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DESIGN OF RADON RESISTANT AND EASY-TO-MITIGATE NEW SCHOOL BUILDINGS

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ABSTRACT

The Air and Energy Engineering Research Laboratory's (AEERL) radon mitigation research, development, and demonstration program was expanded in 1988 to include the mitigation of schools. Application of technology developed for house mitigation has been successful in many but not all types of school buildings. School mitigation studies carried out to date in the AEERL program have been reviewed in order to determine those architectural features which affect radon entry and ease of mitigation. This paper details those features having the most effect and recommends the design parameters which should be most cost-effective in controlling radon in new school buildings.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

The Air and Energy Engineering Research Laboratory (AEERL) of the U.S. Environmental Protection Agency (EPA) has been developing and demonstrating radon mitigation technology in houses, both existing and new, since 1985. In 1988, the program was expanded to include radon mitigation in existing schools. In the intervening 3 years, detailed diagnostic studies have been carried out in about 40 schools in 8 states and mitigation studies in 20 of these schools. Walk-through examinations and reviews of architectural drawings have been conducted in many additional schools.

Over the past year, architectural features of the schools studied have been carefully reviewed in an attempt to identify those features which affect radon entry and ease of mitigation. Results of the studies are currently being used to develop a guide for construction of radon resistant and easy-to-mitigate schools. This new guidance document will be available later this year. The purpose of this paper is to briefly summarize some of the design and construction features which have been identified as important in this study.

Nearly all new schools being built today are slab-on-grade (SOG), and this paper is limited to this architectural substructure. However, what is stated for SOG schools normally applies to schools with basements and is applicable to them. Few, if any, new schools are being built today with crawl spaces, so they are not covered in this paper.

DESIGN FEATURES WHICH AFFECT RADON ENTRY

Two design features are known to affect the rate of radon entry into large buildings--slab cracks and penetrations and pressure differentials resulting from the building shell construction and the design and operation of the heating, ventilating, and air conditioning (HVAC) system.

SLAB CRACKS AND PENETRATIONS

Slab cracks, expansion joints, and penetrations in schools are similar to those in houses as is their control. These can be eliminated by a change of building design, or their effects can be minimized by proper sealing. Great care should be taken in slab design to minimize slab cracking.

Sealing is even more difficult in existing schools than in houses since the cracks are frequently hidden and cannot be readily found. However, this is not true in new school construction where all cracks and openings in the slab are readily accessible at some stage of construction.

Expansion joints are the largest source of cracks in SOG construction. Where codes do not require them, they should be eliminated since, in most cases, they serve no useful purpose. A slab is at its largest size during curing in the first few hours after pouring due to the heat of hydration of the cement. As a result, the only slab which can be larger at a later date (requiring an expansion joint) is one that is poured and cures in extremely cold weather. Allowance for shrinkage, the other function of an expansion joint, is better accomplished using pour joints (without expansion joints) or control saw joints, both of which are much easier to seal than are expansion joints. Where pour joints are used without expansion joints, both slabs should have a tooled edge to make possible a good polyurethane (PU) seal.

Control saw joints, pour joints, and expansion joints, where used, should be carefully sealed with a flowable PU caulk applied according to the manufacturer's specifications. With expansion joints, the top 1/2-in.* should be removed to make space for a good PU seal.

A second source of openings in the slab are utility line penetrations. These can be minimized by running all utility lines, except sanitary sewer, overhead in the area above the drop ceiling, a practice found in some existing schools visited in our mitigation studies. Overhead utility lines are recommended in radon-prone areas in order to minimize slab penetrations by utility lines. Utility penetrations, when present, must be carefully sealed. If any type of wrapping has been put around a utility pipe to protect it from the concrete, it frequently allows soil gas passage. This type of wrap must be designed so as to not allow any soil gas passage or it must be removed after the concrete is set and the resulting space filled with a PU caulking.

In some design situations, utility pipes penetrate the slab in groups to enter pipe chases. In these situations, great care should be taken to design and construct in such a way that no slab openings are left between the pipes.

HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS

Most schools being built today are air-conditioned. This usually results in the use of large HVAC systems supplying many rooms. These large systems are always built with provisions for ventilation by the addition of outdoor air to the air handling system. This results in pressurization of the building as long as the circulating fan of the air handler is in operation and an adequate quantity of outdoor air is being brought into the system continuously. Pressurization by this means will significantly reduce radon-containing soil gas entry as long as the circulating fan is operating and fresh air is being brought in. When the

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(*)Readers more familiar with metric units may use the factors at the end of this paper to convert to that system.

circulating fan goes off, as is usually the case during night or weekend temperature setback, radon-containing soil gas can enter the building and in some cases has been found to reach high levels in some classrooms. Once the circulating fan of the HVAC system starts operating continuously in the morning when heating or cooling is called for, soil gas entry is stopped and the radon in the building is diluted over some period of time by the outdoor air being brought in by the HVAC system. If the radon level reached during the night is high, this dilution process can take several hours. Studies underway, some of which are being reported at this meeting, are aimed at determining under what conditions the HVAC system can be depended upon to control radon to a satisfactory level. Viability of HVAC system design and operation as a radon mitigation approach cannot be determined until these studies are completed.

Return air ducts have been found to be an entry route for radon-containing soil gas. These should never be routed below the floor since they are always under negative pressure when the HVAC fan is running. Where the ceiling plenum is used as an unducted return air space, any block walls penetrating the slab and ending in the plenum should be capped with a solid block. Otherwise radon-containing soil gas can reach the plenum through the block wall which is very porous below the slab. Radon levels can also build up in supply ducts under the slab when the circulating fan is off and then be brought into the room when the circulating fan comes back on.

Buildings can also be heated and air conditioned using unit ventilators (UVs) supplied with hot water or steam from a boiler and with chilled water furnished from a central chiller. All UVs are designed for fresh air addition at the unit. Use of pressurization to control radon in this type of system is similar to that of a large central HVAC system.

Exhaust systems for large rooms such as kitchens, lunchrooms, gymnasiums, multipurpose rooms, and shops create special problems since they can create negative pressure and cause radon-containing soil gas to be brought in. This can be eliminated by supplying more conditioned outdoor air than is removed by the exhaust system. Although this may appear to be an expensive solution, it is the only known way to ensure no soil gas entry.

Restrooms also contain exhaust fans which frequently cause elevated radon levels in these rooms. This can be minimized by keeping the exhaust fan as small as code requirements will allow. In addition, since the amount of time per day any person spends in a restroom is presumed small, exposure in this area is relatively small.

Schools without air conditioning are frequently ventilated by the use of exhaust fans usually mounted in the plenum above the hall ceiling. The use of exhaust fans should be minimized in radon-prone areas since this will usually result in a radon problem. Rooms should always be ventilated by bringing in outdoor air rather than by exhausting room air.

DESIGN FEATURES AFFECTING EASE OF MITIGATION WITH ACTIVE SUBSLAB DEPRESSURIZATION (ASD)

The most successful mitigation technique for existing schools has been the use of ASD, the same as in existing houses. This is true as long as the school has aggregate under the slab. Since the presence of aggregate can be required in new school construction (and is, in fact, common practice), then it is logical that, until similar information for other mitigation options becomes available for performance and cost comparison, ASD should be the mitigation system of choice in new schools. Thus the rest of this paper will dwell on factors which affect the ease of application and the effectiveness of ASD in new schools.

In a paper which the authors presented at the last symposium in Atlanta(1), two schools mitigated in Nashville, TN, were compared. One required 16 suction points to mitigate 15 rooms, whereas 15 rooms were mitigated to a lower radon level in the second school with only 1 suction point. This striking difference in ASD effectiveness was the motivation for these authors' beginning to review the factors which affect the ease of mitigation in schools and has led to this paper.

In the authors' experience, pressure field extension (PFE), is the most valuable diagnostic tool in determining the ease of application of active subslab depressurization (ASD) to mitigation of houses, schools, and large buildings. PFE measurements are even more important in large buildings than in houses since much larger subslab areas are involved and subslab barriers frequently exist that are not normally found in houses. For example, PFE measurements led to the prediction of the difference in ease of application of ASD to the two previously discussed Nashville schools which was then confirmed by the results obtained. Thus PFE is used as a surrogate for ease of mitigation in the subsequent discussion in this paper.

A review of the PFE measurements that have been made on all of the schools in EPA's program, examination of their architectural drawings, and many discussions of the factors affecting flow of gases through aggregate beds with fellow scientists working on radon have led to the identification of the following factors which affect PFE:

- Aggregate
    - Bulk density (or void volume)
    - Particle size (both average size and particle size distribution)
    - Type (naturally occurring stone from moraine deposits or crushed bed rock)

Layer thickness and uniformity of thickness
Subslab barriers
Subslab suction pit size
Amount of suction applied
Size and location of openings in slabs (both planned and unplanned)

These factors are discussed in the following sections.

AGGREGATE

The four properties of aggregate listed above are known to affect the flow of a gas through stone beds. Bulk density is actually controlled by particle size distribution and type of stone (naturally occurring moraine gravel, which is rounded, packs more efficiently than crushed bedrock with its greater variation in shape).

The following tentative conclusions are postulated on the effect of aggregate properties on PFE:

1. PFE is proportional to average particle size--the smaller the particle size, the less the PFE assuming the same particle size distribution.
2. The narrower the particle size distribution range the greater the void volume and hence the greater the PFE.
3. The smoother the shape of the stone, the lower the void volume; hence moraine stone (with its rounded corners) will give lower PFE for the same average particle size and particle size distribution than crushed aggregate.

AEERL is sponsoring work at Princeton University to verify and quantify these effects. The first report of this work is being made by Kenneth Gadsby in a poster paper given at this symposium(2).

SUBSLAB BARRIERS

One of the greatest differences between mitigation of houses and schools is the presence of subslab barriers which are commonplace in schools and other large buildings and are rarely found in houses. PFE measurements made in schools have shown a very strong correlation with the presence or absence of these barriers. Their presence is determined by a review of the foundation plan in the structural drawings. Based on school plans reviewed to date, foundation designs can be divided into the four types shown schematically in Figures 1,3,5,and 6. These types determine the ease of mitigation and the number of suction points necessary assuming other factors are the same. They are presented in the order of difficulty to mitigate by ASD starting with the most difficult.

The type shown in Figure 1 (schematic) is the most common and unfortunately the most difficult to mitigate. In this type, all walls around each room extend below the slab to footings in undisturbed soil resulting in the same number of compartments under the slab as number of classrooms above the slab. A section of this type of wall is shown in Figure 2. PFE measurements made in Nashville showed that some PFE could be achieved through one subslab wall but not two. Unfortunately, installation of a suction point in every other room was not sufficient to mitigate the intervening rooms, and it is now believed that a suction point will normally be necessary in every room in this type of school. Obviously, this is not a recommended footing configuration for new schools built in radon-prone areas.

In the plan shown in Figure 3, the hall walls extend through the slab to footings, but the walls between rooms are set on the slab. The slab under these walls are normally thickened slab footings as shown in Figure 4. Aggregate continues under these thickened sections; consequently, they do not adversely affect PFE. One suction point on each side of the hall will mitigate a number of rooms in this configuration, the number depending on other variables which affect PFE (such as type of aggregate). A third suction point might be needed in the hall but it is unlikely if the rooms on each side of the hall are adequately mitigated. In this type of structure, the bar joists for the roof are placed perpendicular to the hall and rest on the hall walls. The walls between the rooms do not carry any roof load and consequently can rest satisfactorily on thickened slab footings.

Figure 5 shows a footing configuration found in three schools mitigated by EPA. In this configuration, the walls between the rooms go through the slab to footings but the hall walls set on thickened slab footings. In this case, the roof bar joists are placed parallel to the hall and rest on the walls between the rooms. The aggregate continues under the hall for the full length of the building; consequently, PFE can be achieved down the hall and into the individual rooms. With this configuration, the suction point is best put in the hall, and the number of rooms that can be mitigated will depend on other variables (such as type of aggregate).

The final configuration found to date, shown in Figure 6, was used in the Two Rivers Middle School in Nashville. In this configuration, no walls go through to footings: all sit on thickened slab footings. This is referred to architecturally as post and beam construction and is commonly used in buildings which are very wide and very long, such as supermarkets. Posts on both sides of the hall at Two Rivers go through to footings and are tied together with overhead beams which in turn carry the roof bar joists. The posts and beams can be either reinforced concrete as in Two Rivers, or more commonly steel as in supermarkets. In this configuration, the aggregate is continuous under the entire building and, consequently, PFE can reach long distances if other conditions are proper. At Two Rivers, PFE easily extended 130 ft, and one suction point mitigated 15,000 ft^2 to less than 1 picocurie per liter (pCi/L). EPA recently arranged to have a hospital building under construction install a suction point in the center of a 200 by 250 ft slab (50,000 ft^2) underlaid with carefully placed coarse crushed aggregate (ASTM #5 stone). Some time this spring, PFE of this slab will be measured, and EPA will have a better feel for just how much PFE can be achieved under a very large slab with optimum aggregate and a large suction pit.

SUBSLAB SUCTION PIT SIZE

The importance of the size and geometry of the suction system under the slab has been the subject of considerable debate and disagreement over the past 3 years. However, it has been the authors' experience that, everything else being the same, the larger the suction pit, the greater the PFE. Although this is not too important in houses, it becomes much more important in large slabs such as schools.

In an existing school, the size that can readily be dug through a hole in the slab is about 40 in. in diameter. However, in new construction, there is essentially no limit to the size of the pit which can be installed. It is believed that the controlling factor in increasing effectiveness is the size of interface between the hole and the surrounding aggregate. With this in mind, one of the authors (Craig) designed the suction pit shown in Figure 7. The pit is constructed by digging out an area of about 6 ft square where the suction pit is desired. Four concrete blocks, 8x8x8 in. in size, are placed in a square 4 ft on a side and covered with a 4x4 ft piece of 3/4-in. treated plywood. The depth of the hole is such that the top of the plywood is even with the bottom of the slab to be poured. The aggregate is filled level with the plywood, allowing it to slope into the hole. The angle of repose of the stone will be about 30° leaving most of the hole open. The 6 in. suction pipe is installed under the plywood as shown in Figure 7 and run to a convenient place for the riser. This arrangement makes it possible to separate the location of the suction pit from that of the riser.

The plywood serves only as a form for the slab over the hole. The strength of the concrete after setting is more than sufficient to span a 4 ft hole unless the slab has unusually high loading. In that case, the slab will need reinforcing.

Perforated pipe can also be used in lieu of the suction pit described above. However, calculations show that the suction pit has an air to aggregate interface equivalent to about 200 ft of perforated pipe with 10 holes of 3/4-in. diameter per lineal foot. As a result, it is believed that the PFE from either system will be about the same. Tests are planned to compare these two techniques in new construction. It is believed that the suction pit is significantly cheaper to install than the perforated pipe.