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Case Study of Radon Diagnostics and Mitigation in a New York State School

Kelly W. Leovic[1], D. Bruce Harris[1], Mike Clarkin[2], and Terry Brennan[2]

Abstract

This is a case study of the radon diagnostics and mitigation performed by the U.S. Environmental Protection Agency's (EPA's) Office of Research and Development in a New York State school building. Research focused on active subslab depressurization (ASD) in the basement and, to a lesser degree, the potential for radon reduction in the basement and slab-on-grade sections using the heating, ventilating, and air-conditioning (HVAC) system.

Based on radon diagnostic measurements in the basement, a five-point ASD system was installed, and recommendations were made to increase the outdoor air supply through the basement unit ventilator. Because of the high radon levels in the basement (1720 bequerels per cubic meter, Bq m^{-3}) and limited subslab pressure field extension, both mitigation approaches were needed to reduce radon to below the current EPA guideline of 148 Bq m^{-3}. The effects of excavating a suction pit under each of the five suction points were also investigated. Pit excavation, together with adjustment of the airflows at the suction points, decreased average radon levels in the basement by an additional 40 percent.

In the slab-on-grade section, it was recommended that the school hire a HVAC contractor to evaluate the unit ventilators for increased outdoor air supply. This was recommended both to improve indoor air quality and because diagnostic measurements indicated that an ASD system would require an excessive number of suction points in the slab-on-grade classrooms.

KEY WORDS:
Radon, Schools, Active subslab depressurization, Building pressurization, HVAC systems, Differential pressure.

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Background on Radon Reduction in Schools

Because elevated radon has been identified in schools throughout the country (Peake et al., 1991), the U.S. Environmental Protection Agency (EPA) has been researching ways of reducing elevated levels of radon in school buildings. The two common radon reduction techniques for schools are: active subslab depressurization (ASD) and radon control using the heating, ventilating, and air-conditioning (HVAC) system (Leovic et al., 1990).

An ASD system is installed by inserting pipes through the concrete slab to access the area under the slab. A fan is attached to the pipes to actively depressurize the area under the slab, i.e., cause the soil of the slab to be at lower pressure than the building interior. This reversed pressure relationship prevents radon-containing soil gas from entering the building. ASD systems are more effective when the slab is underlain with a clean, coarse layer of aggregate that facilitates airflow and extends the field of negative pressure. A suction pit is often excavated under each suction point to increase the effectiveness of the ASD system. Measurements of the pressure fields under a slab are common-

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[1] Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, USA

[2] Camroden Associates, Inc. Oriskany, New York 13424, USA

ly referred to as pressure field extension (PFE) or subslab communication measurements. If an ASD system is installed in a school to control radon entry, it must overcome any negative pressures that are generated by the HVAC system and/or the natural stack effect. For details on ASD systems, see EPA (1989).

Research has shown that HVAC systems in schools can dramatically influence the pressure relationship of the building envelope relative to its surroundings and, consequently, affect radon entry (Leovic et al., 1990; Saum et al., 1990). If the HVAC system induces negative pressure in the building interior relative to the subslab area, radon entry into the building can be enhanced. Conversely, if the HVAC system pressurizes the building, creating positive pressure in the building relative to the subslab area, it can suppress radon entry as long as this pressure relationship exists. The additional outdoor air provided to pressurize the building can also help to dilute any radon that is already in the building or that enters the building through diffusion. However, school buildings typically have areas such as laboratories, gymnasiums, locker rooms, auditoriums, cafeterias, kitchens, restrooms, and shops that are operated under negative pressure to exhaust odors or other airborne contaminants. Even if the classrooms are designed and normally operated under positive pressure, operation of exhaust fans without adequate makeup air may cause certain building zones to be under negative pressure, potentially increasing radon entry in these areas. The effects of these fans must be considered when using the HVAC system to control radon levels.

If pressurization through the HVAC system is under consideration as a long-term solution for radon control, proper operation and maintenance of the HVAC system are critical. Building pressurization with the HVAC system has been effective in reducing radon levels in some schools, depending on system design and operation (Leovic et al., 1991). However, many schools that operate under positive pressure while the building is occupied have actually installed ASD systems in order to control radon levels when the HVAC fans are not operating (Leovic et al., 1989). This paper discusses experience with a combination of both approaches for radon reduction (ASD and pressurization and dilution with the HVAC system) in a school researched by the EPA and Camroden Associates, Inc. in New York State.

Case Study of New York State School

The school discussed in this case is located in south-west New York State. The original school building was constructed in 1965 with an addition constructed in 1986. The building is approximately 4450 square meters (m^2) in area. The foundation is a combination slab-on-grade (3600 m^2) and basement (750 m^2) with a small crawl space (less than 100 m^2). All foundations including the crawl space are constructed of poured concrete walls with concrete floor slabs. The primary HVAC system consists of unit ventilators.

The basement area was the focus of this research because of the relatively high radon levels and because EPA research in basement schools was limited. The slab-on-grade portion of the school is discussed separately because it presents an example of a "difficult-to-mitigate" school. The remainder of the paper focuses on diagnostics and mitigation in the basement.

Integrated radon measurements in this study were made with 2-day charcoal canisters that were placed by school personnel with instructions provided by EPA. For quality assurance, collocated charcoal canisters were placed for 22 of the measurements made in this school during the period discussed in this paper. The average standard deviation of the collocated canisters was 0.23, and the average coefficient of variation was 5.89 percent. These results are discussed in

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more detail in the EPA report which includes this school (Leovic et al., 1990). Continuous radon measurements were made in the basement using a Pylon AB-5 monitor.

Slab-on-Grade (SOG) Area

Pre-mitigation Radon Levels (SOG)

Charcoal canister measurements made in December 1989 while the school was occupied (HVAC system operating) showed that 12 of the 21 classrooms in the SOG section exceeded EPA's current guideline of 148 becquerels per cubic meter (Bq m^{-3}). The highest screening measurement in the SOG area was 770 Bq m^{-3}. Although elevated levels of radon were measured in the crawl space, elevated levels were not measured in the classrooms above. As a result, crawl space mitigation was not part of this study.

HVAC System (SOG)

The HVAC system in the SOG section classrooms consists of individual room unit ventilators mounted on the outside wall in 19 of the classrooms and overhead in the other two. Hot water for each room unit ventilator is supplied by a central boiler located in the basement. There is no central cooling system in the school. The unit ventilators are rated at 470 liters per second (l/s), and the minimum and maximum capacities for outdoor air for these units are estimated to be about 80 and 140 l/s, respectively. Outdoor air dampers in each unit ventilator are controlled by temperature sensors and time clocks. However, during the building inspection, little or no outdoor air was being introduced into the rooms through the unit ventilators because the outdoor air dampers were not open. Investigation of the controls revealed that the pneumatic lines had been disconnected at the control board and at most unit ventilators.

School officials indicated that outdoor air was not being supplied by the unit ventilators because they are disconnected during the heating season to save energy. The New York State Education Department requires that classrooms be supplied with 4.7 l/s of outdoor air per student when the outdoor temperature is above 2 °C. Consequently, outdoor air is typically not supplied to the classrooms during much of the winter season. As a comparison, the most recent ASHRAE ventilation standard 62-1989 (ASHRAE, 1989) recommends that 7 l/s of outdoor air per person be supplied to occupied classrooms. The SOG section of the school also has exhaust fans in some areas (e.g., corridors, kitchens) that cause the building to be under negative pressure when they are operating.

To investigate the potential for radon control by increasing the outdoor air supplied by the unit ventilators, the outdoor air dampers for seven classrooms in one wing were opened to provide approximately 80 l/s of outdoor air during the occupied periods. (The HVAC system operates from about 7 a.m. to 1 p.m. and is on setback – with no outdoor air – during other times.) Spot differential pressure measurements under these conditions showed that the building interior was at a negative pressure of roughly 8 pascals (Pa) relative to the outdoors, even when the outdoor air intakes to the unit ventilators in this one wing were opened to their minimum position. This indicates that the negative pressures induced by the exhaust fans and natural stack effect overwhelmed any pressurization by the seven unit ventilators with the dampers set on the minimum position. It is not known how the proper operation of all unit ventilators in the building will affect the differential pressures in the building.

The investigators were unable to evaluate the effect of the additional outdoor air on radon levels in the classrooms. The outdoor air was not adequately heated by the unit ventilators and, according to the occupants, the rooms were uncomfortably cold. As a result, the outdoor air dampers were closed. Subsequent carbon dioxide measurements in the occupied classrooms confirmed the need for additional outdoor air. In order to reduce radon levels and improve indoor air quality during cold weather, the school is attempting to adjust the unit ventilators so that they bring in minimum outdoor air through all the unit ventilators even during cold weather.

Subslab Pressure Field Extension (SOG)

To evaluate the potential effectiveness of an ASD system in the SOG area, subslab communication was measured in two of the classrooms with elevated radon levels. The classrooms were located at opposite ends of the building. PFE was relatively poor and did not extend much beyond 4 m. Consequently, effective mitigation by ASD would require many suction points since there are 12 SOG classrooms with elevated radon levels. (Note that PFE in the basement is better than in the SOG section. This is probably because the subslab material in the basement contains more gravel which facilitates subslab airflow.)

Basement (BSMT) Area

Pre-mitigation Radon Levels (BSMT)

Charcoal canister measurements were made in the basement in December 1989 while the school was occupied (HVAC system operating). These measurements ranged from a low of 230 Bq m^{-3} in the boiler room to a high of 1720 Bq m^{-3} in a storage area. Radon levels in a four-room office area in the basement averaged 1080 Bq m^{-3}. Continuous radon measurements collected in the basement office area during December 1989 averaged 1265 Bq m^{-3}.

HVAC System (BSMT)

The HVAC system in the basement area is a unit ventilator that services only the basement. During the building investigation it was noted that outdoor air intakes for this unit had also been disabled. However, some leakage of outdoor air into the air handling system was apparent.

The boiler room, located in the basement, has combustion air supplied at a rate of roughly 1100 l/s with the boiler operating at low speed. With the boiler operating at high speed, no appreciable difference in makeup air volume was measured. It is therefore suspected that the passive air intake for the room is supplying all of the air possible. Although further investigation of the boiler room was beyond the scope of this project, additional air intake capacity may be warranted in order to reduce depressurization of the basement when the boiler is operating.

Investigation of Radon Entry Routes (BSMT)

Radon "sniffs" were made in a number of locations to help determine potential radon entry routes. Typically, floor drains in the school contained filled water traps, and radon concentrations in these drains did not exceed the concentrations measured in the ambient air. Radon concentrations in wall penetrations did not greatly exceed the indoor ambient levels either. Investigation of the small number of floor/wall joint cracks revealed radon concentrations in excess of 11100 Bq m^{-3} in the cracks. Although the floor/wall joint cracks were introducing relatively high radon concentrations into the basement area, the small leakage area and low volume of airflow through the cracks combined to convince the investigators that the floor/wall cracks were only a minor source of the indoor radon, and only limited sealing was performed (about 1 linear foot). Subslab radon concentrations in the basement area were found to range from 14800 to 53650 Bq m^{-3}.

Subslab Pressure Field Extension (BSMT)

Foundation drawings for the basement indicated that the subslab aggregate consisted of

Table 1 Results of subslab communication testing in basement

Test hole	Distance from suction point (m)	Pressure difference (Pa)
FA	0	-218
FB	0.30	-193
FC	0.71	-129
FD	0.76	-124
FE	1.37	- 89
FF	1.98	- 79
FG	3.35	- 50
FH	4.88	- 30
FI	5.49	- 12
FJ	6.40	- 25
FK	9.45	- 7
FL	9.45	- 2
FM	10.68	- 5
FN	12.20	- 0

a layer of compacted sand and gravel. A layer of polyethylene sheeting was placed on top of the compacted subslab aggregate prior to the pouring of the concrete floor slab. The majority of the interior walls in the basement are non-load-bearing stud walls resting on top of the floor slab; however, hollow-core block walls rest on thickened slab footings in some areas. Thus, subslab barriers to communication are limited in the basement.

Subslab pressure field extension (PFE) in the basement was measured using a Kanalflakt XL-4 in-line centrifugal fan (rated at 25.5 l/s at 248 Pa) for depressurization. Basement-to-subslab pressure differentials were measured using a digital micromanometer. Pressure differences and approximate distances from the suction point are listed in Table 1. Although PFE was somewhat limited, PFE measurements in the basement showed that the negative pressure field extended at least 10 m from the suction point, indicating a multi-point ASD system would control radon levels in the basement.

Installation of ASD System in Basement

Based on the results of the PFE measurements, a five-point ASD system was installed in the basement. All five points (P1, P2, P3, P4 and P5) were manifolded to a common exhaust constructed of 10 cm diameter schedule 40 PVC piping as shown in Figure 1. Vertical drops from the exhaust manifold were 7.6 cm diameter schedule 40 PVC piping. A valve to restrict airflow (if needed) was installed in each vertical drop. The exhaust manifold penetrates the roof at a point where the exhaust soil gas will not re-enter the school through outdoor air intakes. A device to cut off the spread of fire was placed in the exhaust piping at the point where the piping penetrates an existing firewall. A system failure device consisting of a pressure transducer and warning light was also installed.

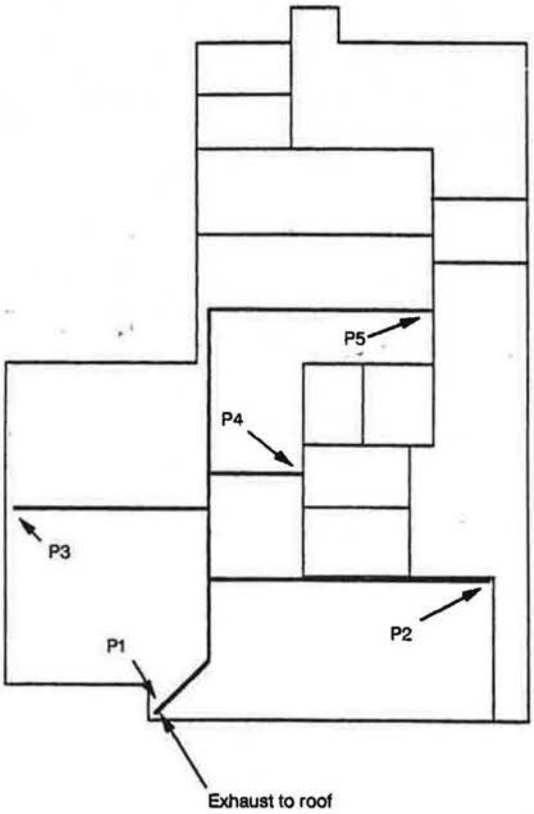

Fig. 1. Active subslab depressurization system layout.

In late January 1990, the ASD system ran passively (without a fan) for approximately 5 days. Continuous radon concentrations in the office averaged 773 Bq m^{-3} during this period, a reduction of about 40 percent from

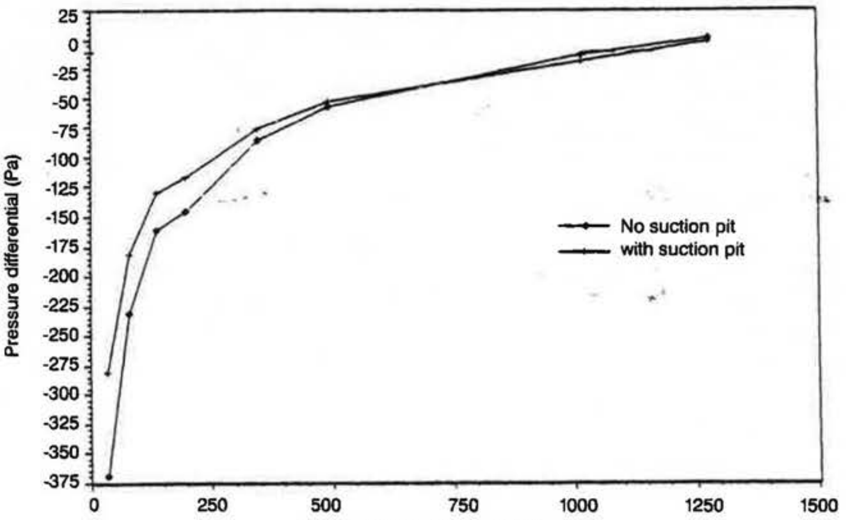

Fig. 2. Subslab pressures at various distances from point P1, before and after suction pit excavation.

the continuous measurements collected in December 1989.

On 31 January 1990, the ASD system was activated with a fan (rated at 190 l/s at 0 Pa). Continuous office radon concentrations quickly fell to an average of 414 Bq m^{-3} over a 3-week period, a reduction of about 65 percent relative to the December levels and about 45 percent relative to the passive mode.

Excavation of Suction Pits in Basement

The radon measurements above were made prior to excavation of pits at the suction points. Suction pits are often excavated to increase pressure field extension. An effort was made in this project to evaluate the effects of suction pit excavation on both pressure field extension and radon levels in the basement.

In early March 1990, suction pits (about 85 liters in volume) were excavated at all suction points in the system to increase the negative pressure field beneath the slab. At this time, adjustments were also made to the ball valves that had been installed in the five suction pipes in order to investigate the effects of restricting the flow through a given suction point. Following excavation of the pits and adjustment of the valves, negative pressures beneath the slab were measured in several areas where positive pressure was measured prior to digging the pits and adjusting the valves. Continuous radon measurements over a 24-hour period in the office averaged 296 Bq m^{-3}, showing a reduction of 30 percent from levels prior to pit excavation and valve adjustment, and a reduction of about 75 percent from pre-mitigation levels.

Figure 2 shows the diffential pressure (in the subslab area relative to the building interior) versus distance from the suction point, both before and after the suction pit excavation. The valves were completely closed at suction points P2, P3, P4 and P5 so that P1 was the only point depressurizing the subslab. These data show that excavation of the suction pit at P1 decreased the negative pressure in the test holes close to P1 and increased the strength and extent of the negative pressure field beyond 10 m. In fact, the farthest hole (about 12.5 m) had a slight positive pressure prior to excavation of the suction pit and a slight negative pressure after the pit was excavated.

In an attempt to reduce radon levels further, the damper for the basement unit ventilator was opened to provide outdoor air (both for pressurization and dilution). These measurements were conducted during the summer of 1990. The continuous radon data

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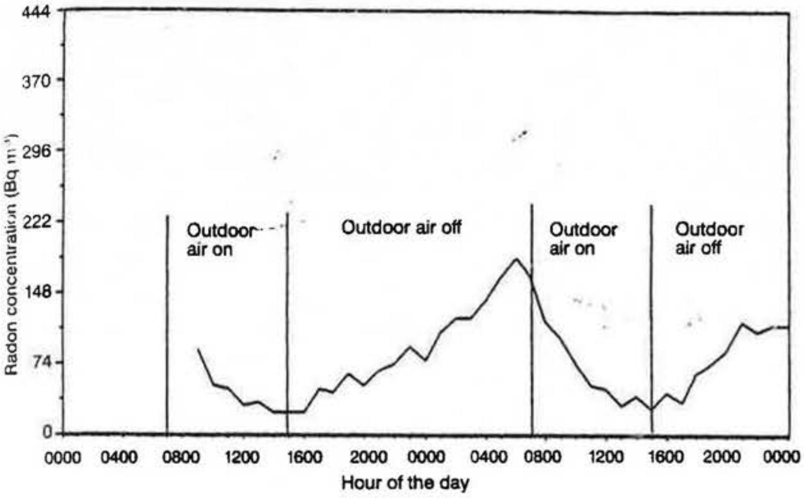

Fig. 3. Radon concentrations in basement office with active subslab depressurization system operating and outdoor air dampers for basement unit ventilator opened and closed.

presented in Figure 3 show the radon levels in the basement office area with the ASD system operating and the outdoor air supply cycled on and off. These results indicate that, in order to consistently keep radon levels below 148 Bq m^{-3}, it is necessary to operate the ASD system and supply outdoor air to the basement. Since these measurements were made and the project completed, the occupants of the basement offices have moved to a new addition of the school and the basement is being used primarily for storage. (Note that radon results for the new addition are not available at this time.)

Conclusions

The following conclusions may be drawn from this research project:

1. In schools that do not have a clean, coarse layer of aggregate under the slab to facilitate pressure field extension, it may be necessary to combine ASD and increased outdoor air supply to sufficiently reduce highly elevated radon levels.
2. Additional radon reductions can be achieved by excavating suction pits and adjusting the flows through individual suction points. In this case study, average radon levels with the ASD system operating were reduced by 30 percent when a suction pit was excavated at each of the five suction points and the ball valves were adjusted.
3. Excavation of the suction pits increased the pressure field extension at the farthest test points from the suction point (over 10 m).
4. Comparison of the five-point subslab depressurization system operated passively (without a fan) and actively (with a fan) indicated an additional 45 percent reduction in radon levels when the system was activated.
5. The slab-on-grade portion of the school presents an example of a "difficult-to-mitigate" school since subslab pressure field extension is poor and use of the unit ventilators (in their current state) to reduce radon levels during cold weather presents difficulties.

Acknowledgements

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