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SCHOOL MITIGATION DESIGN CONSIDERATIONS

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ABSTRACT

The state of New Jersey recently required all schools in the state to test for radon. This spring the NJ DEP contracted with WPB to produce a one day class to instruct New Jersey certified mitigators how to mitigate schools. Radon mitigators predominately installed ASD systems in residential buildings. Although commercial radon mitigation systems have most of the same features as a residential system, there are some significant differences in the system design and installation. The most important difference is the heating venting and air conditioning system (HVAC). The HVAC system in schools and commercial buildings can cause the radon problem, fix the radon problem and interfere with an ASD system performance. In addition the construction characteristics of school buildings and their large size require more careful design than residential systems. This paper will review some of the differences between these two types of installations.

TEAM APPROACH AND MEETING

Schools are obviously more complicated buildings than residences. The variation in construction characteristics and operation between different schools is also great. A radon mitigator therefore needs to gather information and expertise from a number of individuals in order to design a radon mitigation system for a school. The team should consist of school officials, some one knowledgeable with the HVAC system, someone who can read construction drawings and possibly an engineer or architect. At the meetings there will need to be, all the radon measurements, construction blueprints and copies of fire escape plans to make notes on.

REVIEW OF RADON MEASUREMENTS

Radon measurements are often just long lists of classrooms and numbers. These measurements need to be transcribed on to a fire plan or other simple floor plan. The date the measurements were made as well as the day of the week should be included on the floor plan. The measurement pattern along with the HVAC zones that are visible on a floor plan can help define where the problem is and what might be the cause. This information may also indicate if additional testing is required to clarify the problem.

UNDERSTANDING THE HVAC SYSTEM

Schools can have multiple HVAC systems that effect classrooms differently. The ventilation portion of the system needs to be thoroughly understood. This includes all exhaust openings and fans in the building as well as outdoor air sources. It is important to identify HVAC zones within the building and each zones HVAC type. There are three generic types of HVAC systems typically used in schools.

Constant Volume System
: This system provides a constant airflow. Comfort is maintained by varying the airflow temperature and humidity

Variable Air Volume (VAV)
: Air temperature and humidity are constant while the airflow to each room is varied by individual VAV boxes

Individual Unit Ventilator
: Each room has its own air handler with hot water or steam and sometimes chilled water provided from a central source.

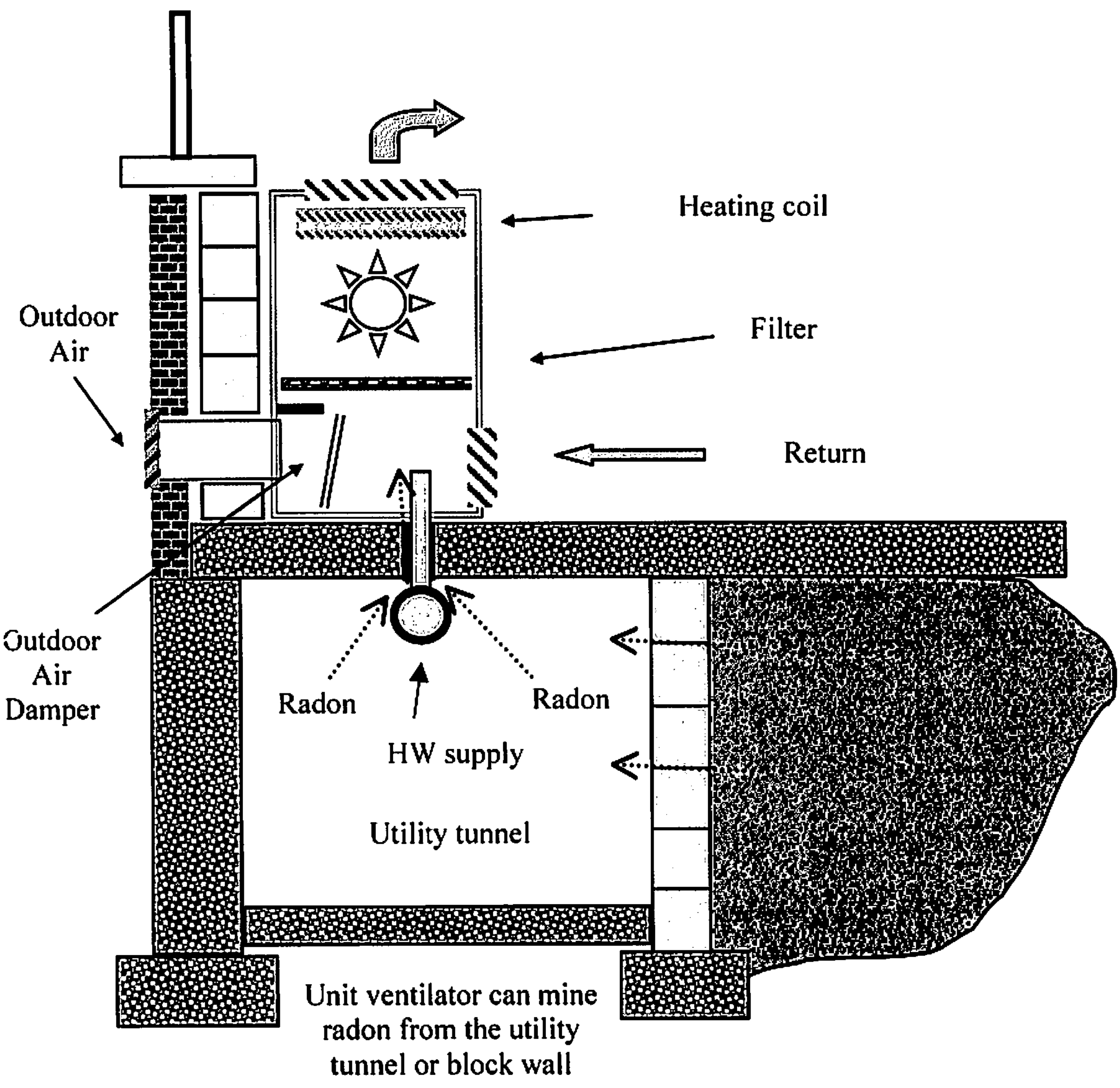
Each of these different HVAC systems can cause individual rooms to have elevated radon levels because of the pressure relationships they create with radon sources, the amount of outdoor air they introduce into the space or the possibility of transferring radon from one area to another. A continuous radon monitor (CRM) can be used to define the HVAC influence on radon levels. Micro-manometer measurements of the pressure difference between the main hallway of the building and the outside and then between individual classrooms and offices and hallway are also important to understand what pressures are being induced by stack effect and HVAC operation. Note the HVAC status when the measurements are made. Another important piece of information is understanding what cycles the HVAC systems are on and how they are controlled or changed. Pressures inside the building will change as the HVAC operation changes and exhaust fans are operated.

The mechanical drawings of the building need to be studied with someone, who can interpret them and locate HVAC components, especially exhaust fans. A list of all the exhaust fans should be made and then each one visited to determine if they are functional and when they are being used. Rooms that typically have independent exhaust include kitchens, bathrooms, chemistry labs, gyms, workshops, nurse's rooms and print rooms.

The outdoor air (OA) supplies to the building also need to be thoroughly understood. This includes the outdoor air to mechanical rooms as well as the HVAC systems. In many cases it is necessary to actually inspect outdoor damper positions to confirm they are allowing adequate amounts of outdoor air into the building. If the school has unit ventilators (uni-vents) in classrooms, it may not be practical to inspect each unit. Any classrooms or offices that have elevated radon levels should have the OA supply checked, especially if the room is running negative in comparison to the outdoors or CO_2 measurements indicate minimum OA supply.

Classroom CO_2 measurements should be less than 1000 ppm. This inspection will give a rough idea of the OA being provided. An actually measurement of the OA being supplied is best done with a flow hood by a trained technician.

Many schools with unit ventilators have passive relief dampers on the roof. These dampers may not be providing much resistance to upward stack effect, especially if the school is two or more stories tall. Designing ASD systems needs to take into consideration the competition from stack effect when the temperatures get colder.



If a school has a central HVAC air handler, it may be mining radon if any of the return ducts are located near radon sources or are depressurizing areas adjacent to the soil. Any return ducts routed through tunnels, crawl spaces or under slabs need to be carefully inspected. Any openings in the bottom half of unit ventilators might be mining radon when the units are running.

ASHRAE ventilation standards for schools 62-2001 are as follows:

Classroom 15 CFM per person
Meeting rooms & offices 20 cfm per person
Gymnasiums 0.6 cfm per square foot
Libraries 0.3 cfm per square foot or 15 cfm per person

Schools built between 1936 and 1975 had a 10 cfm per person classroom standard

Schools built between 1975 and 1989 had a 5 cfm per person classroom standard.

Older schools may be providing OA just from windows and leakage. Most schools have some sort of HVAC system that has either a fixed position damper set 10% open or higher or a motorized damper that adjusts for each HVAC cycle. Some more sophisticated HVAC systems may have economizer functions that alter the outdoor air depending upon indoor heat loads and outdoor temperatures and humidity. Keep in mind that unusual HVAC settings may have been set that way for good reason.

Many school districts have very tight budgets that cut into HVAC maintenance. Common problems from inadequate maintenance include clogged filters, OA supplies that are blocked or fixed to minimum position, broken controls, or freeze protection stats that have tripped into a minimum OA setting.

As HVAC problems are uncovered it may be best to correct the deficiencies and then re-test. Sometimes, however, the cost of fixing the HVAC is much greater than installing an ASD system. ASD systems also tend to be a more permanent fix. Minimum OA, however, still needs to be provided to the students and staff. Any increases in OA are going to provide a pollutant reduction equal to the inverse of the OA increase, assuming pressures changes across the shell do not cause any significant changes. In other words if the outdoor air is doubled, the indoor pollutant will be half. In general HVAC changes to fix radon levels are usually only practical if the radon levels are below eight to ten pCi/l. For example, if the radon levels were 8 pCi/l it would be necessary to have four times as much OA coming into the school to get the new radon levels to be below 2 pCi/l.

BUILDING CONSTRUCTION CONSIDERATIONS

School foundations are typically slab on grade construction, although there may be individual mechanical rooms built with basements and sometimes classrooms are built partially below grade if the building is on a sloped lot. If the slab is placed over a continuous stone based layer, sub-slab communication might be achieved with only one suction point. Many schools, however, are built with multiple compartments below the slab that are divided by bearing walls. Sometimes these bearing walls are just on either side of the main hallway. There can also be bearing walls between each classroom or office. These bearing walls present two obstacles to achieving sub-slab communication. The first is the disruption of the sub-slab gravel. The second is the leakage that takes place at these barriers. Bearing walls made of hollow core blocks typically extend a few courses below the slab. These walls are often penetrated below grade by utilities that allow easy airflow into the hollow sections of the block. In addition the slab often has a half-inch bond breaker material installed between the slab and the foundation that allows lots of leakage in and out of the sub-slab. There may also be large or small utility tunnels blocking communication. Block walls that don't penetrate the slab can also block sub-slab communication if the slab below the wall is thickened by eliminating the sub-slab gravel at this location.

Along with the problems with bearing walls and slab leakage there is always the issue of what is under the slab. Although some kind of stone base would be expected in areas of the country where stone is available, it may be a type that provides limited pressure field extension. One way to visualize the effect of airflow through different stone bases is to imagine the airflow through an empty 4" or 6" pipe. Fill the pipe with crushed, clean, 3/4 inch, stone and you can imagine a reduced but measurable airflow. Now place lots of fines in between the 3/4" stone and you can imagine how this would reduce airflow. Or imagine the pipe filled with sand. Even though water will flow through the sand, airflow is highly restricted. Slab on grade commercial buildings often use a modified fill that has lots of fines.

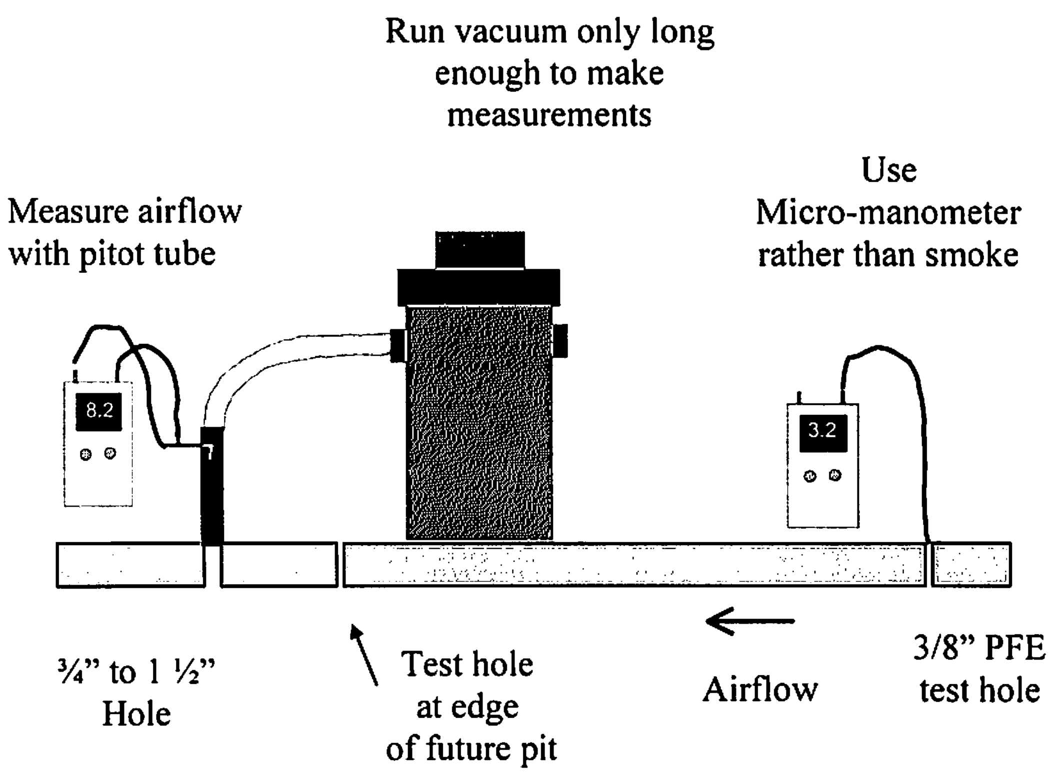
COMMUNICATION TESTING

Communication testing is using a common shop vacuum to emulate an ASD system by having it suck on a one to one an a half inch hole through the slab and then measuring the pressure changes that take place a distances from the suction hole. This test is only done occasionally in most residential mitigations. In commercial and school buildings it is almost a necessity to properly design a multiple room ASD system.

The type of shop vacuum used and the size of the suction hole define how much air can be pulled from beneath the slab. Included is a chart of maximum airflows with different vacuums and suction holes. Note that the Craftsman and Rigid shop vacuums have about twice as much airflow through a one and a half inch hole, versus a three quarter inch hole.

Vacuum Type	0.75" hole	1.0" hole	1.25" hole	1.5" hole
12 amp Dirt Devil	45 cfm	51 cfm	53 cfm	54 cfm
10.0 amp Craftsman 5.5 hp	63 cfm	87 cfm	113 cfm	117 cfm
12.0 amp Ridgid 6.5 hp	70 cfm	102 cfm	140 cfm	154 cfm

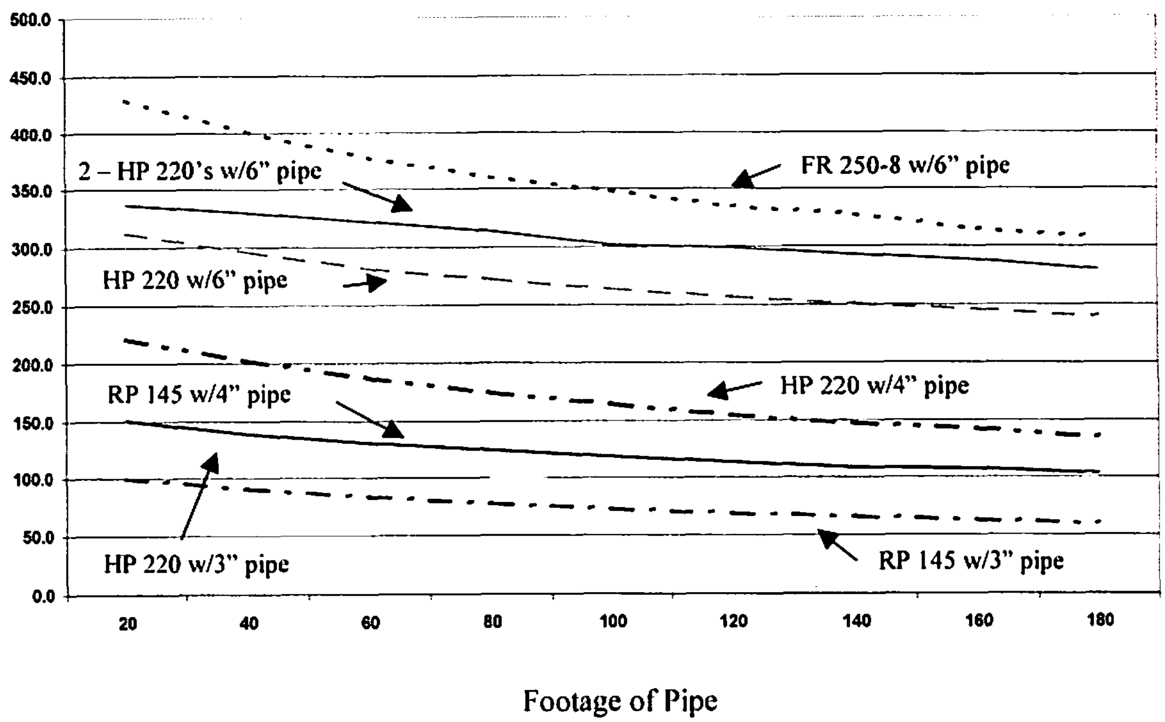
Commercial and school ASD systems can be very high flow situations. It is important to determine this before the system is installed. It is also important to size the radon fan correctly. A communication test does not include the performance enhancement provided by sealing of leaks and digging out of the suction pits. The shop vacuum, however, has a higher capacity suction, close to 80 inches of water column, compared to the typical maximum vacuum of 2 to 4 inches of water column produced by common radon fans. To better size the final radon system, a pressure measurement is made at a test hole about 18 inches from the suction hole. This pressure should be adjusted to create the same pressure that would be created if the suction pit was dug out and a common radon fan was used. This pressure measurement combined with a measurement of the shop vacuum airflow can be used to define what size radon piping is needed and the size of the radon fan. This will also define how many suction holes a single fan system can effectively handle. In school mitigation systems, it is often more practical to install multiple fan systems rather than manifold piping between them. See the drawing of a common communication set up below. To minimize the risk of drilling through sub-slab utilities, study the "As Built Mechanical Drawings, use a metal scanner, use a metal sensing ground fault, use common sense.



The airflow coming out of the suction hole is measured by placing a 2" pvc pipe over the suction hole and attaching the vacuum hose to the top of the 2" pipe. The velocity pressure in the 2" pipe is measured with a micro-monometer and a pitot tube. The square root of the velocity pressure using inches of water column scale is multiplied times 4000 and then multiplied times the square foot area of the pipe to determine the CFM of air flow.

DETERMINING NECESSARY PIPE SIZES

Once the airflow necessary to achieve adequate pressure field extension is determined, the necessary pipe size can be deduced using ASHRAE pressure drop tables for air flow in round pipes. If multiple suction pits are required then the combined airflow needs to be determined from the point the two or more systems are joined together up to the final exhaust point. The total pressure drop induced by the piping at the required airflows then defines how powerful the fan needs to be. Obviously if the pressure drop can be reduced by using larger pipe, the size of the fan can also be reduced. The maximum airflow achieved with increasing pipe length using different fans and pipe sizes is depicted in the graph below.



The graph above clearly shows the difference using larger pipe sizes has on airflow. An RP145 uses half as much power as an HP220 fan and yet will move more air in a 4" pipe than a HP220 can move in a three inch pipe.

The chart below obtained from the ASHRAE pressure drop table gives the pressure drop for 100 feet of pipe for different pipe sizes.

Top row is CFM flowing through different pipe sizes

Pipe	20	40	60	80	100	125	150	175	200	250	300	400	600
3"	0.14	0.5	1.1	1.8	2.8	4.2							
4"	0.04	0.12	0.25	0.4	0.6	1.0	1.3	1.8	2.4	3.5			
6"	0.01	0.02	0.03	0.06	0.09	0.13	0.18	0.23	0.3	0.5	0.7	1.3	2.5
8"				0.01	0.02	0.03	0.04	0.06	0.08	.12	0.2	0.3	0.6

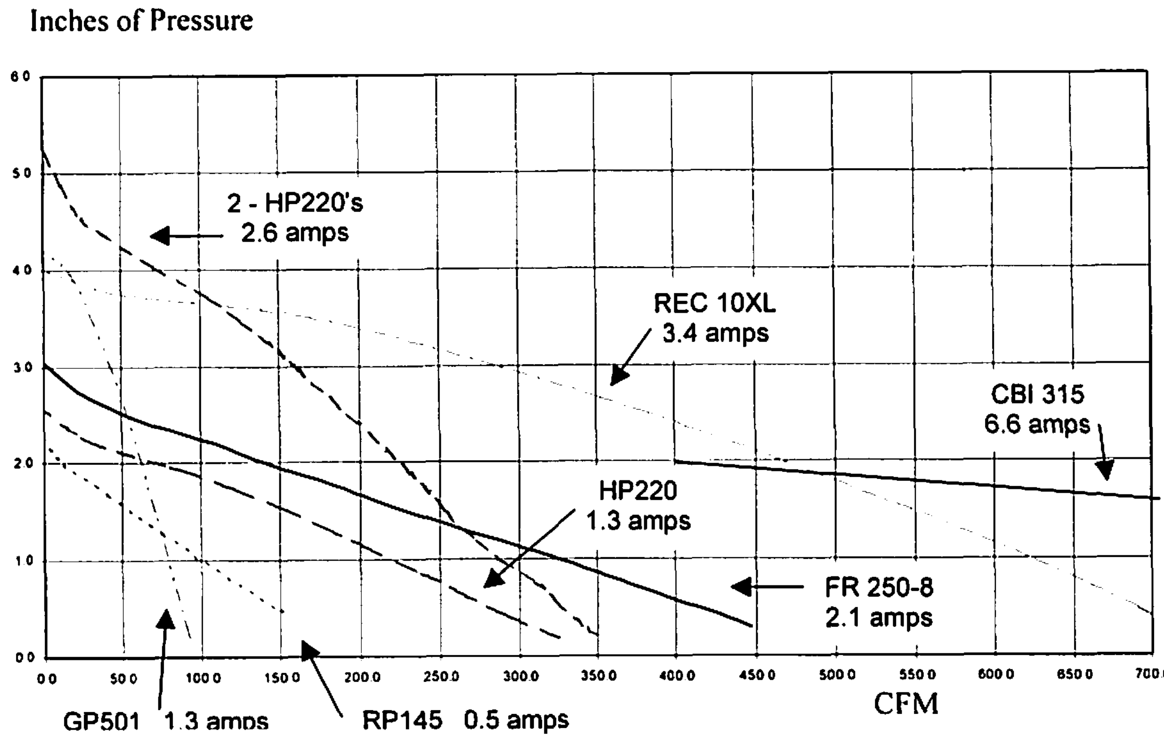
Pressure drop in inches of water per 100 feet of pipe

Along with the pressure drop of the piping there is pressure loss for each elbow or fitting as well as the pressure drop from the initial suction hole. The chart below gives the approximate pressure drop for different fittings in equivalent feet of pipe. If four 90 degree sweeps are included with a four inch pipe run, then multiple the number of fittings times the equivalent feet from the table below. In this case it would be 4 times 6 equivalent feet and thus 24 equivalent feet would be added to the actual pipe footage. Note that a sharp elbow, which is an elbow that makes a sharp edge turn, has more than double the resistance of a sweep elbow.

Pipe size	Sweep 90°	Sharp 90°	Sweep 45°	Sharp 45°	Reducer	Pipe end
3"	3'	11'	2'	5'	19'	17'
4"	6'	15'	3'	6'	30'	20'
6"	15'	26'	4'	7'	85'	42'

For each length of pipe find the pressure drop for its size and the airflow flowing through it. Then multiple the 100 foot pressure drop by the length of the pipe divided by 100. Add up these pressure drops from the exhaust to the first suction point or tee fitting to get the total pressure drop. The fan needs to be able to produce the necessary airflow and pressure required in the suction pit with the added resistance of the piping. Lets assume a proposed simple system has a total equivalent length of 150 feet of four inch piping and the airflow required is 80 cfm. A final pressure of 0.8 inches of water column was necessary in the suction hole. The four inch pipe loss at 80 cfm, which is 0.4 inches, would be multiplied by 1.5 (150 divided by 100) times. This would give a total piping pressure drop of 0.6 inches and a required pressure of 0.8 inches for a total pressure of 1.4 inches at 80 cfm. A RP145 fan can just about provide this performance as seen in the fan chart below.

Fan Performance Curves



OTHER DESIGN CONSIDERATIONS

School classrooms are typically fire-rated between the classroom and hallways, adjoining rooms and any rooms above or below the classroom. No flammable materials such as PVC piping are allowed to be installed in any return ducts. The fire marshal needs to be consulted during the design phase to ensure compliance with all fire code regulations.

CONCLUSION

Schools can often have complicated HVAC systems that require expertise beyond what a mitigator might provide. A team approach is often needed. The size of the school and the typical construction features of schools requires obtaining more information to careful design a radon system than would be required to mitigate a residential building.

REFERENCES

Radon Measurement in Schools
EPA 402-R-92-014 July 1993

Radon Prevention in the Design and Construction of Schools and Other large Buildings
EPA 625-R-92-016 January 1993

Reducing Radon in Schools: A Team Approach
EPA 402-R-94-008 April 1994