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CHARACTERISTICS OF SCHOOLS WITH ELEVATED RADON LEVELS

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ABSTRACT

Radon mitigation systems installed in houses have sometimes been modified and applied to schools to reduce elevated radon levels. However, substructure type and building size and configuration, heating, ventilating, and air-conditioning (HVAC) system design and operation, and location of utility supply lines have been identified as school characteristics that can influence radon entry and possibly require radon mitigation strategies different from those for residential housing. One of the most significant factors contributing to radon entry in schools is room depressurization resulting from the HVAC system's exhausting more air from a room than the supply fan is furnishing to the room. Conversely, if the HVAC system pressurizes the room, it can prevent radon entry as long as the fan is operating.

This paper represents a current assessment of school characteristics and how they may relate to radon entry and mitigation system design. The information was collected from inspecting over 25 schools in Maryland and Virginia. The study will eventually be expanded to characterize several hundred schools representing a range of geographic areas.

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

Since the discovery of elevated radon levels in residential houses, a number of public school buildings with radon levels exceeding 4 picocuries per liter* (pCi/L) have been identified. Radon mitigation systems installed in houses have sometimes been modified and applied to these schools; however, no systematic effort has been made to assess the fundamental characteristics of schools that may require radon mitigation strategies different from those for residential housing. Factors such as substructure type and building size and configuration, heating, ventilating, and air-conditioning (HVAC) system design and operation, and location of utilities can vary considerably between schools. If elevated levels of radon are present in the soils beneath a school, these characteristics may influence indoor radon levels and consequently impact mitigation system design and performance.

To identify and better understand the various characteristics that may influence radon entry in schools and to develop a testing program to efficiently and effectively study various radon control options for schools, a preliminary survey of over 25 schools was carried out. These schools were visited in cooperation with the Directors of Facilities Maintenance in Fairfax County in Virginia, and Prince Georges, Montgomery, and Washington Counties in Maryland.

This paper represents a current qualitative assessment of the key characteristics influencing radon entry in schools. To confirm and quantify this information, the study will eventually be expanded to characterize several hundred schools in many geographic areas to help gain a better understanding of the types of substructures and characteristics that are common to schools throughout the U.S. Identification of building characteristics that may indicate a potential radon problem and understanding radon entry in schools will assist in determining the focus of future school mitigation research. The ultimate goal is the development and demonstration of cost-effective mitigation techniques for school buildings. It is anticipated that this information will also be applicable to many other similar structures such as office buildings, retail establishments, and public buildings should they require radon mitigation. The information collected thus far has already been useful in providing school districts with guidance on radon resistant new construction.

The significant school characteristics identified are discussed in terms of estimated prevalence, apparent relationship to indoor radon levels, and potential impact on radon mitigation. Some specific examples are cited. As a larger number of schools are surveyed, other characteristics relevant to radon entry and mitigation will probably be found, but it is believed that most of the causes of elevated radon levels in schools have been identified in the work to date.

* 1 pCi/L = 37 Bq/m^3

RESULTS

A qualitative assessment has been conducted of the following school characteristics: substructure types and building size and configuration, HVAC systems, location of utility supply lines, and other factors influencing radon levels.

SUBSTRUCTURE TYPES AND BUILDING SIZE AND CONFIGURATION

The three basic substructure types found in houses, slab-on-grade, crawl space, and basement, are found in schools but in different degrees. Slab-on-grade substructures were the most prevalent in the schools profiled to date. Details of the major substructures are discussed below.

Schools are commonly much larger than houses. In addition to larger buildings and rooms, schools often have interior footings and subslab foundations, most likely reducing air flow between areas. The location of these subslab barriers will depend on the configuration of the building, and foundation plans should be examined for siting of subslab depressurization points.

Slab-on-Grade Schools

Slabs for schools are poured similarly to those for houses. Construction plans of 10 of the schools visited were examined: all showed aggregate under the slab. As a result, it should be possible to mitigate these schools using subslab depressurization. However, it is anticipated that some older schools will not have aggregate under the slab. Where this is the case, problems will arise for mitigation using subslab depressurization, and other mitigation approaches will be necessary.

Crawl Space Schools

During the 1950s and 1960s many schools were built with crawl spaces primarily under slabs supported on periphery and internal foundation walls. We have not yet identified any crawl space schools built within the last 10 years. One school has been identified with conventional wood joist and floor construction over a crawl space. Two additions to this school are slab-on-grade, and all of the rooms in the school exceed 4 pCi/L.

The height of the crawl space can range from less than 3 ft* to more than 15 ft depending on structure design and original terrain. The crawl spaces examined were divided into compartments (by load-bearing walls) that are usually the size of the room above. The compartments are all interconnected by open passages allowing access to utility pipes in the crawl space. To avoid freezing of insufficiently insulated pipes, some schools

* 1 ft = 0.305 m

have no vents in the crawl space. As a result, high levels of radon may collect in the crawl space although this has not been found to date.

Basement Schools

Basement schools are not common in the areas of Virginia and Maryland visited. Where they exist they are normally used only for storage and for boiler or furnace rooms. However, some basements are used for classroom space. This is uncommon except in the case of walkout basements. A walkout basement can range from a relatively small area to buildings where one entire side is a walkout basement at ground level and the other side is below grade. In this case, the below grade wall can be a significant radon entry route resulting in elevated radon levels in the basement classrooms.

HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) SYSTEMS

One of the significant factors contributing to elevated levels of radon in schools is building or room depressurization. If a negative pressure is induced by the HVAC system, radon in the soil gas can be pulled into the building through floor and wall cracks or openings in contact with the soil. Conversely, if the HVAC system pressurizes the building (a common finding) it can prevent soil gas entry as long as the air circulating fan is running.

The size and complexity of large building HVAC systems is a problem not encountered in house mitigation. Sometimes schools and similar buildings were not designed with adequate ventilation, and in other instances, ventilation systems are not operated properly for reasons such as increased energy costs or uncomfortable drafts (1,2). HVAC systems in the schools surveyed to date include central air handling systems, room-sized unit ventilators, and radiant heat. The unit ventilators and radiant heat can exist with or without a separate ventilation system. Central air handling systems and unit ventilators were most prevalent in the schools visited and are used in most newer, air conditioned schools.

Central Air Handling Systems

In most buildings with air-conditioning, some type of air handling system is used for HVAC. The systems vary considerably in size and configuration. The locations of air handling fans depend on many factors including the type of substructure and architectural requirements. The most common locations are a mechanical room, in the area above a drop ceiling, or on the roof.

For relatively small systems, the air handler usually has a single fan with an air handling system similar to that in a house. The air is distributed to the rooms (under pressure) by the air handling fan, and the return air is pulled back by the same fan. There usually is a fresh air intake in the air return system, and the amount of fresh air is regulated by the opening and closing of dampers in the fresh air supply. The ventilation may be handled by either a separate exhaust system or exfiltration due to overpressurization by the supply fan.

Larger air handling systems often have two fans: an air distribution fan and a smaller return air fan. The return air fan allows for the forced exhaust of recycled air. Louvers regulate the amount of fresh air brought into the air supply and the amount of recycled air that is exhausted. If the return air fan pulls more air from any room than the supply fan is furnishing, then the room can be run under negative pressure causing soil gas to enter the room if openings to the soil beneath the slab are present. Consequently, proper balance is imperative in a two fan system.

In large systems, the individual room temperature is handled by a dual air supply system. The air is split into two streams after the air supply fan: one stream is heated by hot water coils, and the other is cooled by chilled water coils. The two streams are carried in parallel ducts with takeoffs to each room. A mixing box in each room controls the percentage of heated and cooled air entering the room depending on the room thermostat. Although there is constant heating and cooling at the air handler at any given time, the ability to regulate the temperature within a given room allows for localized control of temperature variations caused by variables such as sun exposure, time of day, and occupant activities.

Air return systems can cause significant depressurization and, consequently, can contribute to elevated radon levels. The drop ceiling over the hall, commonly referred to as a plenum, is frequently used for air return with no return ducting. As a result, the entire ceiling plenum is under a negative pressure. Many of the block walls intersecting the plenum also penetrate the slab and rest on footings under the slab. Radon-containing soil gas under the slab may travel up through the core of the block wall to the return air system in the ceiling plenum and be distributed throughout the building by the air handling system.

Although most observed cold air systems are overhead, a number of systems with cold air returns under the slab have also been identified. If the surrounding soil contains elevated radon concentrations, this will create a very difficult mitigation problem.

Since the discovery of elevated indoor radon levels, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has recommended that, where soils contain high concentrations of radon, ventilation practices that place crawl spaces, basements, or underground ductwork below atmospheric pressure be avoided since such practices tend to increase indoor radon concentrations (3).

Unit Ventilators

Many schools have individual unit ventilators in each room. These air handlers are made by a number of different companies although they all follow the same basic design. The self-contained unit ventilators are normally mounted on the outside wall of each room with an opening in the rear to bring in fresh air and an opening in the front at floor level to recycle room air. An air filter at the bottom of the unit cleans both the return room air and outside air. The air then passes through heating and/or cooling coils, and from one to six squirrel-cage fans circulate the air in the room. The heat is normally furnished by hot water from a central boiler, and cooling is furnished by chilled water from a central chilled water unit. In one school visited, the fresh air intake in at least one room was open to the soil in the concrete block walls, possibly allowing soil gas to enter the room through the unit ventilator.

Some schools with unit ventilators have no installed ventilation system. In these, the only ventilation is that forced by a slight overpressurization of the room by the unit ventilator fans with exhaust air leaving the room through exfiltration. In some schools, air is exhausted through registers in the ceiling to the hall plenum or through a special light fixture that has a chamber around it for either supplying or exhausting air. If the air is exhausted with power fans, the rooms are frequently found to be under significant negative pressure (as much as 15 to 20 Pa), greatly increasing the potential for radon entry.

Radiant Heat Systems

Radiant heat systems identified in schools can be of three types: hot water radiators, baseboard heaters, or hot water radiant heat within the slab. Many old schools still have radiators furnished with hot water from a central boiler. Many of these schools have no ventilation system except infiltration.

Baseboard heaters are normally installed along the outside walls and are basically fin heaters with a hot water pipe running down the middle. Circulation is by the rise of hot air through the fin heater and out through the top of the cover. Schools with baseboard heaters normally have active or passive ventilation through the plenum above the hall ceiling. Where active ventilation is accomplished with powered roof ventilators (PRVs), severe depressurization can occur.

Many schools built in the 1950s and early 1960s have radiant heat in the slab. This type of heat was becoming popular in houses at that time and appeared to be the heating system of the future. However, central air-conditioning, resulting in the need for central air handling systems in both houses and commercial buildings such as schools, has made radiant heat uncommon in buildings constructed in the past 20 years. In addition, large amounts of concrete are warmed by a radiant heat system during the night and early morning. When cold nights are followed by warm days, the building can become overheated during the day due to the residual heat in the concrete slab.

Schools heated with radiant systems normally should have a ventilation system to achieve the air circulation required by ASHRAE (1,2). However, many of these schools have no ventilation system. In other schools, there are exhaust ventilators on the roof. These can be passive, allowing some ventilation through the chimney effect, or they can be powered. The use of PRVs can cause significant building depressurization if a fresh air supply is not provided.

One school with radiant heat in the slab had a small forced air system to distribute conditioned outside air to all the rooms. This outside makeup air forces air to be exhausted through exfiltration. This type of system should keep the building pressurized when in operation and thus limit radon entry. However, the system is turned off at night, and during the day many teachers frequently have the fans turned off or tape over the registers because of drafts. As a result, this school has elevated radon levels in all but one room.

LOCATION OF UTILITY SUPPLY LINES

The location of entry points for utility supply lines can have a significant influence on radon entry in schools. Supply line locations depend on many factors such as substructure type, HVAC system, and architectural needs or practices. Locations identified thus far include overhead above drop ceilings, beneath the slab, in the crawl space or basement, or in a below grade utility chase. Potential radon entry points caused by utility supply line locations were identified during the preliminary visits and are discussed below.

Overhead

Utility supply lines located overhead should not cause significant radon entry problems and is the preferred location as far as radon entry is concerned.

Subslab and Crawl Space

Frequently, the utility penetrations from the subslab or crawl space to individual rooms are not completely sealed leaving openings between the soil and the building interior. This is commonly the case with sanitary sewer lines where there is potential for radon entry around the commode ring. One slab-on-grade school on a public water supply had no classrooms above 10 pCi/L; however, all restrooms had elevated radon levels, some as high as 40 to 50 pCi/L. These restrooms had exhaust fans that operated continuously during the day causing radon-containing soil gas to be pulled in. Since several restrooms are usually located in the same area, a single subslab depressurization point should reduce radon levels in these restrooms.

Utility Chases

In some slab-on-grade schools, the utility lines are located in a subslab utility chase that follows most of the perimeter of the building. The chase is normally about 5 ft wide and 5 ft deep with concrete floors and concrete block walls (unsealed on both sides of the block). The chase has many openings to the soil beneath the slab-on-grade and, consequently, can be a potential radon entry route. Risers to unit ventilators frequently pass through unsealed penetrations in the floor so that soil gas in the utility chase can readily enter the rooms.

If the surrounding soil has elevated levels of radon, a utility chase could be a major radon entry route in schools. However, it is also possible that the utility chase could be used as a radon collection chamber for a subslab depressurization system.

OTHER FACTORS INFLUENCING RADON LEVELS

Floor and Wall Cracks

As with houses, floor and wall cracks can be significant radon entry points in schools. Sometimes these entry routes may be difficult to identify. Carpeting, for example, may conceal cracks in a concrete slab. If the building is under negative pressure, as discussed in the HVAC Systems section, radon can be pulled into the school through these cracks. Fibrous expansion joints are widely used, and these can also serve as radon entry routes.

CONCLUSIONS

The following conclusions on school characteristics are based on the more than 25 schools in Maryland and Virginia studied to date. As a larger number of schools are surveyed, other characteristics relevant to radon entry will probably be found, but it is believed that most of the causes of elevated radon levels in schools have been identified in the work to date.

General

1. Since schools exhibit many characteristics that could require radon mitigation strategies different from those for residential housing, these fundamental characteristics need to be assessed as part of the school mitigation program. It is anticipated that much of this information will also apply to other similar structures such as office buildings, retail establishments, and public buildings.

2. A preliminary survey of more than 25 schools has identified the following characteristics that were found to vary among schools as likely to impact radon levels and mitigation approaches: substructure type and building and room size and configuration, HVAC system design and operation, location of utility supply lines, and the presence of cracks or expansion joints.

Substructures

3. Slab-on-grade substructures are by far the most common. Crawl space schools follow in prevalence. Classrooms in basements are uncommon but do exist.

4. Construction plans for 10 of the schools visited were examined and all specified aggregate under the slab. This should facilitate mitigation using subslab depressurization. However, it is anticipated that many older schools will not have aggregate under the slab, thus requiring an alternative mitigation approach if a radon problem exists.

HVAC Systems

5. One of the most significant factors contributing to elevated levels of radon in schools and influencing the mitigation approach is the design and operation of the HVAC system. The complexities of large building HVAC systems present problems not previously encountered in house mitigation.

6. Central air handlers with a single fan normally have a fresh air intake in the return air system prior to the distribution fan. Since the system is under negative pressure at this point, fresh air is readily pulled into the system. This tends to pressurize the classrooms and limit radon entry as long as the fan is operating. However, these fans are normally turned off at night and on weekends, and as a result, radon levels can rise. It can take some time the next morning to dilute indoor radon through ventilation.

7. A dual fan air handling system can cause significant negative pressures in the school if the return air fan pulls more air from any room than the supply fan is furnishing to it. If elevated levels of radon are present in the surrounding soil, radon levels in the room can increase due to the negative pressure induced by the HVAC system. Consequently, individual room balance is extremely important in a two fan system.

8. If the plenum over the hall is used for an air return with no return ducting, radon-containing soil gas may enter the return air system if there are block walls penetrating the slab and opening into the plenum. Radon would then be

distributed throughout the building by the air handling system.

9. If the cold air return is located beneath the slab (as was found in two schools), soil gas is pulled into the system due to the negative pressure in the ducting. If this soil gas contains elevated levels of radon, it will be distributed to all rooms on the air handling system. This situation may represent a severe mitigation problem.

10. Some schools with unit ventilators have no powered ventilation system. In these, ventilation is accomplished by a slight overpressurization of the room by the unit ventilator fans with exhaust air leaving the room through exfiltration. In some schools with unit ventilators, air is exhausted through registers into the hall plenum and then out through active or passive roof vents. If ventilation is active (PRVs), the rooms are normally found to be under significant negative pressure, greatly increasing the potential for radon entry.

11. Many schools heated with radiant systems have no ventilation. In other schools, active or passive ventilation systems are present as discussed in conclusion No. 10.

Location of Utility Supply Lines

12. Utility supply lines located beneath the slab or in a crawl space can increase radon levels in the school if there are unsealed openings through the slab and a radon source under the school.

13. Some slab-on-grade schools have utility chases with many openings between the soil and the chase. If the surrounding soil has elevated levels of radon, a utility chase could be a major radon entry route.

Other Factors Influencing Radon Levels

14. Floor and wall cracks and expansion joints can be significant radon entry points in schools. If the building is under negative pressure, as discussed in the HVAC System section, radon can be pulled into the school through these entry routes.

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