Radon mitigation in schools

HVAC systems in schools tend to have a greater impact on radon levels than HVAC systems in homes

By Kelly W. Leovic, A.B. Craig and David W. Saum

The primary mode of radon entry into a school with significantly elevated radon levels is normally from soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior. If the building interior is at a lower pressure than the soil surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and openings that are in contact with the soil.

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The amount of radon in a given classroom will depend on the level of radon in the underlying material, the ease with which the radon moves as a component of the soil gas through the soil, the magnitude and direction of the pressure differentials, the number and size of the radon entry routes, and dilution and mixing of the room air. Heating, ventilating, and air-conditioning (HVAC) systems in schools vary considerably and tend to have a greater impact on pressure differentials—and consequently radon levels—than do heating and air-conditioning systems in houses.

The first part of this article discusses radon entry into schools, radon mitigation approaches for schools, and school characteristics (such as HVAC system design and operation) that influence radon entry and mitigation system design.

The second part of this article, which will be published in the February issue of the *ASHRAE Journal*, will discuss specific mitigation systems that were installed by the U.S. Environmental Protection Agency (EPA) in four Maryland schools.

Elevated levels of indoor radon have been found in houses throughout the United States and the growing concern of the lung cancer risks associated with radon is spreading to high occupancy public buildings such as schools. Since children spend such a large portion of time in schools, elevated levels of radon there present a health concern. Also, since children have smaller lung volumes and higher breathing rates than adults, they may be at a greater risk from exposure to radon.

In late 1987, elevated levels of radon were identified in several rooms of a school in Fairfax County, Virginia. This led to extensive radon measurements in Fairfax County schools and other counties in Virginia, Maryland, Tennessee and North Carolina (EPA 1989a). Over 40 schools in these states have been visited by EPA and school characteristics that potentially influence radon entry and impact mitigation system design and performance were identified. Mitigation systems that had proven successful in house mitigation were then installed in several of these schools. Many of the systems were installed by school personnel with some assistance from EPA and an experienced radon diagnostician.

Although radon mitigation experience in schools is limited, this initial research indicates that radon reduction technologies proven successful in houses are applicable to some schools. The applicability of these mitigation approaches to other schools will depend on the unique characteristics of each school.

Radon entry into schools

The primary mode of radon entry into a school with significantly elevated radon levels is normally from soil gas that is drawn in by pressure differentials between the soil surrounding the substructure and the building interior (EPA 1989b). If the building interior is at a lower pressure than the soil surrounding the substructure and radon is present in the soil, the radon can be pulled in through cracks and openings that are in contact with the soil.

Pressure differentials that contribute to radon entry can result from operation of a HVAC system under conditions that cause negative pressures (in the building relative to the subslab area), indoor/outdoor temperature differences (including the "stack effect"), use of appliances or other mechanical devices that depressurize the building, and wind (Leovic *et al.* 1989).

HVAC systems in schools and other large buildings vary considerably and tend to have a greater impact on radon levels than do HVAC systems in houses. If the HVAC system induces a negative pressure in the building relative to the subslab area, radon can be pulled into the building through floor and wall cracks or other openings in contact with the soil. (Even if the HVAC system does not contribute to pressure differentials in the building, the natural stack effect can cause the building to be under a negative pressure so that radon-containing soil gas is pulled into the school.)

Figure 1 shows the trend between negative pressure (in the classroom relative to the corridor) and elevated levels of radon, with the highest radon levels in the rooms with the highest negative pressures.

If the HVAC system pressurizes the building (which is common in many systems), it can prevent radon entry as long as the fan is running. However, school HVAC systems are normally set back or turned off during evenings and weekends. Even if the HVAC system pressurizes the school during operation, indoor radon levels may build up during setback periods.

Once the HVAC system is turned back on, it may take several hours for radon levels to be reduced. Adjustment of the setback timing may, in some cases, achieve acceptable indoor radon levels during periods of occupancy. Measurements with continuous radon monitoring equipment in each classroom with elevated radon levels are necessary to de-

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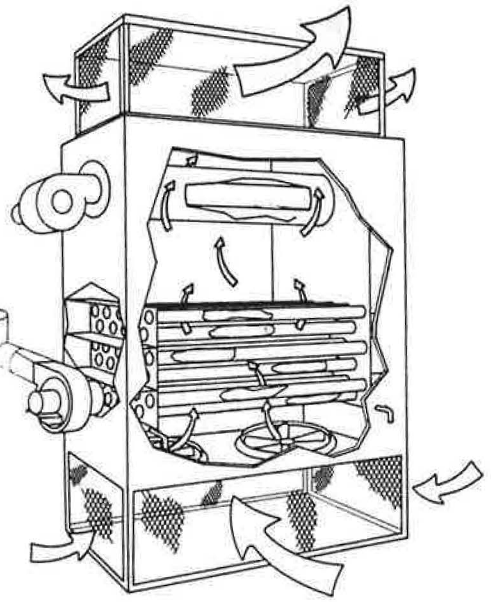

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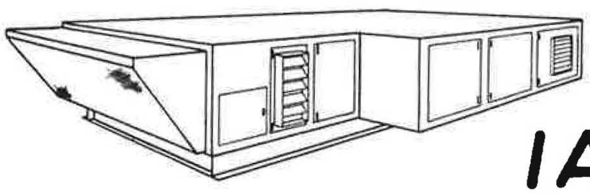

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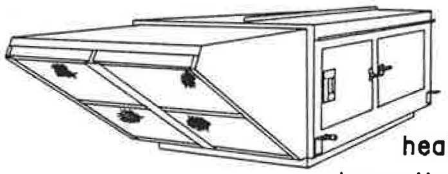

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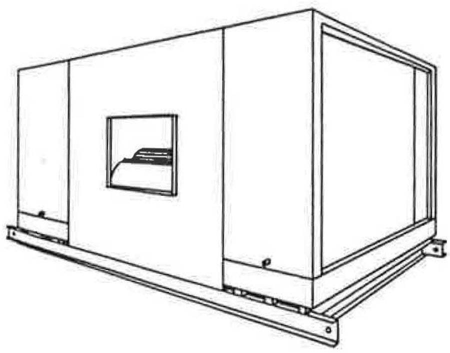

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termine the appropriate setback timing in such situations.

Typical radon entry routes include cracks in the slabs, walls, and floor/wall joints, porous concrete block walls, open sump pits, and openings around utility penetrations. Radon present in crawl spaces may also enter a building. In addition, many schools have other radon entry points such as slab pour joints (control joints) and subslab utility tunnels.

Experience has shown that there can be large differences between radon levels in classrooms on the same floor. Causes for these room-to-room differences are thought to include variations in the soil under the classrooms, the construction between rooms, the number and size of cracks and openings in contact with the soil in different rooms, and the design and operation of the HVAC system. This room-to-room variability makes it difficult to detect and mitigate all the rooms with high radon levels unless every classroom on or below ground level is tested.

Radon mitigation techniques

Subslab depressurization. Subslab depressurization (SSD) has been the most successful and widely used radon reduction technique in slab-on-grade and basement houses and, so far, it has reduced radon levels in a number of schools (EPA 1988). If HVAC system operation or the natural stack effect exerts a negative pressure in the building relative to the subslab area, then a successful SSD system must overcome this negative pressure.

Installation of an SSD system involves inserting pipes through the concrete slab to access the crushed rock or soil beneath. A fan is then used to reverse the pressure differential. That is, the fan causes the soil side of the slab to be at a lower pressure than inside the room. This reversed pressure relationship prevents radon-containing soil gas from entering the building.

The material under the foundation slab must be permeable enough to allow air movement under the slab so that adequate suction can be induced across the entire slab. (Subslab permeability or air flow is often referred to as subslab "communication" or "pressure field extension.") When subslab air flow is inadequate, additional suction pipes may be able to increase the mitigated area.

Initial results indicate that SSD can reduce radon levels in some schools by over 90 percent if crushed aggregate or other permeable material is under the slab to allow for adequate air flow (Leovic *et al.* 1989). However, schools with poor subslab air flow and those using return-air ductwork beneath the slab may require an alternative mitigation approach to SSD.

Sealing. The effectiveness of sealing alone as a radon reduction technique in schools is limited by the ability to identify, access and effectively seal major radon entry routes. Most buildings have so many radon entry routes that sealing only the obvious ones may not result in a significant degree of radon reduction.

However, complete sealing of all radon entry routes is often impractical. In some buildings, certain areas will be difficult, if not impossible, to access and/or seal without significant expense. In addition, settling foundations and expanding floor cracks continue to open new entry routes and reopen old ones. Typical initial radon reduction from extensive sealing in houses is usually about 50 percent.

Classroom pressurization. A potential mitigation approach for schools is adjustment of the air-handling system to maintain a positive pressure in the school relative to the subslab area, discouraging the inflow of radon. This technique, referred to as pressurization, has been shown to be an effective temporary means of reducing radon levels in some schools, depending on the design of the HVAC system (Leovic *et al.* 1989).

If pressurization through the HVAC system is under consideration as a long-term radon mitigation solution in a given school, proper operation and maintenance of the system are critical. Responses to changes in environmental conditions and any additional maintenance costs and energy penalties associated with the changes in operation of the HVAC system must also be carefully considered.

School characteristics

To help understand the causes of elevated radon levels in schools and to better design school mitigation systems, three building components are of primary concern: the school substructure(s); the design and operation of the HVAC system(s); and the location of utility lines. The following sections discuss how these building components tend to affect radon entry in schools and how they may impact mitigation system design and operation.

School substructures. The three basic substructure types are slab-on-grade, basement and crawl space. Most substructures in the schools studied so far are slab-on-grade. Schools often have one or more additions and each addition may have a different type of substructure. Subslab aggregate (or gravel) is normally indicated on the construction plans. However, the grading of the aggregate (and consequently the subslab air flow) is variable.

Because of larger building and room sizes, schools often have interior footings and/or thickened slabs that may create subslab air flow barriers between areas. The location of subslab barriers and their influence on subslab air flow will depend on building size, building configuration and architectural preferences for carrying roof load.

The locations of these barriers may affect the number and placement of SSD suction points in a slab-on-grade or basement structure. Foundation plans, if available, should always be examined when selecting suction point locations to help ensure that all areas with elevated radon levels are adequately treated by the SSD system.

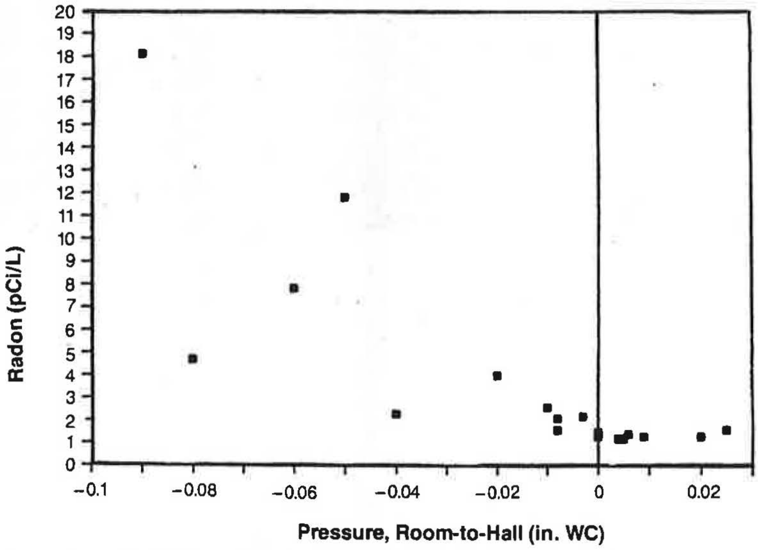

Figure 1. Correlation between room pressure, relative to hall, and radon level.


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School HVAC systems. Understanding the school's HVAC system often plays an important role in determining the source of (and the solution to) the radon problem. ASHRAE *Standard 62-1989* "Ventilation for acceptable indoor air quality" (ASHRAE 1989) should be consulted to determine if the installed HVAC system is designed and operated to achieve recommended minimum ventilation standards for indoor air quality.

Sometimes schools and similar buildings were not designed with adequate ventilation. In other instances, ventilation systems are not operated properly due to factors such as increased energy costs or uncomfortable conditions caused by a design or maintenance problems.

HVAC systems in the school districts initially researched by EPA include: central air-handling systems, room-sized unit ventilators and radiant heat. Unit ventilators and radiant heat were found both with and without a separate ventilation system. Central air-handling systems and unit ventilators tend to be most prevalent in newer schools, particularly if the schools are air-conditioned. Often, schools have more than one type of HVAC system because of building additions. The types of HVAC systems are discussed below in terms of radon entry and mitigation approaches.

Central air-handling systems can vary widely in size and configuration and the different types of systems have unique effects on radon entry and subsequent mitigation. Three types of central air-handling systems common in schools are single-fan systems, dual-fan systems and exhaust-only systems.

In single-fan systems, air is distributed to the rooms (under pressure) by the air-handling fan. Return air is brought back by the same fan. These systems are similar to forced-air systems in houses, except that fresh air can usually be mixed with the return air.

The air-handling fans may operate continuously during the day or they may operate only when heated or cooled air is required, cycling on and off with thermostat control. In any case, the systems are normally set back or turned off during evenings and weekends.

These single-fan systems are normally designed to generate neutral or positive pressures in all rooms. In a single-fan system that brings fresh air into the system, stale air leaves the building either through a separate exhaust system, by relief, or by exfiltration through cracks and openings due to overpressurization by the fan.

Larger air-handling systems often employ a dual-fan system: an air-distribution fan and a smaller return-air fan. The return-air fan permits forced exhaust of return air. Louvers regulate the amount of fresh air brought into the air supply and the amount of return air that is exhausted.

Dual-fan systems are usually designed so that they generate positive pressures in all rooms when operating. However, if the return-air fan pulls more air from a room than the supply fan is furnishing, the room can be run under negative pressure, causing soil gas to enter the room through openings beneath the slab. The fans usually operate continuously during the day and are either set back or turned off during evenings and weekends.

Although single- and dual-fan systems are commonly designed to operate at positive or neutral pressures, pressure measurements in schools have indicated that such systems can cause significant negative pressures in the building (Leovic *et al.* 1989). HVAC system modifications (such as reducing the amount of fresh-air intake), lack of maintenance (such as dirty filters), unrepaired damage, or other factors can result in substantial negative pressures in some rooms, thereby increasing soil gas entry.

If positive pressures are not achieved in a single-fan system, the system should be checked to ensure that the fresh-air intake meets design specifications and that the intake has not been closed or restricted. Increasing the fresh-air intake and operating the fan for a sufficient time prior to occupancy and then continuously while the school is occupied will help reduce radon levels that have built up during setback periods. These steps will also help maintain low radon levels during occupied hours by maintaining a positive pressure to prevent radon entry and by providing fresh (dilution) air.

If positive pressures are not being achieved in a dual-fan system, the return-air fan can be set back or restricted so that all rooms are under a positive pressure with only the supply fan operating. The fresh-air intake to the supply fan can also be increased up to the system's design limit.

If radon control through HVAC system operation is under consideration as a permanent mitigation strategy, proper system operation and maintenance are critical. Many schools have installed SSD systems to control radon levels even when their HVAC systems are not operating.

The third type of central air-handling system is an exhaust-only system in which no supply air is provided mechanically. Such systems are generally used for ventilation in schools that heat with radiant systems or unit ventilators and have no central air-handlers. Here, the fans usually exhaust air through a central ceiling plenum above the rooms or with roof-mounted exhausts in many locations.

Exhaust-only systems are designed to draw fresh air into the rooms by infiltration through above-grade cracks and openings. However, radon can also enter through below-grade cracks and openings.

The fans in exhaust-only systems are normally off at night, but may operate continuously during the day. This can generate a negative pressure in all rooms and, consequently, increase the potential for radon entry. For schools with exhaust-only ventilation systems, positive pressurization will probably require major modifications if the HVAC is considered as part of the mitigation strategy.

Unit ventilators are self-contained units that provide heating and/or air-conditioning in individual rooms. They are usually installed on outside walls with an enclosure that contains finned radiators and/or coils. They can also be located overhead in each room and are sometimes above the drop ceiling.

Unit ventilators normally contain one or more fans and a vent to the outside so that fresh air can be pulled in by the fan(s). An adjustable damper allows a variation in the mix of recycled room air and fresh air fed to the circulating fan. Fresh-air intake can be minimal because the outdoor vents are obstructed due to poor maintenance or energy conservation practices. (Units that do not provide any outdoor air by design are referred to as fan coil units, not unit ventilators.)

In some cases, there is a central-building exhaust-fan system in schools with unit ventilators, as discussed above. This exhaust fan provides ventilation by pulling air in through the unit ventilators (if their fresh-air vents are open). But, it also creates a significant negative pressure that can pull radon into the rooms with the soil gas. If the fresh-air intakes in the unit ventilators are blocked for any reason, operating the exhaust-only fans will increase the negative pressure in the building relative to the subslab area.

Radon mitigation strategies in schools with unit ventilators might include: opening the fresh-air vents to improve ventilation and running the unit ventilator fans continuously to pressurize the room; replacing an exhaust-only ventilation system with a system that operates under a slight positive pressure; or installing a SSD system that could overpower all negative pressures in the building. If the current HVAC system is providing adequate ventilation to the building or if the first two options are not feasible, then SSD would be the most practical strategy if there is good subslab air flow.

Radiant heat systems in schools

tend to be either hot water radiators, baseboard heaters or warm water radiant heat within the slab. Schools heated with radiant systems should have a ventilation system to achieve the fresh air requirements recommended by ASHRAE. However, many of these schools provide no ventilation other than infiltration.

In other schools, there are exhaust ventilators on the roof (as discussed above). These can be passive, allowing some ventilation through the stack effect, or they can be powered. Powered Roof Ventilators can cause significant building depressurization, particularly if a fresh air supply is not provided. This can cause considerable radon entry into the building while such exhaust systems are operating.

If SSD is under consideration as a mitigation option in a school with intraslab radiant heat, the building plans should be carefully studied to avoid damaging any pipes when placing the SSD points. Satisfactory locations for SSD pipes may be very limited in such schools.

Location of utility lines. The location of entry points for utility lines can have a significant influence on radon levels since the lines provide entry routes for the radon into the indoor air (Leovic *et al.* 1989). Utility line locations depend on many factors including substructure type, HVAC system, and architectural needs or practices. However, utility lines located above-grade should not cause significant radon entry problems.

In slab-on-grade and crawl space schools, the utility penetrations from the subslab or crawl space area to individual rooms are frequently not completely sealed, leaving openings between the soil and the building interior. For example, there is a potential for radon entry around plumbing penetrations and electrical conduits.

In some slab-on-grade schools, the utility lines are located in a subslab utility tunnel that tends to follow the building perimeter or central corridor. Utility tunnels often have many openings to the soil beneath the slab-on-grade and, consequently, can be a potential radon entry route.

In addition, risers to the unit ventilators frequently pass through unsealed penetrations in the floor so that soil gas in the utility tunnel can readily enter the rooms. If the surrounding soil has elevated radon levels, a utility tunnel could be a major radon entry route in schools. If no asbestos is present, it is possible that the utility tunnel could be used as a radon collection chamber for a SSD system.

Conclusion

Radon normally enters a building from soil gas that is drawn in because the building is at a lower pressure than the soil surrounding the building substructure. To prevent radon entry, it is therefore necessary to reverse this pressure differential so that the building is at a higher pressure than the surrounding soil.

Subslab depressurization (SSD) has been the most successful and widely used radon reduction method in houses. Thus far, it has also substantially reduced radon levels in a number of schools.

Schools often have interior footings or thickened slabs that may create barriers for subslab air flow if a SSD system is the mitigation option. Review of foundation plans and subslab air flow testing will help to determine the presence and effect of such barriers.

HVAC systems in schools vary considerably and tend to have a greater influence on pressure differentials (and consequently radon levels) than do heating and air-conditioning systems encountered in the radon mitigation of houses. As part of any radon mitigation method, ASHRAE *Standard 62-1989* should be consulted to determine if the installed HVAC system is designed and operated to achieve minimum ventilation standards for indoor air quality.

If the HVAC system pressurizes the building, it can prevent radon entry as long as the fan is operating. However, school HVAC systems are normally set back or turned off on evenings and weekends. Even if the HVAC system pressurizes the building during operation, indoor radon levels may build up during set back periods. Many schools have installed SSD systems to control radon levels even when their HVAC systems are not operating. ■

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