house with both a two-suction-point/single-fan system and a single-suction-point/single-fan system. Four houses were instrumented for continuous data acquisition.

Five of the systems were installed between May and November 1989, three in Gainesville and two in Ocala. These houses were all of simple, single rectangular slab configuration with slab areas ranging from 158 to 195 m^2 (1700 to 2100 ft^2).The system at the smallest house consists of a single suction point and a single fan; all of the others are two-suction-point/single-fan systems. The Gainesville houses were equipped with continuous data acquisition systems.

During the summer of 1990, systems were installed in two additional houses with simple rectangular slabs (149 to 181 m^2 or 1700 to 2100 ft^2) and in two larger (195 to 203 m^2 or 2100 to 2200 ft^2) houses with L-shaped floor plans. All of these systems had two suction points connected to a single fan. The system in the largest house also had a third suction point with a second fan. A continuous data acquisition system was installed in one of the rectangular houses.

Table 1. *Summary of Mitigation Installations North Florida Project*

House	*Slab, m^2 (ft^2)*	*Operation Date*	*Indoor Rn, pCi/L Unmitigated*	*System on*
Rectangular Slabs (7 houses):				
Ocala-1	*167 (1800)*	*May 1989*	*16*	*2.5*
Ocala-2	*164 (1760)*	*May 1989*	*10*	*2.0*
*Gainesville-1**	*164 (1760)*	*Jul 1989*	*11*	*3.5*
*Gainesville-2**	*194 (2087)*	*Nov 1989*	*25*	*2.5*
Gainesville-3+*	*158 (1700)*	*Oct 1989*	*9*	*2.0*
*Gainesville-4**	*181 (1950)*	*May 1990*	*11*	*2.6*
Ocala-3	*149 (1608)*	*Aug 1990*	*30*	*2.0*
L-Shaped Slabs (2 houses):				
Gainesville-5#	*195 (2100)*	*Jul 1990†*	*25*	*2.5*
Gainesville-6	*203 (2188)*	*Jul 1990†*	*26*	*2.5*

** Continuous data acquisition systems (4 houses).*
† Although Gainesville-5 & -6 were turned on July 1990, they required further adjustment and became successful Oct 1990.

System Types:

+ Gainesville-3: Single-suction-point system	*1 house*
# Gainesville-5: Dual installation (Two-suction-point/single-fan system plus single-suction-point/single-fan system)	*1*
All others: two-suction-point/single-fan systems	*7*
	9 houses

Mitigation Results

The mitigation successfully reduced indoor radon concentrations originally on the order of 10 to 30 pCi/L to post-mitigation values of < 4 pCi/L in all nine houses. Levels were reduced to values on the order of 2 pCi/L or less in three of the houses.

Design and Installation Experiences

Mitigation Design

As indicated above, the UF soil depressurization model was used as a design tool in placing suction points and sizing system components. The results of this work are presented in the Part II report.

Moisture Condensation

The early installations had some undrained low points in the horizontal piping runs in the attics; with the advent of cool weather in November 1989, water condensation from the moist exhausted air essentially blocked these systems and compromised their effectiveness. This problem was overcome by installing drain lines from the moisture traps.

Sub-Slab Leakage

It was observed that air leakage near the suction point can compromise the system effectiveness. For example, in one case, “short-circuit” flows from a leakage crack near one suction point of a two-point, single-fan system resulted in excessive flows at that suction point, an imbalance of the system, a compromised pressure field, and unsatisfactory effectiveness. Caulking the crack resulted in satisfactory performance. Subsequent failure of the silicone caulking resulted in degraded performance; this was remediated by recaulking with urethane elastomer. Other experimental work and simulation with the computer model indicated that leakage at points more remote from the suction point has much less influence on effectiveness.

Re-entrainment

An adventitious experience indicated the potential for re-entrainment problems. Following the initial installations in two houses, indoor radon levels were $\geq$10 pCi/L when the systems were operating. Attic levels of 10’s of pCi/L were found in subsequent radon monitoring. Investigation revealed that the roof penetration was not sealed around the vent pipe, apparently providing the opportunity for discharged sub-slab gases to enter the attic and be drawn into the house ventilation system. Sealing the roof penetrations reduced radon concentrations in the attics and indoors to <4 pCi/L (Table 1).

Optimization Studies

Pipe Sizing

Nominal 50-mm (2-in.) suction piping was installed as planned. For most of the cases (61% of the suction holes), flows were sufficiently low that calculated pressure losses due to flow were ≤15 Pa/10 m, and for 90% of the holes losses were calculated to be <100 Pa/10 m. In the two cases of the highest flows where calculated losses were ≥100 Pa/10 m, actual pressures on the order of -300 Pa (-277 to -328 Pa) were observed. The systems, involving these suction points in combination with a second suction point, were effective in reducing indoor radon levels by factors of 3 to 10, resulting in indoor radon levels of 3.5 pCi/l or less for these houses. The use of the smaller piping permitted savings in cost, space, and installation effort.

Suction Points

The effectiveness of single-suction-point operation was tested in several of houses with two-hole systems by operating these systems for a period of time with one or the other suction line valved off. These experiments indicated that:

1. Two suction points successfully maintained levels below 4 pCi/L for slab areas up to 2100 ft^2.
2. A single suction point was sufficient on three houses with 1700 to 1800 ft^2 slabs.

Passive Ventilation

The potential effectiveness of passive sub-slab ventilation was tested in several of the houses by monitoring indoor radon with the fans off and the suction lines open. These experiments indicated that passive venting (fan off, vent line open) was not effective for a packed sand/soil sub-slab medium.

Durability

Special questions were posed concerning durability for systems operating under Florida conditions. Would continued operation impact the sub-slab environment in a manner that affects the continued effectiveness of the system? If there were effects on the sub-slab environment, would these have structural effects on the building? Would continued performance of the fans be compromised by the low flow and high temperature in Florida installations?

As of the end of 1990, the 1989 installations had been monitored for post-mitigation periods on the order of 13 to 19 months. Insufficient time had elapsed for significant durability monitoring on the 1990 systems which had been installed during the period May through August. During the limited observation period (3 to 18 months), the following were observed:

1. With the transient exceptions noted below, the systems exhibited relatively constant performance and retained their effectiveness in maintaining reduced indoor radon concentrations.
2. In one case, failure of silicone caulking of a leakage crack near a suction point resulted in increased "short-circuit" flows. This was remediated by re-caulking with urethane elastomer, a more durable material.
3. With the advent of cold weather, condensation formed in horizontal attic runs that were not self-draining. This resulted in an audible gurgling noise, reduced flow, and increased fluctuations in indoor radon concentrations. This condition was remediated by installing traps and drains.
4. No fan failures were observed--any effect of low flow on fan life was not expressed during the available observation period.
5. No structural effects were observed.
6. With the exception of the "gurgling" associated with the water condensation before the installation of traps and drains, there were no homeowner complaints of noise or other annoyances.

Conclusions and Recommendations

Design Considerations

1. SSD was effective for North-central Florida slab-on-grade houses of both simple rectangle and L-shaped floor plans.
2. For the sub-slab media found in this region, low flows permitted use of smaller diameter, nominal 50 mm (2 in.) piping.
3. Two suction points were successful for slab areas up to 200 m^2 (2100 ft^2).
4. A single suction point was sufficient on three houses with single-level, rectangular slabs with areas on the order of 160 to 170 m^2 (1700 to 1800 ft^2).
5. Experiments with installed active systems (fan off, vent line open) indicated that passive ventilation is not likely to be effective for this type of sub-slab medium.

Installation Considerations

1. Air leakage near the suction point can compromise system effectiveness; leakage at points farther from the suction point has much less influence on effectiveness.
2. Even in Florida, moisture can condense in the system during cooler weather; it is important to avoid low points in horizontal attic runs and to install traps and drains if water trapping points cannot be avoided.
3. It is important to seal around the discharge duct at the roof penetration to prevent re-entry of the exhausted sub-slab gases. Examination for other sources of re-entrainment is also warranted.

Performance and Durability

The following conclusions are limited by being based on short observation times--3 to 18 months:

1. Pressure and flow values in SSD systems may exhibit some temporal variability; documentation of performance from point measurements should be based on averages from a series of measurements taken on different days.
2. On a near-term basis, SSD systems as installed in this project retain effectiveness in maintaining reduced indoor radon concentrations.
3. Continued integrity of sealing of potential short-circuit air flow sources near suction points is essential to continued effectiveness. System maintenance should include inspection of such sealing.
4. During cooler weather, unintended trapping of moisture condensation in horizontal attic runs can compromise system performance. Maintenance should include inspection for such inadvertent effects.
5. Fan failures have not been identified as a problem in the short term (based on observing a small number of systems).
6. Structural effects have not been identified in the short term.
7. Other than for the noises associated with the water condensation before correction, these systems have not generated homeowner complaints.

Short-term durability information would be enhanced by following all houses for at least a year, and long-term durability information would be gained by following all the houses even longer.

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The complete report consists of two volumes entitled "Design and Testing of Sub-Slab Depressurization for Radon Mitigation in North Florida Houses: Part I. Performance and Durability."
"Volume I. Technical Report" (Order No. PB96 -103 585; Cost: $21.50, subject to change)
"Volume II. Data Appendices," (Order No. PB96-103 593; Cost: $35.00, subject to change)
The above reports will be available only from:
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