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Radon Mitigation In Crawl Space Houses In Nashville, Tennessee

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INTRODUCTION

Crawl space houses can be defined as those in which a part or all of the living areas of the house are built over an enclosed area containing exposed earth. Clearance in this enclosed area can vary with the house type and site geometry from a few inches below the floor joists to several feet. In most cases the clearance is sufficient so that access can be gained through the outside wall of the house foundation. However, in some houses access can only be gained through the floor of the house itself. Prior to the collection of recent radon data [1], crawl spaces were even considered to be a viable alternative for radon control in new construction [2].

The major radon entry points from the crawl space into the house proper are through the numerous electrical and plumbing penetrations in the house floor and via the return air ducting often located in the crawl space. As the pressure in the house decreases relative to the pressure in the crawl space, radon gas emanating from the exposed soil is rapidly drawn into the house. Operation of the HVAC system can greatly enhance the normal stack effect produced by temperature differentials between house interior and ambient conditions. Thus, the radon levels can be as much as 2 or 3 times higher in the winter as in the summer.

HOUSE SELECTION

The houses for this demonstration were selected from respondents to a media announcement for homeowners whose houses had previously been tested and found to contain elevated levels of radon (greater than 4 pCi/l). From approximately 100 respondents, 30 houses were selected for possible participation in a more extensive house evaluation and mitigation demonstration. These 30 houses in Davidson and Williamson Counties, which comprise the Nashville Metropolitan Area (NMA), were screened between September 8 and 11, 1987, by a team of scientists from EPA, Tennessee Department of Health and Environment, Southern Research Institute, and Camroden Associates. As a result of these screening visits, 15 houses were selected to be included in the mitigation demonstration program. The houses selected included: nine crawl space (C/S) houses, three houses with basements converted from crawl spaces, two combination basement/crawl space houses, and one slab-below-grade house. This cross section is representative of the existing houses in the NMA and in portions of other states in the mid-south. The results of mitigation efforts on the crawl space houses will be presented in this paper.

DIAGNOSTIC PROCEDURES

An additional extensive diagnostic visit to each house was conducted between October 21 and 27, 1987. During this visit each house was subjected to a series of diagnostic tests which included: (1) radon grab and sniffer measurements, both in the lower living areas and in the crawl space, (2) communication tests using smoke and tracer gas to determine the leakage between house and crawl space, (3) infiltration tests using fan doors to quantitate the leakage areas in the house construction,(4) pressure differential measurements between house and crawl space and between the house or crawl space and outside, and (5) a gamma ray survey of the house, crawl space, and the surrounding lot site. During these diagnostic visits sufficient data were obtained to develop detailed mitigation plans for each house. Also, charcoal canisters (CCs) and alpha track detectors (ATDs) were placed in the crawl space and on the first habitable level to obtain a pre-mitigation radon background. In each location, duplicate detectors were colocated in an effort to determine the variation that could be expected in these houses. The CCs were recovered by the homeowner after 48 hours and mailed to the analysis laboratory (Scientific Analysis, Inc., Montgomery, AL). The ATDs were left in the houses until just prior to installation of the mitigation equipment. At that time they were returned for analysis (Terradex Corp., Glenwood, IL).

The results from the colocated CC measurements in October 1987 for the C/S houses are shown in Table I. The average temperature during the period over which these CC measurements were taken ranged from 42 to 61°F (5.6 to 16.1°C), with a minimum of 26°F (-3.3°C) and a maximum of 73° (22.8°C). Based on prior measurements made by the homeowners it is clear that these CC measurements were not taken during a period of maximum radon level inside the house. As a result, additional CC measurements were carried out just prior to mitigation work on each of the houses. These measurements were carried out over either 48 or 72 hour periods between November 28, 1987, and February 29, 1988. Thus, the later measurements occurred during the peak heating season for the NMA. These later results for those C/S houses mitigated to date are shown in Table II. In most cases the radon levels were higher than those measured in October.

RADON MITIGATION SCHEMES

The mitigation schemes developed for the nine crawl space houses in this study can be grouped into six classes. Not all of these techniques have been tried nor were all intended to be tried on each of the nine C/S houses. In most cases a two or three stage mitigation strategy was developed for each house. The first stage or phase of mitigation was intended to be the least expensive and the least difficult to install. The second would be moderately expensive, and finally the third or last phase the most expensive but with the highest probability of controlling the radon levels in the house.

Isolation of the Crawl Space from the House

In this mitigation technique the intent is to seal all possible penetrations between the crawl space and the house in an effort to simply prevent the passage of radon up into the living areas. The houses selected for this mitigation technique were those with low to moderate leakage between the crawl space and house. Sealing was accomplished using expandable closed-cell foam sealant and one part urethane caulking. Areas of particular concern include openings in the sub-floor for waste pipes (such as tub, toilet, and shower drains), water supply lines, and electrical wiring. Another area that needed careful attention was the return air ducting for the HVAC system. Joints in the duct work were inspected with a smoke stick while the HVAC fan was running. Also, the common practice of constructing a return air plenum using the floor joists and the sub-flooring had to be carefully inspected. This construction technique had multiple leakage points into the crawl space that were difficult to seal completely. No effort was made to seal the crawl space leaks to the outside of the house. Block vents were left to operate in the customary manner, open in the summer and closed in the winter. This mitigation technique was fairly simple to implement at low cost for those houses with low to moderate communication between the crawl space and the house.

Isolation and Passive Ventilation of the Crawl Space

In this modification of the above technique, the leakage points are sealed as before along with all but two or three of the block vents in the foundation wall. These were left open even in the winter in order to produce air flow in the crawl space. Thus, the radon gas is diluted by outside air and removed from the crawl space by convection air currents. To prevent water and waste pipes near the open vents from freezing, they were wrapped with insulation. This mitigation method could only be used on those houses either with no HVAC ducts in the crawl space or those where the ducts were well insulated beforehand. Attempting to wrap existing ductwork was ruled out as both costly and difficult to achieve. For this technique to be effective, not only must the sealing be adequate but also there must be ample air flow through the block vents. The air flow is greatly influenced by the lot topology and house orientation relative to prevailing winds.

Isolation and Active Depressurization of the Crawl Space

This is a variation on the above technique wherein a fan is placed in the crawl space to actively exhaust the air from underneath the house. The leaks up into the living areas have to be sealed to prevent loss of conditioned air and hence constitute an energy loss. Ideally the block vents are sealed in an effort to produce a negative pressure in the crawl space. Practically, there is sufficient outside air in-leakage to cause the radon soil gas to be diluted in addition to being exhausted. One possible drawback to this technique is that there is the potential to raise significantly the radon levels in the crawl space. Thus this method cannot be used where the crawl space is frequently entered by the homeowner.

Isolation and Active Pressurization of the Crawl Space

In this mitigation strategy the crawl space is isolated from the house and outside air is actively inducted into the crawl space in order to suppress the radon flux from the soil. As the crawl space becomes pressurized, the excess air is ducted back outside and exhausted. Because of energy considerations, the excess air is exhausted through a heat exchanger to condition the incoming air. Both the inlet and the exhaust are located at roof level with the heat exchanger located in the connecting ductwork to the crawl space. The device used in this study is commercially available (Current Model 300, Current Indoor Air Systems, Inc., Boulder, CO).

Depressurization Under Polyethylene Sheeting

This mitigation technique is a variation of the successful sub-slab depressurization method used for slab-on- or below-grade houses. In many of the nine houses there was at least some polyethylene sheeting covering the dirt in the crawl space. This covering is a popular method used to control moisture in the living areas. The intent of this technique is to supplement the existing polyethylene where possible in order to completely cover the exposed dirt. This gastight barrier forms a small-volume plenum above the soil in which the radon gas collects. A fan is installed to pull the collected soil gas from under the sheeting and exhaust it outside the house. Initially, no attempts were made to seal the polyethylene to the foundation walls or to any support piers located in the crawl space. The sheets were laid directly on the earth in most cases in such a manner as to produce laps of at least 1 ft (30 cm) at joints. In at least one location, drainage material (Enkadrain Type 9010, BASF Corp. Fibers Div., Enka, NC) was placed under the sheeting to improve air flow. In general this is not necessary unless the soil surface is excessively hard and smooth or the crawl space area is exceptionally large. When excessive air leaks prevented effective removal of the radon, the joints between sheets were sealed with a bead of caulking. Also, where the number of support piers was large or located close to the suction point the plastic sheeting was sealed to the piers with caulking and wood strips. In some of the houses the plastic sheeting was also sealed to the foundation walls to reduce air leaks. This technique was easily implemented on some of the houses but was somewhat labor intensive on those with limited clearances.

Depressurization of the Crawl Space Soil

This mitigation design is most novel in that the depressurization is created directly in the soil itself. Four pits approximately 18 in. (46 cm) deep and 24 in. (61 cm) in diameter were dug in the soil, one in each quadrant of the crawl space. Each pit was covered by a 3 ft (91 cm) square piece of treated plywood countersunk into the soil around the pit. The plywood was covered with dirt, and a 4 in. (10 cm) PVC pipe was attached through the wood. The pits were connected to a single inline suction fan (Model K6-XL4, RB Kanalflakt, Inc., Sarasota, FL) with the exhaust through a block vent in the foundation wall. No effort was made to seal the floor of the house since the radon gas would be removed before it escaped into the crawl space.

The matrix of mitigation schemes for the nine Nashville crawl space houses is shown in Table III along with the order in which the various phases were implemented. As of this writing only houses DW03 and DW84 have had no mitigation equipment installed. Also notice that not all phases have been implemented on some houses.