#5482

EFFECT OF WINDS IN REDUCING SUB-SLAB RADON CONCENTRATIONS UNDER HOUSES LAID OVER GRAVEL BEDS

by: P. C. Owczarski
D. J. Holford
K. W. Burk
H. D. Freeman
G. W. Gee
Pacific Northwest Laboratory

ABSTRACT

Wind pressures on houses can affect the availability of radon beneath houses that are surrounded by highly permeable materials. The Rn3D computer code was used in a two-dimensional study of the effects of winds on radon concentration profiles beneath a slab-on-grade house when dry gravel of various thicknesses surrounded the outer surfaces of the slab. Four generic soil types (sand, silt, loam, and clay) at several moisture saturations underlaid the gravel layer and house. For a typical annual distribution of wind speeds, radon concentrations under the houses were obtained as functions of gravel thickness and underlying soil type and saturation. Results show that for a gravel depth of 0.1 m, radon concentrations are reduced by up to 50% for sand and loam, 60% for silt, and 90% for clay. At a depth of 0.3 m the percent reductions are correspondingly 75, 75, 85, and 95%.

INTRODUCTION

In a recent study (1), we used the Rn3D computer code to examine the effects of winds in reducing sub-slab radon concentrations under houses laid over deep homogeneous dry soils with uniform radium concentrations. Only with gravel was a significant reduction seen. This recent study led to the present study of the significance of the radon-reducing effect of winds on houses deliberately laid over low-radium-content gravel beds. The technical concerns of this study were the effects of controlling parameters: wind speed, gravel depth, and underlying soil type and moisture saturation. The ultimate goal is to determine the practicality of using gravel beds in new home construction.

STUDY SYSTEM

To describe this study it is necessary to first discuss the study house and then the computational tool, the Rn3D code. The properties of the soils and annual wind speed distribution used are also discussed.

The study building consists of a two-dimensional 15-m wide slab-on-grade house (Figure 1). The soil surrounding the house and gravel bed is homogeneous directly underlying the slab. The gravel bed is of a uniform thickness around the edges of the slab. The gravel around the edges is necessary to ensure a flow path to communicate wind pressures to the sub-slab gravel.

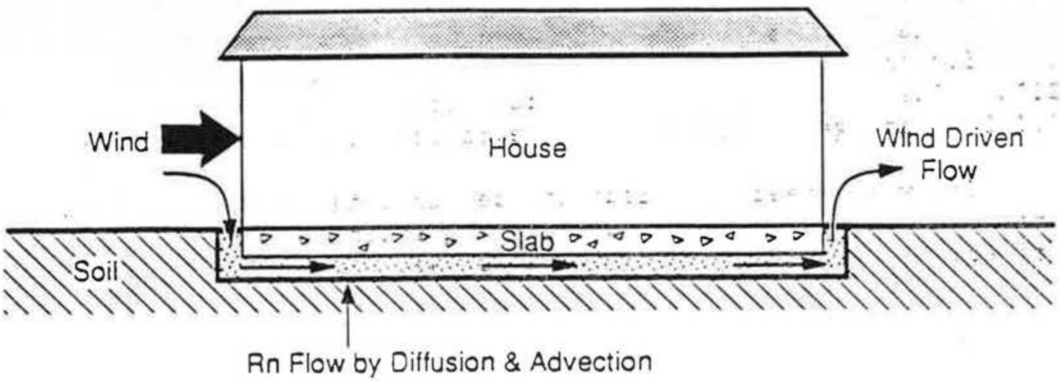

Figure 1. Schematic diagram of the two-dimensional study house showing gravel bed laid under and alongside the 15-m-wide slab in uniform thickness. Wind is assumed to be perpendicular to the side of the house.

Rn3D is a variably saturated, three-dimensional version of CRACK (2,3), a two-dimensional finite element model that simulates soil and crack pressure gradients that are caused by atmospheric pressure variations at the ground surface. The resulting soil gas flow drives the advective transport of radon gas, affecting the flux density of radon across the soil/air boundary. The soil in the model may be heterogeneous and anisotropic. Molecular diffusion of radon is assumed to be governed by Fick's Law and occurs in both the air and water phase. The flow of soil gas is assumed to be laminar and governed by Darcy's Law. The water phase is static. The code can be run for one-, two-, and three-dimensional problems, both steady-state and unsteady-state.

The initial boundary conditions used for the Rn3D code simulation are no radon concentration gradient at large depth, zero radon flux upward into the slab, zero radon concentration at the free soil-air surface, and a linear pressure gradient from windward to leeward under the slab. The wind-induced pressures (in Pa) on the free soil surface are (1): 1. Upwind, $\Delta P = 0.422U^2$, where $U = \bar{U}(1 - x^2/9)$, $\bar{U}$ = wind speed (in m/s) above the house, and x = upwind distance (in m) from the windward house wall. 2. Downwind, $\Delta P = -0.1507U^2$, where $U = \bar{U}(1 - z^2/9)$ and z = downwind distance (in m) from leeward wall.

The soil properties used in the simulation are as follows. (See Reference 4 for methods used in calculating these properties.) Radium activity of 110 Bq/kg was assigned to dry sand, silt, clay, and loam, and 0 Bq/kg was assumed in gravel. The following bulk dry soil densities (kg/m^3) were assumed: gravel 1275, sand 1934, loam 1494, silt 1583, and clay 1290. The emanation coefficient, e, for each soil is assumed to be the same for each water saturation level with the following dependence on saturation, S: $0 \leq S \leq 0.2$, $e = 0.1 + 1.5S$; $S > 0.2$, $e = 0.4$. This simple representation approximates the observed behavior of the emanation coefficient in many soils.

Table 1 summarizes the essential soil property inputs used in the Rn3D runs for this study. All computations were made for soil temperatures of 20°C. The gravel size distribution used here had a geometric mean radius of 0.371 cm and geometric standard deviation of 2.41 (4).

The wind speed distribution used to determine the annual effects of gravel-bed reductions in radon concentration is listed in Table 2. These wind properties are those of the Richland, Washington, airport.

TABLE 1. SOIL PROPERTIES

Soil type	Saturation (%)	Porosity	Permeability (m^2)	Rn diffusivity at 20°C (m^2/s)
Gravel	0	0.519	1.9×10^{-9}	7.72×10^{-6}
Clay	0	0.5131	1.0×10^{-15}	1.98×10^{-8}
	30		4.9×10^{-16}	1.51×10^{-8}
	47.5		2.8×10^{-16}	8.64×10^{-9}
	65		1.2×10^{-16}	3.35×10^{-9}
Silt	0	0.4026	1.5×10^{-15}	2.57×10^{-6}
	30		7.6×10^{-15}	7.95×10^{-7}
	65		1.8×10^{-15}	1.48×10^{-7}
Loam	0	0.4362	2.0×10^{-13}	6.89×10^{-6}
	30		9.8×10^{-14}	2.50×10^{-6}
	65		2.4×10^{-14}	3.82×10^{-7}
Sand	0	0.27	3.4×10^{-12}	7.10×10^{-6}
	30		1.7×10^{-12}	5.20×10^{-6}
	65		3.4×10^{-13}	9.59×10^{-7}

TABLE 2. WIND SPEED CLASSES AND ANNUAL PERCENTAGES

Range (mph)	Speed class used in model (m/s)	(mph)	Percent of class annually
1-3	0.95	2	19.8
4-7	2.62	5.5	43.0
8-12	4.77	10.0	23.3
13-18	7.39	15.5	10.6
19-24	10.26	21.5	2.7
>24	(not modeled)		0.6

RESULTS

We began this study by searching for a suitable gravel bed depth. To determine an optimum thickness of gravel for radon venting, we examined a case where the soil type (clay) and saturation (47.5%) were held constant and the gravel bed thickness and wind speed were varied. The Rn3D results for this case are plotted in Figure 2. In this figure, the slope of each wind speed curve, representing gravel-region average soil gas concentration versus gravel bed depth, starts leveling out at a gravel depth of 0.1 m. Increments of gravel depth at larger gravel depths do not produce as much reduction in radon concentrations. Even at no wind, there is about a factor of three reduction in sub-slab radon concentrations for a gravel bed of 0.1-m depth above 47.5% saturated clay.

Figure 3 shows the effects of moisture saturation and wind speed on sub-slab radon concentration in 0.1-m-deep gravel above clay. The effect of saturation on percent reduction is small for clay, since clay transports radon slowly even when dry. Figure 4 for dry soils shows that clay provides the greatest sensitivity to wind speeds. Since the air permeability and radon diffusivity in clay are lower than those of the other soils, radon removed by the wind cannot be replenished into the gravel region as quickly from clay.

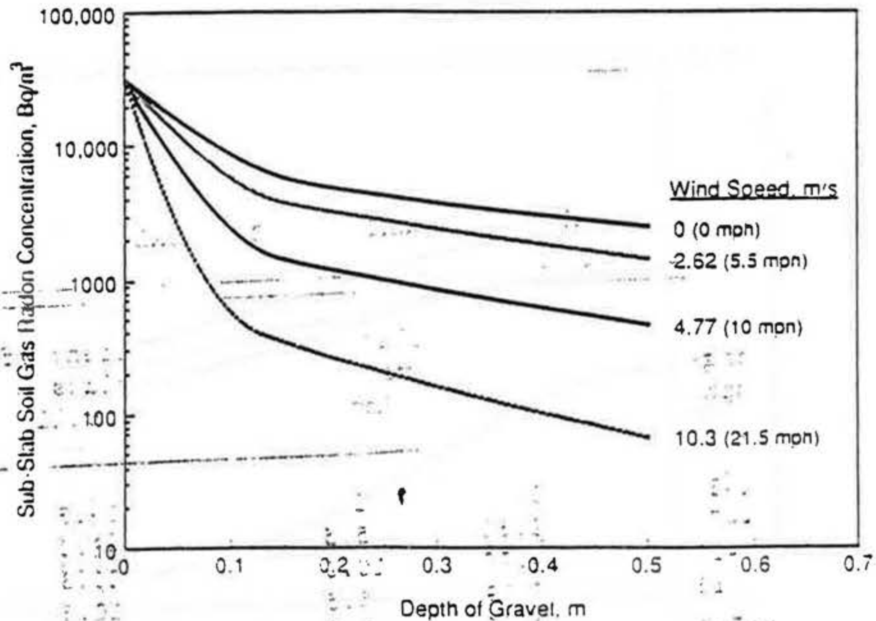

Figure 2. Effects of bed depth and wind speed in reducing average sub-slab radon concentrations. Underlying soil is 47.5% saturated clay.

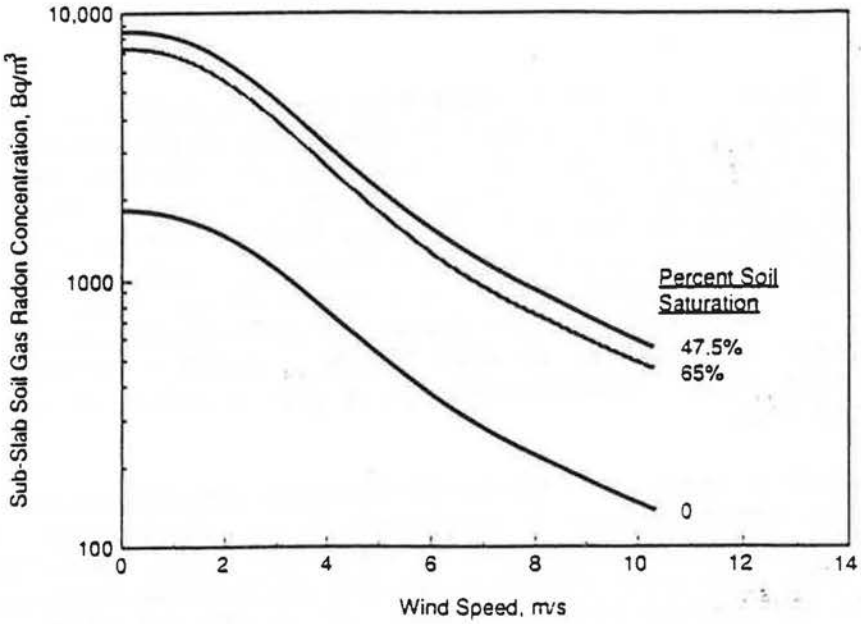

Figure 3. Effects of wind speed and saturation in reducing average gravel-region sub-slab radon concentrations. Gravel bed is 0.1 m thick and underlying soil is clay.

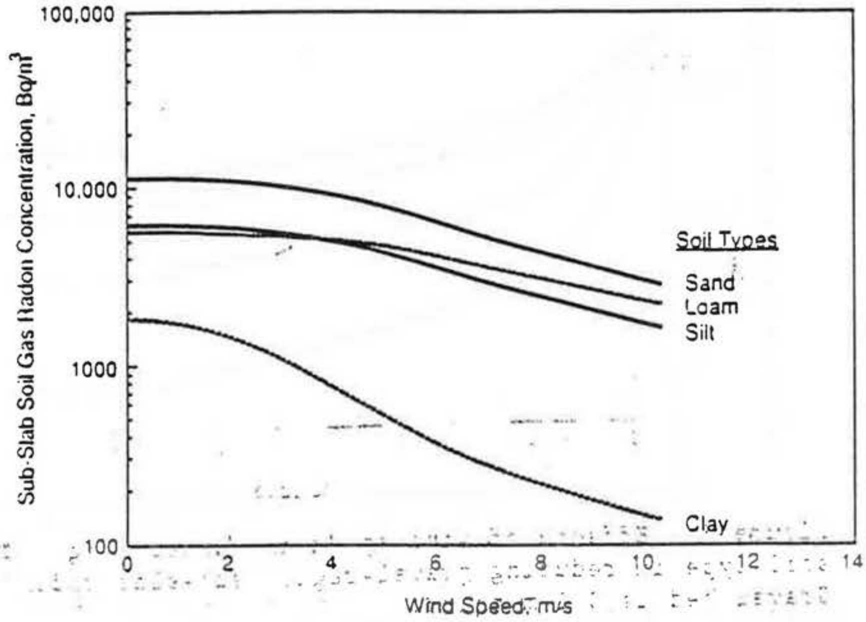

Figure 4. Effects of wind speed and underlying dry soil type in reducing gravel-region sub-slab radon concentrations. Gravel bed is 0.1 m thick.

As soils become more saturated, this replenishment ability diminishes, as we see in Figure 5. Here 65% saturated soils show a greater sensitivity to wind speed than the previous soils.

We now look at the end results of this study where we determined the annual average reduction in sub-slab radon that could be expected if a gravel bed underlaid the study house. Using the wind classes of Table 2, we constructed Figures 6 and 7. Figure 6 shows the percent reduction that could be expected from 0.1 m of gravel as a function of saturation. At 65% saturation, clay reaches 90% reduction, followed by silt at 60% and sand and loam at 50% reduction. Figure 7 shows that even greater percent reductions is achieved for 0.3 m (1 ft) beds. Here reductions achieved at 65% saturation were 95, 85, 75, and 75% for clay, silt, sand, and loam, respectively. The reader can easily extrapolate on Figure 7 to gravel beds of depth greater than 0.3 m.

Simplifying assumptions used in producing Figures 6 and 7 were 1) constant temperature (20°C) of air and soil throughout the year and 2) constant saturation throughout year at each saturation level. Running Rn3D for all temperature and saturation variations that would occur at a specific site were beyond the scope of this paper.

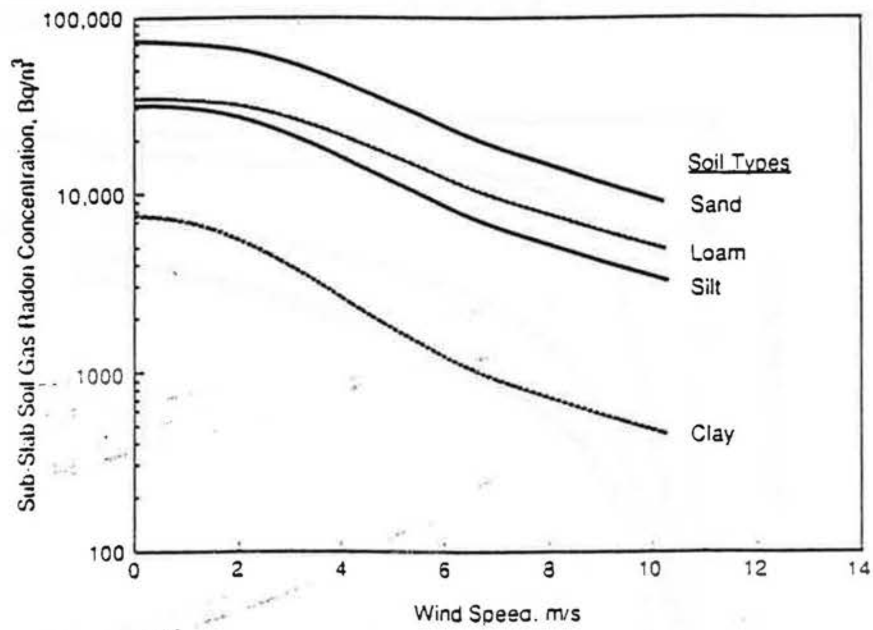

Figure 5. Effects of wind-speed and underlying 65% saturated soil-type in reducing gravel-region sub-slab radon concentrations. Gravel bed is 0.1 m thick.

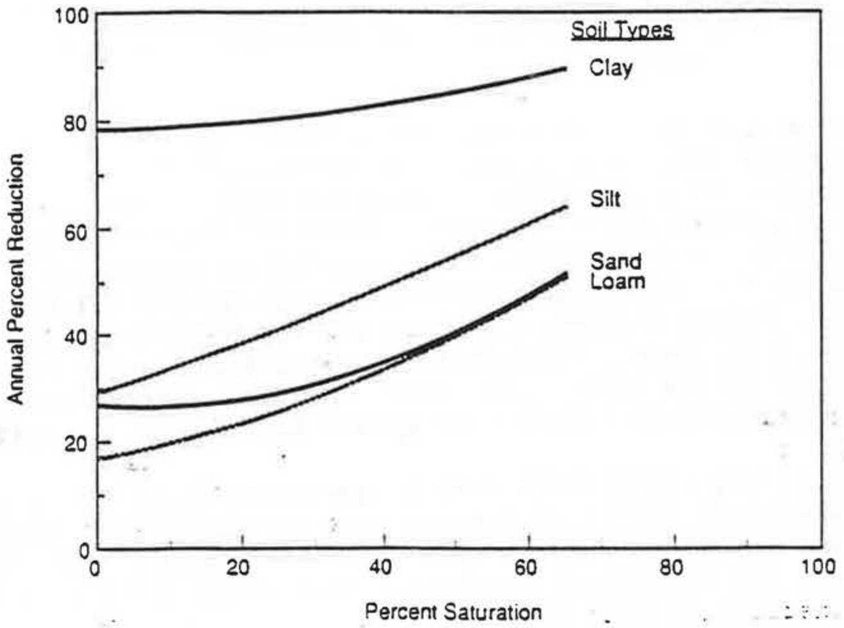

Figure 6. Effects of 0.1 m gravel bed, soil saturation, and soil type in reducing gravel-region sub-slab radon concentrations for annual spectrum of wind speeds.

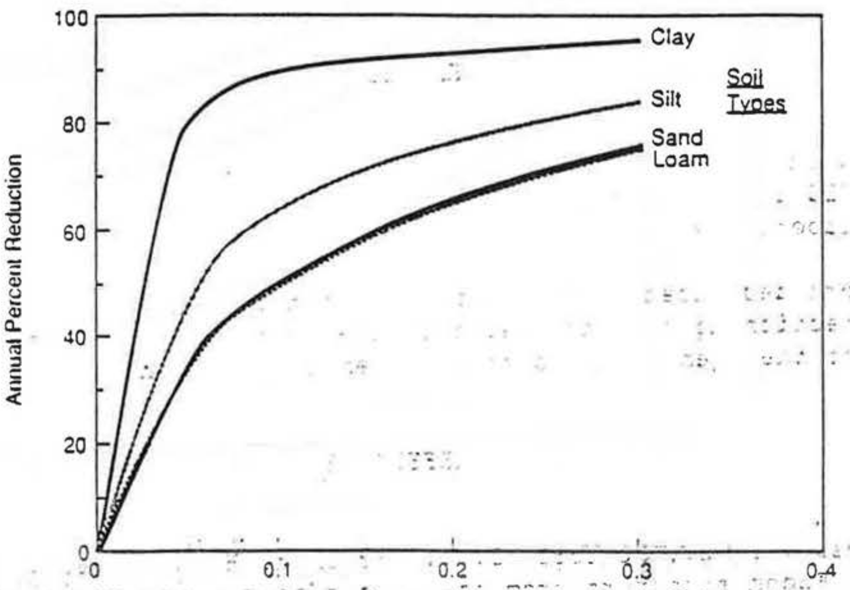

Figure 7. Effects of gravel bed depth and 65%-saturated soil type in reducing gravel-region sub-slab radon concentrations for annual spectrum of wind speeds.

CONCLUSIONS

The following general conclusions can be made from the results above and from the related information:

- Gravel beds underlying slab-on-grade houses can be useful in reducing sub-slab radon concentrations.
- Similar achieved reductions can be expected from basement houses having gravel beds if the gravel path length from windward to leeward sides of the basement is about the same as the slab-on-grade house.
- Use of gravel beds in conjunction with a sub-slab barrier immediately beneath the slab could achieve greater reductions.
- The presence of gravel beds beneath a slab or basement would make sub-slab ventilation more effective if needed.
- The beneficial effects of winds can only be achieved if the gravel beds are well drained. However, there are possible benefits in saturating the gravel beds. In such a situation radon cannot be easily transported to entry paths in the house foundations.
- Tightly packed houses in residential neighborhoods might see higher frequencies of low wind speeds than those of this study.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy under Contract DE-AC06-76RLO 1830. Battelle Memorial Institute operates the Pacific Northwest Laboratory for the U.S. Department of Energy.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

REFERENCES

1. Owczarski, P. C., Holford, D. J., Freeman, H. D., Gee, G. W., and Burk, K. W. Radon transport from the subsurfaces: the roles of certain boundary conditions at the subsurface/environment boundaries. Paper presented at Twenty-Ninth Symposium on Health and the Environment: Indoor Radon and Lung Cancer: Reality or Myth? Richland, Washington. October 16-19, 1990.

2. Holford, D. J., Schery, S. D., Wilson, J. L., and Phillips, F. M. Radon transport in dry, cracked soil: two-dimensional finite element model. PNL-7116, Pacific Northwest Laboratory, Richland, Washington, 1989.

3. Schery, S. D., Holford, D. J., Wilson, J. L., and Phillips, F. M. The flow and diffusion of radon isotopes in fractured porous media: Part 2, semi-infinite media. Rad. Protect. Dosimetry 24: 191-197, 1988.

4. Owczarski, P. C., Holford, D. J., Freeman, H. D., and Gee, G. W. Effects of changing water content and atmospheric pressure on radon flux from surfaces of five soil types. Geophysical Research Letters 17: 817-820, May 1990.