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Project Summary

Effectiveness of Radon Control Features in New House Construction, South Central Florida

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The State of Florida has a radon standard for new construction. This study was conducted to evaluate the effectiveness of two slab types (monolithic and slab-in-stem wall) in retarding radon entry in new houses built in accordance with the proposed standard over high radon potential soils. Fourteen houses were monitored during their construction on sites whose soil gas radon concentrations were screened to be over 1,000 pCi/L. Some of the house sites had concentrations over 12,000 pCi/L. Slab integrity was monitored over time, and post-construction ventilation and radon entry were measured in all the houses. The houses with slab-in-stem wall foundations exhibited more slab cracking than did those with monolithic slabs. Those houses also had higher average radon entry rates, radon entry velocities, and concentration ratios than the monolithic slab houses. Both slab types proved to be effective in retarding radon entry, especially when penetrations were properly sealed. Six of the houses had post-construction average indoor radon concentrations of less than 2 pCi/L; six had average concentrations of 2 - 4 pCi/L; and two had average concentrations exceeding 4 pCi/L. One of the two houses with elevated indoor radon concentrations was on the site with the highest soil radium content (averaging 13.9 pCi/g), radon flux measurements through the compacted fill soil (6.1 pCi/m²s), and sub-slab radon concentrations (12,000 pCi/L). The other house was suspected of having an inadequately sealed tub trap.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention 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).

Introduction

Background

The Florida Radon Research Program (FRRP) was implemented to provide radon research related to the detection, control, and abatement of radon in new house construction and in existing buildings. The purpose of this research effort was the development of construction standards for radon resistant buildings and corresponding standards for mitigation of radon in existing buildings. From the fundamental studies in the first years of the program came a draft standard for radon-resistant building construction. The FRRP then shifted emphasis to field evaluation or validation of specific areas of the proposed standards. The majority of these demonstration studies have been evaluations of new houses constructed either in Alachua and Marion Counties or in Polk and Hillsborough Counties. In these studies it was found that implementing the standard recommendations resulted in low indoor radon concentrations in most cases. However, many of the houses were built on sites that had soil gas radon concentrations of less than 1000 pCi/L. In many of the houses built on more elevated radon potential soils, the passive construction features alone did not seem to control radon entry sufficiently to keep indoor radon concentrations below 4 pCi/L. One possible contributing factor to some of the failures was the fact that the builders did not always communicate schedule changes reliably to the investigators, who then were not able to inspect all of the slab sealing features as they were supposed to be accomplished. Finally, in the course of these studies, it was determined that some measurement or experimental protocols were not as effective as others in determining certain critical parameters, and that the frequency or timing of collecting other useful data could be improved.

Project Objectives

Part of the Florida approach has been to map different levels of radon potential within the state. The results of some of the previous studies have indicated that, in the lower and medium potential areas of the state, application of requirements of the standards seems to be effective in controlling indoor radon concentrations. However, results from the few houses from previous studies that were built in the higher radon potential areas have been inconclusive. The overall purpose of this work was to evaluate the performance and effectiveness of the radon resistant features of the "passive" barrier floor system in 14 new houses built over relatively high radon potential (>1000 pCi/L) soils in South Central Florida. Areas where houses were being constructed on reclaimed phosphate mining lands and mineralized former groves where the soil gas radon was closer to 10,000 pCi/L or higher were actively sought in order to test the radon resistant features in close to "worst case scenarios."

Within the context of this overall purpose, two objectives influenced the approach to the research:

1. Evaluate the relative effectiveness of two slab edge details, monolithic slab (MS) and slab-in-stem wall (SSW), in providing resistance to radon entry, and
2. Evaluate the effect of sealing slab penetrations on radon entry into houses.

Technical Approach

Sites were sought in areas of the region that were known or projected from past experience to have high probability of elevated soil gas radon concentrations. A package of information on the project, the standard, and the requirements for participation in the study was prepared and presented to builders and/or prospective homeowners in these areas, and their involvement was solicited. The construction of each selected house was monitored with the aid of a construction check list, and diagnostic measurements were made of the site, the slab, and the completed house according to predetermined protocols. All of the houses used in this research were of slab-on-grade (SOG) construction, and efforts were made to have a balanced number of MS and SSW houses. An active sub-slab depressurization (ASD) system using ventilation matting was installed in each house selected and constructed as part of the study. Data were collected of: the site; the fill soil (if used); the concrete placement, curing, and cracking; the installation of the air handling (AH) system; and the completed house radon entry characteristics. Throughout the data collection and analysis, predetermined checks were made of data quality indicators, including calibrations of the measurement devices, replication of certain measurements, and the ongoing adherence to good measurement practices.

Materials and Methods

Site selection

Once a candidate site was identified and permission was obtained from either the builder or the owner, at least one soil gas radon grab sample was taken in accordance with the FRRP Standard Measurement Protocols. The sample was usually extracted from a 1.2 m (4 ft) depth and from as near the center of the projected slab footprint as could be estimated. If the results of this radon grab sample estimated the soil gas radon concentration to be greater than the target value of 1000 pCi/L, then the house site was selected for the project. No houses with any portion of the main floor underlain by either a basement or a crawl space were considered for inclusion. Eight builders were used, who constructed from one to four of the houses each. The only two-story house in the study had only 81 m^2 of conditioned slab area in contact with the soil; while five of the smaller single-story houses ranged from 150 to 200 m^2, six others ranged from 215 to 285 m^2, and the two largest houses had conditioned areas of over 330 m^2. Eight of the houses had MS foundations (one a post-tensioned MS), and six were of SSW construction.

Pre-Slab Activities

When the site was prepared for the slab placement, site characterization measurements were made of the compacted fill and native soils. These measurements consisted of soil gas permeability and radon measurements, soil core extractions, and the placement of soil radon flux canisters. Permeability was usually measured at two locations near the center of the slab and at two to four others within the slab footprint. These measurements were made at depths of 0.3, 0.6, 0.9, and 1.2 m. Radon grab samples were taken at the 1.2 m depth. Between the two center permeability probe locations, a soil core was extracted of the fill and native soils, usually to at least 1.2 m. These samples were boxed and shipped to the University of Florida (UF) Environmental Radiation Laboratory where they were analyzed for soil radium content and soil radon emanation coefficient. If weather and scheduling permitted, the compacted fill radon flux canisters were placed within the footprint, left overnight, and collected for shipment to the analysis laboratory the next morning. If rainfall was predicted or if a weekend interfered with a shipment, then the data quality was reduced to the point that deployment and shipment were not reasonable. The ventilation matting was installed for the ASD system, with careful attention to ensure that the exhaust riser would be placed in a wall with other plumbing risers or in a chase if one was available. The riser was connected to the matting with a toilet flange. The mat and flange were recessed into the fill soil so that the slab thickness was not reduced around the flange. Sub-slab sampling lines were placed, usually with one under each quadrant of the house and one in the installed ventilation matting near the house center. After all of these features and the termite treatment were placed, the proper placement of the vapor barrier was monitored. The primary areas of attention were to ensure that an adequate barrier quality was used, correct overlaps were maintained, penetrations and tears were sealed and repaired, and the edge was treated correctly. While these activities were being performed on the vapor barrier, slab reinforcement was placed at reentrant corners and at large rectangular openings or penetrations (such as tub or shower traps) as required by the standard.

Slab Placement

Once the pre-slab installations were complete, the site was ready for the slab placement. This activity was closely monitored at all sites. The project sponsor, the Florida Department of Community Affairs (DCA), required that all concrete was to have high range water reducing admixture (superplasticizer) incorporated in the mix design. The standard required that the added water be kept below a fixed minimum. To ensure that the mix design was formulated properly, a quality control specialist from the corporate office of one of the local batch plants was called in to aid the plant in formulating and mixing the concrete properly. Most of the contractors used wood grade stakes not conforming with the standard, but no clear alternative to this common practice was found that they would accept and use. The curing and loading practices specified in the standard were monitored carefully.

Post-Slab Activities

Metallic penetrations through the slab were treated with tar, plastic sleeves, or some other interface to separate the metal from the concrete. The use of tar both insulated the pipe from corrosion by the concrete and bonded the pipe to the slab. Sleeves, however, protected against corrosion while often leaving an air gap between the pipe and the slab. Penetrations made of plastic, such as polyvinyl chloride (PVC), unless treated with tar, also left a sub-slab soil gas entry route. Extra measures for sealing these gaps were employed. This penetration sealing was monitored for durability during the curing and loading visits and afterwards when slab cracking was checked. After the slab curing process was completed, the slab was inspected periodically for evidence of slab crack formation. Before the floor coverings were placed, the cracks were mapped on a floor plan of the house, usually with the lengths and widths of the cracks recorded, and portions of one or more of the cracks were measured. The measurement protocol followed was similar to that used in earlier studies, except a for few modifications to improve the seal of the test chamber to the slab and to ensure a more reproducible grab sample of the chamber gas. The measurements were analyzed to determine the crack leakage area and to measure the radon concentration of the gas pulled through it.

Air Handling System and Other Post-framing Installations

The continuation of the ASD piping up a wall or chase into the attic and out the roof required supervision because leaks in this system would be extremely counterproductive to the radon resistance of the house. Once the framing and roofing were complete, the AH system was installed. Specifications of the sealing and placement of plenums, ducts, grills, and boxes were monitored during the installations. The wiring and operation of exhaust fans in bathrooms, kitchens, attics, etc., were also monitored to ensure standard compliance. Certain features were common to all the houses including the use of ventilation matting for ASD soil gas collection, a 152 µm (6 mil) vapor barrier, superplasticizer in the concrete mix, and acceptable sealing of slab penetrations and AH ducts in accordance with Florida energy code requirements.

Post-Construction Ventilation and Radon Entry Characteristics

After the house shell was completed and the AH system was installed, tested, and powered, the radon entry characteristics of the house were measured. The basic protocol followed was that used by UF in their Alachua and Marion County study, with minor adjustments in some of the houses. Indoor radon concentrations in one or more rooms, sub-slab concentrations from one of the sub-slab sampling lines, and outdoor (ambient) concentrations were measured hourly for at least six days. Simultaneously, half-hourly indoor/outdoor, indoor/sub-slab, and room-to-room pressure differential averages and indoor, outdoor, and other relevant temperatures were recorded. Sub-slab grab samples were usually taken before, between, and after the house ventilation adjustments were made. These house conditions were AH off/interior doors opened, AH on/doors open, AH on/doors shut, operated for about two days at a time. Generally this testing was attempted after the house was completed and before the occupants moved in. However, a few of the houses were completed when there were breakdowns in the measurements system, and some of the houses were finished within the same week as another, making for situations in which the houses were already occupied before the equipment was available for testing. In those situations, the testing had to be done with the owners' cooperation.

Results

In each of the 14 houses, three sets of diagnostic measurements were taken: site characterization (including site selection measurements), slab crack, and post-construction ventilation and radon entry. When the site characterization measurements were being made at house F-04, the permeameter probe was leaking at the weld of the head, and ultimately broke. A replacement could not be found before the slab was placed; so the characterization soil gas radon and permeability measurements were not usable. Sites F-05 and F-09 had more clay in the native soils, and the permeability measurements were lower there than at the other sites, except for F-14. The resulting flows through the radon grab scintillation cells were too little for adequate sampling, leading to low radon concentration measurements during the site characterization visits. Site F-14 had drainage problems; therefore, the permeability was very low, and the site characterization soil gas radon concentrations were taken at depths just above the apparent water table. Rainfall or scheduling problems prevented placement of the radon flux canisters at sites F-02, F-08, F-09, F-10, F-13, and F-14.

The screening measurements (one or two probes) at sites F-01, F-02, and F-03 were within the standard error of the characterization measurements (average of four to six probes). Those at site F-06 also agreed reasonably well (within 20%). The screening samples at sites F-05 and F-09 were taken in very clayey layers, whose radon concentrations were higher than expected, and the characterization measurements were artificially low because of low gas flows. However, the discrepancies between the selection and characterization measurements at sites F-07, F-08, F-10, F-11, F-12, F-13, and F-14 were more difficult to explain. They may reflect the wide range of variability inherent in reclaimed soils; they may be the result of soil mixing that occurred between the two measurement times; or they may have been influenced by changes in the soil condition, such as moisture content. The recorded radon fluxes did not show any correlation with the soil gas grab radon concentrations, but they were measuring different spaces. The grab samples were usually from 1.2 m depths-well into the native soil in all cases. The flux canisters were placed on top of the compacted fill. The average soil gas permeabilities were basically within an order of magnitude of one another, except for sites F-05, F-09, and F-14. House F-02 had excessive slab cracking, some of which was caused by having to move some plumbing after the slab had been placed because the plans had been misread. The slab quality overall improved as the project progressed. None of the three major concrete suppliers were familiar with the use of superplasticizer in the concrete mix design. Many of the early mixes were not formulated properly, which necessitated calling in a quality assurance officer from one of the home offices to assist in developing the mix design and training the operators in mixing it.

The soil radium content of the surface soils on these sites was well in excess of the recommended radium concentrations for foundation backfill material of 0.8 to 1.0 pCi/g, with the lone exception of site F-02. High radium fill may have been imported to site F-11, or it may have been below the recommended concentration. At six other sites, the fill or top horizon of the prepared base was higher in radium content than the lower horizons of the native soil. At sites F-01 and F-07 the fill was tested and found to be higher than any of the lower horizons, and at sites F-03, F-08, F-10, and F-14 it is suspected that imported fill may have contributed to higher radium contents in the uppermost layer of prepared soil. Site F-02 was the only one where low concentration fill was known to have been imported, but it appears that lower concentration fill than the native soil may have been used at F-05, F-12, and F-13. At site F-06 the fill had 7 pCi/g radium concentration, about what the native soil had. At site F-04 the soil radium concentration was very high from the surface down to 1.5 m. The radon flux through the compacted base corresponded very well with the soil radium concentrations in either the fill soil or in the uppermost horizon, which was a reasonable correspondence.

After the house shells were completed, the house radon entry was measured. House radon was measured in 13 of the houses under the three house conditions: AH off/interior doors open, AH on/doors open, and AH on/doors shut. The data were collected in house F-09 with the house shut (most of the time) and the AH in its normal operating mode. In 10 of the 13 houses for which most of the data are available, the indoor concentrations exhibit the following pattern: AH off ≥ AH on, doors opened ≥ AH on, doors shut. In the two of the houses in which this pattern was not observed, there were some possible explanations that may have contributed to the deviation from the norm. In house F-04, there was some evidence that the house may have been entered when the measurements were being made, especially during the AH off condition. In house F-06, there appeared to have been a heavy rain that led to elevated indoor (and sub-slab) radon concentrations during the AH on, doors open condition. It also rained during the whole week of data collection in house F-10, which may account for its high indoor concentrations. Further measurements were made there later, confirming elevated radon concentrations, but not as high as with the rain. House F-04 had the highest sub-slab radon concentrations (and radon flux and soil radium content) and also had the second highest indoor concentrations, while house F-02 had the lowest sub-slab concentrations and some of the lowest indoor concentrations. The other houses had intermediate sub-slab and indoor concentrations with no clear pattern of correlation.

Discussion

From the hourly or half-hourly indoor and outdoor radon measurements, the net radon concentration (C_{net}) was calculated by subtraction. The radon entry rate (RER) was then calculated by:

$$RER = C_{net} * \lambda_h * V_h / 3.6$$

where λ_h is the rate of house ventilation by outdoor air and V_h is the interior house volume. The radon entry velocity (or conductance) (REV) was calculated by lumping several velocity terms into one variable to produce:

$$REV = RER / (A_h * C_s)$$

where A_h is the house area and C_s is the sub-slab radon concentration. The radon concentration ratio (CR) was calculated by taking the ratio C_{net}/C_s. The means of these various measures of slab barrier effectiveness (C_{net}, RER, REV, and CR) for the two types of slab edge details were compared statistically. The net indoor radon concentrations in the two groups of houses showed no significant differences. The RER, which takes into account the house ventilation rates and house volumes, showed definite differences between the two slab types, but the variability within and between the groups was so great that these differences were not significant at a 5% significance level. The REV, taking into account the house slab area and the sub-slab radon concentrations, and the CR, taking into account the sub-slab radon concentrations, produce significant differences for the AH off and AH on/doors shut conditions. With this small sample size and the high variability in the measured and calculated parameters, it was difficult to show significance in all the analyses. It is expected that an increased sample size would reduce the variability in some of these parameters, increase the power of the comparisons, and indicate more significance in the results.

In earlier work, others had collected the measured radon and house data from two years of studies based on houses from the same general area as those reported here, and calculated CRs based both on the measurements and on lumped parameter model calculations. For MS houses in those studies, the overall geometric means of their measured and calculated CRs for houses with the ASD system installed but either capped or passive were 5 to $6x10^{-4}$. For SSW houses the corresponding geometric means ranged from 7 to $9x10^{-4}$. The respective CRs from this study were 2 to $3x10^{-4}$ and 4 to $6x10^{-4}$. These reductions were assumed to be attributable to the improved sealing procedures enforced in this year's study. One other comparison between the slab types showed a noticeable difference: the amount of slab cracking. The MS foundations averaged less than 6 m of slab crack length per slab, while the SSW houses had over 20 m of cracks per slab. However, house F-02, which had the alterations in the plan design after the original slab was placed, was a SSW foundation. The moving of some of the plumbing penetrations required breaking the slab, which caused some additional cracking. This activity biased the slab cracking data in favor of the MS foundations, but it did not account for all of the difference.

Conclusions

The results from this study demonstrated that houses built over MS foundations show less slab cracking and greater resistance to radon entry than did those built over SSW foundations, in accordance with previous findings. But both types of slabs were shown to be effective at retarding radon entry, even in houses built over relatively high radon potential soils (1000-5000 pCi/L or higher). The performance of these slabs was evaluated using measures such as REV and CR. When compared with CRs from previous studies in the same area of the state, those from this year's houses were lower by about half. Most of the improvement is attributed to stricter enforcement of the sealing of slab penetrations.

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The complete report, entitled "Effectiveness of Radon Control Features in New House Construction, South Central Florida," (Order No. PB96-177761; Cost: $44.00, subject to change) will be available only from:
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