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Cost and Effectiveness of Radon Resistant Features in New School Buildings

Infiltec, Falls Church, VA

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COST AND EFFECTIVENESS OF RADON RESISTANT FEATURES IN NEW SCHOOL BUILDINGS

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ABSTRACT

Recent concerns over elevated levels of radon in existing buildings have prompted the design and construction of a number of school buildings which either are radon-resistant or incorporate features that facilitate post-construction mitigation if needed. This paper describes initial results of a study of several schools with radon resistant features that were recently constructed in the northeastern U.S. These designs are generally based on experience with radon mitigation in existing houses and schools and radon-resistant new house construction.

The study was limited to slab-on-grade schools where the most common radon resistant school design is active subslab depressurization (ASD). The additional construction costs for eight schools built with ASD ranged from \$3 to \$11 per square meter of slab area. The radon contractors who designed these systems have tended to overdesign the radon reduction systems in the absence of specific written guidance to follow to lessen potential liability in the event of system failure. Design features include detailed sealing of all slab cracks, multiple exhaust stacks, and extensive subslab piping.

Recent EPA research on radon mitigation suggests that simpler ASD systems may provide sufficient radon resistance in new large buildings at lower costs. Components of a specification for radon resistant school construction are discussed, based on comments from radon system designers. Another school being studied was built with a heating, ventilation, and air-conditioning (HVAC) pressurization radon control system, and considerations for this type of system are examined.

INTRODUCTION

If a new school is built in an area where elevated radon concentrations have been identified, the need to design the school to be radon resistant (or easily mitigated if excessive levels of radon are found after construction) must be addressed. This research topic, along with the related topic of radon mitigation in existing schools, has been the subject of continuing EPA radon mitigation research since 1988. The progress of this research has been presented at previous ASHRAE IAQ conferences (1,2), in the ASHRAE Journal (3,4), and at a recent symposium (5). A primary objective of this research is to develop written guidance on cost-effective techniques for radon resistant and easy-to-mitigate school construction. This paper summarizes preliminary results from an ongoing EPA study of current practices in radon resistant new school construction including costs, techniques in current use, and advantages and disadvantages of the different approaches.

Specific features in new school building design which have been installed or modified in an effort to reduce radon levels vary considerably in complexity and cost. The minimum features include sealing of major radon entry routes such as utility penetrations and expansion joints, and providing a layer of coarse subslab aggregate so that an active subslab depressurization (ASD) system can be added if elevated radon levels are found in the building after construction. Depending on the location, these minimum features generally add little to school construction costs, yet make the success of a future radon control system more likely. However, they generally provide only minimal radon mitigation in themselves, and retrofit radon mitigation systems installation can be costly and more disruptive than including additional steps during the construction phase.

An intermediate approach to installing radon resistant features involves providing a subslab coarse aggregate layer and sealing major entry routes combined with a rough-in of radon control system piping so that future costs and building disruption for activating a system (with a fan) are minimized. A rough-in is thought generally to provide a higher level of performance and lower costs and building disruption than a post-construction retrofit system could provide. If all of the piping is completed without installing an exhaust fan, there is a possibility that the system could provide some radon mitigation by passive venting of radon due to stack effect pressures. However, passive subslab depressurization has not been researched extensively in schools, because of all the competing pressures typically in these buildings.

Some schools have chosen to install fully active radon control systems which use fans to depressurize the subslab aggregate and/or building HVAC fans to pressurize the building. Several newly constructed slab-on-grade schools in the northeast U.S. that were built with active or passive systems are being evaluated since they are thought to represent a range of current practices in radon-resistant new school construction. The additional costs of installing radon-resistant features have been tabulated for each of the schools. As the buildings are completed, system effectiveness (including radon source strength, subslab pressure field extension, indoor radon, and differential pressure induced by the HVAC system and ASD system) will be measured in selected schools.

ADDITIONAL COSTS FOR RADON RESISTANT FEATURES IN NEW SCHOOLS

In 1988 when school systems began asking for information on radon resistant new construction and radon mitigation in existing buildings, little research data or radon mitigation contractor experience were available. Since then, many existing schools with elevated radon levels have been successfully mitigated, and a number of new schools (or additions) have been built with radon resistant construction features. Most of this work has applied ASD, a technique that has been successfully used for radon mitigation in thousands of houses across the country over the past 5 years. Powered by a continuous exhaust fan, ASD operates by lowering the pressure under the slab relative to inside the building, so that radon-containing soil gas cannot enter the building through the many small openings generally found in the slab. Sealing methods used alone have limited application and have not typically proven very effective in preventing radon entry in schools or homes.

As part of this study, several radon mitigation contractors who had experience in designing or installing ASD systems in new schools or school additions were contacted. Table 1 is a summary of these results for eight slab-on-grade schools or major additions where ASD systems were installed during school construction. All these data were provided by the contractors and/or architects involved with the building construction. The system designers and installers are identified by the letters A through E. For one of the schools, the system was installed by the plumbers on site. All of these ASD systems included extensive slab crack sealing, stacks running from the subslab through the roof, and a network of subslab perforated piping.

The radon mitigation contractors' system designs typically included an excess of radon reduction capacity because contractors were working without written EPA guidance, and they were concerned about liability for poor system performance. Design features included detailed sealing of slab cracks/openings, extensive perforated piping under the slab, multiple stack pipes, insulation of stack pipes, use of large diameter pipes, use of thick wall pipes, and trenching around subslab perforated pipes to maximize flow. For some ASD installations where detailed cost breakdowns were available, sealing costs represented 28 to 44% of the total installation cost.

RECENT RELATED RADON RESEARCH IN SCHOOLS

Recent radon mitigation research in existing schools suggests that excellent radon mitigation performance in new schools may be possible with simpler and less expensive ASD designs than those presented in Table 1. A 1991 EPA Radon Symposium research paper on radon resistant and easy-to-mitigate schools discussed the effects of suction pits and subslab barriers on pressure field extension for ASD systems on large slabs (5). These results suggest that, for excellent pressure field extension under large slabs, ASD subslab perforated piping might not be necessary if there is a good subslab aggregate layer, a stack exhaust fan capable of about 188 liters per second at 2.54 centimeters of water column pressure, and a large suction pit in the aggregate surrounding the stack. An experimental single point ASD system with a suction pit in an area greater than 4650 square meters tested in the spring of 1991 showed excellent depressurization of the entire area. Cost of this system, installed in a hospital building, was about $1 per square meter. The system will be the subject of a detailed paper in the near future. At the 1990 EPA radon symposium, successful radon mitigation was reported for an existing 1,395 square meter school slab with good communication and one suction point (6).

In summary, research data in both existing and new schools suggest that simpler and lower cost ASD designs can effectively mitigate much larger areas than the average of 492 square meters covered by the new school ASD designs presented in Table 1. This research suggests that ASD systems may be much more tolerant of design or installation flaws than those that many radon mitigation system designers for new schools are assuming. Future EPA radon mitigation research will explore these ideas by testing the actual performance of some of the existing school installations, as well as new designs.

SPECIFICATIONS FOR RADON RESISTANT NEW SCHOOL CONSTRUCTION

A number of features must be specified to ensure that radon resistant new school construction is correctly designed and installed. Sealing of large openings in the slab such as expansion joints and pipe penetrations were considered to be cost effective, but the cost effectiveness is less for sealing smaller cracks. Since sealing was reported to represent as much as 40% of the installation cost of current new school ASD radon systems, changes in sealing specifications alone could have a significant cost impact.

Table 2 lists the construction details that radon contractors generally specified in their designs for active or passive subslab depressurization systems that are installed during construction of a new school. Their experience suggests that, unless these construction details are clearly specified, they are quite likely to be misinterpreted. A discussion of these construction details follows.

The designers generally specified 15 centimeter diameter stack pipes, although 20 centimeter pipe was occasionally used when several pipes were manifolded. Since the stacks are under very small air pressure differentials, there is no pressure requirement for high strength pipe, but schedule 40 is often used so that it will not be damaged on the construction site or by occupants. Some architects changed the requirement to more expensive schedule 80 pipe. The cost of piping and fittings escalates very quickly for larger pipe diameters and thicker walls (schedule 40 versus schedule 80). For each building, all state and local codes should be followed.

System designers generally agreed that they did not have confidence that aggregate alone was enough to guarantee that each suction point would be effective in depressurizing larger areas of the slab. Therefore, they typically ran perforated pipe under the slab to guarantee good communication, and each suction point was then assumed to be capable of mitigating a few hundred square meters of slab. Many slabs have subslab walls and footings that limit communication, and typically require one ASD point for each area. The designers felt that a conservative estimate of the area that could be mitigated by one suction point in new school construction was 500 to 2,000 square meters. Recent EPA research in an existing school has shown that 1,395 square meters is possible (6), and recent research in new construction showed that depressurization was possible under a greater than 4,650 square meter slab, perhaps greater than 9,000 square meters if the building substructure is properly designed.

None of the designers used suction pits under the stacks as a simple method of improving subslab communication. Perforated subslab pipe was considered as the best way to guarantee subslab communication over a subslab area filled with aggregate. If perforated pipe is specified, it can be much less expensive to use corrugated drainage pipe rather than rigid pipe. Not only is corrugated pipe much less expensive, but on some job sites all rigid pipe must be installed by plumbers while corrugated pipe can be installed by laborers. In any case, research has shown (5) that excellent pressure field extension is possible if the aggregate layer is good, there are no subslab barriers, and there is a large suction pit, even if no subslab piping is used.

It is possible that, if the HVAC system is operated to generate a negative pressure in parts of the building (in a kitchen for example), the subslab negative pressure from the ASD system may be overcome, and radon containing soil gas may enter the school. Most of the new school ASD designers contacted for this study did not consider this to be a significant risk because their ASD systems were quite powerful and the slab sealing was thorough.

Roof detail refers to the way in which the ASD exhaust pipe is terminated outside the building. Most designers include a rain cap on each stack, although they questioned whether it reduced air flow and whether any rain protection was necessary in stacks which typically have continual condensation (8). It is also very important to locate the ASD exhaust at least 9 meters away from any outdoor air intakes so that it does not re-enter the building.

New school ASD designers generally specified a 150 to 250 watt exhaust fan for each stack, capable of drawing 140 to 235 liters per second at 2.54 centimeters of water column pressure. Although passive stacks were occasionally specified, the designers agreed that little performance data are available for larger buildings, and most passive stack systems should be considered rough-ins in case a radon problem is found in the future. In that case, a stack exhaust fan would be added to complete the ASD system.

Although most school ASD designers specify extensive crack sealing, many of them question whether all of the sealing is cost effective. They agree that if the cracks are large they may disrupt the performance of the ASD system. It is considered necessary to seal large cracks such as expansion joints and openings around plumbing; however, the benefits of sealing the control joints in the slab or the floor/wall crack may not be worth the effort. There was general agreement that the most durable and adhesive sealants are the urethane caulks.

Recent EPA research (5) has identified footing structures that have a significant impact on the performance and cost of ASD systems. If this information can be provided to the architect early enough, a footing structure might be selected that greatly simplifies ASD design by minimizing the number of stacks needed.

The ASD design should be detailed enough for the school architect to produce a drawing showing the layout of all stacks, subslab pits, or perforated piping. These drawings should be detailed enough to prevent improper installation during construction. The preferred design is the one commonly used in large buildings such as supermarkets.

CONSIDERATIONS FOR HVAC PRESSURIZATION FOR RADON CONTROL

HVAC pressurization for radon control was attempted in one new school, although it met with limited success because of operational problems. The major reason for the failure of the system was that the energy management department was responsible for the HVAC system operation, and their energy conservation objectives were in conflict with the radon control objectives. Since the school was built with subslab aggregate, a single point ASD system was installed in the one wing with elevated radon levels, and the radon concentration was substantially reduced in the wing. Although it is very important for indoor air quality concerns, experience in existing schools has implied that it may be difficult to permanently implement positive pressurization in many schools as an effective radon control technique since it can be easily defeated. Table 3 lists some of the considerations for school HVAC pressurization that may need to be considered.

Recent EPA research (2, 10, 11, 12) has shown that HVAC systems generally have the potential to provide radon mitigation, and further research is underway to investigate how to use this potential most effectively. Although it is technically feasible to design and operate a school to maintain a positive pressure to reduce radon entry, experience has shown that, in order to reach the long-term national goal of indoor radon levels as low as outdoor radon levels (1988 Indoor Radon Abatement Act) in schools with a significant radon source strength, it is probably necessary both to install an ASD system and operate the HVAC to pressurize the building.

CONCLUSIONS

Radon mitigation contractors in the northeastern U.S. are attempting to incorporate conservative ASD radon mitigation systems in new school (and major addition) designs. In the schools studied the additional costs ranged from about $3 to $11 per square meter of slab area. Ongoing EPA radon mitigation research is substantiating equivalent radon mitigation performance at reduced costs by developing specifications for radon resistant new school construction that reduce the current emphasis on large numbers of ASD stacks, detailed crack sealing, and extensive subslab piping. For example, a 4650 square meter slab in a hospital was effectively depressurized with only one suction point at an additional cost of about $1 per square meter.

HVAC pressurization has the capability to provide both radon reduction and improved indoor air quality in new and existing schools. However, it is inherently more complex than ASD, and more subject to operational and maintenance problems since HVAC pressurization systems depend on proper maintenance as well as a consistent control strategy which may be in conflict with other objectives such as energy conservation. ASD systems have been very successful in reducing the entry of radon-containing soil gas and do not require significant maintenance as they are generally independent of the operation of the other building systems. Combining the two approaches is generally the most desirable approach both for radon reduction and indoor air quality.

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Table 1. Summary of Additional Costs for Installing Radon Resistant Features

School location, slab area, square meters	System designer, installer	Date, new school or addition	Estimated, cost, active or passive	# of stacks, average slab area per stack, square meters	Cost per square meter, per stack
Pennsylvania, 3,515	designer A, installer A	1990, addition	$25,000, active	6 stacks, 586	$7.11, $4,170
Pennsylvania, 4,233	designer A, installer A	1991, new	$13,000, active	5 stacks, 847	$3.07, $2,600
Pennsylvania, 2,911	designer B, installer A	1990, new	$21,000, active	7 stacks, 416	$7.21, $3,000
Connecticut, 3,069	designer C, installer C	1990, addition	$34,000, active	8 stacks, 384	$11.08, $4,250
New Jersey, 5,432	designer D, plumbers	1991, new	$25,000, passive	11 stacks, 494	$4.60, $2,270
Pennsylvania, 4,464	designer B, installer B	1990, new	$38,000, passive	9 stacks, 496	$8.51, $4,200
Pennsylvania, 4,650	designer B, installer F	1990, new	$46,500, active	10 stacks, 465	$10.00, $4,650
Pennsylvania, 3,720	designer E, installer E	1991, addition	$32,400, active	15 stacks, 248	$8.71, $2,160
AVERAGE: (unweighted) 4,000			$29,362	8.9 stacks, 492	$7.34, $3299

Table 2. Construction Details in Specifications for New School ASD Systems

Construction detail	General considerations
Subslab aggregate	particle size, size distribution, depth of aggregate (5,7)
Stack type	diameter, wall thickness, sealing of joints
Number of stacks	area covered, effect of subslab barriers (footings and walls)
Detail under slab	suction cavity under slab, perforated pipe extensions
HVAC system design and operation	measures to avoid HVAC room depressurization
Detail on roof	rain cap, distance from fresh air intakes
Stack exhaust fan	passive stack, fan performance specification
Crack sealing	expansion joints, pour joints, control saw joints, plumbing penetrations, floor/wall crack, sealants
Subslab footings & walls	impact on ASD, optimum layout for ASD (5)
Layout of ASD system	relative to footings, walls

Table 3. Considerations for School HVAC Pressurization Radon Control

Considerations	Comments
Building airtightness	Tighter buildings are easier to pressurize.
Minimum fresh air supply rate	An outdoor air supply is generally required for building pressurization.
More supply air than return air in each room	A net positive air flow into rooms is required for pressurization.
Night setback	If the HVAC is off at night, a building's substructure is generally depressurized by stack effect. This allows radon to build up all night. This may be acceptable if the building is unoccupied at night, and the radon can be diluted in the morning.
HVAC type	Some HVAC systems cannot produce positive pressures (e.g., exhaust only system).
HVAC control philosophy	The HVAC control for energy conservation may be different than optimum HVAC control for radon mitigation and indoor air quality.
Ventilation standards	Building pressurization for radon control is consistent with ASHRAE 62-1989 Ventilation Standards. (9)

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