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Project Summary

Development and Demonstration of Indoor Radon Reduction Measures for 10 Homes in Clinton, New Jersey

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In the spring of 1986, the New Jersey Department of Environmental Protection (DEP) found a cluster of houses with extremely high radon levels in the town of Clinton, New Jersey. Research Triangle Institute was contracted to develop and demonstrate radon reduction techniques in 10 of these houses. The work was to be completed before the 1986-87 winter heating season began.

The demonstration homes were selected from 56 houses in the subdivision of Clinton Knolls. All of these houses had shown radon concentrations in excess of 64 pCi/l when monitored in the spring of 1986. Each of the houses was inspected, and 10 representative houses were selected for the radon reduction demonstration project.

Following intensive diagnostic work and monitoring in each of the houses, a radon reduction plan was developed. With the agreement of the homeowners, radon reduction systems were installed during the summer of 1986. All 10 houses had radon concentrations significantly reduced by the fall of 1986. The average cost of radon reduction was $3,127.

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

The discovery of high indoor concentrations of radon gas in the Reading Prong area of New Jersey, New York, and Pennsylvania, and in other locations in the United States, has raised serious concerns about a large number of people being exposed to the radioactive gas. In response, the U.S. Environmental Protection Agency (EPA) issued guidelines recommending corrective action in houses with radon concentrations in excess of 4 picocuries per liter (pCi/l), or 148 Becquerels per cubic meter, of air. At radon concentrations of 200 pCi/l, temporary relocation is recommended.

In the early spring of 1986, more than 50 of the houses with indoor radon concentrations greater than 100 pCi/l were identified in the subdivision of Clinton Knolls. Many of these houses had radon concentrations of 600 pCi/l or higher.

The primary purpose of the work described in this report was to develop and demonstrate cost-effective radon reduction techniques in 10 representative Clinton Knolls houses. Radon reduction was to be completed before the beginning of the 1986-87 heating season to keep the exposure of residents to a minimum. Additional data were collected to add to the general body of information on radon transport and its control in houses; however, this data collection was secondary to the pressing need to demonstrate effective radon reduction techniques by the fall of 1986.

Background

The subdivision of Clinton Knolls is near the center of the town of Clinton, New Jersey. The neighborhood is dominated by frame houses with approximately 139 m^2 (1500 ft^2) of floorspace. This uniformity is the result of development of the subdivision by a single builder. Some custom-built houses, similar in style and size to the developer-built houses, are scattered among those built by the prime contractor. While most of the houses are approximately 18 years old, many of the 56 volunteer houses that were surveyed were still occupied by their original owners, making this neighborhood a stable one.

The development is built on a dolomitic limestone hill that rises above Main Street and ends at the edge of an abandoned quarry. The hill crests at the interior streets of the subdivision with bedrock rising to the surface in the area. Several homeowners reported that the bedrock beneath their houses had to be blasted before basements could be built or before sewer lines could be put in place. Residents also reported the appearance of sinkholes throughout the neighborhood where the formation of underground caves had caused the earth to subside.

Selection of Demonstration Houses

Participants in the DEP radon survey in March and April of 1986 — 103 homeowners — were asked to volunteer their houses for the radon reduction demonstration effort. Of the volunteers, 56 were selected for screening. Table 1 shows the range of radon concentrations for the 103 houses participating in the DEP radon survey.

Three basic floorplans were repeated throughout the subdivision and are reproduced from the original developer's promotional brochure in the full report. In addition, a small number of diverse floorplans built by independent contractors were also investigated.

During a 1-week period, each of these houses was investigated by a diagnostic team of EPA and Research Triangle Institute (RTI) personnel. The objective of EPA's house screening effort was to characterize the pool of houses and select 10 houses as representative of the Clinton housing stock which could be used to demonstrate radon reduction measures.

Diagnostic Procedures Used Prior To Radon Reduction

Diagnostic techniques focused on the detection and isolation of three main mechanisms of radon entry and transport in a structure:

- Simple transfer through substructure openings. Radon enters a house through openings connecting the house substructure to the soil. These entrances need not be very large to constitute a significant radon pathway. Small slab-cracks, hollow pipes, sump holes, or any other features that penetrate the foundation of the house are likely sources.
- Negative-pressure-driven transport. Negative air pressure over the portion of the structure with soil contact results in a pressure-driven transport of radon and other soil gases into the house. Negative pressure can be induced by the use of fans, appliances, and natural ventilation in the house.
- Thermally driven transport. Differences in temperature between the soil-contacting portions of the building and the rest of the structure due to normal heating of the house may cause the thermally driven transport of radon from the soil into the house.

Although numerous sources have confirmed these general mechanisms, little information is available on the effect on indoor radon levels as the three mechanisms interact with one another in a house. Also, limited data are available to describe the interactive effects of other factors such as the tightness of a house or the operation of an assortment of common indoor venting devices such as a whole house fan.

Consequently, the 10 houses in Clinton were diagnosed using two approaches. The first approach was to identify and characterize all possible sources of in-leakage, negative pressure, and thermally induced transport in each house. The second approach was to simulate, in isolation, conditions that might enhance or reduce radon transport and then measure the actual effect. The second approach was used in a small number of houses. Experiments in this latter category include:

- Measuring the effect of whole house fan operation.
- Investigating the negative pressure induced on the basement by the use of various household appliances.
- Using a high volume fan to simulate winter-time stack effect.
- Measuring the effect that furnace operation has on basement pressure.
- Experimenting with supplied outdoor makeup air to reduce negative pressure.

In all cases, the objective of the diagnostic procedure was to understand the mechanism and identify sources of radon infiltration to develop a low-cost and effective radon reduction strategy for each of the demonstration houses.

Table 1. *Clinton Radon Levels*

Concentration (pCi/l)	*No. of Houses*	*% of Sample*
>2048	2	1.9
1024-2047	3	2.9
512-1023	13	12.6
256-511	17	16.5
128-255	17	16.5
64-127	12	11.7
32-63	12	11.7
16-31	14	13.6
8-15	5	4.9
4-7	6	5.8
<4	2	1.9
	103	

Radon Grab Sample Measurements

Radon grab samples, used in the diag nostic procedures, were obtained using Pylon scintillation cell in conjunction wit a Pylon AB-5 fitted with a Lucas ce adapter. Following EPA recommende procedures, grab samples were used t identify suspected soil gas entry route In all houses with sump holes, gra samples were taken in the stream of a exiting the footer drain pipe.

Qualitative Measurements of So Gas Entry

In all cases, the floors, joints, ar undergrade walls of each house we visually examined to identify potenti entry points. A simple smoke tube te was then made at any potential site entry to determine the direction of airflo

Characterization of Subslab Aggregate

Because of the high radon concentrations encountered in the 10 demonstration houses, it seemed likely that soil depressurization would be necessary. Consequently, all houses were inspected to determine the composition of the subslab aggregate.

Measurement of House "Tightness"

House tightness is used, in the context of this report, to indicate relative leakage area in a house. Air exchange rates were measured for each of the 10 homes in Clinton using a standard blower door test (ASTM Method E779-81). The objective was to determine the extent of leakage into the house. If the leakage was extensive, structural rebuilding might have been necessary for the radon reduction efforts to be effective. If tightness showed a good correlation with high radon levels, radon reduction measures might concentrate on compensating for the low volume of available dilution air in a house.

Data from blower door measurements were fitted using various models for the prediction of air exchange rates.

Infiltration rates predicted by the models range from 0.4 to 1.1 air changes per hour (ACH) with an average of 0.62 ACH (excluding results from the Shaw combined model). Correlation between predicted air exchange rates and radon concentrations in the 10 houses was low, with a coefficient of correlation of 0.60.

On the basis of these results, it was concluded that the extremely high radon concentrations encountered in the Clinton homes were not due to the tightness of the structures, but were more likely due to the unusually high source strength.

Whole House Fan Test

A test was made to gain some insight into the potentially competing effects of increased soil gas entry versus added dilution air when a whole house fan was used for ventilation. The results are shown in Figure 1. Although the fan dramatically increased ventilation (in the neighborhood of 2,000 cfm), the large negative pressure differential (≈28 Pa) increased the rate of soil gas entry sufficiently to overwhelm the diluting effect. Since this test was made in only one house, the results may depend on factors that are peculiar to the individual building, soil gas, and soil characteristics.

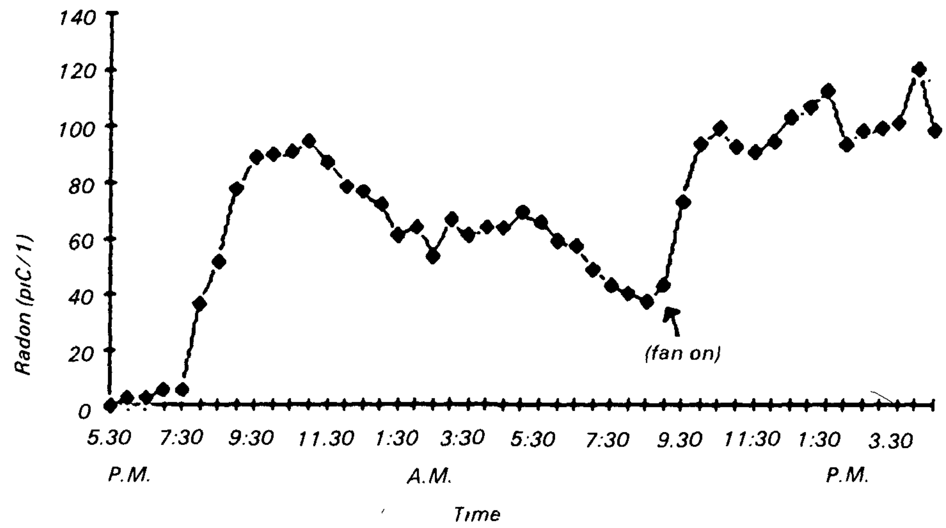

Figure 1. Effect on radon concentration of whole house fan use with all windows open

Investigations of Negative Pressure Induced on Basements

In the majority of houses, differential air pressure between basement air and outside air was measured. Temperature-driven stack effects and mechanical equipment effects were isolated, and the induced pressure differences were measured.

Simulation of Winter Conditions

Data from a variety of sources have confirmed that winter indoor air concentrations of radon are even higher than those measured under closed-house conditions in other seasons. Work in Clinton took place in the summer. As a result, a variety of means were attempted to simulate winter conditions. These approaches were largely unable to produce summer radon concentrations that were similar to those that had been recorded the previous spring.

Increasing Makeup Air

Additional negative pressure in basement areas produced by the normal operation of furnaces can result in increased indoor radon levels. One approach to controlling this effect is the introduction of makeup air to the basement or the furnace itself. Several methods of providing makeup air were tested in one of the houses in Clinton. Results of these tests are reported.

Radon Monitoring

Two radon monitoring techniques were used during this program: continuous radon monitoring using a Pylon AB-5 monitor together with a passive radon scintillation cell detector (PRD), and an integrating short-term technique using charcoal canisters. Protocols for the use of these techniques are detailed in the project Quality Assurance Project Plan (QAPP).

To differentiate between random fluctuations in concentration levels and any real reductions due to the radon reduction efforts, control houses were selected for simultaneous monitoring with radon reduction demonstration houses to be mitigated. Control houses were chosen on the basis of proximity and similarity in floorplan to the radon reduction demonstration houses.

Installation of Radon Reduction Equipment

The report describes in detail both the radon reduction equipment installed in each house and a rationale based on diagnostic measurements and house structure for the methods used. Materials employed are also detailed. Summary cost estimates for the installations are presented in the report.

Results and Discussion

Table 2 shows the estimated radon reductions achieved for each of the houses in Clinton. Since pre-installation radon measurements were made in the summer when radon concentrations are lower than in any other season, two estimates are shown. The first shows the

Table 2. Approximate Reduction In Radon Concentrations Using Charcoal Canister Data Following Application of Radon Reduction Techniques (pCi/1)

House No.	Before Radon Reduction (Early Spring) (DEP)*	Before Radon Reduction (Summer) (Closed House)	After Radon Reduction** (Late Fall) (Closed House)	Minimum Percent Reduction	Maximum Percent Reduction
A30	2,254	1,450	4.1	99.7	99.8
A39	1,500	10.4 (1,250 w/Pylon)	4.3	58.7	99.7
A8	791	409	2.9	99.3	99.6
A46	635	772	9.0	98.8	99.2
B10	418	15.8 (70 w/Pylon)	16.0	0	97.6
B31	691	89.0	5.8	93.5	99.2
B48	936	771	11.1	98.6	98.8
C33	1,190	304	4.7	98.5	99.7
D32	1,357	29.0 (130 w/Pylon)	11.3	61.0	99.2
E24	426	91.0 (210 w/Pylon)	12.3	86.5	97.2

* DEP screening study charcoal canister measurements taken in March and April of 1986.
** Highest post-radon reduction charcoal canister measurements taken in August 1985 through January 1986.

difference before and after installation of the radon reduction systems using pre-installation summer radon concentrations. The second relies on data collected in the spring by the New Jersey DEP to calculate the difference between pre- and post-installation levels of radon gas.

Recommendations

- A database of houses receiving the application of radon reduction techniques in Clinton Knolls should be maintained and analyzed. The database should contain pre- and post-radon reduction radon levels. A summary of the radon reduction method used, the house floorplan, and any unusual features of the house or the property on which it is built should be included.
- Long-term followup monitoring should be carried out in each of the mitigated houses to determine the average annual radon levels. This monitoring should be carried out for a period of at least 2 years and should include continuous monitoring for 1 week in each season in an effort to identify seasonal effects on the radon concentrations in the houses and peak exposures.
- In future radon reduction projects, at least 1 control house for each 10 demonstration houses should be monitored continuously during the entire period that radon reduction work and monitoring is being done. The control house should not be subjected to radon reduction methods during this time.
- The mechanisms controlling the strong diurnal variation in radon concentration in indoor air should be investigated. If periods of high radon levels during the day can be reliably predicted, radon reduction techniques could be directed toward reducing or eliminating those peaks.

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The complete report, entitled "Development and Demonstration of Indoor Radon Reduction Measures for 10 Homes in Clinton, New Jersey," (Order No. PB 87-215 356/AS; Cost: $18.95, subject to change) will be available only from:
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