United States
Environmental Protection
Agency

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Research and Development
EPA/600/SR-95/090 July 1995

EPA

Project Summary

Lumped-Parameter Model Analyses of Data from the 1992 New House Evaluation Project—Florida Radon Research Program

Kirk K. Nielson, Rodger B. Holt, and Vern C. Rogers

The report documents analyses of Phase 2 data from the Florida Radon Research Program's (FRRP's) New House Evaluation Project that were performed using a lumped-parameter model. The houses evaluated in Phase 2 were monitored by the Florida Solar Energy Center (FSEC) and the University of Florida (UF). Based on experience from the Phase 1 of the NHEP, the Phase 2 monitoring was aimed at better isolating the effects of specified radon-resistant construction features. The FSEC data included 15 houses, and the UF data included 14 houses. The lumped-parameter analyses focused primarily on empirically characterizing the radon resistance of the house/soil interface for different foundation designs. The analyses were also aimed at comparing the effectiveness of active and passive radon protection features.

This Project Summary was developed by the 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).

Introduction

Inhalation of indoor radon (^{222}Rn) and its decay products dominates exposures to natural radiation in the U.S. population. Radon causes 7,000 to 30,000 lung cancer fatalities annually from chronic exposure. Indoor radon comes mainly from decay of naturally occurring radium (^{226}Ra) in underlying soils, although contributions from water, building materials, and outdoor air may also be important. Radon enters buildings through cracks and pores in their floors and foundations, and its rate of accumulation depends on the competing rates of entry and of dilution by outdoor air. Indoor radon levels therefore vary significantly with time due to pressure-related changes in entry rate (from wind, temperature, and air-handler changes) and pressure- and occupant-related changes in dilution rates (e.g., from the pressure changes, door and window openings, ventilating appliances, and fireplace or flue openings). Since radon-related health risks accumulate over years or even decades, hourly or daily variations are relatively unimportant except as they affect the long-term average occupant exposure rate or the results of short-term radon measurements. The U.S. Environmental Protection Agency (EPA) recommends remedial action where long-term average radon levels are 4 pCi L^{-1} or higher. Indoor radon levels in the U.S. average about 1.25 pCi L^{-1}, and about 1% of all homes have levels that exceed 8 pCi L^{-1}.

The Florida Department of Community Affairs (DCA) is developing radon-protective building standards to help reduce radon-related health risks. The standards and their technical basis are being developed under the FRRP, which has studied building designs, materials, dynamics, basic processes, and radon source potentials. The FRRP also has evaluated various radon-resistant construction features by incorporating them into new houses under the NHEP. Under this program, test houses with radon-resistant features are monitored to assess each feature's effectiveness.

The effectiveness of radon-resistant construction features has been difficult to estimate because of the complexity of radon entry and accumulation processes, and because of uncontrolled differences among the houses. These differences include varying soil radon potentials at the different sites, differences in house pressure and ventilation characteristics, and differences in the coupling of radon potentials with house dynamics. Soil radon potentials depend on soil radium concentration, radon emanation coefficient, moisture, air permeability, diffusion coefficient, and density. Indoor air pressures affect both radon entry rates and house ventilation. House floor and foundation properties also affect radon entry rates for a given soil radon potential. Although the effects of these parameters can potentially be separated by sophisticated mathematical models, the models usually require more detailed data than are available from the NHEP projects.

To deal with the complexity and variability of radon entry, a simplified, lumped-parameter model was developed to help interpret the NHEP data by accounting for the uncontrolled differences among the houses. The lumped-parameter model was developed from numerous sensitivity analyses with a detailed numerical model, and from analyses of empirical data on house ventilation rates and concrete slab properties. In its initial comparisons with NHEP data, the lumped-parameter model suggested relatively large uncertainties in the performance of the radon-resistant construction features.

Theoretical Basis and Parameter Sensitivity

The lumped-parameter model was derived previously from sensitivity analyses with the detailed Radon Emanation and Transport into Dwellings (RAETRAD) model and from empirical definitions of typical house parameters. RAETRAD computes radon entry into a house using an elliptical-cylindrical form of two-dimensional gradient operators. With this computationally efficient approach, two-dimensional arrays of properties represent the house foundation and its vicinity soils for use in finite difference calculations. The detailed RAETRAD numerical model has shown that the primary radon entry routes and mechanisms are diffusion through the concrete floor slab and advection and diffusion through cracks in the concrete floor.

The lumped-parameter model is based on simplified empirical approximations of the RAETRAD sensitivity analyses that allow it to represent various soil properties, house sites, floor cracks, and indoor air pressures. It explicitly represents radon entry by pressure-driven advective flow through foundation cracks and by diffusive movement through both the cracks and the intact concrete slab. The model characterizes radon resistance by the ratio of net indoor radon concentration to sub-slab radon concentration, C_{net}/C_{sub}. This approach normalizes the different radon source strengths for soils under different houses to a common basis for comparison of the house radon resistance.

House Parameters and Radon Measurements

The FSEC houses included eight houses with floor slabs poured into hollow-block stem walls (SSW) and seven with monolithic poured-concrete slab and stem wall construction. The UF houses similarly included nine houses with SSW construction and five with monolithic slabs. The house areas, volumes, widths, and numbers of stories averaged higher for the SSW houses than for the monolithic-slab houses in both data sets, suggesting the tendency to use SSW designs for larger houses. The concrete slumps for the floor slabs were higher for the UF houses due to the more frequent use of super plasticizers. Slab reinforcement included wire mesh, glass fibers, and (in some FSEC houses) post-tensioning. Sub-slab ventilation (SSV) systems included both suction pits and ventilation mat, with well-point pipe being used in some of the FSEC houses (generally in connection with suction pits). All of the houses had SSV systems. The houses were monitored with the SSV systems in capped, passive, and (in some cases) active (fan-ventilated) modes.

Indoor radon levels measured for each SSV mode were compared to capped-SSV sub-slab radon levels for consistent comparisons of radon resistance. Indoor radon data were reduced by estimated outdoor radon levels to obtain C_{net}, the net soil-related component of the indoor radon concentration. The outdoor levels were estimated from an empirical function of the sub-slab radon concentrations.

Lumped-parameter model calculations for comparison with measured C_{net}/C_{sub} ratios used house parameters and surrogate measurements. House ventilation properties and air pressures were estimated from blower-door test data. Concrete slab water/cement ratios were estimated from reported values of the concrete slump. House dimensions were taken from direct measurements, and soil water saturation fractions were estimated from soil moisture measurements. SSV effectiveness was estimated from changes in sub-slab radon measurements under different SSV operating conditions.

Comparisons with the Lumped-Parameter Model

The comparisons of measured radon concentrations with predictions from the lumped-parameter model were made using C_{net}/C_{sub} ratios to normalize the different radon source strengths for each house to a common basis. Parameters for determining the measured C_{net}/C_{sub} ratios were estimated from measured sub-slab radon concentrations. Parameters for use in the lumped-parameter model were defined directly from measured values or were calculated from surrogate measurements in certain cases. The resulting calculated values of C_{net}/C_{sub} were then compared with measured C_{net}/C_{sub} ratios defined directly from the indoor and sub-slab radon measurements.

Conclusions

The present analyses estimate more precisely the effectiveness of radon-resistant building features than the previous NHEP data. They also suggest that the lumped-parameter model may accurately predict C_{net}/C_{sub} ratios when houses are built according to the FRRP construction standard. The accuracy of the lumped-parameter model is suggested by a ratio of 1.01±0.16 for the calculated/measured geometric means of the C_{net}/C_{sub} ratios.

Several other important conclusions about radon resistance are suggested by the data analyses. SSW construction, in accordance with the FRRP standard, reduces indoor radon to about 9×10^{-4} of the sub-slab concentration (with an uncertainty of a factor of 2.2). Capping the SSV system does not significantly alter its radon-resistance effectiveness compared to leaving it in the passive mode. Monolithic slab construction may improve radon resistance by approximately 33%, reducing indoor radon levels by a factor of 0.67 compared to SSW construction. Activation of SSV systems with exhaust fans may improve radon resistance by approximately 70%, reducing indoor radon levels to about 0.3 times the levels that occur when the SSV system is in the passive or capped mode. The present data on active SSV systems are sparse and uncertain, however, due to the few houses where the SSV systems were activated. Future analyses should include more data on active SSV systems to better define their effectiveness.

K. Nielson, R. Holt, and V. Rogers are with Rogers and Associates Engineering Corp., Salt Lake City, UT 84110-0330.
***David C. Sanchez** is the EPA Project Officer (see below).*

The complete report, entitled "Lumped-Parameter Model Analyses of Data from the 1992 New House Evaluation Project—Florida Radon Research Program," (Order No. PB95-243077; Cost: $17.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

United States
Environmental Protection Agency
Technology Transfer and Support Division (CERI)
Cincinnati, OH 45268