RADON MITIGATION MANUAL

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INTRODUCTION to RADON MITIGATION MANUAL

The Federal Indoor Radon Abatement Act of 1998 essentially stated that the goal for radon mitigation should be that indoor radon concentrations approach or equal outdoor radon concentrations. Methods which reduce or defeat the factors that cause the entry and accumulation of radon are referred to as "mitigation" techniques. Note that the word mitigation is used rather than a term like elimination because radon cannot be eliminated but only reduced or mitigated. Although the outdoor concentration can vary depending on local factors, typical ambient outdoor radon concentrations average 0.4 pCi/L. Mitigating a home to ambient levels is certainly achievable with available technologies, but may not always be economically practical. What is reasonably achievable depends primarily upon the skill and effort of the mitigator as well as the willingness of the client to have the necessary work done and absorb the cost.

Historically, industry practice has been to design a radon reduction system that reduces radon levels to less than the EPA Guideline of 4.0 pCi/L in the lowest potentially livable location of the home. Note that this is not a legal requirement set forth by the EPA, but rather a guidance. However, since measurements above the EPA guidelines of 4.0 pCi/L generally precipitate action, in the form of confirmatory measurements and/or a desire for mitigation work, it is reasonable to assume that the building owner will not be satisfied unless levels are reduced below the EPA guidance level. It should be further noted that levels just below 4.0 pCi/L still present a risk, and further reduction of the radon levels can provide significant health benefits to the occupant.

Since the inception of the residential radon mitigation industry in the early 1980s, it has been repeatedly demonstrated that, regardless of the initial concentrations observed, radon levels can cost-effectively be reduced. The challenge confronting the mitigator is not whether the radon can be reduced, but rather how to do so without compromising the aesthetics or integrity of the building, or the health and safety of the occupants and workers, while providing the mitigation at a reasonable cost.

These first four chapters discuss mitigation techniques for reducing radon concentrations from soil gas entry as well as entry from diffusion and building material emanation. (Chapter 5 addresses reducing radon that enters from water sources.) It provides the mitigator with a broad basis for understanding the techniques typically employed in the industry. The implementation of these techniques requires a thorough working knowledge of building and construction practice. A more detailed guidance can be obtained in the EPA publication, "Radon Reduction Techniques for Existing Detached Houses" (Third Edition Technical Guidance) ref [11]. In addition, the professional mitigator is encouraged to stay current with developing trends through relevant symposia, technical journals, and continuing education classes.

RADON MITIGATION MANUAL

1.0 MITIGATION THEORY and DESIGN

ABSTRACT to RADON MITIGATION MANUAL

There are seven sections or chapters in the total Radon Mitigation Manual. In this portion of the manual the first four chapters will be covered dealing with all aspects of radon in air mitigation installations. The remaining three chapters will deal with Radon in Water, Worker Health and Radon Resistant New Construction. The predominate mitigation method for radon in air has been and continues to be active soil depressurization. This manual covers all aspects of designing and installing soil depressurization systems in residential buildings. The first chapter begins with an overview of the various approaches to radon mitigation. The remaining portion of the chapter covers the important aspects of air flow dynamics and fan performance. The second chapter describes the methods used in conducting Building Investigation. The third chapter describes accepted construction practices used in installing Active Soil Depressurization systems. The fourth and last chapter in this portion of the manual discusses ventilation as a reduction method as well as the use of pressurization. This chapter finishes with a review of Emanation, Diffusion and Filtration. There is also a short discussion of the considerations required for installing radon systems in commercial buildings.

Relevant sections from the EPA Radon Mitigation Standards (RMS) (ref 11) are included at the beginning of each sub-section since these standards are often requirements that must be complied with to maintain certification. These standards have recently been re-written and approved as a new standard from ASTM, document E2121. Each certification body or state radon department may re-cognize these or a revised version of these standards. It is important that each mitigator be familiar with the standards of the state he is doing work in as well as any local or state code requirements.

INTRODUCTION to MITIGATION THEORY and DESIGN

In order to gain a complete understanding of current radon mitigation methods one must understand the theory of different mitigation methods as well as an understanding of basic concepts of air pressures, air flows and fan performances curves.

1.1 OVERVIEW OF RADON MITIGATION METHODS

A home with elevated radon levels has:

- A radon source,
- Pathways through the soil
- A force that draws soil gas into the building
- Openings through which radon can enter the building
- An insufficient building ventilation rate to keep radon levels below acceptable levels

Although varying in execution, radon mitigation techniques revolve around all of the last three factors above.

1.1.1 Active Soil Depressurization (ASD)

If radon in buildings is derived from the soil beneath and/or around the structures, there is obviously a driving force that is drawing the radon inside. The driving force can be the concentration gradient between the building and the soil but this usually only contributes a small amount of the radon entry. Radon can be in building materials but this condition is rare. In some parts of the country radon enters from elevated radon in the well water. This is also typically a small source. The major driving force is predominately the negative pressure exerted on the soil by the building itself. This negative pressure (also referred to as a partial vacuum or suction) can be caused by thermal stack effect, wind, mechanical exhaust, combustion appliances and HVAC (Heating, Ventilation, Air Conditioning) air handlers. Other environmental factors that can influence radon entry are: soil moisture content, heavy precipitation and fluctuating barometric pressures.

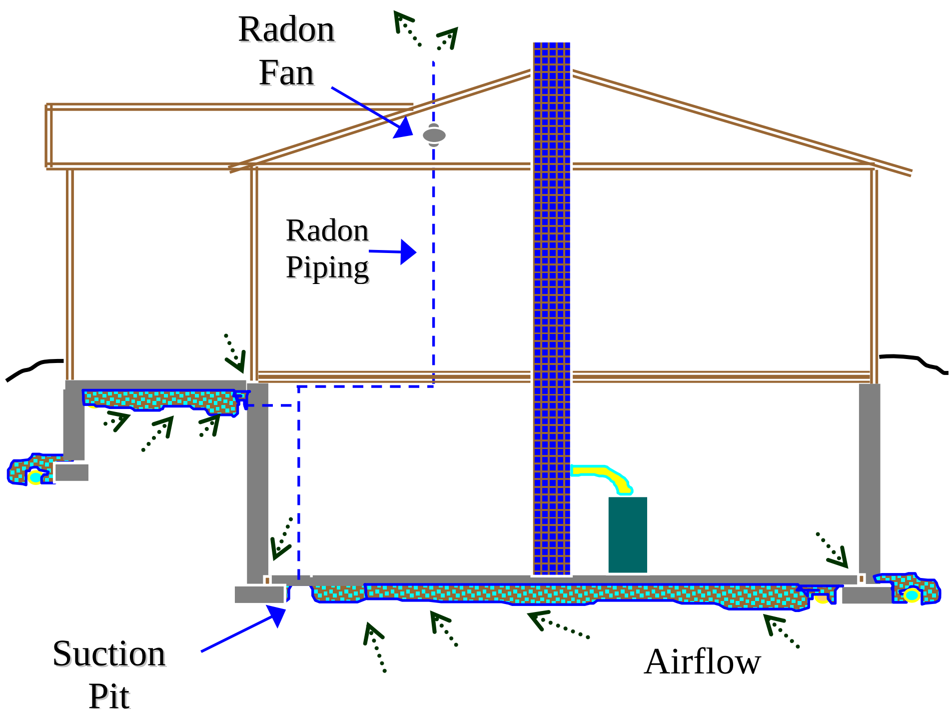


Fig 1-1 ASD principles

The most successful mitigation technique has been reversing the soil to building pressure difference. This could be accomplished by pressurizing the building with outdoor air. In commercial buildings this can be a practical approach because many commercial HVAC systems are already set up to do this. In residential construction it is not practical or cost effective in most cases to redesign the building to be a positive pressure as compared to the outside. It is, however, reasonably cost effective to make the building positive in relationship to the soil by depressurizing the soil under the building. This method is known as **Active Soil Depressurization** (**ASD**). Active Soil Depressurization removes enough air from the soil under the building to create a partial vacuum that is greater that the partial vacuum applied to the soil by the building. ASD systems can be installed in a variety of ways, but most have common elements consisting of vacuum-producing blowers or fans connected to a pipe which draws soil gases from the underlying soil. The radon laden soil gas is thus drawn to the fan and then safely exhausted above the roof outside the home (see Fig 1-1).

All of the methods that use a fan to create suction beneath the house are referred to as ASD systems. Soil depressurization systems have proven to be reliable and successful and are able to reduce even extremely elevated radon levels below the current EPA 4 pCi/L guideline. Depressurization has been successfully applied to:

Soil and aggregates under concrete slab floors,

Sump pits,

Interior and exterior footing drains,

Block wall foundations

Membranes placed on bare earth floors.

Crawl Spaces

The key to achieving the best radon reduction by soil depressurization is to extend the negative pressure field under as much of the house footprint as possible. It is even better if the negative pressure field extends under the entire building foot print and up the cores of the hollow block exterior walls or up the outside of the foundation. This negative pressure field needs to be stronger than the competing interior pressures generated by the building throughout the year. Several variations of ASD systems exist:

Sub-Slab Depressurization (**SSD**) (Fig 1-1)

Interior or Exterior Drain Tile Depressurization (**DTD**)

Sub-Membrane Depressurization (**SMD**) (Fig 1-2)

Crawl Space Depressurization (**CSD**) (Fig 1-3)

Block-Wall Depressurization (**BWD**) (Fig 1-4)

Stem Wall Depressurization (**SWD**)   (Fig 1-5)

Or a combination of the above systems.

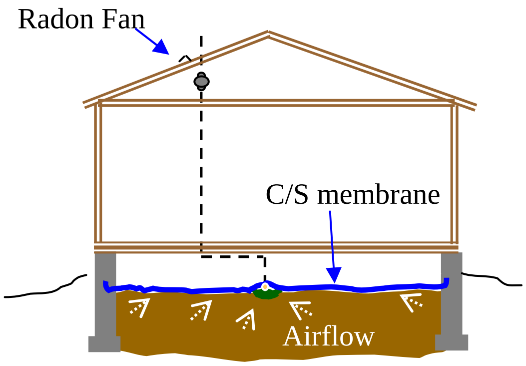


Fig 1-2 Sub-Membrane Depressurization

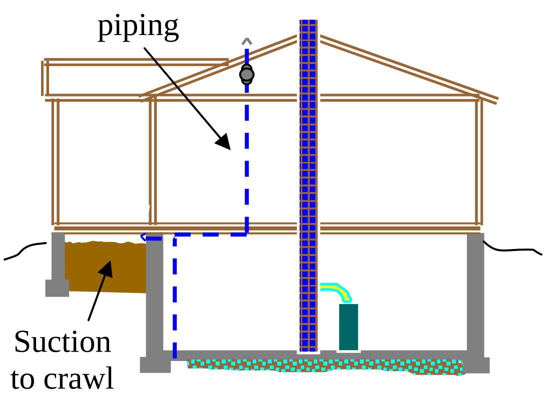


Fig 1-3 Crawl Space Depressurization

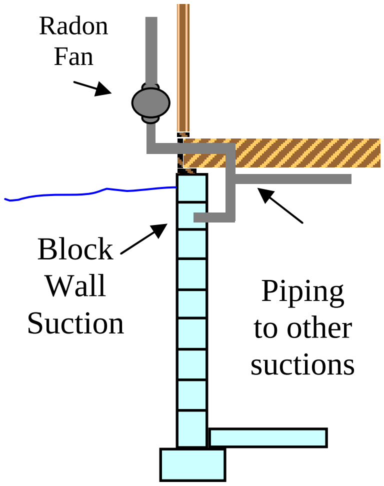


Fig 1-4 Block Wall Depressurization

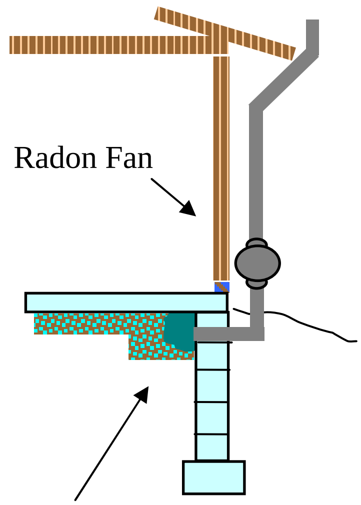


Fig 1-5 Stem Wall Depressurization

Surveys done in the early 1990's indicate that 91% of basement homes and 81% of slab-on-grade homes were mitigated with a combination of ASD and entry point sealing. These percentages are most likely even higher today. Consequently chapter three will be devoted to ASD systems.

1.1.2 Sealing Entry Points

In addition to a radon source and a driving force, there must also be an opening into the structure through which the gas can enter. Theoretically, radon entry could be significantly reduced if all of the openings could be sealed. In practice radon entry only requires very small openings. In addition many of these openings cannot be reasonably sealed in a permanent manner. Although floor crack sealing by itself has proven to be a poor stand-alone technique, it does improve the performance of ASD systems.

1.1.3 Ventilating Indoor Radon

When radon enters a building, it quickly mixes with the indoor air and is diluted to the final concentration to which the occupants are exposed. The more air with which the radon is mixed, the lower the final radon concentration will be. One method of reducing indoor radon is to simply increase the ventilation rate of the building. The reduction, assuming the entry rate does not change, will always be the inverse of the ventilation increase. In other words if the ventilation rate is doubled, the pollutant level will be half its original level. This is assuming radon levels outdoors are minimal. The effectiveness of increased ventilation is very dependent upon the initial ventilation rate. If the building already has a large ventilation rate then it will take a large amount of air to double the ventilation rate. If the building has a low ventilation rate then it would be easier to increase the ventilation rate by a factor of four and thus reduce the pollutant to one quarter of its original strength.

Increasing the ventilation rate can also have the added benefit of reducing or eliminating a buildings negative pressure in relationship to the soil, thus reducing radon entry. Increased ventilation can be accomplished by opening windows or turning on a window fan that blows air into the building. These procedures cannot typically be considered a year round option. It may, however, be practical to have the HVAC system bring outdoor air into the return side of the air handler so that it can be conditioned first. This approach would only be beneficial when the HVAC system was operating. A more constant fix would be to install a heat recovery ventilator (**HRV**) or air to air heat exchanger (**AAHX**). These units which simultaneously supply and exhaust air have the added benefit of reducing the energy penalty associated with additional ventilation by utilizing a heat transfer mechanism. Although generally not as cost-effective as ASD systems in reducing radon levels especially if the levels are greater than 10 pCi/L, they have the added benefit of improving indoor air quality.

1.1.4 Pressurizing Lower Level

Pressurizing rooms that are in contact with the soil is the other side of depressurizing the soil. In most cases it is easier and more practical to depressurize the soil rather than pressurize the rooms directly above the soil. There are cases however where the soil cannot be easily de-pressurized and pressurization may be the best option. The two considerations for this method is how much air will it take to pressurize and where will the air come from? If the air comes from outside, how will it be conditioned? The ability to condition the air is related to how much air is required to pressurize. If the amount of air required for pressurization can be reduced to a small amount then it simplifies conditioning the air. In commercial installations the HVAC system is already set up to bring in outdoor air and condition it. In residential construction this is rarely the case. A simple duct routed from the outside to the HVAC return duct could be installed that would bring outdoor air into the building but it has two limitations. The first is the additional outdoor air needs to pressurize the whole building rather than just the lower level. This most likely requires significant more outdoor air. The second problem with this approach is the HVAC system must be operated 100% of the time all year round. Most attempts to pressurize a lower level area in residential construction have been done by instead drawing air from the upper levels that is already conditioned using a standard radon fan. This simplifies the installation but brings up additional concerns. The first concern is that the upper level floors will become de-pressurized which could induce backdrafting of any combustion appliances on the upper floors such as a fireplace. The second concern is the lower level must remain isolated from the upper levels.

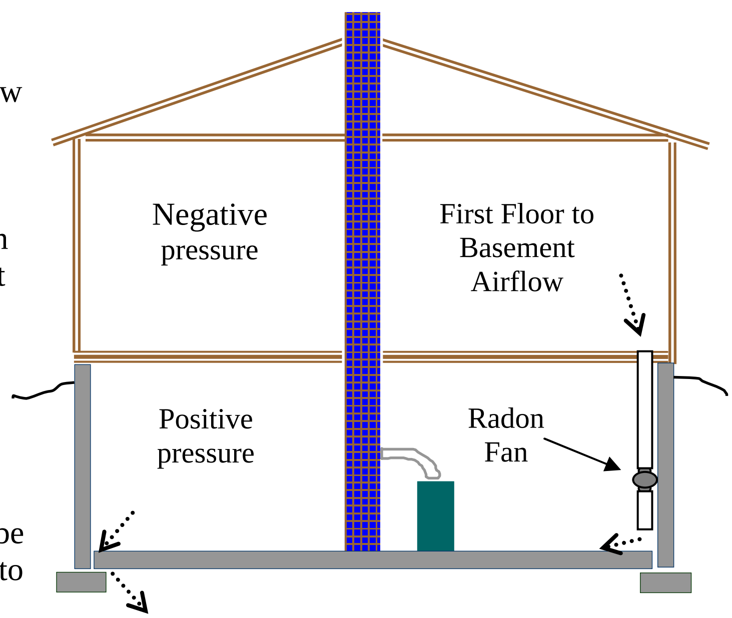


Fig 1-6 Pressurizing Lower Level

1.1.5 Pressurizing Soil

Pressurizing the soil would appear to be totally counter effective at controlling indoor radon levels. Initial work with this technique was done in the Northwestern states. During a mitigation research project they discovered if they turned a sub-slab depressurization radon fan around, the radon levels were reduced even further. Later the same researchers tried reversing the fan to pressurize the sub-slab at research houses in New Jersey. This time the radon levels went higher than they were without the fan running. The difference in the system performance was attributed to different soil porosities. The houses in the Northwest had very porous sub-slab soil while the New Jersey houses had tight, clay like soil under the slab. If the soil is very porous, blowing air under the slab will actually push the radon-laden air away from the house. Any cracks or openings in the slab must still be carefully sealed. If the soil is not porous, then the system strips the radon off the soil and diverts it back into the basement through leaks that aren't sealed. This technique might be applicable to houses over Karst geology.

1.1.6 Reducing Building Emanation or Diffusion

Emanation of radon from building materials within the structure (such as stone foundations) is a serious concern because the treatment is difficult. Emanation rates are a function of the radium content of the material and the porosity and surface area of the material itself. For example, although stones in a stone wall foundation may appear to be a physically large surface, their exposed surface is actually very small compared to the much larger surface area if the same rock were crushed into very small pieces (as would be found if the rock was sand sized particles in the soil beneath the home). Treating emanation usually requires installing a membrane or barrier over the emanating surface and then venting the space in between.

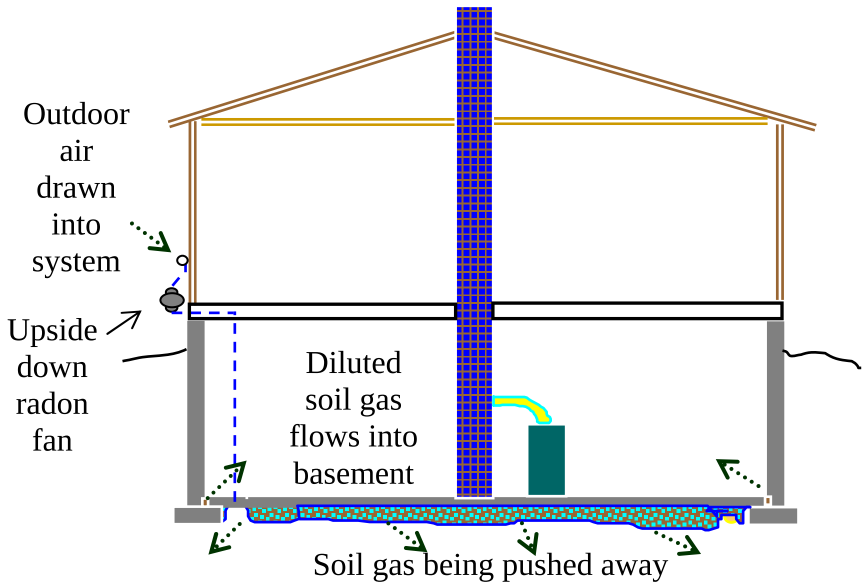


Fig 1-7 Sub-Slab Pressurization

Diffusion is the movement of gas from an area of high concentration to an area of lower concentration. Diffusion causes radon coming from a single source into an open room, to diffuse rapidly until the concentration is not significantly different from one side of the room to the other. The force of diffusion will cause radon to move through seemingly solid materials like concrete. This transfer is not typically a significant source unless the ventilation rate of the room above the slab is low and the concentration gradient between the sub-slab and the room is great. Diffusion through concrete will take place even though there is a negative pressure under the slab. The amount of diffusion taking place is determined by a flux test and a determination of the ventilation rate of the space. Reducing diffusion rate usually requires sealing the surface or reducing the sub-slab radon concentration.

1.2 MOVING AIR and CREATING PRESSURES

ASD mitigation revolves around changing pressures. It is critical that mitigators be very familiar with pressures, airflows and resistances to them.

1.2.1 Static Pressure Theory

To understand static pressure imagine a fan that is moving air through pvc piping. The air in the pipe is being drawn along by the lower pressure created below the fan and the higher pressure after the fan. This pressure can be measured with a simple tube in the shape of a "U". If the tube is filled with water and one of the tubes is connected into the radon pipe below the fan it will experience the lower pressure in the pipe in comparison to the ambient air outside the pipe. This pressure difference will cause the column of water to rise on the radon pipe side and fall on the ambient air side. The difference in height between the two water columns is the actual static pressure difference in inches of water. Since water will evaporate over time these u-tube columns are filled with oil which has a different viscosity than water. The scale included with the u-tube is calibrated to inches of water for this oil. If u-tube scale is measured with a tape it will not be actual inches. Another pressure scale is pascals. 250 pascals is the same pressure as one inch of water column or one pascal is equal to 0.004 inches of water column.

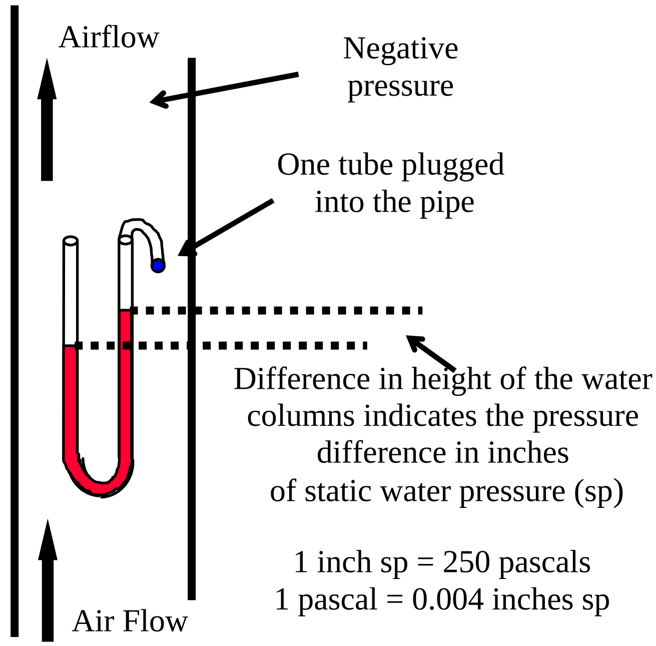


Fig 1-8 Static Pressure in inches of Water Column (W.C.) measured with a U-Tube

1.2.2 Pressure Measuring Equipment

In order to make proper pressure or airflow measurements a digital micro-monometer capable of reading down to 0.1 Pascals or 0.001" of water column should be used. These instruments typically cost $500 to $650 apiece. An alternative is to use a needle gauge magnehelic. These instruments come in different ranges. The most sensitive magnehelic is ¼ inch scale which will indicate a thousandth of an inch change as the movement of about half the thickness of the needle. These instruments cost about $80 apiece. It would be beneficial to have different scale magnehelics. A ¼ inch maximum scale is good for very slight-pressure difference readings while a 1 inch scale is useful for larger differences. A digital micro-manometer will have a maximum pressure capability of 2 to 4 inches of water column, depending upon the instrument. No matter which instrument is used, be sure to carefully seal the tubing into the slab with putty or a rubber stopper.

If neither instrument is available use smoke as a tracer. A chemical produced smoke is preferable. These are marketed as smoke pencils or puffer bottles. Don't confuse puffer bottles with smoke bottles that are used to release large quantities of colored smoke as a tracer. The smoke pencils typically only last a day. The smoke puffers last a few days. A durable Teflon smoke bottle that costs about $45 and is not affected by the chemical smoke can be used. The Teflon smoke bottle can be re-charged with fresh cotton & chemical. Be careful storing the smoke puffers or pencils because the chemical that is commonly used, titanium tetra-chloride, is highly corrosive to other tools.

Fig 1-9 Pressure measuring devices

Smoke is used by gently puffing, in a horizontal position, a small amount near the test opening and then watching for any change of direction down into the test hole. Note that this only indicates a positive or negative condition of the sub-floor in relation to the room. The strength of the pressure field cannot be determined with smoke. If the building is negative in relation to the outside, it may never achieve a flow reversal when the fan is turned on, even though there has been a pressure change from positive to less positive pressure under the floor. Opening a basement window will reduce the competing house pressure but may cause the pressure reading to fluctuate because of the influence of wind.

If no pressure instruments are available, the sub-slab pressure can be checked using a match. Hold the match over the test hole and watch if the match flame is turned down into the hole by the sub-slab negative pressure or put out the match flame and use the trail of smoke as a flow indicator.

1.2.3 Measuring Airflow in Pipes

In radon mitigation airflow measurements are primarily used for two functions. One is to determine if one suction hole is allowing a significant amount of airflow versus another suction hole. The other common use is to determine how much air is being removed from a suction test hole during a diagnostic communication test. Airflow measurements for these cases can be determined with a number of different instruments. In general however the simplest instrument is a pitot tube with a micro-manometer or magnehelic. Since most qualified mitigators would

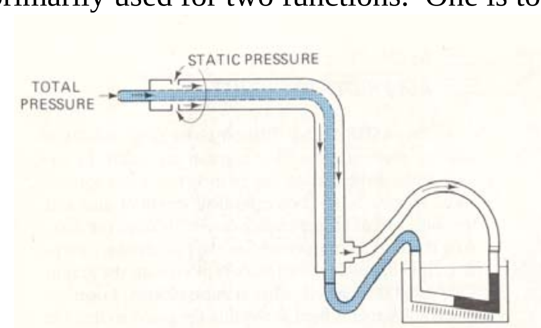


Fig 1-10 Pitot Tube

typically already own a digital micro manometer, the pitot tube would be the only additional required piece of equipment along with a simple calculator.

A pitot tube measures the velocity of airflow by having an open tube that faces into an air stream. Inside a pipe or duct with moving air there are two pressures. The pressure of the moving air and the static pressure. The pitot cancels out the static pressure component of the airflow by having holes on the side of the pitot tube that are connected with tubing to the reference side of the micro-monometer or magnehelic. If the pitot tube is faced into the airflow, the pressure instrument connected to it measures the velocity pressure in the pipe or duct. The velocity pressure is then converted into a feet per minute unit. Once the feet per minute airflow velocity is know, it is multiplied by the cross sectional square foot area of the pipe to give airflow in cfm or cubic feet per minute.

The speed or velocity of the air flowing through a duct is not uniform even though the cfm of air leaving a duct has to equal the air entering the duct. This is most pronounced after a bend in the duct. Imagine a car speeding down a highway towards a curve. Before the curve its easy to keep the car in a straight line. Half way through the curve and after it is where the trouble happens. The rule of thumb for making airflow measurements is they should be made at least two pipe diameters before an elbow or bend and at least ten pipe diameters after an elbow or bend. In other words at least 8 inches before the air enters a bend in the 4” duct and at least 40 inches after a bend in the same 4” duct. This is because the airflow must slow down on the inside of the bend and speed up on the outside of the bend. In addition to the distances from a bend there may be different airflows near the inside walls of a duct versus in the center. For this reason at least three locations should be sampled inside the duct and the variation averaged.

In order to determine cfm measure the velocity pressure first. The formulae for converting the velocity pressure to feet per minute is the following:

$$\sqrt{VP} \; * \; 4000 \; = \; \text{FPM}$$

Where VP = Velocity pressure measured with a pitot tube in inches of water
* is the symbol for multiplying
÷ is the symbol for dividing

Substitute the pitot tube measurement for VP in the above formulae by entering the velocity pressure on a calculator. Now find the square root function on the calculator $\sqrt{\;}$ and press it. Now multiple this number by 4000. The final product is the approximate velocity in feet per minute. Now determine the cross sectional area of the duct or pipe and convert it to square feet. If the duct is rectangular then just multiple the inch height by the inch width and then divide this by 144 to obtain the square foot area.

FPM * sq.ft. area of the duct = CFM

If the duct or pipe is round use the following formulae to determine the square foot area of a circle.

$$\text{Pi} \; * \; r^2 \; \div \; 144 \; = \text{Square foot Area of a circle}$$

where:

Pi = 3.142 (a constant)
r = radius (half the diameter of a circle)
r^2 = radius times radius
144 = used to convert square inches to square feet

In other words if a velocity pressure is measured to be 0.015 inches of water column with a pitot tube in a 4” pvc pipe then the cfm is determined by the following.

1) Determine fpm from vp: $\sqrt{0.015}$ * 4000 = 490 fpm

2) Calculate the area of the duct: 3.142 * (2 × 2) ÷ 144 = 0.087 sq. feet

3) fpm times area gives cfm: 490 fpm * 0.087 sf = 42.6 cfm

1.2.4 Developing a Negative Pressure Field

Development of a negative pressure field is critical to the success of any soil depressurization mitigation approach. The number and location of suction points required depends on four factors, permeability of the sub-slab space, amount of available airflow from slab leakage, the airflow from soil porosity, and the fan and piping capacity. One EPA study found a single suction point could depressurize a 100,000 square foot commercial slab. Obviously in the above case the slab and soil had minimal leakage while the sub-slab material was very porous. The following illustrations demonstrate the factors effecting the depressurization of a contained area.

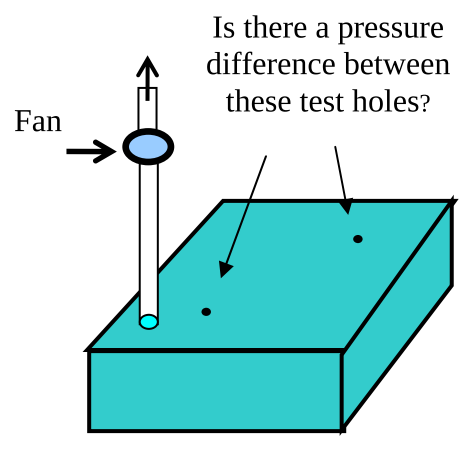


Fig 1-11 Vacuum on Empty Box Simulating very porous Sub-Soil with No leakage

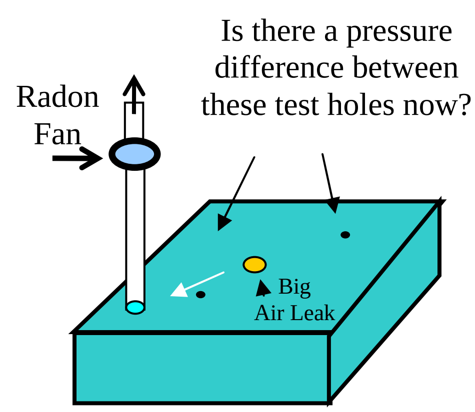


Fig 1-12 Box Simulating Sub-Slab with a large Air Leak

The best possible situation for creating a uniform negative pressure field is a tightly sealed box with nothing in it to resist airflow as shown in Fig 1-11. In this case, a fan pulling on one suction point anywhere in the box will result in a uniform pressure extending to all areas of the box. The pressure across all of the walls of the box will be the maximum that the fan can produce.

If a hole is opened in the box, as shown in Fig 1-12, the pressure in the box will be reduced because air is being supplied to the blower. The pressure field will no longer extend uniformly throughout the box because of the location of the air leak. In fact if the hole is large and near the suction point, there may be very little pressure field extension past the hole. If the large hole is closed and small air leaks are made at each corner of the box, a fairly uniform

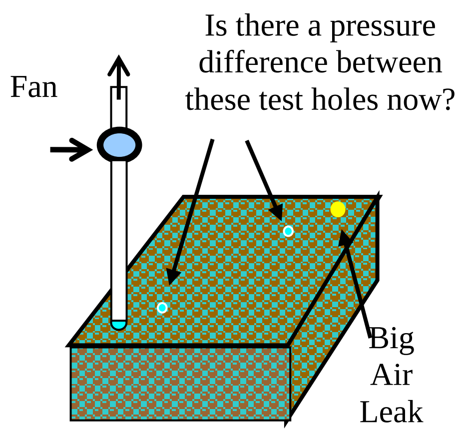


Fig 1-13 Box simulating pressure loss from porous soil with large leak

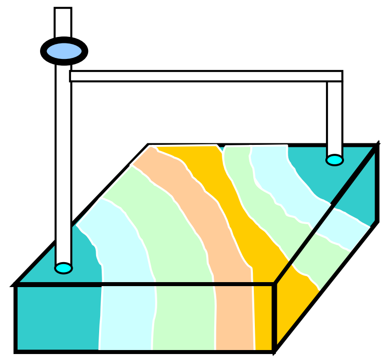


Fig 1-14 Box Simulating Sand Beneath Slab with Two Suction Points

pressure field will develop. The closing of this hole and its effect on increasing the strength of the pressure field at the far test holes is the same effect that sealing has on an ASD system.

If the box is next filled with porous soil and a hole made at the end corner furthest from the suction point, (see Fig 1-13) the pressure field will no longer be uniform because of the resistance to airflow caused by the soil. The negative pressure field (or suction) will be strongest near the suction point and weakest at the air leak in the corner. Thus, the strength of the pressure field at any given location depends on the pressure-flow characteristics of the blower, the airflow resistance of the box contents, and the size and location of any air leaks into the box.

If the box is filled with sand, (see Fig 1-14) the negative pressure field will be even stronger near the suction point and weaker near the air leaks. The pressure field distribution in this example can be improved most dramatically by adding more suction points rather than increasing the strength of the radon fan.

1.2.5 Fan Capacity and Design

There are a variety of commercially available fans designed for the radon industry. Which fan to select is based on one of these four questions.

(1) Is the pressure field extension easy to obtain?
In this case a low wattage fan will do the job, cost the least, save energy, and generally be the quietest.

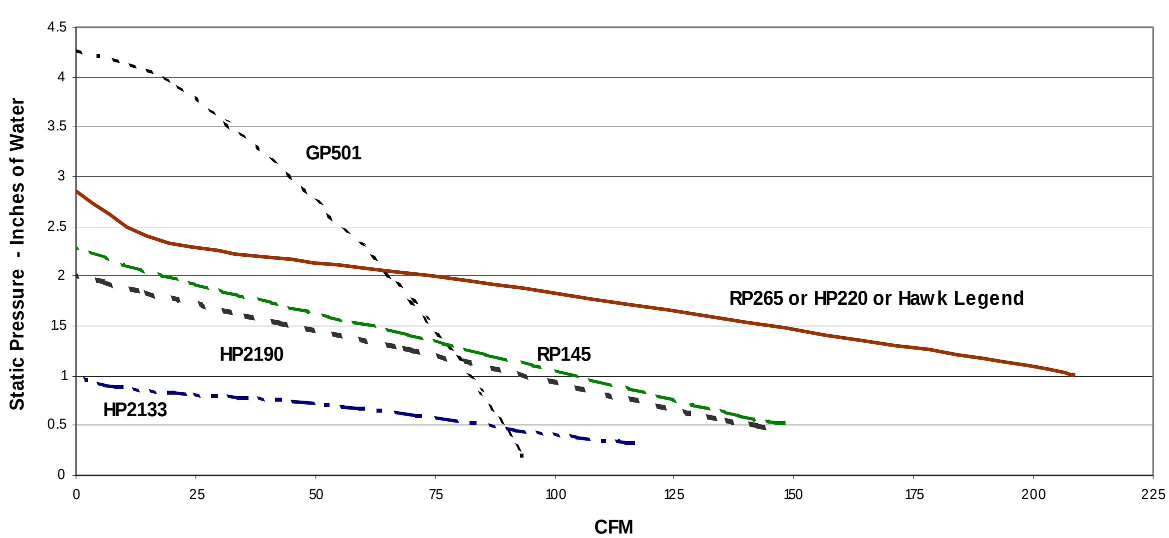
(2) Is the pressure field extension (PFE) questionable?
Then a mid-range fan that provides good airflow and vacuum would be the choice.

(3) Will the final system require maximum vacuum and have minimal airflow?
In this case a fan that provided maximum vacuum would obviously be required. Although low flow is not a fan requirement, in general, high vacuum radon fans have low airflow characteristics.

(4) Will the final system be a high flow situation?
This would require a radon fan that can move a lot of air at a reasonable static pressure load. To understand the dynamics involved, it is necessary to define some terms and concepts.

1.2.5.1 Fan Curves

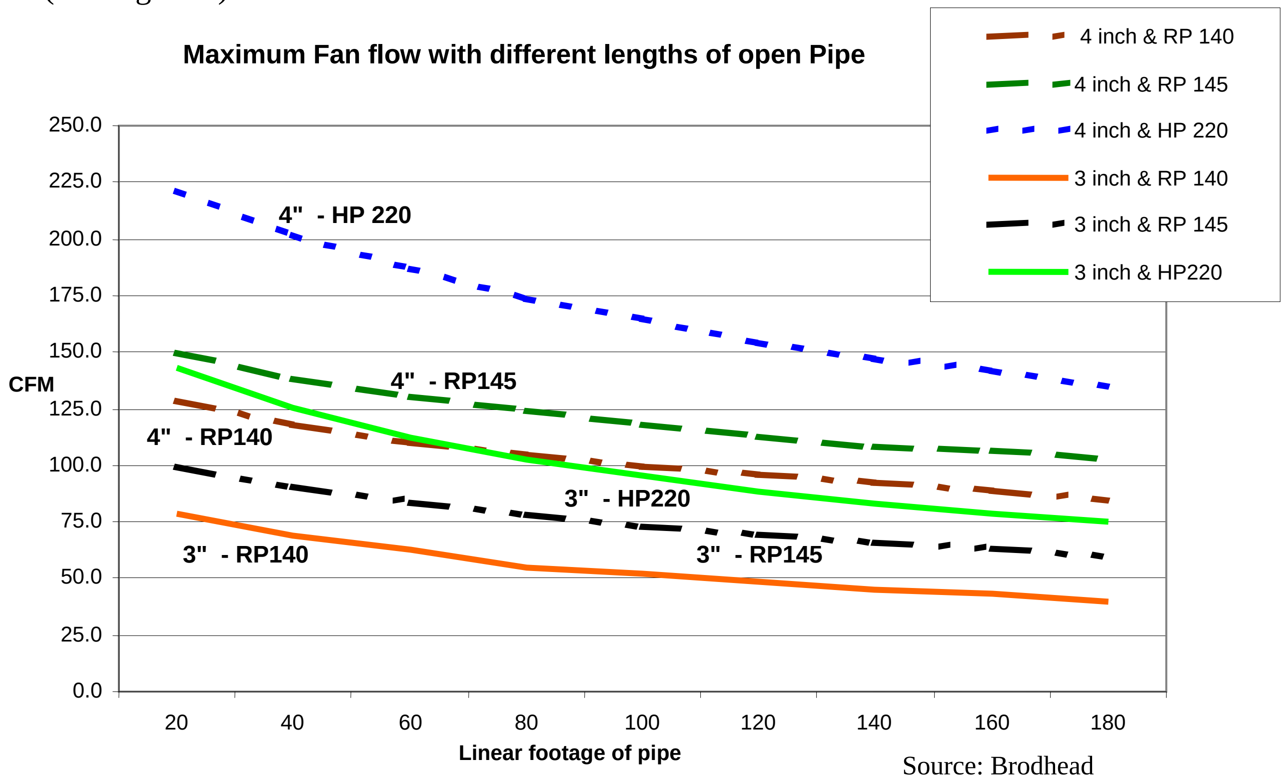
Fan curves are graphic representations of how much air a fan will move against changing resistances. Fig 1-15 demonstrates the performance curves of some typical radon fans connected to five feet of four inch piping at the inlet and outlet of the fan. This data was obtained by graphing the performance of each fan at different restrictions on the intake. The left column of the graph is static pressure, while the bottom line shows the volumetric air flow, typically expressed in cubic feet of air per minute (**CFM**). Static pressure can be given in a number of convertible units, but, for the purpose of this discussion, inches of water column (**in W.C.**) will be used. The fan curve on the left side shows the maximum attainable



Source: Brodhead

Fig 1-15. Performance curves for some typical radon fans

vacuum the fan can create if there is no airflow. The right side of the curve indicates the maximum airflow output if there is only the restriction of ten feet of open 4 inch pipe on the fan's output. Fan curves express the relationship between pressure and air flow. Note how each fan has increased suction as air flow decreases, as defined by its performance curve. For example, when available air flow decreases, as in the case of a sub-slab suction system on a tightly compacted soil, the u-tube connected to the system will show increasing static pressure. Conversely, when the available air increases as it would if the sub-slab was large aggregate and there were large unsealed cracks through the slab, the air flow of the fan would be high, but the suction pressure would less, and the u-tube would be showing a relatively small amount of static pressure. The rate of decrease, however, depends on the fan design. (See Fig 1-15)



Source: Brodhead

Consider two identically sized slabs, one built on tight soil and the other on loose soil. To develop a complete negative pressure field beneath both slabs, the fan servicing the tight soil slab (which would provide limited airflow) would not require a high airflow fan but, because of the higher resistance of the soil to air flow, would require a strong suction capability. The GP501 in Fig 1-15 would be a good choice in this case. In contrast, the fan drawing on the loose soil with unsealed leaks (which would have a lot of free air available and less resistance to flow) needs the characteristics of high airflow fan. The HP220 or the RP265 fan in Fig 1-15 would be a good choice for this case.

If the low flow, high vacuum fan were incorrectly installed on the loose soil, then the sub-slab near to the suction hole would be able to supply the fan all of the airflow it could handle. The other portions of the sub-slab would have no air being removed and thus no change to the radon entry. Similarly, if a high flow fan that had a limited (low) vacuum capacity were incorrectly installed on the tight soil, the resistance to flow would be greater than the vacuum capability of the fan, limiting the negative pressure field extension (PFE). Obviously, it is essential to select a fan suited to the conditions under which it has to operate.

It is also important to note that any fans ability to create a PFE under a slab will be greatly influence by the amount of leakage into the sub-slab through the slab and from the soil itself. Caulking and sealing entry points (such as floor-wall joints, large floor cracks, open sumps, and floor drains) can increase the pressure difference between the sub-slab and the room by a factor of ten. A sixteenth of an inch crack around the perimeter of a 30 foot by 40 foot basement equals the opening of a hole 105 square inches, or 10 inches by 10 inches.

1.2.5.2 Fan Electrical Usage

The table below shows the operating cost of different radon fans. As the airflow through a fan decreases (large difference in the u-tube) its power consumption also decreases. The mid wattage is used in determining the yearly and the ten year operating cost of the fan. The difference between the low wattage fan and the high wattage fans is quite significant. The high wattage fans will actually cost more to operate over ten years than the typical initial radon installation cost. It should be noted that this example only deals with the energy penalty associated with the electrical operation of the fan. In one small study as much as half of the air handled by an ASD came from inside the home.[4] When interior house air is drawn through unsealed openings in the home to the ASD system, conditioned air is lost. Sealing of these openings can reduce this potential increase in house operating costs as well as improve radon reduction. An even larger savings can be had from sealing if it allows use of a low wattage radon fan.

It is also important to note that a large amount of interior air drawn into an ASD system could backdraft a combustion appliance and cause a significant health hazard to the occupants.

Electrical Operating Cost = (Hours) * (Wattage) ÷ (1000) * (Kilo-watt per hour rate)

Fans	Wattage range	Maximum vacuum & cfm	Kilowatt Hr/rate	Average yearly cost	10 Yr cost with 3% inflation
HP2133 RP140	14-20	0.8” 100 cfm	$ 0.12	$ 17.87	$ 210.94
RP145	37-71	2.1” 150 cfm	$ 0.12	$ 56.77	$ 670.11
RP265 HP220	86-140	2.7” 210 cfm	$ 0.12	$ 118.78	$ 1402.16
GP501	70-140	4.2” 90 cfm	$ 0.12	$ 110.38	$ 1303.00

Table 1-1 Typical radon fan electrical consumption

In the table below are listed a series of extreme suction fans manufactured by one radon company that can induce vacuums of 15” to 35” while moving 25 to 40 cfm.
These fans cost over $800 apiece.

Model	Wattage.	Yearly Operating cost	Maximum Vacuum & cfm	Mid-range Performance
HS2000	150-270	$ 220.75	18” - 110 cfm	10” @ 72 cfm
HS3000	105-195	$ 157.68	27” - 40 cfm	15” @ 30 cfm
HS5000	180-320	$ 262.80	50” - 53 cfm	20” @ 38 cfm

Table 1-2. Performance Characteristics of specialized High Suction Fans applicable to High Vacuum and Low Air Flow requirements

1.2.5.3 Fan noise

Fans and fan systems should be designed and installed for minimal noise transmission into living spaces. There are probably more homeowner complaints about system noise than any other aspect of ASD systems.

In-line style fans are typically used on ASD systems. The fan is attached to the system piping with rubber couplings which allows easy fan removal for maintenance. Although some mitigators refer to these boots as vibration isolators in fact these couplings are made out of hard rubber and tend to transmit fan vibration. Fan mounting brackets installed outside can transmit their vibration through the exterior wall to the interior drywall surface. The occupants may complain about this noise transfer if it happens in a location that is frequently occupied like a bedroom or sitting room. Sometimes switching the fan to a lower wattage or better balanced fan may remedy the situation. A softer material like closed cell backer rod can sometimes be used between the pipe mounting bracket and the building to minimize noise transfer.

Fans routed through attics can also transmit vibration if the fan piping is allowed to directly touch the framing. At strapping locations close to the fan, place backer rod between the framing and the piping to minimize vibration transfer.

Some of the system noise may be due to the airflow through the pipe or where it exists the piping. System noise transfer is especially apparent if the piping is within easy eyesight. If the pipe is routed through a closet to the attic it can be encased in oversized flexible duct insulation to reduce airflow noise.

1.2.5.4 Positive Pressure Side Leaks

The ASD system extracts the air from beneath the slab where the radon is highly concentrated. Any leakage which occurs from the fan housing or the piping system can be assumed to be a potential health hazard if it occurs at a location inside the living space of the house. The EPA Radon Mitigation Standards and ASTM standards require that ASD fans not be located within or below the living space of the house. This means that the fan can only be:

Outside,

In an Attic

In a garage if there is no living space above the garage.

1.2.5.5 Methane

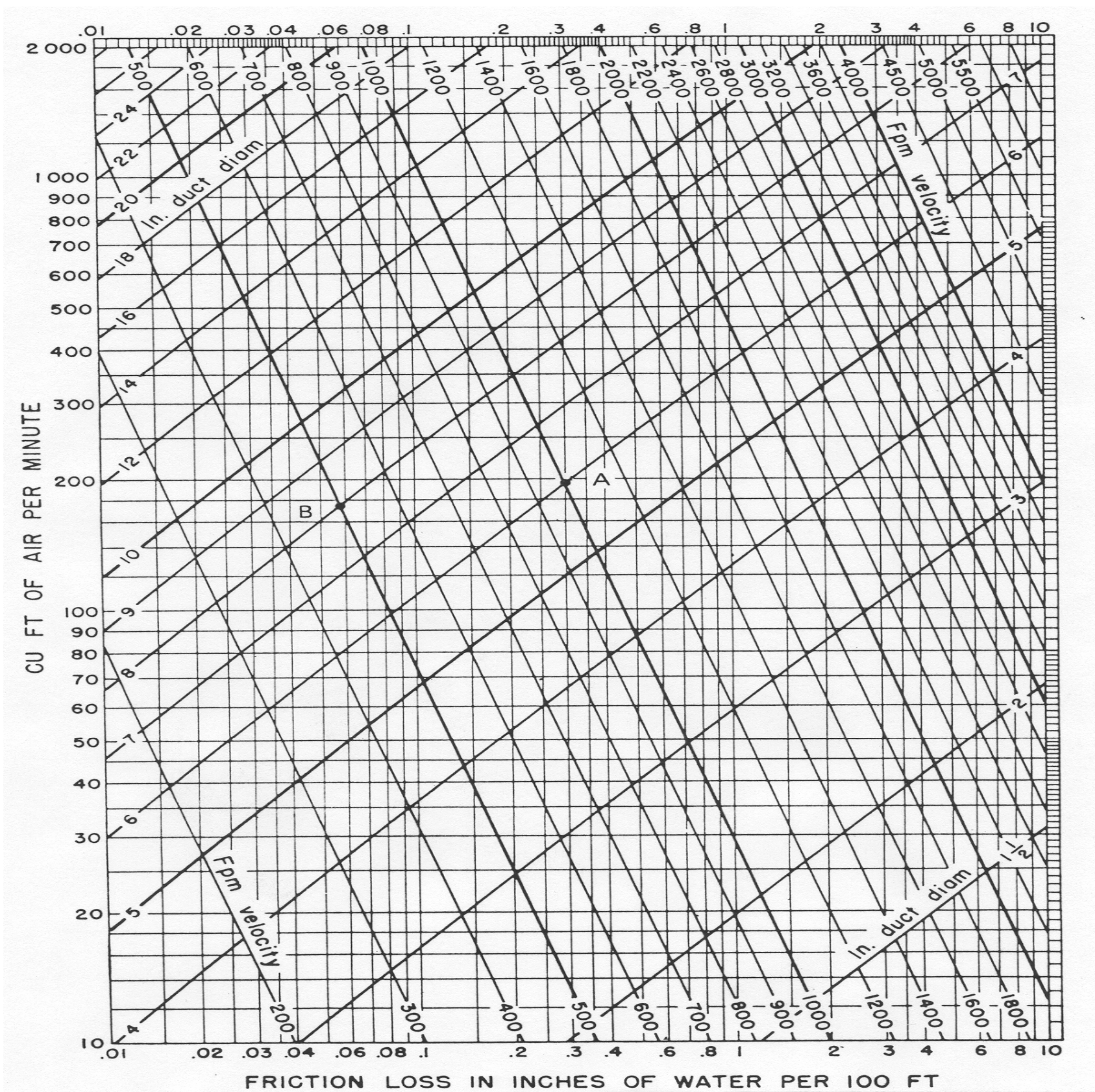
An ASD system removes not only radon gas but also other soil gases, such as methane. In some instances, this removal process can present particular operational and safety concerns. Methane comes from the decomposition of organic material in the soil. The organic material can be from natural origins, but is generally of most concern where structures have been constructed above old landfills. Methane is a highly flammable gas. An active sub-slab system could end up exhausting a concentrated methane-air stream that approaches or even exceeds the lower explosive limit in areas where appreciable amounts exist in the soil. Blowers typically used in the radon industry are not designed for this type of service. An electrical arc from the motor or a static spark inside the piping system could ignite the methane-air stream. Mitigators should consider using an explosion proof fan when installing systems in areas close to old landfills or known methane concentrations exist in the soil.

1.2.6 Pressure Loss in Pipes and Fittings

Apart from the fan selection and installation, there are several aspects of the installation of the piping system that can seriously affect the overall system performance, including pipe size, fitting design, number of fittings, length of piping, suction pit size, and system airflow requirements.

The effect of soil porosity on air flow resistance was discussed earlier in this chapter. A similar resistance to air flow is also presented by the system piping itself, which, if not sized properly, can significantly reduce the system's effectiveness. The following chart show in Fig 1-16 quantifies the friction loss in round piping depending upon pipe size and airflow rate. Note that the friction loss is given in inches of water along the bottom row of the chart for each 100 feet of pipe. The diameter of the round duct is given in the diagonal lines that start low on the left and rise up the right side. The airflow through the duct is given on the left side of the chart in cfm. The chart also includes the feet per minute velocity of the air with the diagonal lines that start high on the left and angle down to the right.

Assume the velocity pressure of 0.030 inches of water in a four inch pvc pipe has just been determined. Using the previous formulae the airflow is 60 cfm. Now find 60 cfm on the left side of the chart in Fig 1-16. Run a pencil line to the right from the 60 until it crosses the 4" pipe diameter diagonal line. Where these two lines intersect run a pencil line straight down and read the bottom number. It reads a friction loss of 0.25 inches of water for every 100 feet of pipe. If the total quantity of 4" pipe equaled 50 feet then half the friction loss listed from the table is used. If the total footage of pipe equaled 200 feet then twice the friction loss or 0.50 inches of water column is used. Keep in mind that the total length of pipe must also include the equivalent pipe footage of all piping elbows. Each style of elbow or transition has a friction loss in an equivalent footage of pipe. See Table 1-4. In a study of 87 ASD systems installed in NJ, (see Fig 1-17) the average airflow out of the vent stacks was 65 CFM. Note that in Fig 1-16 the velocity friction loss of three inch pipe is four times greater than four inch pipe for the same cfm. Most radon systems have at least 100 equivalent feet of pipe when the fittings and open pipe are taken into consideration. See Fig 1-18. If we consider the maximum acceptable pressure loss to be around one inch of static pressure, a three inch pipe would have a maximum airflow of 60 cfm versus twice that amount or 120 cfm for a four inch pipe with the same pressure loss.



Source: ASHRAE Fundamentals

Fig 1-16. Pressure Loss Due to Friction in Ductwork

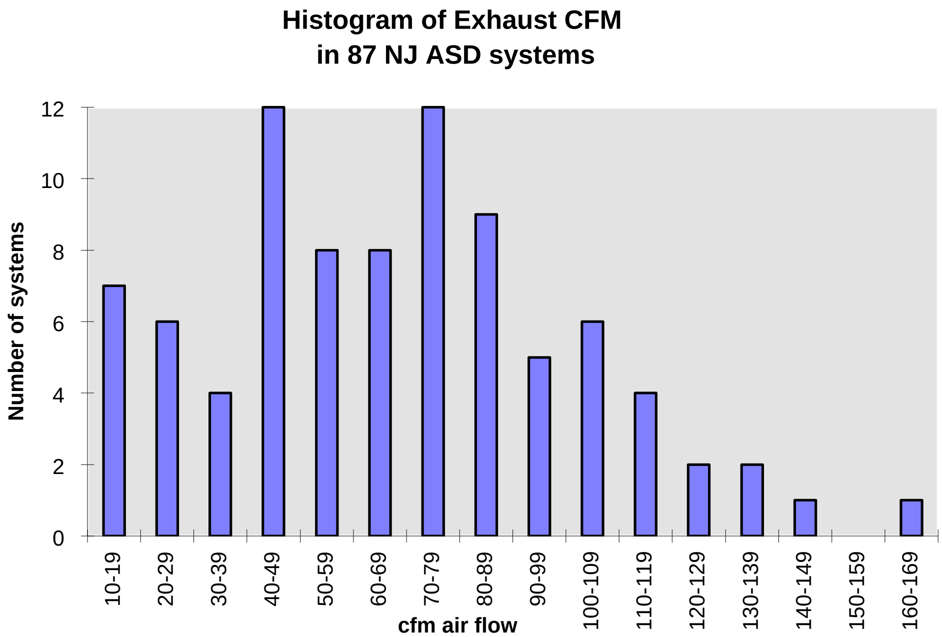


Fig 1-17 cfm exhaust of 87 ASD systems in NJ

One might question how often 100 feet of pipe is actually used in a residential situation. It is important to remember that the chart in Fig 1-16 is referring to equivalent length of pipe, which is the sum of the actual pipe length plus the resistance of the elbows and other fittings expressed in equivalent pipe length. This has to be calculated for each size and type of fitting. Friction loss in equivalent feet is given in the following table. Note that some fittings have two types, sweep and sharp. A sweep is a fitting that has a sloping turn. A sharp is a fitting that has a sharp or right angle turn. Note that two sharp 45-degree elbows have a greater pressure drop than one 90-degree sweep elbow.

Pipe Size	Sweep 90°	Sharp 90°	Sharp 45°	Straight Tee	Open Pipe
2”	1.9’				
3”	3.8’		6.1’	17.9’	17.4’
4”	7.0’	16.4’	5.5’	22.0’	20.4’

Source: Brodhead

Table 1-3. Fitting friction loss in equivalent feet of piping

In Fig 1-18 below, a standard radon system is depicted with one suction hole. A typical amount of fittings and pipe footage is being used. The final system vacuum in the suction hole is given if the system was routed with three or four inch piping with different system airflows. If the airflow is less than 40 cfm, there is no significant difference between using 3” and 4” pvc piping. If the airflow is 60 cfm then the 4 inch pvc system is able to generate more than twice the vacuum in the suction pit as the three inch system using the same fan.

The piping cost difference in 2001 dollars between using 3 inch or four inch schedule 20 versus schedule 40 pipe is also given.

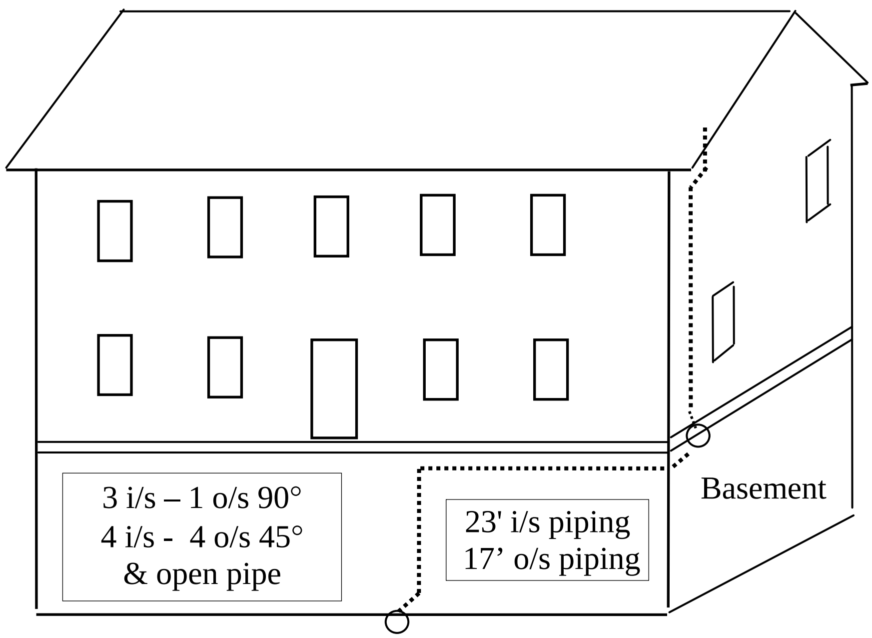


Fig 4-18 An example of a typical radon system piping

Fittings	3" pvc	4" pvc
4 - 90°	15	28
8 - 45°	49	44
40' pipe	40	40
opening	17	22
Total ft	121	134

Table 1-4 Equivalent Pipe Footage

RP 145	Static Pressure	1.85"	1.70"	1.50"	1.25"	1.00"
Piping size	Sch20 vs sch 40 $	20 cfm	40 cfm	60 cfm	80 cfm	100 cfm
4" pvc	$ 36 vs $ 100	1.7"	1.6"	1.25"	0.8"	0.2"
3" pvc	$ 31 vs $ 68	1.63"	1.2	0.5"	-	-

Table 1-5 Piping Cost & Performance Comparison

2.0 BUILDING INVESTIGATION

INTRODUCTION to BUILDING INVESTIGATION

The following requirements of the Radon Mitigation Standards clearly show the importance of doing a building investigation before any radon work is begun. It is risky giving estimates over the phone without making a visual inspection of the building. Even if an estimate is given over the phone, a certified person must still be at the job site deciding on the system design prior to initiating the work. This chapter reviews all the considerations and tests that can be done to determine the best mitigation system for all the existing conditions.

RMS 10.1 In the initial contact with a client, the contractor shall review any available results from previous radon tests to assist in developing an appropriate mitigation strategy.

RMS 11.1 The Contractor shall conduct a thorough visual inspection prior to initiating any radon mitigation work. The inspection is intended to identify any specific building characteristics and configurations (e.g., large cracks in the slabs, exposed earth in crawl spaces, open stairways to basements) and operational conditions (e.g. continuously running HVAC systems or operational windows) that may affect the design, installation, and effectiveness of radon mitigation systems. As part of this inspection, clients should be asked to provide any available information on the building (e.g. construction specifications, pictures, drawings, etc.) that might be of value in determining the radon mitigation strategy.

RMS 11.2 To facilitate selection of the most effective radon control system and to avoid the cost of installing systems that subsequently prove to be ineffective, it is recommended that the contractor conduct diagnostic tests to assist in identifying and verifying suspected radon sources and entry points. Radon grab sampling, continuous radon monitoring, and use of chemical smoke sticks are examples of the type of diagnostic testing commonly used.

RMS 11.5 As part of the building investigation a floor-plan sketch shall be developed (if not already in existence and readily available) that includes illustrations of the building foundation (slab-on-grade, basement or crawlspace area.) The sketch should include the location of load-bearing walls, drain fixtures and HVAC systems. It should be annotated to include suspected or confirmed radon entry points, results of any diagnostic testing, the anticipated layout of any radon mitigation system piping, and anticipated locations of any vent fan and system warning devices for the envisioned mitigation systems. The sketch shall be finalized during installation and shall be included in the documentation.

2.1 Walk Through Diagnostics

Giving an estimate based solely on information obtained over the phone is always risky. Many owners have no idea what types of foundations the building has and important details are often left out. It is always preferable to see the building before any estimates are given. Even if the homeowner agreed to have the work done based on a phone estimate, a certified mitigator would still need to be at the job site before work could proceed. Customers are also more likely to schedule the work with someone who has taken the time to pre-visit the building.

Once at the home, important information can be gathered quickly. Most mitigators complete their estimates without doing communication testing or obtaining additional radon measurements. There are situations, however, when the extra time and expense to do diagnostics is crucial to a successful system installation. This is especially the case for commercial or large buildings.

During the site visit, previous radon measurements results need to be reviewed. Placement location of the detectors and time of year they were exposed can sometimes reveal patterns. If appropriate, the homeowner should also be asked if he was present during the construction of the house and if so, does he have any recollection of a stone base being laid under the concrete slab. Homeowners who witnessed the construction of their home will also often have construction photo's that can be useful in determining how the foundation was constructed and if there is any aggregate under the slabs. The homeowner may also have building blue prints even if he was not the first building owner. The blue prints might specify how much stone was supposed to be under the slabs and how the foundation was laid out.

A drawing or sketch of the lowest level is a final system requirement and a helpful asset during and after the investigation. It is best to draw the foundation as close to its actual shape as can be easily done. Leave room on the drawing for any adjoining slabs such as the garage, front entrance or rear patio. Any adjoining slabs around the basement or lower level can allow trapped soil gas to flow into the building. Discrepancies between the drawing of the lower level and shape of the upper level can often define crawl spaces or slabs that even the homeowner was not familiar with.

The drawing should show the utilities including furnaces, boilers, bathrooms, plumbing drops, sump pits, floor drains, etc. It is also helpful to include other building features to make it easier to remember this particular drawing from the many others one is bound to complete. Often jobs aren't scheduled until months latter and the extra detail helps the memory put the building back in perspective.

The drawing or a separate list should mention problem or non-problem site conditions. Problem conditions would include dirt floor crawl spaces, drains open to the soil, slabs that are flush with the top of the wood floor, return ducts in a slab, unbalanced HVAC air handlers or even air handlers with no return ducts. Non-problem items might include floor drains with a filled water trap, poured foundation garage slab set two steps down, solid sump pits used only for gray water.

After the house drawing has been created, the fan location needs to be determined. There are often several choices where the fan could be located. The fan has to be either outside, in the house attic or in the garage attic. The exhaust has to be routed above the roof eave. The possible fan and exhaust locations define where the first lower level suction holes might be placed. Sometimes it's a choice between the most convenient location and one optimized for good PFE. Once this location is determined, additional suction holes can be located as needed for the design and final system performance. If the building has multiple foundations that need to be treated then the routing of the pipe to these locations often defines the next sub-slab suction location. A suction hole is sometimes located where a needed pipe run creates a low spot so that trapped water can be drained. The final system could be designed in stages depending upon the results of post mitigation testing. In general this is not considered a preferable practice since the untreated areas could create elevated radon levels during different seasons. It is a better practice to treat all crawl spaces and slabs with living space above them. Additional suction holes may however be included in the design in the event that sub-slab conditions or leakage requires additional piping.

2.2 Multi-Location Testing

Many buildings, even if they have been tested more than once, have only been tested in one location. Testing in multiple locations can define which areas of a building need to be treated. The results from multiple test locations do not, however, automatically define radon sources or the areas to be treated. This is because radon easily diffuses from one area to another or is easily moved and mixed if the building has an operating air handler. Multiple measurements can be made using expensive grab sampling or radon sniffing equipment to obtain on site results or by placing multiple passive detectors and retrieving them a few days latter. If traditional grab samples are taken than differences as small as 10% between locations can be seen. Traditional scintillation cell grab sample results can't be obtained in less than three hours. Some continuous radon monitors that use pumps can be set for sniff mode function. This allows significant radon sources to be seen after sampling a location for two to ten minutes. The accuracy of the CRM is reduced because of the short sampling period but radon levels that vary by 50% or greater can typically be seen. Sniffer measurements have the benefit of being able to use each measurement to decide if more or less sampling needs to be done. Because radon entry is predominately caused by pressure differentials, the least amount of radon entry may be happening at the sampling period when the stack effect may be weakest. For this reason windows and exterior doors need to be closed and any equipment that might increase the lower level negative pressure such as an air handler should be left running.

Passive detectors can be used for source identification. They have the advantage of being available for all mitigators to use. Passive detectors should be able to see differences as small as 20%. If duplicates are used at each location, a 10% difference can be seen. Passive detectors have the additional advantage of averaging each locations concentration over the exposure period. Radon sniffers and grab samples will only give the result of the radon levels at the sampling time.

It is necessary to both carefully choose the test locations and carefully evaluate the results. Radon sniffers can be moved from location to location to determine radon levels but keep in mind that most active detectors will build-up a background count. Measurements should always start with locations that would be expected to have low concentrations and then followed with locations of expected increasing concentrations. When using a radon sniffer, the instrument background needs to be obtained first. The room concentration then needs to be roughly determined. Now source locations can be sniffed. Radon level differences of 50% or greater within a room would indicate a possible source. Sampling within a confined space such as inside a block wall will typically always have radon levels higher than the adjoining room. A significant source inside the block wall would need to be two or three times higher than the room levels. Radon measurements under the slab could be very deceptive. The highest sub-slab radon levels may be because the location has the least radon entering the building. In other words, the center of a slab with only cracks around the perimeter would tend to have the highest sub-slab readings. If the leakage is equal, then sub-slab readings may indicate a higher source but even this may not rule out that the lower sub-slab radon concentration areas aren't also a problem.

Initial diagnostic sniffer measurements usually do not provide enough information to define which areas should or should not be treated because of all the compounding factors. Considering this and all the time it takes to make radon sniffer measurements, it is typically better to treat all slabs and crawl spaces with living spaces above them as mentioned previously. Sniffer measurements or multiple passive detectors are, however very useful if the initial mitigation treatment is not successful in reducing the radon levels below the guideline. Once a radon system is treating the obvious radon sources it is easier to use sniffer measurements to locate other sources that need to be treated.

2.3 Communication Testing

RMS 11.4 If installation of a sub-slab de-pressurization system is contemplated and the characteristics of the sub-slab material are unknown, a communication test is recommended.

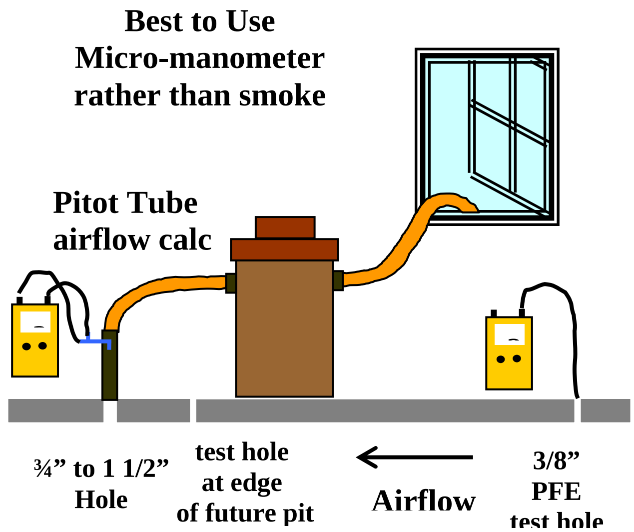


Fig 1-19 Sub-Slab Communication Test

Sub-slab communication testing is a method that tries to emulate a finished sub-slab depressurization system in order to determine the number of suction holes that may be needed and the performance requirements of the radon fan and piping to be used. It is accomplished by first picking out locations that would be practical spots for sub-slab suction piping. A 0.75 to 1.5 inch hole is then drilled through the concrete floor with a rotary hammer drill. The risk of damaging sub-slab utility piping needs to be considered before doing any slab drilling. Minimize the risk of hitting sub-slab utilities by studying all building mechanical plans, logical try to deduce where utilities might be located from visible slab utility penetrations, consult with anyone who might have knowledge of utility pipe locations, and use metal sensing equipment such as floor/wall metal scanners or grounding relay boxes.

A standard shop vacuum is used to draw air out of this small suction hole. At varying distances from the shop vacuum suction hole, drill smaller test holes, typically 3/8" in size. A digital micro-monometer or magnehelic is used to measure the pressure change between the sub-slab and the room with the vacuum off and then on. A digital micro-monometer that measures changes as small as 0.001 inch of water column or even down to 0.1 pascals (one pascal is equal to 0.004 inches of water column) is best. Any change in building or soil pressure other than the shop vacuum can make interpreting the results difficult or impossible. Building pressure changes can be easily induced by air handler operation or the more common problem of outdoor wind. Wind pressurizing or depressurizing the soil can be especially problematic if the building is on a slope. Wind induced building pressures are related to the size and location of openings into the building.

Maximum Communication Test Airflow

Suction Hole Size 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
!0.0 Amp 5.5 HP Craftsman	63 CFM	87 CFM	113 CFM	117 CFM
12.0 Amp 6.5 HP Ridgid	70 CFM	102 CFM	140 CFM	154 CFM

When the pressure difference across the slab is measured before the vacuum is started, it is often indicating a sub-slab positive reading. This is an indication of the buildings negative condition in relationship to the soil and the tightness of the slab. The tighter the slab, the closer the slab differential will be to the differential across the building shell. If the slab has lots of openings there may be little if any pressure difference across the slab before the vacuum is turned on. A communication test does not need to indicate a pressure reversal to indicate sub-slab communication but rather any change in pressure induced by the vacuum. This is why a pressure instrument needs to be used rather than a flow tracer like smoke. An instruments main benefit over a flow tracer is its ability to measure the actual pressure changes.

A communication test in addition to determining how far pressure field extension can be measured from the suction hole can also be used to determine the appropriate radon fan and system pipe sizing. A shop vacuum produces static pressure from 60 to 80 inches of water column at zero flow compared to radon fans with a maximum suction of 1.5 to 4.0 inches of water column. If there is no resistance to air flow below the slab, a shop vacuum can move from 50 to 150 cfm through a 1" to 1.5" hole through the slab. To better determine what sub-slab pressure the vacuum is creating in the soil, a measurement of the differential pressure across the slab is made 12 to 18 inches from the suction hole. This is approximately the size of the final suction pit excavation and the suction performance of the shop vacuum at that airflow. The airflow measurement is determined by placing an 18" length of two inch pvc pipe between the suction hole and the vacuum hose. A pitot tube measurement inside the upper half of the two inch pipe with a micro-monometer or magnehelic is used to determine the air flow out of the suction hole. If pressure differential readings at the close test hole are made at different airflows you can obtain a graph of the resistance of the sub-slab and then compare this to different fan curves to determine how the final system will perform. The pressure drop of the radon piping at the airflows being considered has to be included by subtracting this pressure from the fan performance.

In many cases the communication test is used to simply determine if PFE extension can or cannot be obtained. The unknown factor is how much will the pressure field extension improve when all visible slab leaks are sealed. It is a hopeful sign if any measurable pressure change takes place. The pressure change may happen with no reversal of pressure taking place. A communication test result of negative one pascal or greater would indicate a high degree of confidence that the final system would have good PFE. Sealing would of course improve the result while multiple foundations to treat would reduce the performance. Because of the sealing, the complete excavation of the suction hole and possibly multiple suction holes into the slab, the final PFE readings will typically be stronger than the original communication test results.

2.4 Number and Location of Suction Points

In many cases the pressure field can be extended under an entire large slab from one suction location even though there is no gravel or perforated drainage pipes under the slab. This happens because of a tight slab and either porous soil or settling that has taken place under the slab, next to footers or around sub-slab plumbing pipes. In contrast, slabs poured on solid bedrock, or over tight compacted soils or fine backfill materials like sand or screenings are significant barriers to extending a negative pressure field. In some cases the sub-slab has porous material but it has been divided into zones by footers or foundations.

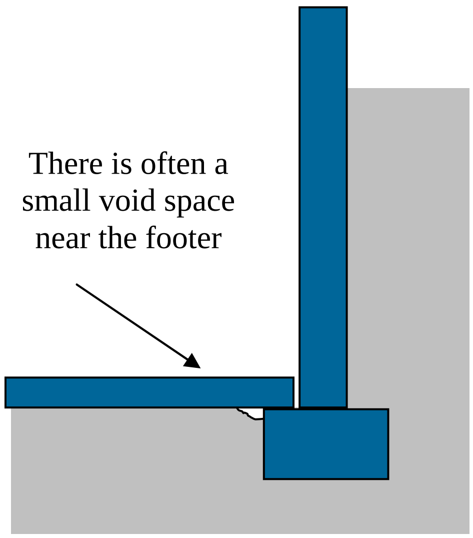


Fig 2-2 Void Space along formed Footings

The number of suction points necessary to fully extend a negative pressure field beneath a slab depends on:

Type of fill beneath the slab,

Compaction and consistency of the soil beneath the sub-slab,

Sub-slab zones created from footers dividing the sub-slab area,

Adequate excavation of the suction hole,

Location and size of leakage through the slab,

Performance of the radon fan and piping,

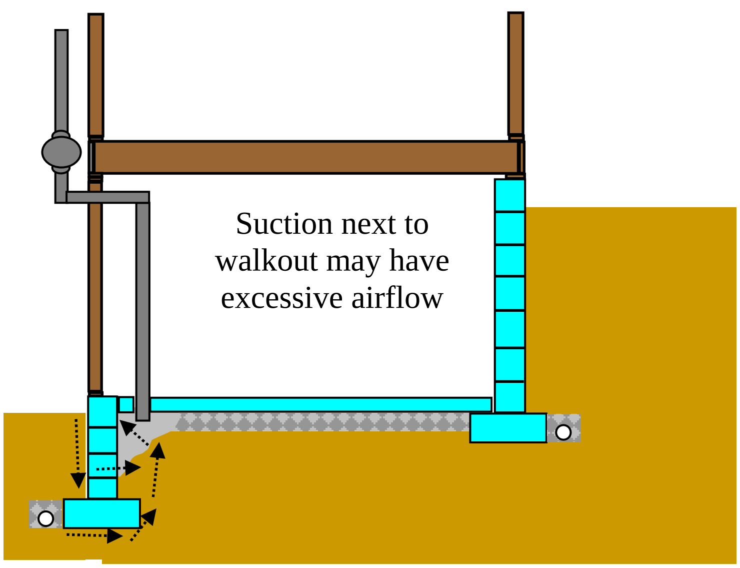


Fig 2-3 Potential Impact of Shallow Footings on Perimeter Suction Point

Choosing the best location for a suction point is dependent upon where the greatest pressure field extension can be achieved, where radon piping would be acceptable to the homeowners and where piping can be route to the radon fan.

If there is good porosity under the slab, the center of the slab is probable the best location for a single suction point. In practice, however, if there is good sub-slab porosity than often any location is adequate as long as there is not too much leakage into the sub-slab. Usually a perimeter suction location is easier to route the piping to the fan and more pleasing to the homeowner. If there is no sub-slab aggregate then a perimeter suction location is usually also preferred to a center location at least in areas where the footer is at least 18 inches below outside grade. There are often void spaces around the edge of the footer especially if the footer was formed rather than poured into a dug trench. (See Fig 2-2) Formed footers are usually hand backfilled after the forms are removed which creates void spaces when the backfill settles. Footers that are poured in trenches tend to have little if any settling along their very rough sidewalls. If a sub-slab void space is cleaned out during the suction hole excavation, it can provide excellent pressure field extension throughout the entire slab area. In addition, reversing the pressure gradient is generally most important at the floor wall joint because this is often a major radon entry point. A perimeter pipe location often makes routing and concealment of the piping easier than a suction point located in the center of a room.

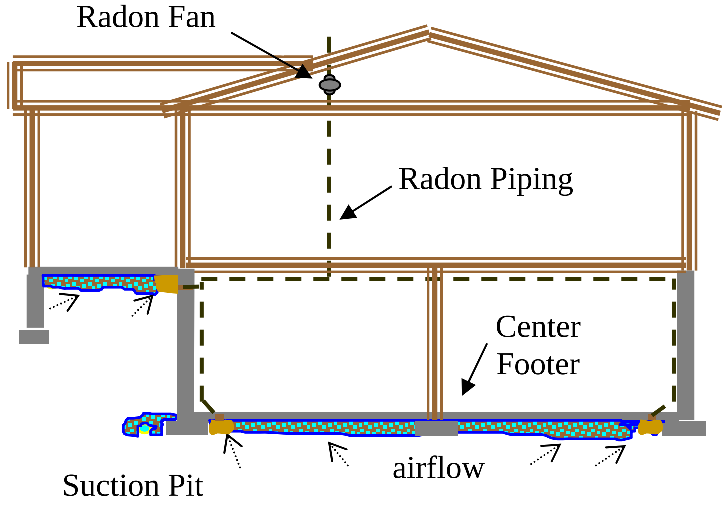


Fig 2-3 Creating a Negative Pressure Field on Either Side of a Footing or Grade Beam

In parts of the country where building foundations are not as deep, such as the Southwest and Southeast, it may be detrimental to locate a suction point next to an exterior wall in a slab-on-grade or walk out basements. (see Fig 2-2) Depending on the compaction of the surrounding soil, the pressure field extension could be defeated because too much air is being pulled from the outside, rather than from beneath the slab. A suction point in the deeper section of the basement would generally be preferred unless the sub-slab had limited PFE, in which case the walk out side might be chosen because of likely void spaces from backfill that had settled.

Fig 2-4 Suction Point Near Sub-Slab Plumbing

Continuous footings or grade beams running beneath a center portion of the slab can disrupt a pressure field extension. (see Fig 2-3) To obtain negative pressures under all parts of the slab, it may be necessary to place suction points on both sides of an interior footing. It is a good practice to pre-test the pressure field extension after a

suction point has been excavated by placing a temporary radon fan in the suction hole and then measuring the PFE in test holes, using a micro-monometer. Be sure the area is well ventilated during and after this test to reduce accumulated radon from running the radon fan inside the dwelling. Keep in mind that the final pressure differential reading will be less because of the piping pressure loss, other suction holes in the system and closed house conditions.
One way to reduce the need for multiple suction points if there is no sub-slab aggregate is to locate the suction hole near under-slab plumbing (see Fig 2-4). Be careful to avoid damaging plumbing pipes when drilling. Since the trench for the utility line is generally not well compacted, a vacuum applied near sub-slab utilities may extend along and out from the trench. This trench may also run under grade beams or bearing wall foundations and allow the pressure field to extend past these barriers.

Split-level homes or houses that have multiple foundations will generally need sub-slab depressurization applied to all levels. Often the adjoining slabs can be treated from the lowest level (basement). See Fig 2-5. In residential construction, the backfill installed under these adjoining slabs is often not compacted. Even though there may be no aggregate under these adjoining slabs, the void spaces created by the settling allow easy pressure field extension. One radon fan can typically treat multiple suction holes and slabs if leakage is minimized. Sometimes it's necessary in multi-suction hole systems to reduce the airflow from high flow suction holes to balance out the system performance. This may especially be the case if the high flow suction hole is located near the fan.

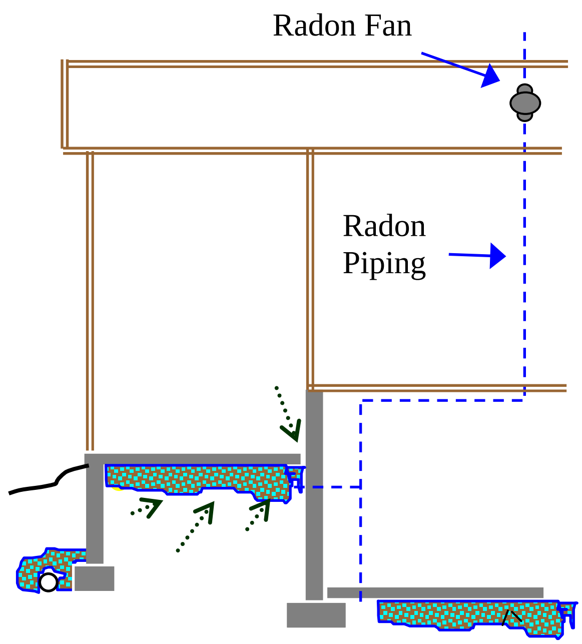


Fig 2-5 Multiple suction points connected to a single radon fan

3.0 ACTIVE SOIL DEPRESSURIZATION (ASD) INSTALLATION

INTRODUCTION to ASD INSTALLATION

RMS 13.3 All radon mitigation systems shall be designed to maximize radon reduction, while minimizing excess energy usage, avoiding compromise of moisture and temperature controls and other comfort features, and minimizing noise.

RMS 13.4 All radon mitigation systems and their components shall be designed to comply with the laws, ordinances, codes, and regulations of relevant jurisdictional authorities, including applicable mechanical, electrical, building, plumbing, energy, and fire prevention codes.

RMS 14.1.1 All components of radon mitigation systems installed in compliance with provisions of the RMS shall also be in compliance with the applicable mechanical, electrical, building, plumbing, energy and fire prevention codes, standards, and regulations of the local jurisdiction.

RMS 14.1.2 The contractor shall obtain all required licenses and permits, and display them in the work areas as required by local ordinances.

3.1 SUB-SLAB DEPRESSURIZATION INSTALLATION

3.1.1 Suction Pit Installation

3.1.1.1 Cutting through the Slab

The smallest suction hole one can get their hand into is about a 3-½ inch hole. This size hole would be adequate if there is stone under the slab since the stone can be easily removed with a standard 2-¼ inch shop vacuum hose. If there is the chance that the sub-slab has no aggregate than a 5 inch diameter suction hole will allow easier sub-soil removal. The hole through the slab can be cut by making multiple holes with a ½ to 7/8 inch carbide drill bit and a hammer drill. After 8 to 16 small holes are drilled through the concrete, a flat chisel is used with the hammer drill to bust out the spaces between the drilled holes. Although this is a common method of many mitigators, it leaves rough edges around the concrete hole that are very abrasive while trying to hand dig out the suction hole.

Fig 3-1 Multi-hole Coring

An alternate method is to use a more expensive (typically $800 to $1200) hammer drill that is capable of driving a 5 inch or preferably a 6 inch carbide core bit. A 5 inch carbide core bit will typically cost $275 to $375 apiece but it should be able to cut 100 holes. It is best to use a shop vacuum with all hammer drilling but it is a necessity with dry core drilling because of the fine concrete dust. The shop vacuum and core drill will need to be plugged into outlets connected to different breakers or there combined amperage will trip even a twenty amp breaker. It is also preferable to use 12 gauge extension cords with these high amperage tools. A good 5 inch core bit and properly sized hammer drill can cut through a 3 to 4 inch concrete slab in four to six minutes. Reference 13. A nice benefit with core drilling is the side walls of the hole are less abrasive during the dig out.

Fig 3-2 Dry Coring

Core drills are especially helpful when side cutting through a poured foundation. Trying to make multiple holes and chiseling through an 8 to 12 inch poured wall is not a lot of fun. A core drill can side core a 3-½ inch hole through an 8 inch poured wall in less than ten minutes. Be especially careful not to get your hand stuck in a small concrete hole especially if one is working alone in a vacant house. It might end up being a long night.

Some mitigators prefer wet core drilling. The set up time and cleanup usually make wet core drilling more time consuming than a dry core system. The distinct advantage wet core drilling has is its ability to cut through steel re-enforcing bars. Even 3/8 inch steel bars are too much for a dry core. If a re-bar is encountered in a floor or wall while using a dry core or multi-hole method it will be necessary to chisel enough concrete away from the bar to fit a metal cutting sawzall blade in the hole to cut the bar out. This can be very time consuming. If a wet core, diamond tipped core will cut right through the steel bars, although obviously at a slower rate than cutting concrete. A wet core drill needs to be attached to the floor or wall using anchor bolts or a special suction pad attachment or a bracing piece from the drill to an opposite ceiling or wall. The water for the core drill can come from a hose or a pressurized water can attachment. Core drill set-ups typically cost $2000 to $3000. A 5 inch diamond core bit costs $450 to $600.

Fig 3-3 Wet Coring

3.1.1.2 Hole Drilling Precautions

Some hole drilling precautions need to be mentioned. Sub-slab utilities can be oil lines to the furnace, water or gas lines, plumbing drain pipes, electrical conduit or telephone lines, slab heating hydronic pipes or electrical cables. As long as the utilities are below the slab, core drilling just the slab will not hit them. The multiple drill method, however, might be more likely to hit something below the slab. There are a number of ways to minimize the risk of hitting utilities. First thing is to always assume there are utilities in the slab and then try to determine from the utility penetrations in the slab where they logically might be. A metal detector can be us3ed to locate metal pipes, unless there is slab re-enforcing wire mesh or re-bar. One company, which makes stud finders, also makes a metal and electrical current locator that works in concrete up to four inches thick. Another company makes a grounding sensor that the drill plugs into. If the drill bit touches a metal pipe, it turns off the drill. The drill must have a grounding plug to use this tool. If the sub-slab utilities are radiant heat pipes embedded in the concrete then its best to turn the heat up a few hours before the work is begun. By carefully feeling for hot and cold spots along the floor, the heat pipes can sometimes be located. Another technique that works for plastic or vinyl hydronic heating pipes installed in the slab is to wet the floor or lay wet newspapers down. The areas that dry out first indicate heat pipe locations.

Fig 3-4 Metal Detectors

If a utility line is damaged, then obviously it needs to be turned off quickly. Oil lines are a special concern because they could go undetected and drain an oil tank into the sub-soil causing a serious and very expensive environmental problem. If an oil line is damaged and the oil cannot be shut off, a trick used by furnace repairmen is to put a slight suction to the oil tank with a shop vacuum to stop the oil flow. Do not put full suction to the oil tank as this could damage the tank.

RMS 12.2.3 The contractor shall ensure that appropriate safety equipment such as hard hats, face shields, ear plugs and protective gloves are available on the job site during cutting, drilling, grinding, polishing, demolishing or other hazardous activity associated with radon mitigation projects.

Fig 3-5 Sub-slab vinyl heating pipes

Take precautions to avoid injury using these powerful drills, especially if someone isn't experienced with these kinds of tools. Always wear ear protection. Years of construction noise can definitely cause hearing loss and permanent ringing of the ears. Instruct inexperienced operators how to properly brace a drill. Kneepads are essential both for kneeling and for bracing large drills while slab coring. Do not allow inexperienced operators to use a drill until they have been properly trained. Make sure the drill has side handles firmly attached and that the drill is properly grounded.

3.1.1.3 Digging the Suction Pit

RMS 14.4.1 To provide optimum pressure field extension of the sub slab communication zone, adequate material shall be excavated from the area immediately below the slab penetration point of SSD system vent pipes.

Suction pits are critical components of a radon SSD system. In order to optimize the performance of the system, minimize pressure drop not only in the radon piping but also in the soil. Imagine a stream of air moving through a radon pipe. Now imagine trying to move the same amount of air with the pipe full of gravel or even worse full of soil. In order to minimize the amount of air flow pressure drop through the sub-slab material have at least as much void area in the soil as cross sectional area of the pipe. This is accomplished by enlarging the suction pit under the slab. The tighter the soil, the more surface area needs to be exposed in the suction hole. If a soil only has a 5% void area then there needs to be at least an open surface area 20 times larger than the area of the pipe to minimize pressure drop. Only 5 times the surface area is needed if the suction hole were filled with crushed stone having a 20% void area. The general idea is that the tighter the soil (the harder it is to remove) the more should be take out. The typical mitigation system installation would remove about 2-½ gallons of sub-slab crushed stone, but 5 gallons of soil. Sometimes, however, the sub-soil is so compacted with rock that less than a gallon of sub-slab material can be removed.

The table below illustrates how much soil surface area is exposed from removing varying amounts of sub-slab material.

Gallons Removed	Width in inches	Depth in inches	side surface area	Ratio to 4” pipe
0.35	4”	4”	0.45 sf	4 x
2	12”	4”	1.0 sf	12 x
4	12”	8”	2.1 sf	24 x
9	18”	8”	3.1 sf	36 x
16	24”	8”	4.2 sf	48 x
24	24”	12”	6.3 sf	72 x

Table 3 – 1 Soil Surface area versus,
Suction Hole Size Dry Coring

Removing four gallons instead of two from the suction hole doubles the exposed surface area. There is increasing surface area but with diminishing effect after more than four gallons is removed. Removing more than 10 gallons is probable not necessary and increasingly more difficult to extract.

Only a shop vacuum is needed to clean out the suction hole if the sub-slab material is gravel. If there is little or no gravel beneath the slab, the dirt will have to be loosened first to get it out of the hole. Most mitigators will use the same hammer drill that they used to cut through the concrete slab to loosen the packed dirt. A long chisel bit installed in the hammer drill can be driven into the dirt and pried back and forth to loosen the dirt and stone enough to suction it out with the shop vacuum. It can take real persistence to get five gallons of packed dirt out of a suction hole. A screwdriver or other small tool can be inserted into the hole and also used to loosen the dirt and probe for any cavities. One of the radon supply companies sells an auger that can be attached to a heavy duty drill to assist digging out the hole. If the suction hole is along the exterior foundation wall and the footer was formed in place, the space between the footer and the soil often has small void areas that can give good PFE even in tight soils. If the footer was installed by digging out a trench with a backhoe and using the trench to hold the concrete then there typically isn’t a cavity in the soil adjacent to the rough concrete footer. In this case it would be beneficial to locate the suction point near underground utilities or where-ever there might be less compacted soil. In some cases there is a more permeable layer below the compacted soil. This would require excavating down to this layer which could be anywhere from one to four feet below the slab.

3.1.2 Fan Installation

RMS 14.3.1 Vent fans used in radon mitigation systems shall be designed or otherwise sealed to reduce the potential for leakage of soil gas from the fan housing.

RMS 14.3.2 Radon vent fans should be sized to provide the pressure difference and air flow characteristics necessary to achieve the radon reduction goals established for the specific mitigation project.

RMS 14.3.3 Radon vent fans used in active soil depressurization or block wall depressurization systems shall not be installed below grade nor in the conditioned (heated/cooled) space of a building, nor in any basement, crawlspace, or other interior location directly beneath the conditioned spaces of a building. Acceptable locations for radon vent fans include attics not suitable for occupancy (including attics over living spaces and garages), garages that are not beneath conditioned spaces, or on the exterior of the building.

RMS 14.3.4 Radon vent fans shall be installed in a configuration that avoids condensation buildup in the fan housing. Whenever possible fans shall be installed in vertical runs of the vent pipe.

RMS 14.3.7 To facilitate maintenance and future replacement, radon vent fans shall be installed in the vent pipe using removable, or flexible connections that can be tightly secured to both the fan and the vent pipe.

3.1.2.1. Outside Fan Installation

RMS 14.3.5 Radon vent fans mounted on the exterior of buildings shall be rated for outdoor use or installed in a watertight protective housing.

RMS 14.3.6 Radon vent fans shall be mounted and secured in a manner that minimizes transfer of vibration to the structural framing of the building.

Radon fans installed on the outside are typically mounted to a PVC elbow attached to the pipe coming out of the building. The fan is attached to the elbow using either black or white rubber boots. There are some radon fans that have brackets that can be mounted directly to the outside of the building. This method, however, increases the possibility of transferring fan vibration to the inside of the building. Vibration transfer can be easily detected by placing ones hand on the exterior wall, next to the fan or on the inside surface of the exterior wall that is adjacent to the fan location.

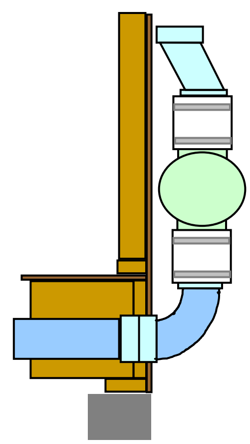


Fig 3-6
Outside Fan

3.1.2.2 Attic Fan Installation

The fan must be installed in a vertical section of piping in order to prevent water accumulation in the fan housing. Once the fan is installed a plumb bob is useful for marking the exact center of the roof penetration above the fan. The hole through the roofing can be cut from below or up on the roof. Battery powered drills and sawzalls eliminate the need to get a power cord through the attic or across the roof. A standard plumbing no-caulk roof flashing is used to waterproof the opening through the roof. The shingle nails above the opening need to be removed so that at least half the roof flashing is installed under the shingles.

Fig 3-7 Fan in attic

3.1.2.3 Fan Wiring

RMS 14.6.1 Wiring for all active radon mitigation systems shall conform to provisions of the National Electric Code and any additional local regulations.

RMS 14.6.2 Wiring shall not be located in or chased through the mitigation installation ducting or any other heating or cooling ductwork.

RMS 14.6.3 Any plugged cord used to supply power to a radon vent fan shall be no more than 6 feet in length.

RMS 14.6.4 No plugged cord shall penetrate a wall or be concealed within a wall.

RMS 14.6.7 An electrical disconnect switch or circuit breaker shall be installed in radon mitigation system fan circuits to permit deactivation of the fan for maintenance or repair by the building owner or servicing contractor. (Disconnect switches are not required with plugged fans).

RMS 15.1 All mitigation system electrical components shall be U.L. listed or of equivalent specifications.

A radon fan needs to have a disconnect next to the fan that allows servicing. The disconnect can be a plug if it is a location where it is unlikely to be unplugged by someone needing an outlet for another appliance. A homeowner should not be tempted to unplug the radon fan so that he can plug in another appliance. It would therefore be acceptable to have the radon fan plugged into an outlet in an unused attic. If a plug is used for the disconnect, the plug cord cannot be longer than six feet. The plug cord cannot pass through a wall. Outdoor outlets are not allowed by the RMS to be used to power the radon fan.

RMS 14.6.5 Radon mitigation fans installed on the exterior of buildings shall be hard-wired into an electrical circuit. Plugged fans shall not be used outdoors.

If the fan is hard wired in an attic, standard romex cable can be used. If the fan is located outside then all wiring and connectors must be rated for outdoor service. This means that the outdoor wiring must be in conduit unless outdoor rated wiring is used that is routed into the fan or electrical switch box with weathertight connectors that are approved for outdoor wire.

Obviously the switch cover needs to be weather tight. Flex conduit can be used as long it is less than six feet in length and lengths over three feet include a building strap. According to the NEC (National Electric Code), single conductor cable needs to be used inside conduit rather than romex cable. The outdoor conduit needs to be routed into a junction box inside. Romex cable can be used from this junction box to a power source.

RMS 14.6.6 If the rated electrical requirements of a radon mitigation system fan exceeds 50 percent of the circuit capacity into which it will be connected, or if the total connected load on the circuit (including the radon vent fan) exceeds 80 percent of the circuit's rated capacity, a separate, dedicated circuit shall be installed to power the fan.

Since radon fans do not draw half the capacity of a circuit breaker they in themselves do not require a separate circuit however they cannot be tied into a circuit that is all ready at 80% of its load. In most cases this is rather difficult to determine. It is therefore preferable to have the system wired into its own breaker. Make sure that the fan, switch box, switch and any junction box connections are properly grounded. The fan wiring must be sized for the circuit breaker capacity that it is wired into. There must be a wire staple within eight inches of a junction box that doesn't include a romex clamp or within 12" of a box that does. Romex cable needs to be secured at least every 4-½ feet. Attic fan locations must have an attic light. There can be no loose fan wiring within three feet of an attic access opening. Any local codes have preference over these requirements.

3.1.3 Piping

RMS 13.1 All radon mitigation systems shall be designed and installed as permanent, integral additions to the building, except where a temporary system has been installed in accordance with paragraph 10.3.

3.1.3.1 Piping Materials

RMS 15.2 As a minimum, all plastic vent pipes in mitigation systems shall be made of Schedule 20 PVC, ABS or equivalent piping material. Schedule 40 piping or its equivalent should be used in garages and in other internal and external locations subject to physical damage.

RMS 15.3 Vent pipe fittings in a mitigation system shall be of the same material as the vent pipes

Radon piping needs to be both air tight and moisture resistant. PVC and ABS are ideal materials for this requirement. In some locations of the country only ABS is readily available. In other areas only PVC is available. Either material is acceptable however do not mix ABS with PVC without adhesives that are compatible with both.

Be careful not to accidentally purchase or use styrene fittings in place of PVC. Styrene fittings are identical to schedule 20 PVC except they have a milky white translucent appearance. Styrene is not sunlight resistant and will become brittle and yellow if exposed to the sun. Styrene fittings do not seal well especially if standard PVC solvent is used. The joints can be broken apart and are prone to leaking.

The minimum piping thickness is schedule 20, also referred to as sewer and drain (S&D). Normal bumping and placing ones full weight on schedule 20 pipe will distort its size but it will typically spring back to its original position. If the placement of the radon pipe is in locations that will not receive significant abuse then schedule 20 is sufficient.

Schedule 40 PVC has a number of advantages. The first advantage is its resistance to abuse and deflection. Although any PVC piping can sag if run horizontally without proper support, schedule 40 is significantly less likely to sag than schedule 20. Any sagging could have the potential to accumulate water and restrict airflow. The other advantage is the fittings are less likely to leak due to the closer tolerances and more rigid characteristics of schedule 40 as compared to schedule 20. The disadvantage as compared to schedule 20 is its higher cost and more time consuming installation.

Consider a simple radon system that had a single suction inside and two stories of radon piping on the outside. There would be about 40 feet of piping and about 12 elbows. The table below gives the cost difference of using schedule 20 versus schedule 40.

Type of Piping	Pricing
4” Schedule 40 piping	$100
4” Schedule 20 piping	$40
3” Schedule 40 piping	$75
3” Schedule 20 piping	$30

Table 3-2 Cost difference between schedule 40 and schedule 20 pvc 3” and 4” pipe for a single hole installation using 2002 prices.

ASTM E2121 standard differs from the RMS by specifying that the minimum size of the piping above the fan shall not be smaller than the piping used between the suction holes and the fan. In addition the minimum piping size above the fan shall not be less than 3” inside diameter piping.

3.1.3.2 Piping Drainage

RMS 14.2.6 Radon vent pipes shall be installed in a configuration that ensures that any rain water or condensation within the pipes drains downward into the ground beneath the slab or soil-gas retarder membrane.

There is a significant amount of moisture condensing inside most radon system piping during any periods when a portion of the pipe is exposed to air temperatures cooler than the sub-slab earth temperature. This moisture needs to drain back to the first suction hole where it will dissipate back into the soil. The typical plumbing requirement of sloping the piping 1/8 to 1/4 of an inch for each 12 inches of horizontal pipe run is just as important for radon installations especially considering the airflow in the piping may reduce the drainage. The smaller the pipe dimension, the more critical the slope.

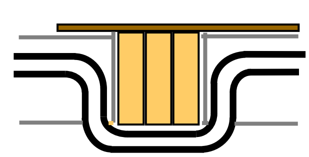


Fig 3-8 Water Trap

The following table defines the minimum slope per foot of run at different airflows as measured by RadonAway.

Pipe Diameter	25 cfm	50 cfm	100cfm
4”	1/8”	1/4’”	3/8”
3”	1/4’”	3/8”	

Table 3-3 Minimum slope per foot of run for varying pipe size and CFM

Let’s assume an inch of water has accumulated in two different systems. In one system with 4” piping, the water has reduced the piping size to 3” and the airflow is at 80 cfm. The pressure drop increases by four fold. In another system, with 3” piping that is reduce to 2”. This time it causes a seven fold increase in pressure drop. Even at 50 cfm, ten feet of the 2” losses 0.35 inches of pressure. The numbers in the table below were obtained from ASHRAE’s table of friction loss from airflow in round pipes.

CFM	P.D. 4”	P.D. 3”	P.D. 2”
80	0.04”	0.17”	1.3”
50	0.0125”	0.05”	0.35”
20	0.0035”	0.014”	0.10”

Table 3-4 Pressure Drop in 10 feet of pipe at varying airflows and pipe sizes

Maintaining water drainage throughout the radon system is important but it is most critical between the first suction hole and the final exit point of the system. After the first suction hole in the conditioned space there is less likely to be significant water accumulation but the piping run must still not trap any water. Piping runs inside the conditioned space after the first suction hole can be run horizontally level. It is still however recommended that all horizontal piping in the conditioned space be sloped towards a suction hole. Good mitigators will therefore often locate suction holes where drainage for overhead pipe runs are needed.

Piping installed horizontally in the attic must be pitched back to the first suction hole. A level should always be used to check the piping pitch. It is also advisable to minimize the radon piping touching any framing to avoid vibration transfer. If the piping is strapped to framing, a piece of backer rod, between the pipe and the framing, will help minimize noise transfer.

3.1.3.3 PVC Glue

RMS 14.2.1 All joints and connections in radon mitigation system vent pipes shall be permanently sealed as specified by the manufacturer of the pipe material used.

RMS 15.4 Cleaning solvents and adhesives used to join pipes and fittings shall be as recommended by manufacturers for use with the type of piping material used in the mitigation system.

The PVC or ABS pipe and fittings are glued together with cleaner and cement that is compatible with each material. There are low VOC adhesive’s that have less odor and do not require a primer. The primer may however be required by ones local building code. The advantages of no primer and little odor can be really appreciated in confined work areas like crawl spaces. The disadvantage is the cost, which is typically 3 or 4 times more than regular glue.

3.1.3.4 Inside Piping Support

RMS 14.2.3 Radon vent pipes shall be fastened to the structure of the building with hangers, strapping, or other supports that will adequately secure the vent material. Existing plumbing pipes, ducts, or mechanical equipment shall not be used to support or secure a radon vent pipe.

RMS 14.2.4 Supports for radon vent pipes shall be installed at least every 6 feet on horizontal runs. Vertical runs shall be secured either above or below the points of penetration through floors, ceilings, and roofs, or at least every 8 feet on runs that do not penetrate floors, ceilings, or roofs.

RMS 14.1.3 Where portions of structural framing material must be removed to accommodate radon vent pipes, material removed shall be no greater than that permitted for plumbing installations by applicable building or plumbing codes.

Pipe strap can be plastic or metal strap that is secured to the building components. Some mitigators prefer to use a plastic J hook manufactured for different pipe sizes. Some of the radon supply companies also have available a section of schedule 40 pipe that is cut down to ¾'s of the pipe circumference with a hole for a screw. This piece is attached to the bottom of the floor joist and the radon system pipe is just snapped into it. The pipe run would therefore be horizontally level so this clamp is typically only used after the first suction hole in the conditioned space. It is best to attach pipe strap or J hooks with screws to allow easy height adjustments after the pipe is installed. Note that with pipe strap the wider the angle of attachment to the building, the more laterally secure the pipe tends to be.

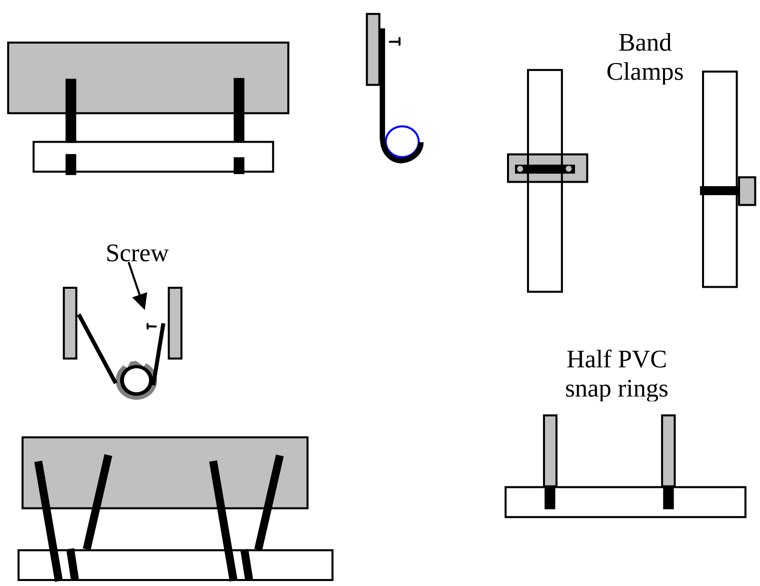


Fig 3-9 Plastic or metal strapping

RMS 14.2.7 Radon vent pipes shall not block access to any areas requiring maintenance or inspection, unless the vent pipe is designed for easy removal and airtight replacement. Radon vent pipes shall not be installed in front of or interfere with any light, opening, door, window or equipment access area required by code.

3.1.3.5 Sealing Radon Piping into a Suction Hole

RMS 14.2.5 To prevent blockage of air flow into the bottom of radon vent pipes, these pipes shall be supported or secured in a permanent manner that prevents their downward movement to the bottom of suction pits or sump pits, or into the soil beneath an aggregate layer under a slab.

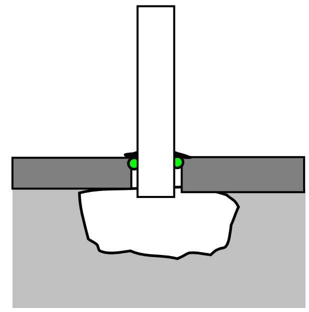


Fig 3-10 Suction hole

The piping must be supported either above the suction hole or at the suction hole. Some mitigators will use an adaptor transition in the suction hole that has a lip around its perimeter that rests on the edge of the suction hole. Most installers, however, will install a pipe support above the suction hole. The piping should protrude down to the bottom of the concrete slab but no farther. Extending the pipe into the suction hole could cause the pipe to be under water if there is any potential for a rising water table under the slab. The radon piping at the first suction hole after the radon fan should not leave any portions of the slab sidewall exposed to the bottom of the pipe. Condensation coming back down the radon pipe can soak a slab enough to create a wet discoloration of the slab around the pipe.

RMS 14.5.2 Openings around radon vent pipe penetrations of the slab, the foundation walls, and the crawlspace soil-gas retarder membrane shall be cleaned, prepared, and sealed in a permanent, airtight manner using compatible caulks or other sealant materials.

The pipe can be sealed in place using mortar or caulking. If mortar is used, do not make the mix too wet since this will cause shrinking and cracking. Just enough water should be added to allow troweling a smooth surface. If caulking is used, pieces of backer rod can be cut to fit the openings around the pipe. The backer rod is pushed down flush with the top of the slab and a layer of gun grade urethane caulk is placed on top. Smooth out the caulk with a small flat piece of cardboard or scrap piece of soft vinyl tile.

3.1.3.6 Outside Piping

RMS 14.2.8 To prevent re-entrainment of radon, the point of discharge from vents of fan powered soil depressurization and block wall depressurization systems shall meet all of the following requirements: (1) be above the eave of the roof, (2) be ten feet or more above ground level, (3) be ten feet or more from any window, door, or other opening into conditioned spaces of the structure that is less than two feet below the exhaust point, and (4) be ten feet or more from any opening into an adjacent building. The total required distance (ten feet) from the point of discharge to openings in the structure may be measured either directly between the two points or be the sum of measurements made around intervening solid obstacles.

The outside pipe or fittings under the fan need to be secured to support the weight of the fan and the exhaust vent piping. The fan is attached to the pipe or a fitting with either white or black rubber boots. Typically a PVC pipe is connected to the exhaust port of the radon fan using the same style rubber boot. The pipe is then routed to the building and attached using a plumbing or conduit clamp or other weather resistant material. The fan exhaust must be routed above the roof eave. This is done using either PVC piping or sometimes aluminum or plastic downspout that more closely matches the exterior décor of the building. The PVC piping has the advantage of being water and airtight but the disadvantage of looking like a misplaced plumbing pipe. The aluminum or plastic downspout tends to look like gutter drainage pipe especially if the color matches the existing downspout/trim and it is installed on the corner of the house. Typical residential downspout is 2" by 3", which is more restrictive to airflow than 3" round piping. Unless it is known that the system airflow will be low, it is preferable to use 3" by 4" downspout or 4" PVC. The main concern with using downspout is air leakage at the joints. As each piece is being assembled it needs to have a bead of urethane caulking installed first.

Fig 3-11 Caulking aluminum joints

The outside vertical piping needs to be supported at least every eight feet and a final support should always be installed as close to the exit point as possible. The outside piping must not be vented below the eave of the roof. If the building has an overhang, the piping needs to be routed either through the overhang, if PVC piping is being used, or more typically around the eave.

3.1.3.7 Interior Routed Piping

Fig 3-12 Flex insulation over pvc piping

The radon system piping can often be routed to the house attic from the basement by routing the piping through one or two closets. This option is almost always available if there is a single story above the basement or crawl space. Typically this pipe is left exposed in the closet but it can be covered with finishing material for additional cost. The radon pipe can sometimes also be routed up through two floors if closets line up from the first floor to the second but this is obviously a more difficult procedure. A hall or bathroom closet is usually preferred over a bedroom closet to minimize the occupants hearing the system noise. A master bedroom closet with louvered doors might be a very questionable pipe location. The piping could be insulated for noise by sliding over-sized flexible insulated duct over the piping. Homeowners may complain about system noise if the radon fan is installed above the master bedroom. Builders will occasionally installed the radon pipe inside the master bedroom wall. One solution is to replace radon fan with another fan that is lower amperage and well balanced.

There have been some isolated cases when the weather is very humid and the radon piping passing through an attic has condensed moisture on the outside of the piping to the point it has dripped down through the insulation and stained the interior ceiling. In these cases it would be necessary to insulate the outside of the piping with a vapor resistant insulation.

3.1.3.8 Garage Routed Piping

If there is an attic over the garage, the radon piping can be routed from the basement through the garage to the garage attic. The radon fan would be installed in the garage attic and vented out the garage roof. Some states may not allow this routing if they require venting the system above the highest roof eave. Many new houses are also being built with walk in closets or other rooms over the garage that prevent routing in this location. There may still however be an attic space beside this room that could be used but might require installing an access.

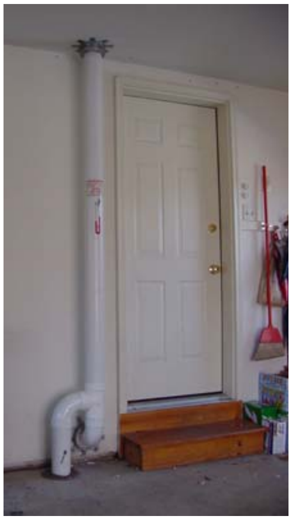


Fig 3-13 Garage Routed piping

RMS 14.1.4 Where installation of a radon mitigation system requires pipe or ducts to penetrate a firewall or other fire resistance rated wall or floor, penetrations shall be protected in accordance with applicable building, mechanical, fire, and electrical codes.

Fig 3-14 Fire collar

The garage is typically fire-rated from the rest of the home. In order to maintain the fire rating, the radon pipe will either need to be encased in fire code sheet rock or have a UL approved fire stop collar installed both at the bottom and top of the radon pipe in the garage. This fire collar must be attached directly to the building and not to the radon pipe. Most of the radon supply companies stock an intumescent type fire collar. This type of fire stop can be used for PVC/ABS pipes up to 4” in diameter. If a fire was to take place, the intumescent wrap expands inward from the heat, crushing the heat softened pipe. The fire stop has metal collars around the intumescent material that does not allow it to expand outward.

3.1.3.9 System Chimney Caps

There are mixed opinions about the need for chimney caps. If a chimney cap is not installed a homeowner, during the final inspection, will often question whether there should be a cap to prevent rain water from getting to the fan motor. Depending on the design of the chimney cap there may actually be more water coming down the pipe with a cap installed then if no cap was installed. This is because there is usually significantly more water accumulation in the piping from condensation than from rainwater. A large glass left outside in the rain would accumulate a few ounces of water. Soil gas, especially during rainy periods, is often close to 100% relative humidity. When this soil gas comes in contact with the interior surface of the piping that is exposed to cooler outdoor temperatures it will reach its dew point and condense inside the piping. It is not unusual for a radon system to condense a gallon of water in a few days of use. A chimney

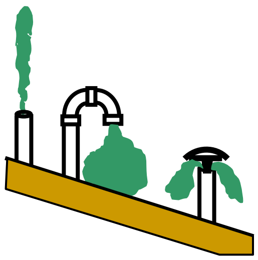


Fig 3-15 exhaust options

cap could actually contribute more condensation accumulation to the inside of the piping than rainwater would normally produce. A popular chimney cap is a coupling or piping insert with a screen. There is a possibility of freezing condensation across the screen surface in very cold climates.

Occasionally an outside system has had a premature failure because a squirrel has mistaken a radon pipe for a downspout gutter and found itself stuck inside the radon fan. This does not seem to happen with vent pipes routed through the roof. A critter screen or chimney cap with screening would prevent this from happening. The final choice of whether to use a chimney cap or screening is left up to the mitigators.

The air exiting a radon pipe makes a white noise. If the exhaust is above the second story roof eave it is likely not to be bothersome to the homeowner. If the exhaust is out a single story roof and the pipe is visible from an outdoor activity area such as a patio or deck, it may create an unacceptable noise to the homeowner. The system exhaust noise in this case can be reduced by installation of a muffler. Mufflers designed for radon systems are available from several radon supply companies. Mufflers do not re3duce fan motor noise or vibration noise but will deepen the tone of the radon exhaust noise, thus making it less objectionable.

3.1.4 System Requirements

3.1.4.1 System Indicator

RMS 16.1 All active radon mitigation systems shall include a mechanism to monitor system performance and warn of system failure. The mechanism shall be simple to read or interpret and be located where it is easily seen or heard by building occupants and protected from damage or destruction.

RMS 16.2 Electrical radon mitigation system monitors (whether visual or audible) shall be installed on non-switched circuits and be designed to reset automatically when power is restored after service or power supply failure. Battery operated monitoring devices shall not be used unless they are equipped with a low-power warning feature.

Each system must have a gauge or light that is visible from three feet away that indicates that the fan is working. There are pressure sensitive relays that can be connected to the radon piping that would activate a light based on the pressure created by the fan in the radon piping. Most ASD systems however use a simple u-tube manometer that has a tube shaped in a U. The tube is half filled with red or blue gauge oil. One side of the u-tube has vinyl tubing routed into the radon piping. The suction of the fan draws the oil up on one side. The difference in height between the two columns is the pressure difference between the room and inside the pipe. The gauge has markings that are calibrated for inches of water because the oil in the gauge has a different viscosity than water.

Fig 3-16 u-tube manometer

The gauge tubing needs to have the hole in the pipe located below the top of the u-tube to minimize the chance that water in the pipe will get into the tubing. A single small drop of water in the tubing will cause the gauge to give a false pressure reading.

Some times it's necessary to route the tubing a distance from the pipe to the system indicator gauge. This might be the case for a new construction home where all the radon piping is covered with studding and drywall. The tubing in this case will need to be installed so that it drains into the radon pipe.

The u-tube or pressure relay should be measuring the system pressure closer to the fan rather than farther away. Although there may be reasons to locate the gauge farther away from the fan, the loss in pressure may make the pressure reading too small to easily determine if the fan is operating.

RMS 16.3 Mechanical radon mitigation system monitors, such as manometer type pressure gauges, shall be clearly marked to indicate the range or zone of pressure readings that existed when the system was initially activated.

The final system vacuum measured by the u-tube can be as little as 1/8 inch difference between the oil columns or as great as 32/8 or 4 inches if a fan such as a GP501 is used. An 1/8 inch reading indicates a high flow situation with very little airflow resistance from the sub-slab area or the u-tube is installed after one or more high flow suction holes. A u-tube reading that is close to the maximum vacuum capacity of the fan indicates the opposite, a low flow situation that is due to either very tight sub-slab material and or a very tight slab. Owners may ask if the u-tube reading is a good one. The answer is that the u-tube reading doesn't measure radon but is used to indicate that the fan is operating to the same capacity as when it was installed. From an installers point of view it's a concern when the final u-tube reading is either showing almost no air flow or one that is showing excessive air flow although these systems are usually still successful if they are carefully installed.

3.1.4.2 Labeling

RMS 16.4 A system description label shall be placed on the mitigation system, the electric service entrance panel, or other prominent location. This label shall be legible from a distance of at least three feet and include the following information, "Radon Reduction System," the installer's name, phone number, and certification number, the date of installation, and an advisory that the building should be tested for radon at least every two years or as required or recommended by state or local agencies. In addition, all exposed and visible interior radon mitigation system vent pipe sections shall be identified with at least one label on each floor level. The label shall read, "Radon Reduction System".

There are a number of required and recommended labels to be installed on an ASD system. There needs to be a label adjacent to the U-Tube that says "Radon Reduction System". A pressure activated relay light would have similar requirements. The system vacuum measured by the u-tube needs to be clearly indicated. This can be done by marking the oil levels on the u-tube with a permanent ink marker or by writing the final pressure reading on a label installed on the pipe. It is best to do both. The label also needs to have a recommendation that the radon system be retested every two years.

RMS 16.5 The circuit breaker(s) controlling the circuit(s) on which the radon vent fan and system failure warning devices operate shall be labeled "Radon System".

The circuit the fan is wired into must be labeled at the main circuit panel. Pre-printed label from a number of different radon equipment suppliers can be obtained to mark the circuit. The more difficult part is finding which breaker the fan is wired to, especially if there is only one person installing the system. When turning the breakers off, one by one to locate the circuit, make sure the homeowner doesn't have a computer or other critical device running.

Any exposed radon piping passing through different floors of a building must have at least one label per floor that says "Radon Reduction System". Labels can be obtained from the radon supply companies or label sheets can be purchased and printed on a standard printer.

All radon system switches must have a label that says "Radon System Switch" or equivalent. It should also say, "Keep on" or "Do not turn off". Note that some labels installed on outdoor switches can fade in the sunlight, especially red lettered labels. Outdoor labels need to obviously be weatherproof. Red permanent markers are especially prone to fading in sunlight and will typically be invisible in less than a month of outdoor exposure.

3.1.4.3 System Documentation

RMS 18.5 Upon completion of the mitigation project, the contractor shall provide clients with an information package that shall include:

(1) Any building permits required by local codes
(2) Copies of the Building Investigation Summary and floor plan sketch
(3) Pre- and post-mitigation radon test data
(4) Copies of contracts and warranties.
(5) A description of mitigation system installed, and its basic operating principles.
(6) A description of any deviations from the RMS or State requirements.
(7) A description of the proper operating procedures of any installed mechanical or electrical systems, including manufacturer's operation and maintenance instructions, drain filling instructions, and how to interpret warning devices.
(8) A list of appropriate actions for the client to take if the system failure warning device indicates system degradation or failure.
(9) The name, telephone number and Certification identification number of the contractor and the phone number of the state radon office.

After an ASD system is installed, it is important to gather all the relevant information into one convenient large envelope and leave it with the system. The envelope should be labeled as to its purpose or it can be a clear envelope with a cover letter exposed inside. Ideally the envelope should be attached to the piping in a location close to the system pressure gauge so that it can be easily identified and available to explain the system operation.

RMS 17.5 To ensure continued effectiveness of the installed radon mitigation system(s), the contractor shall advise the client to retest the building at least every two years or as required or recommended by state or local authority. Retesting is also recommended if the building undergoes significant alteration.

Fig 3-17 System information packet

The envelope should contain a system description and a drawing of the basement showing the final pipe layout and sub-slab pressure readings as well as any test results that were done both before and after the system was installed. The envelope needs to include a description of the u-tube or pressure gauge and what to do if it indicates a problem with the system. The packet also needs to include building permits, a copy of the contract and warranty, and the name, phone number and certification number of the installer as well as the phone number of the state radon office. Finally it needs to include a description of any required system maintenance.

3.1.5 Final Performance Checks

RMS 17.1 After installation of an active radon control system (e.g. SSD), the contractor should reexamine and verify the integrity of the fan mounting seals and all joints in the interior vent piping.

RMS 17.2 After installation of any active radon mitigation system, the contractor should measure the suction in the system piping to assure system is operating as designed. (Note: When SSD systems are installed and activated, a test of pressure field extension is a good practice, particularly when there is uncertainty regarding the permeability of materials under all parts of the slab.)

Fig 3-18 Checking PFE

3.1.5.1 Pressure Field Extension (PFE) Measurements

A final measurement of the strength and completeness of the pressure field extension needs to be done after the ASD system and all sealing is complete. This measurement is the most important indicator that the system will be effective and a re-test can be scheduled. If there is incomplete or weak pressure field extension then additional work should be considered.

The pressure field extension measurement is typically done by drilling a 5/16” or 3/8” hole(s) through the concrete floor at the farthest distance(s) from any single suction points or the farthest mid-span between multiple suction holes. At each of these locations the dust from the drilling is vacuumed up and then the pressure difference between the sub-floor and room is measured. If the reading indicates that there is a strong and complete pressure field extension then these numbers can be used as the final sub-floor pressure readings. If these measurements show incomplete or weak readings then competing negative pressures need to be taken into consideration. A strong sub-slab pressure field is at least three to six Pascals negative. To check the effect of competing negative pressures, the exterior doors and windows throughout the building need to be closed. If the building has a forced air heating or cooling system, the sub-slab pressure difference should be made with the air handler off versus on. This is especially important if the air handler is in the basement. If the readings are indicating weak or no sub-slab negative condition, it is helpful to drill additional test holes closer to the suction points to determine the exact pressure field extension.

3.1.5.2 Back Draft Testing

RMS 11.3 It is recommended that during the building investigation, the contractor routinely perform diagnostic tests to evaluate the existence of, or the potential for, back drafting of natural draft combustion appliances.

If spillage is confirmed from any natural draft combustion appliance, clients shall be advised of the back drafting condition and that active (fan powered) radon mitigation systems cannot be installed until the condition has been corrected. The contractor should advise the client to contact an HVAC contractor if correcting an existing or potential back drafting condition is necessary.

RMS 17.3 Immediately after installation and activation of any active (fan powered) sub-slab depressurization or block wall depressurization system in buildings containing natural draft combustion appliances, the building shall be tested for back drafting of those appliances. Any back drafting condition that results from installation of the radon mitigation system shall be corrected before the system is placed in operation.

Fig 3-19 Turning heat down first

An ASD system can draw air from the basement or living space causing that area to become more negative in pressure. This would especially be the case if significant leaks could not be sealed. An example of this would be a basement with finished exterior walls and an unsealed canal drain around the perimeter of the slab. Depressurized crawl space membranes or block wall suctions can also sometimes draw significant air from the habitable space. This additional negative pressure could cause a back draft condition. A back drafting combustion appliance means that the natural draft of combustion products is not being drawn up and out of the chimney. The combustion products are instead spilling into the room. This is typically caused by one, two or all of the flowing conditions: the chimney is blocked, there is wind induced downdraft or there is too much competing negative pressure in the room the combustion appliance is located in.

All natural draft combustion appliances (NDCA) in the building should be tested except the fireplace. The combustion appliances that typically need to be tested are propane and natural gas water heaters and furnaces. Oil burners a less likely to back draft because they have an internal combustion fan to power assist the draft.

The backdraft test is done by first turning off all NDCA’s to allow the chimney time to cool off. The initial thermostat setting of the appliance needs to be recorded so that it can be returned to the proper temperature after the test. Next, all the windows and exterior doors in the building are closed. Some authorities also recommend opening all the HVAC dampers in the building but this would operate the building differently than the way the occupants operate the building. The radon ASD system fan should be on. All exhaust fans in the building, such as the dryer, range hood exhaust and bathroom fans should be turned on. If there is an air handler for the HVAC system in the area where the NDCA is being tested, then it should be turned on. If there is a door between the basement and the first floor, it should be closed.

Fig 3-20 Checking draft

Now turn up the temperature control on the NDCA until the burner fires. Watch for indications that the combustion gas air is going up the chimney. The easiest way to determine this is to monitor the temperature of the chimney. If it starts going from warm to hot, there is a draft. If it doesn't get warm, then feel around the base of the chimney, and try to locate where the warm exhaust is going. Be careful not to burn yourself. A chemical smoke puffer or pencil can be used to see if a draft is taking place. If a draft has not been induced with-in five minutes then the NDCA can be assumed to be back drafting.

Fig 3-21 Checking draft with smoke

If the NDCA is back drafting then turn off the radon fan without opening the basement exterior door or door to the first floor. If the NDCA starts drafting then the radon system is contributing to the back drafting. Typically this is not the case. Try opening the basement to first floor door and check the draft. This is the most common cause of back drafting. Try closing the door to the basement and see if the back drafting resumes. It may or may not resume depending on how much negative pressure the HVAC system is inducing on the lowest level since the chimney is now warm. Turning off the other exhaust fans to determine if back drafting takes place with just the HVAC air handler running and no other exhaust fans on.

To test the negative pressure induced by a basement HVAC air handler, run the signal tubing of a micro-monometer or magnehelic under the basement to first floor door with the door closed and the air handler running. If no pressure instrument is available, stand at the top of the basement stairs and open the door an inch. Feel how much air is being drawn into the basement and how quickly the door is pulled shut. It's not unusual to have one or two Pascals of negative pressure in the basement as compared to the first floor with the air

Fig 3-22 checking basement pressure

handler running. Some air handlers have induced as much as 8 to 10 Pascals of negative pressure in the basement as compared to the first floor. The return ducts almost always have more leaks than the supply ducts. This is especially the case if the HVAC contractor used the spaces between the floor joists for the returns by simply blocking off the bottom of the joist bay. Some of the return side leaks are from the spaces around the air handler filter.

Fig 3-24 No return ducts

If the HVAC is making the basement very negative, three to eight Pascals, then the back drafting is probably all due to the HVAC ductwork. An HVAC system this unbalanced is probable due to major holes in the return ducts that are wide open. Careful inspection of the return ducts will probable reveal many small leaks and some unintentional large ones. The large ones are typically on top of the return duct where they can't be easily seen. During the initial installation a return branch duct is planned and a hole is cut in the main return trunk. Then after the main trunk is installed, the branch return is located in another location and the initial hole is never sealed. If the basement is very negative, inspect the top of the main return trunk and as well as the end capping of all joist spaces that are being used as return ducts.

Some houses have air-handling systems that never had any return ducts installed from the air handler to the main floors. They sometimes refer to this as a gravity system. The whole basement in this case is the main trunk return. A house with this system will typically have open return grills from the first floor into the basement or the basement door will be louvered or have a large grill in it. The total size of all of these openings versus the capacity of the air handler will determine the amount of negative pressure induced in the basement. An ASD system would need to have the pressure field extension tested with the air handler running to be sure that the air handler doesn't overpower the radon system. It may be necessary to install return ducts to the first floor especially if the PFE is weak.

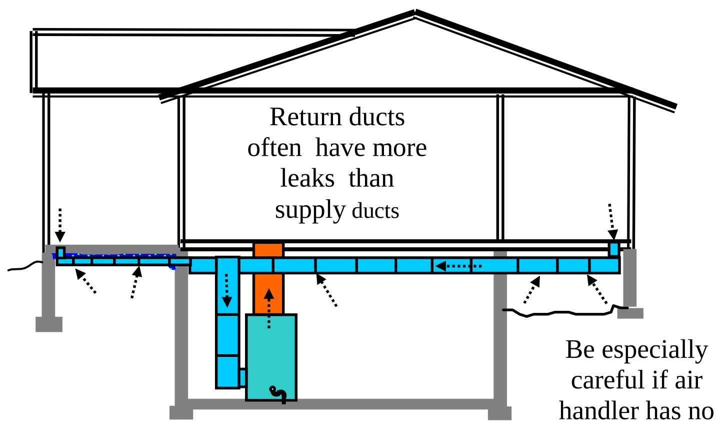


Fig 3-23 Leaky return ducts

3.1.5.3 Post Mitigation Testing

RMS 17.4 Upon completion of radon mitigation work, a test of mitigation system effectiveness shall be conducted using an RMP listed test device and in accordance with EPA testing protocols or state requirements. The test should be conducted no sooner than 24 hours nor later than 30 days following completion and activation of the mitigation system(s). The test may be conducted by the contractor, by the client, or by a third party testing firm. If this test is conducted by the mitigation contractor, and the test results are accepted by the client as satisfactory evidence of system effectiveness, further post-mitigation testing is not required. However to avoid the appearance of conflict of interest, the contractor shall recommend to the client that a mitigation system effectiveness test be conducted by an independent state certified testing firm or by the client. The contractor should request a copy of the report of any post-mitigation testing conducted by the client or by an independent testing firm.

After a radon system is installed, it cannot be assumed that the radon levels are now below the guideline. A post mitigation radon measurement needs to be made in the lowest level suitable for occupancy if the previous testing or system installation was part of a real estate transaction. Otherwise the radon test should be performed in the lowest level that was previously tested. If the previous measurement was made in a location that is not the lowest level being occupied or planned to be occupied it should now be tested in this location.

The test needs to be made within 30 days after a radon system is installed. The whole house must have closed house conditions during the test and for 24 hours before the test is begun. This means that the radon test cannot be started for at least 24 hours after a radon system is installed. A single passive detector is often used for a post mitigation radon test but it is preferable to always use two passive detectors or one continuous radon monitor for the test. It is also recommended that every living or livable space above each unique foundation type be tested. If a house had a basement, a living room over a crawl space and family room on a slab it would be best to test all three of these locations at the same time.

3.1.6 Common Failure Modes

If a post mitigation radon test is at or above the guideline, the radon system needs to be inspected to determine how the performance can be improved. The inability to reduce the levels below the guideline is due to one or a combination of all of the following items. It is important during the re-evaluation to consider each item carefully.

3.1.6.1 Fan Not Running

The first question to ask if a post mitigation test result shows very little change from the pre-mitigation levels is whether the fan is actually operating. Occasionally it happens that the radon fan is wired into a circuit that is switched. This could be the garage light for a garage routed system or the basement lights for an outside system. In each case turn the lights off in the general area where the fan power is coming from and check to see if the fan is still operating.

3.1.6.2 Inadequate PFE and Competing Negative Pressures

The second thing to carefully check is the PFE. Use the existing test holes in the floor and drill new ones in every corner of the slab and between each multiple suction location. Close all the windows and exterior doors in the house and the basement to first floor door. Measure the pressure difference across the slab with a micro-manometer or magnehelic. Measure the pressure difference with the air handler on versus off. Repeat this test with any other significant competing exhaust fans operating such as a dryer or downdraft range hood. Mark all this information on a drawing of the lower level of the building.

If there are any test holes reading less than 1 Pascal of negative pressure compared to the basement with the competing fans running, then additional suction holes may need to be installed. The lack of PFE can be due to compacted fill beneath the slab, which would cause the U-tube to display a high vacuum reading. The lack of PFE could also be caused by too much leakage through the slab or from a very porous sub-soil. This condition would produce only a slight difference in u-tube oil columns, high flow with limited (low) vacuum. In either case it is always beneficial to seal any leaks in the slab or crawl space membrane. If the u-tube is showing a large vacuum, low flow situation then sealing even small cracks can make a significant difference in the pressure field strength.

If there are still areas of weak pressure field then additional suction points in these locations is usually the next choice. Be sure to thoroughly excavate the suction hole. As mentioned before, it is preferable to locate the suction hole next to the footing and any sub-slab piping runs. Some mitigators will listening for hollow sounds through the slab by tapping the floor with a hammer or heavy object to try and find the best suction hole location. If the sub-slab is dirt or compacted fill, test the PFE by placing a temporarily wired radon fan into the suction hole. Ventilate the area with outdoor air while doing this. Check the amount of increased PFE obtained from this new hole. If it seems ineffective then it may be necessary to locate a more productive site.

Fig 3-25 Fan used to check PFE

It may be beneficial in multi-hole systems to install a damper in the radon pipe above the suction hole that is allowing more airflow than is needed to create adequate PFE. The use of dampers is most important for high flow suction holes that are closer to the radon fan. (See section on pipe damper installation).

3.1.6.3 Un-Treated Other Sources

If radon measurements are still elevated after adequate PFE has been obtained, other radon sources should be considered. The first other source consideration is radon in water. This would typically only be a concern if there is well water. If one owns a continuous radon monitor with a sniffing mode it could be placed in a small bathroom with the water running for ten to twenty minutes. This would indicator whether the water needed to be tested. Pulling a water sample for direct analysis is the only sure way to test the water.

It may be helpful to try to measure radon levels at other suspect locations as compared to the radon measurement in the center of the basement or lowest level of the building. These are diagnostic measurements so the standard detector placement rules don’t need to be followed. The testing can be done with a continuous monitor that has a sniffing mode or by placing multiple passive detectors in suspect locations. Some test locations to consider include crawl spaces, near the perimeter floor wall joint in areas with weak or no PFE, next to foundation openings especially ones that have a slab sealing the soil on the other side of the foundation, open drains, or any other suspect location. One or two test kits should also be left in the middle of the basement to get a base line result. It is usually not helpful to leave detectors scattered around an open basement because radon diffuses so rapidly there is usually not much significant difference between detectors. If passive detectors are used they need to be left in place for at least two days with closed house conditions. It is not critical to have 12 hours prior closed house conditions for this diagnostic test, especially if the detectors can be left in place for more than two days. The detectors must all be exposed at the same time. The results from these detectors are then placed onto a drawing of the lower level of the building. The greater the variation in results, the more conclusive the data indicates a significant radon source.

If one owns a radon sniffer than air samples can be taken from the inside of the block wall, or adjacent to cracks in a poured foundation or open floor drain. The top of a poured foundation wall can be a source if the soil behind it is backfilled up near the sill plate. This is often the case along the foundation wall adjacent to the garage slab, back yard patio, or front entrance slab. Check any open conduits through the foundation that may be use to carry wire or piping through the foundation to the well pump or other equipment or lights.

Fig 3-26 Radon sniffer checking block wall

Occasionally a building will have a cantilevered floor into the garage space that leaves a small crawl space with the garage sub-floor gravel or dirt exposed directly to the basement. This is an easy feature to miss during the initial building investigation. A radon sniffer or passive detector might verify that this is a source.

Another sometimes overlooked radon source is the air condition condensate line that drains directly into the sub-slab. If the A/C has not been running for a few months because of cooler weather, the normally filled trap may be dry. This small ¾” PVC pipe running into the soil can maintain radon levels above the guideline if it is connected to the return side of the air handler.

Once the un-treated source is determined an additional suction pipe from the main system to this source is the most assured treatment method. The PFE needs to be re-checked and if necessary the system may need to be balanced using dampers or varying the pipe size. The radon levels would then be measured according to standard post mitigation guidelines.

3.1.6.4 Re-Entrainment

Any part of the radon system that is pushing air can be a source of radon escaping back into the building. To avoid this occurrence, radon fans must be installed outside or in the attic. They can be installed in the garage if there is no living space above the garage. Placing the fans outside the conditioned space would seem to ensure there would not be a problem with re-entrainment. There have, however, been cases where fans or piping above the fan was not sealed completely and radon was leaking back into the building. This has happened where a transition to aluminum downspout was used and the joints were not adequately sealed. The most critical locations for leaks are near the bottom of a building especially if there is little air change happening near the leaks. Airflow in most buildings is “in” at the bottom and “out” at the top. If the post mitigation radon results are above the guideline check the fan and any fittings above the fan for leaks.

3.1.6.5 Mining Radon

Occasionally an HVAC system will be mining radon from the soil. If radon measurements made in multiple locations all have very similar readings, radon mining may be taking place. A radon sniffer or grab sample measurement may need to be made of any suspicious duct runs in order to determine which if any return trunk has this condition. If a duct run is mining radon then either the source has to be carefully sealed or that particular trunk run needs to be eliminated. New returns would need to be installed as needed to balance the system. It is always best to consult an experienced HVAC designer before modifying an HVAC system.

3.2 OTHER DEPRESSURIZATION METHODS

3.2.1 Sump or Interior Drain Tile Depressurization

RMS 14.2.7 If radon vent pipes are installed in sump pits (with sump pumps), the system shall be designed with removable, flexible couplings to facilitate removal of the sump pit cover for sump pump maintenance.

3.2.1.1 Basement De-Watering Issues

Wet basements range in severity from window well leaks during hurricane conditions to actual streams that flow constantly through the basement during the rainy season. It’s important to understand the basic flow of water into a basement. There are two major types of water problems. The most common is the rising water table. When it rains the water entering the soil, flows down to the level of the excavation of the house and then begins to rise. If a sump pump is installed it will catch the rising water table and pump it down before it reaches the top of the basement slab. The two primary issues with sump pumps is; can they keep up with the rising water table and can the water under the floor get to the sump before it backs up, onto the floor. If there has been occasions when the sump cannot keep up or the sub-soil is not porous enough to transfer the water then a second sump may correct the problem. If the sub-slab material is compacted soil then it may be necessary to actually excavate a trench either partially or all the way around the perimeter of the basement and replace the soil with a perforated pipe set in gravel. This is the most common type of basement de-watering.

The second type of water problem involves the basement foundation. In this case water is entering the basement from cracks in a poured foundation or into the cores of a block wall foundation and either leaking into the basement or causing discoloration and dampness on the inside surface of the block wall. This condition is most typically seen in the corner of the foundation. If this is the case, there is almost always a rain gutter downspout on the outside of the foundation, dumping excess amounts of water at this corner. Considering that as much as half the square foot area of the roof is dumping all the rainwater it collects next to one corner of the foundation, it’s no wonder there is a water problem here. If this appears to be happening, inform the homeowner that he has this condition and he needs to divert the rainwater from the gutter well away from the house. The grading around the house may also be aggravating the situation.

3.2.1.2 Base-Board De-Watering System

RMS 14.5.5 When installing baseboard type suction systems, all seams and joints in the baseboard material shall be joined and sealed using materials recommended by the manufacturer of the baseboard system. Baseboards shall be secured to walls and floors with adhesives designed and recommended for such installations. If a baseboard system is installed on a block wall foundation, the tops of the block wall shall be closed and sealed as prescribed in paragraph 14.5.3.

There are a number of different methods used to install basement de-watering systems. One method that was popular a few years ago used a plastic baseboard that was glued to the floor around the basement. Holes were drilled in the bottom of the block wall to allow water to flow around the perimeter of the basement inside the baseboard molding to a sump pit. Sometimes in older houses this method will be done using a 4" high brick wall on top of the slab to divert the water. If the house needs re-mediation with this water system left active, try installing a standard sub-slab suction system if there is some porosity under the slab. The sump pump however will need to be sealed with a one-way drain in the lid to catch water diverted by the baseboard system. There are a number of variations of these one-way drains. Sometimes a larger drain is necessary with an 1-½ inch ball float that is less likely to become clogged with dirt.

Fig 3-27 De-Watering System

Make sure the drain can be cleaned. If the open holes in the block wall are a significant radon source or the sub-soil is very tight it may be necessary to use the baseboard system as a suction channel. A radon vent pipe would be routed into the baseboard. The top and ends of the baseboard molding would need to be sealed and a sealed channel installed over to the sump pit. This channel would allow water to get into the sealed sump pit without exposure to the basement.

3.2.1.3 Sealing a De-Watering Trench

The most common basement de-watering technique is to chop out the concrete floor and dig a trench either completely around the perimeter of the basement or along the problem foundation walls. A perforated pipe is laid in a bed of clean stone inside the trench. A new concrete slab is installed on top of the gravel and perforated pipe. The edge of the concrete adjoining the foundation wall is either poured right up to the wall or a ¾" to 1" channel is left open. The idea is that any water running down the inside of the foundation would flow into the trench. Some de-watering installers now place a ¾" thick corrugated plastic strip around the perimeter against the foundation. If the foundation wall is constructed of block then each individual core or block will typically have a ½" to ¾" hole drilled below the top of the slab. These holes drain any water that accumulates inside of the block wall. If there is an exterior doorway the waterproofing company may lay a drainage gutter into the floor in front of the door. The perforated pipe laid in the trench will be routed to one or two sump pumps. If the de-watering system can be sealed it may only require one suction point. It can be a real problem if the drainage system cannot be sealed because finished walls now cover the openings.

The Mitigator can use the perforated pipe as a collection pipe for his radon system but the openings into the waterproofing system need to be sealed. If a single radon pipe is connected into an unsealed drain tile it will draw all the air it can handle from the first 10 to 20 feet of waterproofing trench and then have little impact after that. In addition the system is drawing almost all of its air from the basement, thus causing the basement to be more negative. This could cause a back drafting problem. In order to minimize the affect of leakage and maximize the PFE, multiple suction locations may need to be installed with each one dampered to allow balancing of the airflow. This will still predominately draw air from the basement but at least the system effectiveness is maximized. An alternative, if there is good gravel under the slab, is to install a center suction hole to more equally draw from the perimeter canal drain that can't be sealed.

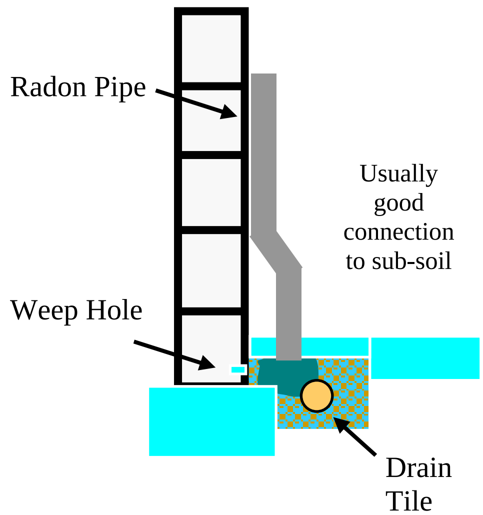


Fig 3-28 Basement De-watering system

It's a similar but different problem if the basement has block walls that have drainage holes drilled into their cores. The open perimeter channel or alternate corrugated drainage board needs to be sealed above the drain holes so they can still drain back into the trench system. If the corrugated plastic is used it can be sealed above the drain holes with backer rod and urethane caulking or expanding foam. The plastic corrugated baseboard can also be first trimmed lower if the block drain holes are below the top of the slab.


Fig 3-29 Aluminum covering canal drain

If there is an open canal drain, insert closed cell backer rod into the canal so that the drain holes are open under it. The backer rod is then caulked along its two edges to hold it in place. If the backer rod will cover the holes an alternative method is to single bend aluminum flashing in eight-foot strips. Pre-caulk the edges of the aluminum and then press it in place against the foundation wall and concrete floor so the drain holes are behind the flashing, under the upper caulk joint.

If the block weep holes are open and exposed to the radon suction system then any other openings in the block wall need to be sealed. This would include sealing any openings along the top of the wall. Methods for sealing the open block tops will be discussed in the block wall depressurization section. Keep in mind that block wall foundations with exterior brick veneers tend to have openings behind the brick that are open to the block cores and these openings cannot be easily sealed.

The sump pit or pits also need to be sealed and a new floor drain installed in the sump coverlid if the lid is flush or below the top of the concrete floor. As an alternative the floor drain can be installed beside the sump pit or other location that has good sub-slab drainage. The drain needs to be installed so that it is easily removed for cleaning. One of the available floor drains has a perimeter rubber sheet that allows it to be installed without caulking.

Fig 3-30 one way floor drain

If there is an open gutter system installed below an exterior door it will be necessary to seal most of the gutter with aluminum flashing and caulk. A one way drain can be installed into the gutter to catch most of the water that might come down the exterior stairs.

Some waterproofing companies will void the system warranty if the openings into the de-watering system are sealed. Since the radon system effectiveness could most likely not be warranted if no sealing is done and the energy penalty and risk of back draft is increased, a homeowner may have no other choice but to proceed with having the openings sealed. If done correctly the sealing, however, will rarely affect the system waterproofing performance.

3.2.2 Exterior Drain Tile Depressurization (EDTD)

Some buildings are constructed with an exterior loop of drain tile set into a gravel bed down at the footer level. Some mitigators have had success with routing a radon pipe from this perimeter drain to a radon fan above grade that is then vented above the house eave. EDTD is, however, not very popular because of the extra work required to excavate down to the footer drain on the outside of the house. In addition there are a number of concerns with this method.

The footer drain may not extend around the whole house. Sometimes the drain is not installed properly or is crushed during the backfilling process. If the drain is not protected by gravel and a drainage filter, silt can enter the drainpipe and clog it up.

RMS 14.2.9 When a radon mitigation system is designed to draw soil gas from a perimeter drain tile loop (internal or external) that discharges water through a drain line to daylight or a soak away, a one-way valve, water trap, or other control device should be installed in or on the discharge line to prevent outside air from entering the system while allowing water to flow out of the system.

If the house is built on a lot with a sloped grade there may be a drain to grade that is open that allows excessive airflow into the system. This can be remedied by install a one way flapper valve in the end of the pipe that is draining to grade. If the house is older, this drain to grade is usually completely covered over and cannot be located. A high air-flow situation can also happen if the perimeter footer pipe is drained into a dry well.

A final concern is whether EDTD will address the primary radon entry route, the interior floor wall joint. If the soil is porous and there is a reasonable depressurization of the exterior footer drain then the PFE should extend to the inside. If the soil is more clay like or impervious then it may not have an effect. After EDTD has been installed the PFE should be measured on the inside of the house. EDTD can work well but the concerns with clogging; PFE, leakage, and additional required work make it a second choice over sub-slab depressurization. There may be occasions however where placing a radon pipe inside a finished basement or slab area is not acceptable. In this case EDTD may be the best option. A phased approach might be considered where the EDTD is done first and then the building is tested for radon. If needed, the second phase would include installing interior radon piping using a second radon fan or possibly using the EDTD radon fan.

3.2.3 Sub-Membrane Depressurization (SMD)

Sub-Membrane Depressurization refers to installing a system that creates a negative pressure under a membrane that is covering a dirt or gravel floor. This system is used to treat bare dirt or gravel covered crawl spaces rather than the alternative of installing gravel and a concrete floor in the space. If there is an adjoining basement then the SMD system is usually connected to the basement SSD system.

3.2.3.1 Crawl Space Membranes

RMS 15.9 Plastic sheeting installed in crawlspace as soil-gas retarders shall be a minimum of 6 mil (3 mil cross-laminated) polyethylene or equivalent flexible material. Heavier gauge sheeting should be used when crawlspaces are used for storage, or frequent entry is required for maintenance of utilities.

The least expensive, acceptable material to use is 6-mil poly ethylene sheeting which comes in rolls 16', 20', and 24' wide by 100' long. We will use the term poly to refer to six-mil polyethylene sheeting. Poly comes in thicker dimensions. Ten-mil is a common size used in commercial work. Poly comes in clear, black or white rolls. Clear has the advantage of being able to see how thoroughly the caulking is sealing the poly. Some of the radon supply companies also stock a white or black 3 mil cross-laminated poly that is stronger than the 6-mil poly. Even though it is half the thickness of 6-mil poly it is more durable. A third material to consider, especially if there is going to be traffic in the crawl space, is EPDM rubber sheets which are available in 45 mil and 60 mil thickness (versus 6 mil poly). EPDM's primary advantage is excellent durability. The negative with EPDM is its much higher cost ($ 0.45/sf versus $0.08/sf for 6mil poly) and it is very heavy which limits how large of an area a sheet can be spread. Sometimes EPDM is used as a runner on top of poly. EPDM is the material of choice if there is a walk in dirt floor storage room or crawl space that will be used for storage.

Fig 3-31 EPDM membrane

3.2.3.2 Installing the Membrane

In order to properly install a crawl space membrane, stored items and debris in the crawl space need to be removed. In some houses this could be a major job. Be sure to specify in the contract who is responsible for moving and disposing of the crawl space materials.

Fig 3-32 Crawl Space debris

Sealing the edges of the crawl space membrane allows complete PFE extension from a single suction point and reduces the amount of air necessary to accomplish this. Most houses with crawl spaces also have a basement. Sealing the crawl space membrane allows the mitigator to damper down the amount of air drawn from under the membrane and thus maximizes the PFE achieved by the other suction holes.

The nastier the crawl space the more protection needs to be used. A properly fitted respirator provides protection from fiberglass, dust, and rodent droppings. A full body Tyvek type disposable suit minimizes the above products getting rubbed into clothing and spread into the truckcab or brought back home. There should always be waterless soap and a large water jug in the job truck to allow frequent hand cleaning.

Fig 3-33 CSM dampered suction

To install a crawl space membrane, first measure the dimensions of the crawl space. Layout the sheets so that overlapping joints are centered at piers or other obstructions. The sheets are cut to a larger size than needed before they are brought into the crawl space. Since the layout is most likely not a square, be careful not to mix up the orientation of the rectangle or the membrane will need to be spun around while crawling on your stomach. Once the membrane is oriented correctly, the excess material around the edges and piers needs to be trimmed. Be sure to push the membrane all the way into the corner before trimming and don’t forget to leave room for the radon pipe. The membrane should be lapped up the foundation around the perimeter about 4 to 6 inches. If the poly is lapped too high up the foundation wall, it will fall down from its own weight, even if it is caulked. If it is lapped up the wall too little, it will pull off the wall as you back away. Ideally the membrane should be tucked all the way into the bottom corner of the foundation before it turns up.

3.2.3.3 Crawl Space Piping

The crawl space radon piping should be installed after the membrane is laid down but before any caulking is done. The membrane reduces the dust and possibility of breathing rodent dropping fumes or other harmful products.

Fig 3-34 Damper

The crawl space suction points are usually routed from a tee fitting installed in the radon piping that is routed along the ceiling of the crawl space. The down pipe is routed through the membrane into another tee fitting. Cut an X to fit the tee fitting under the membrane. Fold up the points of the X on the down pipe and wrap duct tape around the membrane points. It is usually not necessary to install additional piping below the membrane. It is a good practice to either size the pipe for the anticipated airflow or use a metal damper in the pipe to adjust the airflow. Note in the chart below that a dampered four inch pipe has the same airflow as a 1 and one half inch pipe. CSM depressurization systems tend to move a lot of air, especially if the membrane is difficult to seal or the foundation wall is block. The advantage of a damper is it allows adjustment after the system is running. An advantage of downsizing the radon pipe rather than using a damper is that it tends to be quieter, although this is usually not an issue in a crawl space especially if the ceiling is insulated.

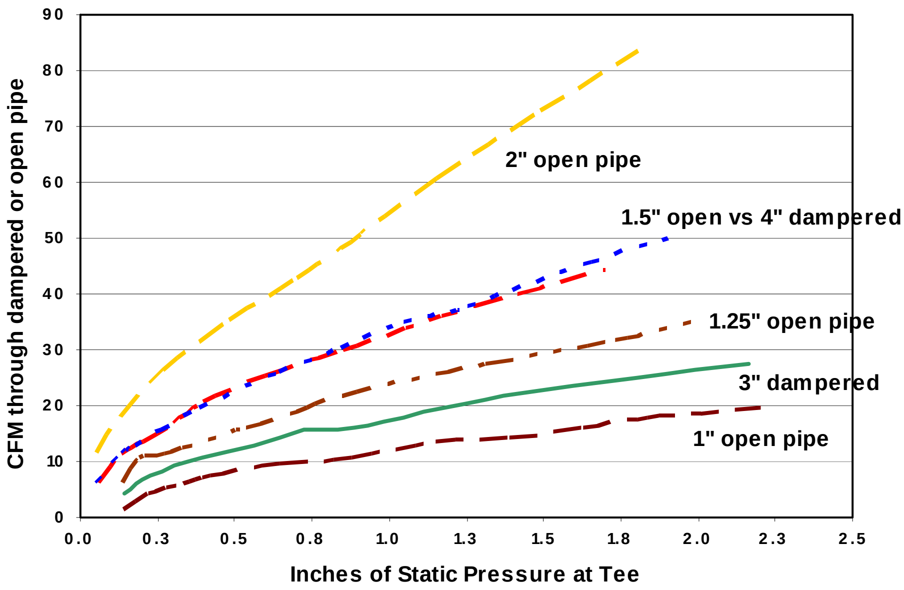


Fig 3-35 Dampered vs small pipe airflow

3.2.3.4 Sealing the Membrane

RMS 14.5.2 Openings around other utility penetrations of the slab, walls, or soil-gas retarder shall be cleaned, prepared and sealed in a permanent air tight manner using compatible caulks or other sealant material.

Piers or plumbing pipes in crawl spaces are best sealed by cutting an x pattern in the membrane so that the pointed corners can be lapped up on the center of the pier or pipe.

Although duct tape does not stick to poly, it will stick to itself. If the pier or pipe is not too large, the duct tape can be wrapped around the pointed edges of the membrane and over itself. If the pier is large, the membrane will need to be caulked to the pier or attached to the pier with furring strips.

RMS 15.10 Any wood, used in attaching soil-gas retarder membranes to crawlspace walls or piers shall be pressure treated or naturally resistant to decay and termites.

The most permanent method to attach a membrane to a foundation wall is to attach wood furring over the membrane using masonry nails installed with powered nail guns. Be sure to wear eye and ear protection when using this equipment. The membrane is then trimmed along the top edge of the furring and a bead of urethane caulk is applied to the edge.

A number of spray adhesive products are available that adhere poly to clean surfaces. Unfortunately most of these products outgas fumes that are not acceptable in the confined area of a crawl space.

Fig 3-36 CSM using 6 mil poly

A common method that requires more caulk but no furring is to apply a generous bead of caulk to the foundation and then rub the membrane into the caulk. Poly in particular is a difficult material to bond to. Urethane caulk will adhere to the poly reasonable well although the poly can be pulled away after it has cured if enough force is used. Construction adhesive is another material that can be used to seal poly to the foundation wall. Caulk cannot be expected to adhere to dirty surfaces. It may be necessary to first scratch the surface with a wire brush. If caulking is used, a generous amount should be applied to the surface of the foundation. Clear poly allows visibility of the thoroughness of the of the sealing with the caulk. Be sure with both methods to push the membrane to the bottom edge of the foundation before attaching it to the wall. The caulking method requires careful body movement to prevent the membrane from being pulled off the wall. The necessary extra folds at corners will require extra caulking. A complete inspection of the perimeter caulking needs to be done before carefully leaving the crawl space. In both cases, care needs to be taken with caulking guns and disposing of empty caulk tubes that always seem to manage to leave caulk right where a hand or leg is placed.

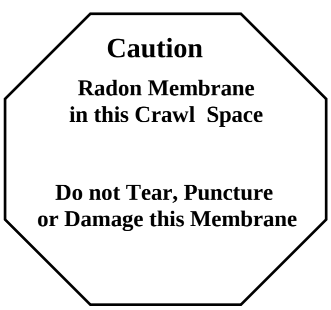


Fig 3-37 sign at entrance to CSM

RMS 14.5.6 Any seams in soil-gas retarder membranes used in crawlspaces for sub-membrane depressurization systems shall be overlapped at least 12 inches and should be sealed. To enhance the effectiveness of sub-membrane depressurization systems, the membrane should also be sealed around interior piers and to the inside of exterior walls.

Overlap membrane seams at least 12 inches. Run a bead of caulk between the two sheets and then rub the top sheet over the caulked area to bind them together. An indispensable tool for crawl space work is a headlamp. The headlamp leaves both hands free. Wherever one looks, there's light. They are available at quality sporting goods stores. Place a label at the entrance to the crawl space that warns anyone planning on entering the crawl space that they need to be careful not to tear or disturb the membrane.

3.2.3.5 Asbestos and Crawl Spaces

RMS 12.2.9 In any planned work area where it is suspected that friable asbestos may exist, radon mitigation work shall not be conducted until a determination is made by a properly trained or accredited person that such work will be undertaken in a manner which complies with applicable asbestos regulations.

If there is suspected asbestos in the crawl space or basement it would be prudent to have the asbestos removed first. No work should be done in these areas, unless a trained asbestos contractor declares the work area safe.

3.2.4 Block Wall Depressurization (BWD)

It most situations block wall depressurization is considered a secondary technique compared to sub-slab suction. There are houses, however, that still have elevated radon levels after a sub-slab depressurization system has been installed or where it is deemed prudent to install block wall depressurization right from the start. The foundation wall that is contributing a significant amount of radon to the basement usually has a concrete slab adjoining it that is trapping soil gas. If the adjoining slab is near or above the top of the foundation, it is more likely to be a problem. Although most buildings have the outside of the foundation waterproofed, it rarely is waterproofed up near the top of the foundation. In addition some walls, like the foundation wall adjoining the garage may have no waterproofing or parging done at all.

3.2.4.1 Installing BWD Piping

There are two ASD methods for treating foundation walls. One method is to depressurize the inside cores of the block wall. Another method is to prevent the radon from entering the block wall in the first place by depressurizing under the adjoining slab. This second method is generally the better approach because the block wall is often difficult to seal and it takes less airflow to depressurize the adjoining slab. If there is no adjoining slab and the block wall is determined to be a significant source then the only choice may be to install block core suction.

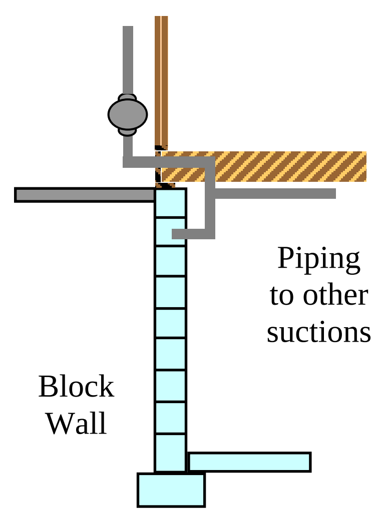


Fig 3-38 Block wall suction

Block wall depressurization is a fairly easy installation. The inside surface of the block wall is core drilled so as to expose a whole block core. A 2, 3 to 4 inch radon pipe is sealed into the opening. The radon pipe should include a damper or be downsized to control the maximum amount of airflow. The PFE is then determined by measuring the pressure difference at varying distances from the suction point.

In general most block walls are open inside from core space to core space. In practice the PFE from a single block wall suction is rarely extended the whole length of the foundation wall because of leakage or a vertical row of solid filled cores. The most common leakage is open cores or joints at the top of the block foundation wall. Even if the top course has solid cores there is often an opening in the joint between the blocks. If the house has a brick veneer there is almost always an air space behind the bricks with openings into the top of the block wall. Sometimes the block wall surface itself maybe very porous, especially if it is constructed out of cinder blocks.

In order to maximize the PFE, multiple block wall suction holes may need to be installed. These suction points would need to be dampered down to balance the airflow. One method that has been successful for some mitigators is to install 1.5 inch jumper pipes from the sub-slab into the block wall. This would only be considered if the sub-slab had a strong pressure differential reading (above 5 Pascals) and the slab suction was not located too close to the proposed block wall suctions. To install these jumpers, core a 2" hole in the block wall close to the floor and an adjacent 2 inch hole in the slab just beyond the footer. A small section of 1.5" pipe is routed from the slab to the block wall. After each small jumper pipe is installed, the PFE created by the jumper needs to be checked to determine how many additional jumpers might be required. Recheck the sub-floor pressure to make sure it still has at least 1 to 2 Pascals of negative pressure. Each of these 1.5 inch jumper pipes is moving less than 10 cfm if the sub-slab has less than 30 pascals of negative pressure.

3.2.4.2 Sealing Block Wall Tops

RMS 14.5.3 Where a Block Wall Depressurization (BWD) system is used to mitigate radon, openings in the tops of such walls and all accessible openings or cracks in the interior surfaces of the walls shall be closed and sealed with urethane or equivalent caulks, expandable foams, or other fillers and sealants. (See paragraphs 15.5 and 15.6.). Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

There are a number of different ways the openings in the top of a block wall foundation can be sealed. The openings can be filled with newspaper with expanding foam installed on top of it. However, with urethane foam, there are often small gaps in between

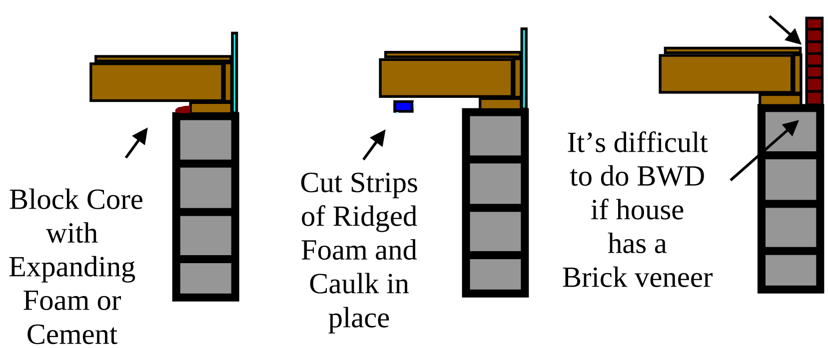


Fig 3-39 seal options for block wall tops the foam that are still open.

Another method is to rip strips of rigid urethane foam sheeting or extruded foam boards into the exact width of the space at the top of the block wall foundation. Each strip can be cut into 4-foot lengths for convenience. A bead of urethane caulking would be applied around the edges of the insulated board and then the whole piece would be placed over the block wall openings and pressed into place. This method works well, but any wiring in the way has to be moved first.

Any holes into the block wall should be sealed. If the block wall is made with cinder blocks, the surface of the wall is also typically very porous. Although it is beyond the scope of most mitigation jobs, it would be helpful to paint the surface of the block wall. Any interior foundation wall damp proof coating would be adequate.

3.2.4.3 Sealing Block Walls

There are two generic types of blocks used for block walls, cinder blocks and concrete blocks. In general cinder blocks are considered very porous. One EPA research project found the porosity of a single cinder block to be equal to a 1/4 inch drilled hole. This is a small amount of leakage until the number of blocks in a typical foundation is taken into consideration. Coating a cinder block wall with any material designed for this use will significantly reduce this leakage and extend the PFE. There may also be concerns with backdrafting or inducing additional radon entry because of the increased negative pressure from the loss of interior air. Coating wall will also reduce these concerns.

3.2.5 Slabs

3.2.5.1 Sub-Slab Depressurization of Adjoining Slabs

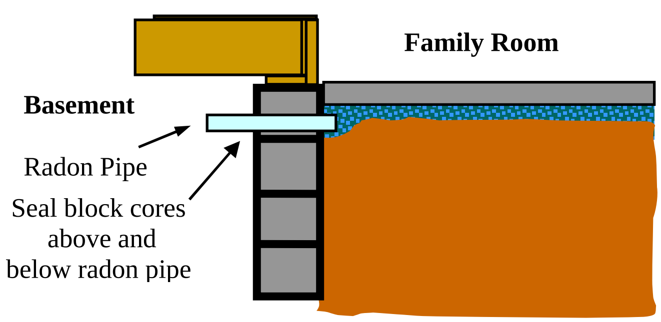


Fig 3-40 Adjoining slab suction

To depressurize the adjoining sub-slab of a basement foundation, core all the way through the poured or block wall. Be careful to locate the cored hole below the adjoining slab but not too far below. When drilling through a block wall, try to drill through the center of the core for easier drilling. After cleaning out the sub-slab, stuff loose fiberglass into the block wall cores above and below the hole to minimize leakage from the block wall. Insert the radon pipe beyond the fiberglass. Seal the radon pipe into the block wall foundation. Do not forget to add a damper to the pipe.

3.2.5.2 Stem Wall Depressurization

Many people have the misconception that a slab on grade house will not have a radon problem because there is no basement. In reality it has all the necessary components. There are openings through the slab from plumbing block outs to expansion cracks. There is heated interior air that induces a stack effect and inside negative pressure in comparison to the soil under the slab. And there obviously can be radon in the soil under the slab. Typically these types of buildings are completely finished inside. In order to install a radon sub-slab system there are usually two choices, install the suction in a closet with the radon fan in the attic if it is one story building or install the suction point from the outside with the fan outside and the exhaust vented above the roof line. The outside routing is usually called a stem wall depressurization because the foundation is not eight foot tall but rather just enough courses of block or poured wall to put the footer below the local frost line. The suction point could be into the block wall or through the stem wall and into the sub-slab material. This is a preferred method because there is usually a void space in this location caused by the settling of the backfill and the block wall cores may have been filled or have excessive leakage.

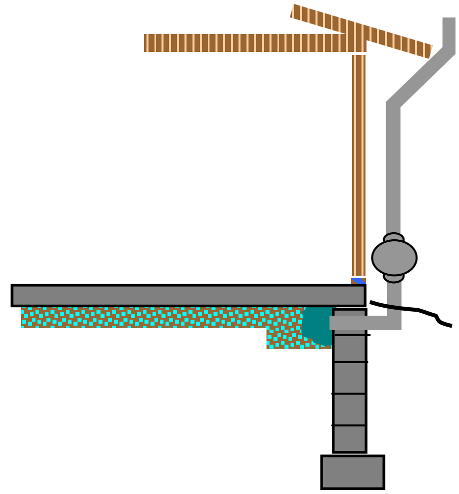


Fig 3-41 Stem wall depressurization

The main concern with this set up is the same as SSD, leakage and sub-slab porosity. If additional suction holes are required, install a tee fitting. Piping could be buried in a hand dug trench around the outside of the foundation to a second or third suction hole. Obviously cement patios and landscaping shrubs may limit how far the second suction hole could be located from the first suction hole. In some cases it will be necessary to install a second fan because piping cannot be routed to the necessary locations or the amount of system airflow and pressure drop in piping runs is too restrictive to be successful with one fan.

Even if the entire system is located outside an indicator of system performance needs to be installed. One choice is to run heavy duty tubing from the radon piping, below the fan, through the exterior house wall to a u-tube gauge mounted on the finished wall of the house. An alternate is to mount the u-tube or system operational gauge or light inside a protective box that has a view port or visible system indicator lights on the exterior wall near the radon fan. Any equipment installed outdoors needs to be weather resistant.

3.2.6 Crawl Space Depressurization (CSD)

There are occasions when a crawl space is discovered with a dirt floor that is too tight a space to get into. These types of crawl spaces are often

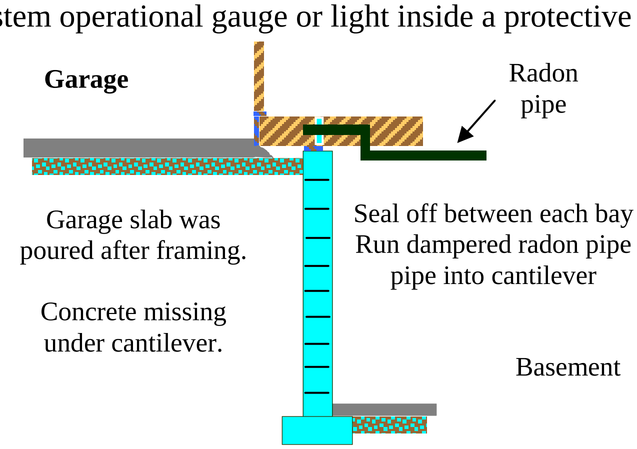


Fig 3-43 Suction to garage cantilever

found in older city row homes or farmhouses. Occasionally this condition is found in new homes where the builder cantilevered the deck into the garage and then poured the garage slab without cementing under this cantilever. In another situation there may be a crawl space that has no access to it and it can't be determine if it has a concrete floor. In all of these cases the best choice is to depressurize the whole crawl space. This can only be done if the crawl space does not have significant leakage. Any exterior vents into the crawl space will need to be sealed.

3.2.6.1 CSD Sealing

RMS 14.5.8 When crawlspace depressurization is used for radon mitigation, openings and cracks in floors above the crawl-space which would permit conditioned air to pass out of the living spaces of the building, shall be identified, and sealed in a permanent manner. Sealing of openings around hydronic heat or steam pipe penetrations should be done using noncombustible materials. Openings and cracks that are determined to be inaccessible or beyond the ability of the contractor to seal should be disclosed to the client and included in the documentation.

Fig 3-42 Cantilever into a garage

All openings between the crawl space and the basement or between the crawl space and the room above it need to be sealed. If the floor joist between the crawlspace and basement are open, foil faced rigid or closed cell insulation can be cut to fit between each bay. A bead of caulk needs to be applied around the perimeter of the insulation boards. Sometimes it takes creative sealing techniques to seal around wires, plumbing and heating pipes. If the space to be sealed is small it can be stuffed with loose fiberglass or backer rod and then coated with expanding urethane foam or caulking. Caulking does a better job but sometimes expanding urethane foam is the only choice.

3.2.6.2 CSD Piping

It is a good idea to damper the radon pipe that is routed into the crawl space. After the sealing is completed, drill a small hole into the crawl space and measure the negative pressure induced at different damper positions. Check the affect the damper position has on other slabs the radon system is connected to. Try and get at least a measurable negative pressure of 0.5 Pascals or better in the crawl space. It is sometimes not possible to get much if any measurable negative pressure because of leaks into the crawl space that can't be sealed.

3.3 SEALING

The EPA has funded research projects to evaluate sealing as a stand-alone mitigation technique. In general, especially when results are checked months or years later, sealing has not consistently reduced radon levels below the EPA guideline. This lack of consistent long-term performance is due to a number of factors. Radon, being only an atom in size, can move through openings that aren't even visible to the eye. Basements sometimes have very little air change, which requires very little radon entry to maintain levels above the EPA guideline. Sealing materials over time can degrade, or lose some of their adhesion to the slab, allowing small fractures in the sealant. If the radon is from a nearby source and the slab is sealed, radon levels under the slab tend to climb significantly higher. The flow is reduced but the radon levels in the flow are correspondingly higher. Sealing may tend to be more effective if the soil below the house is very porous. Sealing a slab laid over porous soil may tend to raise the flow of soil gas coming from a distance without significantly increasing the radon level under the slab.

Sealing does however play a critical role in the performance of almost every active soil pressure or depressurization system. There can be a ten-fold increase in the strength of the PFE measurements made before and after sealing even if only a small perimeter crack is sealed. There could also be enough air leakage from unsealed cracks, especially if there is good stone under a slab, to induce back drafting or causing an increased or new radon flow from an area not influenced by the PFE. If there is good aggregate under the slab, sealing larger cracks is important but smaller cracks are usually not critical. If, however, the sub-slab soil is tight, then sealing even very small cracks can make a significant difference with the strength and area of PFE because there is such a small amount of system induced airflow under the slab. In this case any loss of air pressure from even small leaks can be significant.

RMS 13.2 All radon mitigation systems shall be designed to avoid the creation of other health, safety, or environmental hazards to building occupants, such as back drafting of natural draft combustion appliances.

3.3.1 Sealing Materials

3.3.1.1 Backer Rod

Backer rod is sold as either an open cell or closed cell flexible foam that is round or half round in shape. The closed cell foam is used because the open cell material is too soft. Backer rod up to 1-¼ inch diameter is sold in coils. Larger dimensions are usually sold in six-foot lengths. Backer rod is used any time there is a gap larger than ¼ inch that needs to be sealed. The correct size backer rod can be easily cut to wedge into different sized or odd shaped spaces. Urethane caulking is then applied over the backer rod, to hold it in place and permanently seal the opening.

3.3.1.2 Urethane Caulking

RMS 15.5 When sealing cracks in slabs and other small openings around penetrations of the slab and foundation walls, caulks, and sealants designed for such application shall be used. Urethane sealants are recommended because of their durability.

Permanent caulking is best done using a urethane-based sealant. Urethane sealants are available in a gun grade caulking, flow able grade caulking, and expanding urethane. Gun grade urethane is similar to most caulks except it is very tacky, slower to dry and very difficult to break lose or remove after it is fully cured. Flow able urethane is similar, except it has a molasses like consistency and must be installed into a trench or recession. If flow-able urethane caulking is installed on a floor crack it would spread across the floor. If the crack is open, flow able urethane caulking will slowly disappear down the crack, leaving the crack open.

3.3.1.3 Silicone Sealant

Silicone caulking is often used in mitigation systems as a crack sealer where it might be necessary in the future to break the caulked joint open. This would be the case with a sump pit cover. The sump pit lid needs to be sealed airtight but it may be necessary to open the sump lid to repair or replace the sump pump. Silicone caulking is ideal for this sealing. The sump lid would need to be mechanically fastened to the floor.

3.3.1.4 Expanding Urethane

Expanding urethane foams are used to fill openings too large to seal with caulking. They might be used to seal an open pipe, open block wall cores, or openings into a de-pressurized crawl space. In general it is still preferable to use a backer rod or other backer material and urethane caulking to seal larger openings rather than expanding foams.

3.3.2 Sealing Cracks

3.3.2.1 Sealing Perimeter Cracks

RMS 14.5.4 Openings, perimeter channel drains, or cracks that exist where the slab meets the foundation wall (floor-wall joint), shall be sealed with urethane caulk or equivalent material. When the opening or channel is greater than 1/2 inch in width, a foam backer rod or other equivalent filler material shall be inserted in the channel before application of the sealant. This sealing technique shall be done in a manner that retains the channel feature as a water control system. Other openings or cracks in slabs or at expansion or control joints should also be sealed. Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

Fig 3-44 Pre-cleaning perimeter

The perimeter needs to vacuumed or swept first. Newer homes often have a fragile concrete ridge around the perimeter that is left from the final smoothing out of new concrete. If this ridge is knocked down with a straight clawed hammer or scraping tool and cleaned up, the caulking is easier to install and less material is used. If the ridges are left in place, it takes more time and material and is not as professional a job. After the caulk is installed, it is best to wipe it down with a small piece of cardboard, backer rod or small piece of flexible vinyl floor tile. This drives some of the caulking into the crack for better sealing and adhesion.

If the perimeter has an extruded or expanded insulation around the perimeter it can be left in place and each edge of the material, if open to the sub-soil, sealed.

3.3.2.2 Sealing Center Cracks

Sweep or vacuum the cracks first. A small bead of caulk is laid on top of the crack. It is best to cut off a small part of the caulking tube tip at a 45-degree angle. Note the position of the cut angle in relation to the writing on the caulking tube to keep the angle properly oriented even when caulk covers the whole tip. The more carefully the caulk is installed over the cracks, the less caulk is needed to do a thorough job. After the caulk is installed, press it into the joint with a piece of cardboard or other flat material.

Fig 3-45 Wiping caulk flat

RMS 10.4 When the selected mitigation technique requires use of sealants or caulks containing volatile solvents, prior to starting work, the contractor shall inform the client of the need to ventilate work areas during and after the use of such sealants. Ventilation shall be provided as recommended by the manufacturer of the material.

Note: Many of the recommended caulks outgas organic vapors. Ventilation and respirators should be used according to the manufacturer's directions. Keep a box of inexpensive latex gloves available to avoid skin exposure to the many (possibly toxic) solvents used with caulks, glues and expanding foam products. Employees should be instructed to clean up with hand cleaner and water as soon as they have completed sealing work with urethane sealants. This is the only time urethane caulking can be easily cleaned up. Ventilation is especially important in regards to impacting occupants of the house. Always make homeowners aware of planned use of caulks and glues and recommend that they continue to ventilate the space for a day or two after the system is installed. Homeowners also need to be carefully instructed about the potential to track uncured urethane caulking into finished areas of their home.

3.3.3 Sealing Canals, Pits and Drains

3.3.3.1 Sealing Canal Drains

Fig 3-46 Installing backer rod

If the perimeter has a canal drain, it will need to be sealed. A canal drain is sometimes referred to as an open french drain or floating slab. During the installation of the concrete slab a continuous length of lumber or insulation strip is placed against the foundation wall. This board or insulation is removed after the concrete slab has set up, leaving a canal around the perimeter to collect water. Typically it allows any water caught in the canal to drain down under the slab. These perimeter drains are so open a person can sometimes slide their fingers below the slab. The recommended method for sealing the canal, if it is wider than a ¼ inch, is to install a closed cell backer rod. The backer rod can be sealed with either flow able or gun grade urethane caulking. If flow able urethane is used, the backer rod must be recessed into the canal below the top of the slab. Backer rod that has been cut the long way in half is often used with the flat side up. Flow able urethane is pumped on top of the backer rod with a caulking gun and will spread out over the whole backer rod. If gun grade urethane caulking is used, the backer rod is wedged into the canal just above the top of the slab so the front edge as well as the foundation edge can be easily caulked. An alternative method is to place full round or half round backer rod just below the top of the slab with the round side up. The front and foundation side are again caulked in place. Smooth the edges of the caulk by running a small piece of cardboard or other material across the surface of the caulk.

3.3.3.2 Sealing Large Slab Openings

RMS 15.6 When sealing holes for plumbing rough-in or other large openings in slabs and foundation walls that are below the ground surface, non-shrink mortar, grouts, expanding foam or similar materials designed for such application shall be used.

Fig 3-47 Sealing under a tub

Large openings in the slab such as a plumbing box under a bathtub or an unsealed area under an oil tank need to be sealed. A slab opening under a bathtub could be sealed by cutting a piece of ridged insulation board to fit and then wedging it into the space and sealing around its edges. Another more practical method is to fill the plumbing hole with stone from the suction pits up to the bottom of the slab. A one-inch layer of mortar cement is then smoothed out on top of this fill. If the plumbing under the tub needs to be repaired this one-inch layer of cement can be chipped out.

3.3.3.3 One-Way Floor Drains

RMS 14.7.1 If drains discharge directly into the soil beneath the slab or through solid pipe to a soak-away, the contractor should install a drain with a mechanically trapped drain.

Floor drains open to the soil will need to be modified. Sometimes it is impossible to determine if the drain is a problem without a radon sniffer. Keep in mind that the basement would need to be negative in pressure at the time the radon sniffer was being used to test if radon is coming from a floor drain. If there is water in the drain, then it is not likely to be a radon source. Any open floor drains should be checked for airflow after a SSD system is running. If there is air moving down the drain then it will need a one-way valve to reduce leakage into the radon system. If there is no apparent airflow it could still, however, to be a radon entry.

Fig 3-48 One way floor drains

There are a number of different drains available from the radon supply companies that are one-way valves. These drains allow water to drain, but restrict gas flow out of the sub-floor. The one-way floor drains are a good idea, but the one-way feature is also likely to get clogged with dirt. It is important to set up the one-way drains so they can be easily cleaned. It is preferable not to seal the drain into the floor with urethane caulking since this would preclude removing the drain for cleaning.

A new floor drain will need to be installed if a sump pit is being sealed and the pit is the only mechanism for draining water accumulated on the slab floor. The new floor drain can be installed in the sump pit cover if the top of the cover is flush or below the top of the slab. An alternative is to install a new drain in the concrete floor. This would require core drilling a 2 inch hole in the concrete slab. This drain may need to be installed next to the sump pit if the sub-slab drainage is poor. The drain could be installed anywhere in the slab if the sub-slab drainage is good. Try to locate the drain where the slab is sloped down or where there might be a future water problem, such as next to a water heater.

3.3.3.4 Sealing Sump Pits

RMS 14.5.1 Sump pits that permit entry of soil-gas or that would allow conditioned air to be drawn into a subslab depressurization system shall be covered and sealed. The covers on sumps that previously provided protection or relief from surface water collection shall be fitted with a water or mechanical trapped drain.

RMS 14.7.4 When a sump pit is the only system in a basement for protection or relief from excess surface water and a cover is installed on the sump for radon control, the cover shall be recessed and fitted with a trapped drain.

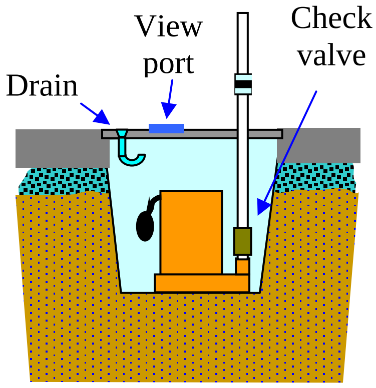


Fig 3-49 Sump pump components

RMS 15.7 Sump pit covers shall be made of durable plastic, or other rigid material and designed to permit air-tight sealing. To permit easy removal for sump pump servicing, the cover shall be sealed to the slab surface using silicone or other nonpermanent type caulking materials or an airtight gasket.

The sump pit needs to be sealed if it is open to the sub-slab. If there is no sump pump then a simple lid needs to be installed over the pit. The sump pit covers need to be durable, rot resistant, easy to trim and reasonably priced. The cover could be made out of stainless steel or aluminum. The cover is usually made out of either PVC plastic, marine plywood, Lexan or Plexiglas. Plexiglas, unless thicker than ¼ inch tends to shatter easily. PVC and Lexan make excellent covers. Lexan and Plexiglas allows easy viewing of the sump pit.

RMS 14.1.5 When installing radon mitigation systems that use sump pits as the suction point for active soil depressurization, if sump pumps are needed, it is recommended that submersible sump pumps be used.

RMS 15.8 Penetrations of sump covers to accommodate electrical wiring, water ejection pipes, or radon vent pipes shall be designed to permit airtight sealing around penetrations, using caulk or grommets. Sump covers that permit observation of conditions in the sump pit are recommended.

Fig 3-50 Sealing sump cover

A submersible sump pump should be used if a new sump pump is needed because the submersible can be sealed more thoroughly than a pedestal pump. The sump pump should always be installed with a check valve. If there is a functioning pedestal sump it does not, however, need to be replaced. The sump cover for a pedestal sump will need to be ripped into two sections. Half circles are cut out for the shaft, drain hose and float rod. The sump cover for either type of pump needs to be attached to the floor with Tapcons or similar anchoring bolts that can be removed. The openings around the perimeter of the cover, as well as any pipes, wires or shafts coming through the lid should be sealed with silicone caulking. The rod for a pedestal sink will need to be left unsealed.

Silicone caulking allows easy removal of the cover for servicing. If the sump pit cover is opaque, a clear plastic view port can be screwed into the lid that allows visibility of the water in the sump and an access port to check sump operation. This feature may be the only means to determine that a submersible sump pump is functional without having to unseal the cover from the floor.

3.3.4 Central Air Conditioner Condensation Drains

RMS 14.7.2 If condensate drains from air conditioning units terminate beneath the floor slab, the contractor shall install a trap in the drain that provides a minimum 6 inch standing water seal depth, or reroute the drain directly into a trapped floor drain or condensation pump.

Fig 3-51 Condensation trap

Fig 3-52 Condensation loop

A central air conditioner (A/C) can drain a gallon of water a day. It is not unusual to find the A/C is being drained below the slab with ¾ inch PVC piping rather than into an A/C condensation pump. An A/C condensation drain located on the return side of the furnace will draw radon directly out of the soil into the HVAC ductwork if the water trap dries up. To keep the trap from drying up in the non-air conditioned months, it should be at least six-inches deep. If the trap is less than this, as in the above photo, re-do the piping so that the trap is at least six inches deep. An alternative is to reroute the piping into a condensation pump the floor and seal the hole in the slab. If it is decided to just enlarge the trap, a pre-made six-inch deep condensation loop purchased from a radon supply company could be installed. If the condensation loop is installed, the P-trap in the line must be removed or a vent hole must be installed between the two traps. A double trap system will not drain unless there is a relief hole in between the drains. Do not forget to fill the trap with water if the A/C is not operating.

4.0 VENTILATION AND PRESSURIZATION

INTRODUCTION to VENTILATION AND PRESSURIZATION

Ventilation and Pressurization are not considered primary mitigation methods. In fact they are presently seldom used in residential mitigations. They are however important techniques to fully understand because radon levels are directly influenced by ventilation rates and pressure changes. Thoroughly understanding of these methods will add to a mitigators understanding of how ASD systems work. In some cases it also may be necessary or prudent for a mitigator to utilize these methods.

Emanation and Diffusion are considered to only rarely be a significant source of radon. There may be cases however where the radon levels are still elevated above the guideline because of either of these sources. Or there may be situations where small sources from Emanation or Diffusion are significant. This chapter includes a discussion of the factors involving Emanation and Diffusion.

4.1 VENTILATION

The effect of ventilation is not due to the amount of additional air but rather the percentage of increased ventilation. This means if there is very little ventilation in an area, it only takes a small additional amount of ventilation to have a significant affect. If there is already a lot of ventilation happening then it will take a lot of additional air to make a significant difference. The increased ventilation has to be from air with low radon levels, such as outdoor air, to decrease the area radon levels. Sometimes increasing the ventilation can also influence the rooms' pressure relationship to the soil and thus be an additional factor. If the basement has supply grills they may be closed. By opening these grills the ventilation is increased to the room and at the same time negative pressure is reduced. If the room is very airtight, the pressure may even be reversed to a positive pressure in relationship to the soil. This would effectively reduce the radon levels below the EPA guideline as long as the air handler is running. Another building might have an open return grill in the basement. If this grill is closed the ventilation in the area will be decreased but the increased negative pressure that it creates will also be reduced. In this case if the room was reasonable airtight one might assume that closing the return grill would reduce the pressure and the radon levels. If the room was not very airtight then it might actually decrease ventilation and thus increase the radon levels. Keep in mind that increasing the ventilation to the basement with main living air might reduce the basement radon levels but could increase the upper floor radon levels. Since significantly more time is spent on the main living floors than in the basement, the actually health risk to the occupants might be increased even though the basement radon levels are being reduced to below the guideline.

4.1.1 Outdoor Air for Combustion Appliances

In commercial construction, combustion appliances must often be located in a room that has a specified amount of opening to the outside to allow make up air to the appliance. Installing an outdoor feed to the oil burner or gas burner in residential construction is also a good idea, but it is not widely practiced. Some residential local or state codes do require all combustion appliances to have a supply of outdoor air. As a general rule, the outdoor air vent should be at least as large as the combustion appliance chimney. For example, if a large oil burner in an older house has an eight-inch chimney, there should be at least an eight-inch duct of outdoor air to the burner. The outdoor air duct does not need to be installed into the burner, just close to it. The outdoor air piping can be flex duct that is routed from a screened dryer-type outside hood. There should be ridged duct at the combustion appliance. It is a good idea to include a mechanical damper in case there is too much airflow.

4.1.2 Adding Outdoor Air to the HVAC

RMS 14.8.1 Modifications to an existing HVAC system, which are proposed to mitigate elevated levels of radon, should be reviewed and approved by the original designer of the system (when possible) or by a licensed mechanical contractor.

In the previous section about basement pressurization, we discussed adding a six-inch outdoor feed to the return ducts as a method to reduce or even reverse house depressurization. This might be a consideration if the owner would like to have some additional ventilation for the house and the HVAC system can handle the additional load. The effectiveness in regards to radon levels will be in relationship to how airtight the house is and how much of the day the air handler runs.

Fig 4-1 Outdoor air supply

4.1.3 Ventilate & Isolate a Crawl Space

RMS 14.8.2 Foundation vents, installed specifically to reduce indoor radon levels by increasing the natural ventilation of a crawlspace, shall be non-closeable. In areas subject to freezing conditions, the existing location of water supply and distribution pipes in the crawl space and the need to insulate or apply heat tape to those pipes, should be considered when selecting locations for installing foundation vents.

Crawl spaces that do not directly open into a basement need to have outdoor ventilation. If the crawl space has a dirt floor, it should have one square foot of ventilation for each 150 square feet of floor area. The crawl space needs only one tenth the amount of ventilation if the dirt floor has a poly vapor barrier or concrete floor or one square foot of outdoor vent area for each 1500 square feet area of concrete floor or poly cover dirt floor.

Crawl space vents can be added to meet these requirements if there is not the required amount of vent area. This might significantly reduce the radon levels in the home if there were no crawl space vents to begin with. If there is already some outdoor ventilation happening in the crawl space, adding additional vents will probably not reduce the radon levels significantly. Keep in mind that adding vents to a crawl space will require thermally protecting any HVAC ducts or plumbing water lines as well as insulating the floor above the crawl space.

Mechanically ventilating the crawl space with fan forced outdoor air will cause the crawl space to be the outdoor temperature and humidity level. The condensation that might accumulate in the crawl space in the summer may be a bigger problem than the heat loss in the winter. In general it is not recommended to fan force ventilation in a crawl space with outdoor air unless the house is located in a dry temperate area. Depressurizing a crawl space does not fall into this category since it is not attempting to use outdoor air.

4.1.4 Heat Recovery Ventilators (HRV)

The use of Heat Recovery Ventilators (HRV's) might be a consideration because outdoor air could be added to a building with as little as 25% of the energy cost. Heat recovery ventilators theoretically do not change building pressures because they are supposed to be designed and installed to bring the same amount of air into the building that they are exhausting. As this air is being exhausted in the heating season, it is passed through a heat exchange coil that allows its heat to be passed to the cooler outdoor air being pulled in from the outside. Thus the out flowing indoor air is preheating the incoming outdoor air during the heating season. If the interior air is 70 degrees, it will pre-heat 30-degree outdoor air to about 55 degrees. The typical HRV heat recovery is about 75% to 90%. During the summer months, the HRV can pre-cool the hot outdoor air about the same percentage.

Fig 4-2 Heat Recover Ventilator

4.1.4.1 HRV Design Considerations

RMS 14.8.3 Heat Recovery Ventilation (HRV) systems shall not be installed in rooms that contain friable asbestos.

RMS 14.8.4 In HRV installations, supply and exhaust ports in the interior shall be located a minimum of 12 feet apart. The exterior supply and exhaust vents shall be positioned to avoid blockage by snow or leaves and be a minimum of 10 feet apart.

RMS 14.8.6 Both internal and external intake and exhaust vents in HRV systems shall be covered with wire mesh or screening to prevent entry of animals or debris or injury to occupants.

The important consideration in the system design is to maintain the optimum airflow in both airstreams and to ensure good mixing inside the building. If the HRV unit is being installed to reduce radon levels, the inside supply and return ducts are typically only installed in the basement. There needs to be at least twelve feet between the inside supply grill, that is bringing outdoor air into the building, and the return grill that is exhausting indoor air to the outside. The outdoor intake and exhaust need to be at least ten feet apart.

RMS 14.8.5 Contractors installing HRV systems shall verify that the incoming and outgoing airflow is balanced to ensure that the system does not create a negative pressure within the building. Contractors shall inform building owners that periodic filter replacement and inlet grill cleaning are necessary to maintain a balanced airflow. This information shall also be included in the documentation.

Fig 4-3 Blocked HRV intake

Maintenance is important with HRV's. If the outside vents are not checked and cleaned once a year, the intake will typically become blocked with leaves or dirt while the exhaust will probably remain clear. This causes the system to unbalance the basement pressure towards a more negative condition that could raise the radon levels higher than if the unit was not operating. Interior filters inside the HRV unit also need to be cleaned or replaced at least once a year.

4.1.4.2 Sizing an HRV

To determine what size HRV to install, combine some measurements with some guesses. The first measurement needed is how much ventilation is taking place in the basement. The precise method for measuring ventilation in a basement is to release a stable gas that is not present in the air and then measure how long it takes to dissipate. Obviously this is a time consuming, expensive test. A blower door is a more practical but less accurate method. The blower door is installed in an outside doorway to the basement. If the door between the basement and the first floor is used, a few windows on the first floor or the first floor outside door would need to be open. The blower door has a pressure instrument connected to a pitot tube inside a calibrated orifice installed in the blower door. A fan with a variable speed motor pushes or pulls air through the orifice into or out of the basement. The change of pressure difference between the basement and the first floor or outside as compared to the amount of fan forced airflow can be used to determine the exact amount of leakage area of the basement. The total leakage area can then be used to approximate how much ventilation is taking place. This is not as time consuming or expensive as the gas decay rate measurement method but it is still requires costly equipment. Less expensive blower doors still typically cost from $2500 to $3500.

The last method to determine the ventilation rate is to just "guess". Most houses have leakage areas that range from 0.1 ACH to 1.0 ACH. The average new house is probably 0.25 ACH to 0.5 ACH. Basements would be expected to have less air change than the upper floors. The two factors to take into consideration is the apparent leakage and the type of HVAC equipment. Consider how much leakage the room or rooms have to the outside as well as to the upper floors. The leakage to the outside is more critical because outdoor air, with its low radon levels, has the greater impact on changing the radon levels. The mixing of air between the upper floors and the lowest level will also tend to reduce the radon levels in the lowest area although at a cost of raising the radon levels on the upper floors. If the HVAC is a forced air system, it will tend to not only change the pressure difference between the room and the soil, but it will also mix the air between the lowest level and the upper levels. Once again the air change rate in the basement could be anywhere from 0.1 ACH to 1.0 ACH.

To guess the ventilation rate of a basement or other room, assume an average ACH rate for its condition. This ACH rate is then multiplied times the cubic volume of the room or rooms to give a ventilation rate in cubic feet per hour, CFH. This number is then converted to cubic feet per minute, CFM, by dividing the CFH by 60 since there are 60 minutes in an hour.

$$ACH * CF = CFH \div 60 = CFM$$

Assume a basement has 0.25 ACH. Assume the basement is 30' by 40' by 8' high. The ventilation of the basement in CFM would be obtained by multiply all these together and then dividing by 60.

$$0.25 * 30 * 40 * 8 = 2400 \text{ CFH}$$

$$2400 \text{ CFH} \div 60 = 40 \text{ CFM}$$

The ventilation per minute is 40 cubic feet.

The performance of an HRV will be dependent predominately on how much the system increases the ventilation levels with outdoor air in the room being tested for radon. The reduction of a stable source pollutant is the inverse of the ventilation increase. In other words if the ventilation is doubled, the pollutant will be reduced to half its original level. If the ventilation is increased by a factor of ten, the pollutant will be reduced to a tenth of it's original level. The initial radon levels and the desired new radon level will determine the required amount of ventilation increase. Ideally the final radon levels should be less than 2 pCi/l. It is generally not practical to reduce radon levels that are above 10 pCi/l using ventilation increases. A decrease in radon from 10 to 2, a five-fold reduction, would require a five-fold increase in ventilation. If the present ventilation was 40 CFM then a five-fold increase would be 200 CFM. Since the ventilation from leakage does not change when the HRV is operating, assuming the HRV does not changing room pressures, the size of the HRV needs to be capable of supplying 160 CFM. The final ventilation rate then is 160 CFM from the HRV and 40 CFM from natural ventilation.

Most residential sized HRV's supply from 100 CFM to approximately 250 CFM. Since the effectiveness of an HRV is dependent on the ventilation increase. It will be more successful if the initial ventilation rate is low and the initial radon levels are also low. If the initial ventilation is already above 100 CFM, a typical HRV residential unit will probably only double the ventilation rate. If the radon levels are above 10 pCi/l the initial ventilation rate will need to be very low for an HRV to be successful.

4.2 PRESSURIZATION METHODS

Besides SSD there are two alternate methods of controlling radon entry, pressurizing the lowest level or pressurizing the soil.

4.2.1 Pressurizing the Lowest Level

RMS 14.3.8 The intakes of fans used in crawlspace pressurization, or in pressurizing the building itself, shall be screened or filtered to prevent ingestion of debris or personal injury. Screens or filters shall be removable to permit cleaning or replacement and building owners shall be informed of the need to periodically replace or clean such screens and filters. This information shall also be included in the documentation.

Pressurizing the lowest level makes sense because it is the other side of depressurizing the sub-soil. Actually it is more effective than sub-slab depressurization because it controls radon entry coming from the slab and the foundation. In addition it usually induces a higher ventilation rate. The air used to pressurize the space could come from the outside but it would need to be conditioned. It is common in commercial HVAC systems to have a percentage of the conditioned air coming from the outdoors. A residential home could be set up in a similar manner by installing a six-inch duct routed from the outside into the return duct of the HVAC system. When the house HVAC system is operating, a six-inch duct would bring in about 100 to 200 cfm of outdoor air. This would dilute the radon in the house and change the house pressure to more positive although it probably would not pressurize the basement unless the house building shell was very tight. This approach would require the HVAC air handler to run continuously all year which would increase the heating and cooling cost.

The HVAC air handler itself could be used to pressurize a lower level if there were supply ducts routed through the basement. In one EPA sponsored study a two story building with a basement used the HVAC air handler to pressurize the basement by installing a grill in the supply duct and carefully sealing leaks in the return grills and in the basement shell. The door at the top of the basement stairs might need to be weather-striped. The basement should be pressurized to one or two Pascals positive in relation to the outside. This or the previous option may not be acceptable to the homeowner because he must keep his air handler running 24 hours a day. The cost of running the typical 1/3 of a hp air handler blower motor can add $15 to $30 to the electric bill per month. The other concern is that homeowners may feel cold drafts in the heating season caused by the system circulating air when the heating elements were not being activated because the thermostat was within in its set temperature range.

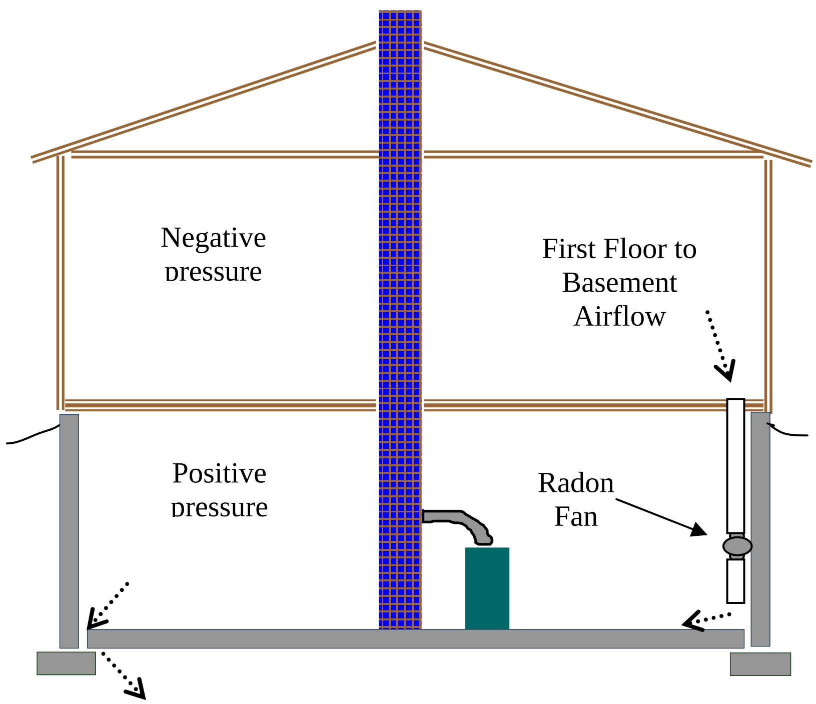


Fig 4-4 Basement Pressurization with first floor air

Another option that might be more acceptable is to use a standard radon fan to pressurize the basement. These fans are much more economical to operate. Noise however can become an issue. To minimize fan noise, install the fan near the floor of the basement in a less occupied area. Route flexible duct from the fan up to a floor grill on the first floor. Try to locate an inconspicuous location for the grill. One location that might work well is under the refrigerator. Adjust the fan airflow with a speed controller. As mentioned previously, sealing the leaks into the basement is critical. This method cannot be used if there are any natural draft combustion appliances on the main floor, such as a fireplace or gas water heater that might back draft. Keep in mind that any time the basement to first floor door is left open, radon levels will return to their previous levels.

Note that the pressure reading can be made between the lower level and the soil or the outside but it cannot be made to the upper floors unless the first floor windows or exterior doors are left open. The tighter the lower level can be sealed the less air required to pressurize the space. The amount of air required to pressurize can be tested with a standard radon fan installed in the door way to the lower level. The doorway would need to be sealed by taping poly around the doorway.

Fig 4-5 Checking basement pressure

4.2.2 Sub-Slab Pressurization

Pressurizing the soil is applicable in cases were the soil is so porous that standard sub-slab depressurization systems are at the maximum amount of airflow and still unable to create a complete PFE. Even in these cases there are still concerns with this method. If soil pressurization is used in a cold climate, the slab areas around the suction hole could become frozen. If in the heating season there is even moderate humidity in the areas where the radon piping is located, the radon pipes will sweat. The inlet to the system must be screened and needs to be kept clean. Any cracks or openings in the slab must still be carefully sealed. If the soil turns out to not be porous enough, then the system will strip the radon off the soil and divert it back into the basement through leaks that aren't sealed.

If the air for pressurizing the soil is taken from the outside, their needs to be a screen installed on the inlet that can be easily cleaned, otherwise the suction pit may clog up with leaves and bugs. The fan used for pressurizing the soil can be installed inside, since there is no concern about small system leaks. The piping inside the house should be insulated in cold climates to avoid condensing moisture. An alternate method to avoid the freezing problems is to use interior basement air to pressurize the soil. This will increase the heating cost, increase lower level negative pressure which could possibly draw radon in from the foundation and back draft any natural draft combustion appliances. In general, soil pressurization is only used in special cases.

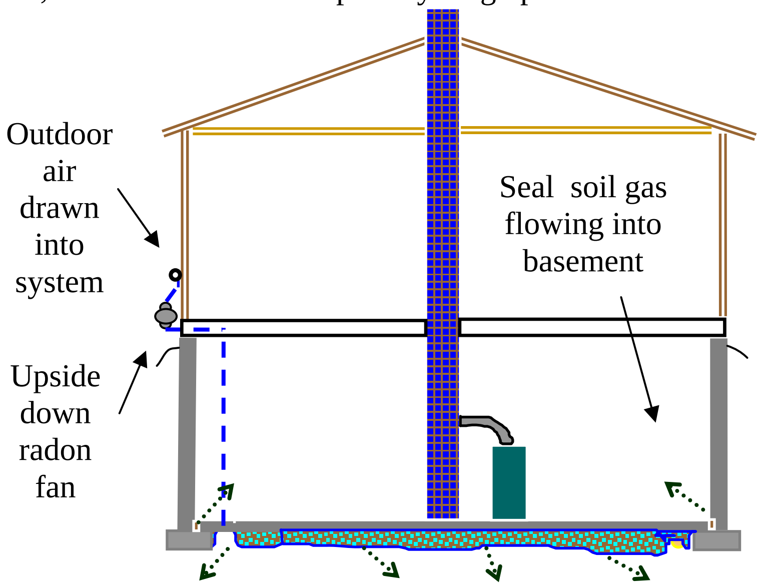


Fig 4-6 Sub-Slab Pressurization

4.3 EMANATION AND DIFFUSION

Generally, radon levels can be reduced to below 4 pCi/l by eliminating soil gas infiltration through the slab. Occasionally, however, there will be a complete negative PFE from a sub-slab suction system, which eliminates soil gas infiltration and yet there will still be elevated radon levels. Typically the levels are still elevated because the foundation walls are a significant source that is not being addressed by the sub-slab system. If the foundation is constructed of stone there might, however, be emanation of radon directly from the stones in the foundation. It is also possible that a significant amount of radon is diffusing through the floor slab if the radon levels are in the thousands under the slab. Radon diffusion through concrete is dependent upon concentration gradient difference across the slab. Note that radon can still be diffusing through the slab even though there is a negative pressure under the whole slab. Both of these possibilities are uncommon but can take place.

4.3.1 Emanation

4.3.1.1 Measuring Foundation Gamma or Radon

A measurement of the gamma levels adjacent to the foundation wall might determine that the foundation wall materials are suspect. This requires a Micro-R meter, which typically costs $1000 or more. In most areas of the country gamma levels range from 5 to 20 uR/hr. Be suspicious of a foundation wall if it was two or three time's higher uR/hr than the center of the basement. Another method for determining if a foundation wall is a significant radon source is to use a radon sniffer and take short grab samples from cracks or openings in the foundation. Be sure to check any foundation sections that might not have soil behind them. If these free standing walls have elevated radon levels inside cracks or openings then the foundation materials are a source. If a radon sniffer is not available, then individual passive detectors can be left at suspect locations and the results compared with the two detectors exposed at the same time in the center of the basement.

Fig 4-7 Micro-R Gamma meter

If it is determined that the soil behind the foundation is a significant source and there is a slab covering the soil or an inaccessible crawl space, it may be possible to bore a hole through the foundation and install a suction pipe from a basement sub-slab suction system. As with any multi-suction system, it may be important to install dampers in each individual suction location piping and then balance the flows.

4.3.1.2 Stone Wall Foundations

Stone foundations that turn out to be a significant radon source are very problematic. There are no easy fixes for this situation. The radon source will need to be either sealed in or captured and ventilated out. Sealing the entire inside surface of the foundation with a new waterproofing stucco coat or other waterproofing material may reduce emanation enough to have a significant influence. Unfortunately there has been very little testing of this method to have confidence that it will work. The alternate technique is to capture the radon coming off the foundation wall by building an air tight wall or membrane covering in front of the foundation and then drawing air from the space in between the barrier and the foundation. The labor and materials for this could be an expensive system. If a negative pressure could be induced inside this barrier, it would be a very effective method of capturing the radon.

4.3.2 Diffusion through a Slab

Generally, diffusion through the slab is not considered to be a significant radon source. However, if the basement has a low ACH and high levels of radon under the slab, it can be significant. Diffusion is a pressure driven mechanism that will vary depending on the concentration gradient across the slab and the resistance of the slab to gas flow. Keep in mind that diffusion can take place even though the sub-slab is negative in pressure in comparison to the basement.

4.3.2.1 Flux Measurement

Two different measurements can be made to determine if diffusion is significant. The first is to measure the radon levels under the slab. If there are thousands of pCi/l under the slab, diffusion may be a significant source if the basement has a low ACH. A more direct measurement is to make a flux test. This test requires a continuous radon monitor (CRM) and a metal bucket. The CRM is placed on the slab floor in a location without floor cracks. A metal bucket is sealed over the CRM. If a plastic bucket is used, radon will quickly begin diffusing through the plastic and distort the results. This flux setup is left in place for 24 hours. The results of the CRM are plotted. If there is a significant in-growth of radon it can be assumed it is from diffusion through the slab. A four to eight hour section of the graph is used to determine the amount of in growth. This in-growth amount is divided by the number of minutes it took to convert it to pCi/minute. This amount is then multiplied by the number of liters the metal bucket contains. This compensates for a tall versus short bucket and gives the true pCi/l/minute in-growth. This number is now divided by the square foot area the bucket covers on the slab. This gives the true flux amount in pCi/l/sqft/minute. If the square foot area of the basement is multiplied by this rate, the approximate diffusion rate of the slab in pCi/l/minute will be determined. This is assuming that the diffusion rate across the slab is the same as the area that was fluxed. Now comes the guessing part. In order to determine if this amount of radon influx is significant, divide the flux by the ventilation rate of the basement. Use the same method described in the HRV section for determining the ventilation rate of an area. This amount needs to be converted into liters per minute ventilation so that it uses the same units as the flux

Fig 4-8 Slab flux test

measurement results. Since there are about 28 liters in a cubic foot, multiple the CFM ventilation rate by 28 to convert to liters per minute of ventilation. Divide the flux emanation rate by the liters per minute ventilation rate to determine the approximate contribution of the diffusion through the slab. Keep in mind that the ventilation rate was only a slightly educated guess.

4.3.2.2 Reducing Slab Diffusion

There are three methods for reducing radon levels if it turns out there is a significant amount of diffusion coming through the slab. The first method would be to increase the ventilation to the room to sweep the radon away. This could be accomplished with a HRV. An alternative is to duct outdoor air to the return side of an air handler. The main problem with this approach is the air handler must run continuously and the ventilation increase will be diluted through the whole house.

The second method is to seal the floor by painting the concrete slab with concrete urethane floor paint. In one particular study in New Jersey, a single coat of urethane floor paint reduced the diffusion rate by 50%. Unfortunately, the long-term effectiveness of the floor painting of the New Jersey house was never checked. There has not been much research documenting the long term effectiveness of different slab coatings.

Another approach would be to reduce the concentration of radon under the slab. This would involve drilling vent holes through the slab at the farthest distances from the suction holes. Basement air would be drawn under the slab, reducing the concentration and thus the reducing the diffusion rate. There are some concerns with this approach. The first is the additional air drawn from the basement could cause a back draft condition to a natural draft combustion appliance. Another concern is the extra negative pressure in the basement might induce a significant radon entry from another location that is not being treated like a foundation wall or an adjoining slab on grade. Sometimes the negative pressure under the floor is so strong that there is a whistling sound coming from the ventilation holes. If the sub-slab has limited porosity the new holes through the slab may eliminate the PFE beyond the holes.
It would be best to repeat the flux test as well as the basement radon test to measure the impact of sealing the slab or reducing the sub-slab radon concentration.

4.4 FILTERING RDP'S

The primary risk from radon exposure is not radon but radon decay products. Radon decay products are charged solid particles that can be captured by a high efficiency filter. Portable high efficiency floor mounted filter machines have been tested and shown to effectively reduce RDP's. The problem is that they are only effective in the room where they are installed in. Even within a room with a filter machine running, there can be areas where the filtering is having very little effect. One solution to this problem would be to install a high efficiency filter in a central air handler. The primary problem with this approach in a residential situation is the air handler doesn't typically run continuously. Keep in mind that filters do not change radon gas levels since radon is a noble gas that is not captured by the filter. RDP levels will quickly build up every time the air handler is off. Filtration may, however, be a viable option in commercial buildings where the air handler is left running during all occupied periods.

4.5 COMMERCIAL MITIGATION ISSUES

Designing radon systems for commercial buildings is not included in this course. Commercial buildings can be significantly more complicated than residential buildings for a number of reasons. The first reason is the foundation often includes interior walls that are made of block walls that penetrate a number of courses below the slab. This will create multiple sub-slab areas that are surrounded by leakage paths that lead directly from the soil up through building that are often very difficult to seal. In addition the sub-slab material is often a compacted modified fill material which limits PFE. There are also often major expansion joints that are open to the sub-slab but have been covered with porous coverings such as carpet.

Commercial buildings often have complicated HVAC systems that create different pressure zones in ground contact rooms that are on the same floor. The HVAC system can also have significantly different settings based on time of day, day of the week or outdoor weather conditions that will typically influence the radon levels in both directions.

The radon testing done in commercial buildings is often inadequate with only a few of the ground contact rooms tested or all the testing has been done during non-occupied weekends. Design of a radon reduction system for a commercial building needs to take all the previous points into consideration. In particular the operation of the HVAC system needs to be understood before a radon system can be designed. This almost always requires the assistance of the personnel who have responsibility for the HVAC system. It is often critical during the building investigation to make differential pressure readings across the building shell and between rooms and the hallway with the HVAC operating in different modes to determine if the HVAC system is mining radon. The dampers controlling the outdoor air supply and any building exhaust fans needs to be closely inspected under different operating cycles. Although most commercial buildings could be fixed with ventilation changes, this may not be the most practical method. Sometimes the cost of HVAC changes far exceeds the cost of installing a sub-slab suction system. An active soil depressurization system will also typically be less likely to be altered by maintenance crews and it is much easier to monitor the performance of the radon fans than changes made to or happening to a commercial HVAC system. There may also be concerns about the HVAC system being able to adequately control humidity in the summer or handle the extra heating load in the winter with the increased amount of outdoor air needed to maintain low radon levels.

If a sub-slab system is to be installed it needs to be carefully designed especially if the building is large, has multiple sub-slab compartments, questionable sub-slab porosity or sub-slab leakage areas that cannot be sealed. Communication testing that includes airflow measurements can ensure that the proper number of suction holes, pipe size and fan size are included in the design. It is also a good idea in the design phase to consult with the local fire marshal about proposed pipe routing to ensure acceptable fire protection is incorporated into the design for any piping passing through firewalls. If asbestos is in any job locations, a trained asbestos contractor will also need to be consulted. Finally, some commercial companies will also require safety plans specifically for the radon remediation installation.

4.6 RECORDS

RMS 18.2 EPA recommends that listed contractors keep records of all radon mitigation work performed and maintain those records for three years or for the period of any warranty or guarantee, whichever is longer. These records should include:

(1) The Building Investigation Summary and floor plan sketch. (See Appendix A.)
(2) Pre and post-mitigation radon test data.
(3) Pre and post mitigation diagnostic test data.
(4) Copies of contracts and warranties.
(5) A narrative or pictorial description of mitigation system(s) installed.

RMS 18.3 Other records or bookkeeping required by local, state or Federal statutes and regulations shall be maintained for the periods prescribed by those requirements.

RMS 18.4 EPA recommends that health and safety records, including worker radon exposure logs, shall be maintained for a minimum of 20 years.

REFERENCES

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2. Canada Mortgage and Housing Corporation, "Procedure for Determining the Safety of Residential Chimneys," Chimney Safety Tests Users Manual (Second Edition), Jan. 1988.
3. Henschel, B.D., "Radon Reduction Techniques for Detached Houses," Second Edition, EPA/625/5-87/019, 1987.
4. Messing, M. and B.D. Henschel, "Radon Mitigation Experience in Houses With Basements and Adjoining Crawlspaces," proceedings of the 1990 International Symposium on Radon and Radon Reduction Technology, vol. 4, 1990.
5. Michaels, L., T. Brennan, and M. Osborne, "Development and Demonstration of Indoor Radon Reduction Measures for 10 Homes in Clinton, New Jersey," 1986.
6. ASTM, "Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances", designation E 1998
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8. USEPA, Office of Research and Development, EPA Radon Mitigation Update, "Effects of Natural and Forced Basement Ventilation on Radon Levels in Single Family Dwellings," EPA/600/N-92/009, June 1992.
9. USEPA, Office of Research and Development, EPA Radon Mitigation Update, "Effect of Suction Pit Volume on Pressure Field Extension," EPA/600/N-92/009, June 1992.
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11. USEPA, Air and radiation, "Radon Mitigation Standards", October 1993 (revised April 1994) EPA 402-R-93-078
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14. ASTM, "Guide for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings, designation E 1465
15. EPA "Handbook, Sub-Slab Depressurization for Low-Permeability Fill material," EPA/625/6-91/029, July 1991
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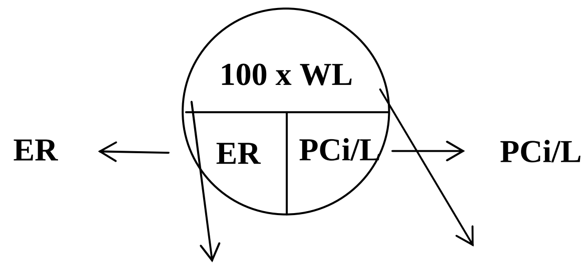
Formulaes

ER = (measured RDP's) ÷ (Total RDP's produced by radon in the air)

ER = (100 x WL) ÷ pCi/L



WL = pCi/L ÷ (100 ÷ ER)

pCi/L = WL x (100 ÷ ER)

100 ÷ ER = 200

WLM = (Avg WL x Hrs) ÷ 170   **170 = (51 weeks ÷ 12 months) x 40 hours**

Amps x Volts = Watts   **Watts x hours ÷ 1000 = Kilo-watt hours**

Fan wattage x operating hours ÷ 1000 x cost per kilo-watt hour = Fan operating cost

VP = Velocity Pressure - measured with a pitot tube facing into an airstream

Feet per minute air flow (FPM) Multiple the square root of VP times 4003

$\sqrt{VP}$ x 4003 = FPM   **sqft area x FPM = CFM**

Sqft area of a circle = π x radius^2   **π = 3.14**   **$\sqrt{\quad}$ = Square root function**

Radius is ½ the diameter of a circle   **$\sqrt{VP}$ x 87 = cfm in 2" pipe**

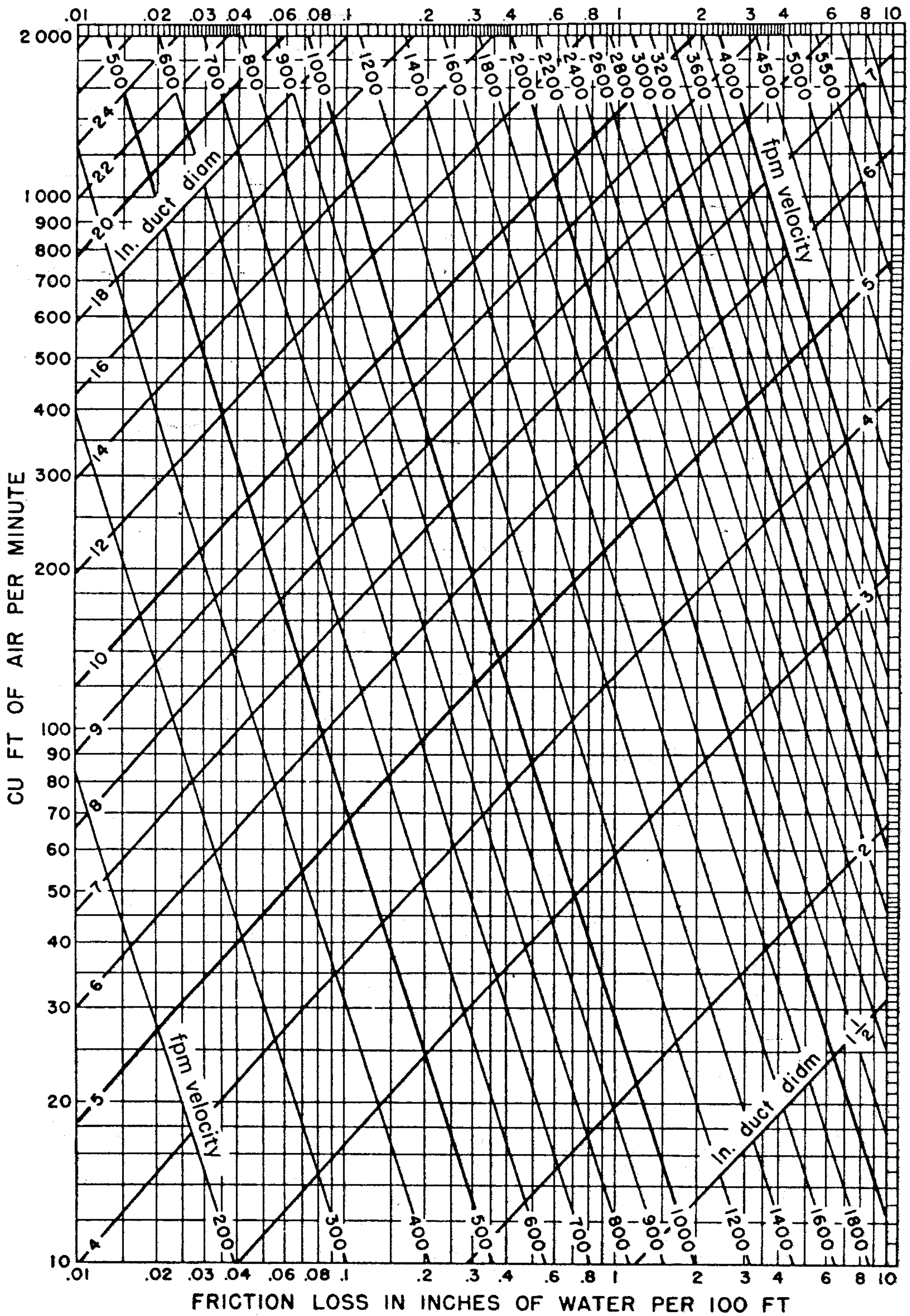
$\sqrt{VP}$ x 196 = cfm in 3" pipe   **$\sqrt{VP}$ x 349 = cfm in 4" pipe**

VR = Ventilation Rate   **ACH = Air Changes per hour**

ACH x House Volume ÷ 60 = VR

Present Radon ÷ Desired Radon x Present VR = Required VR

Required VR = Present VR + Additional VR from HRV
SUPPLIER LIST for RTM Course



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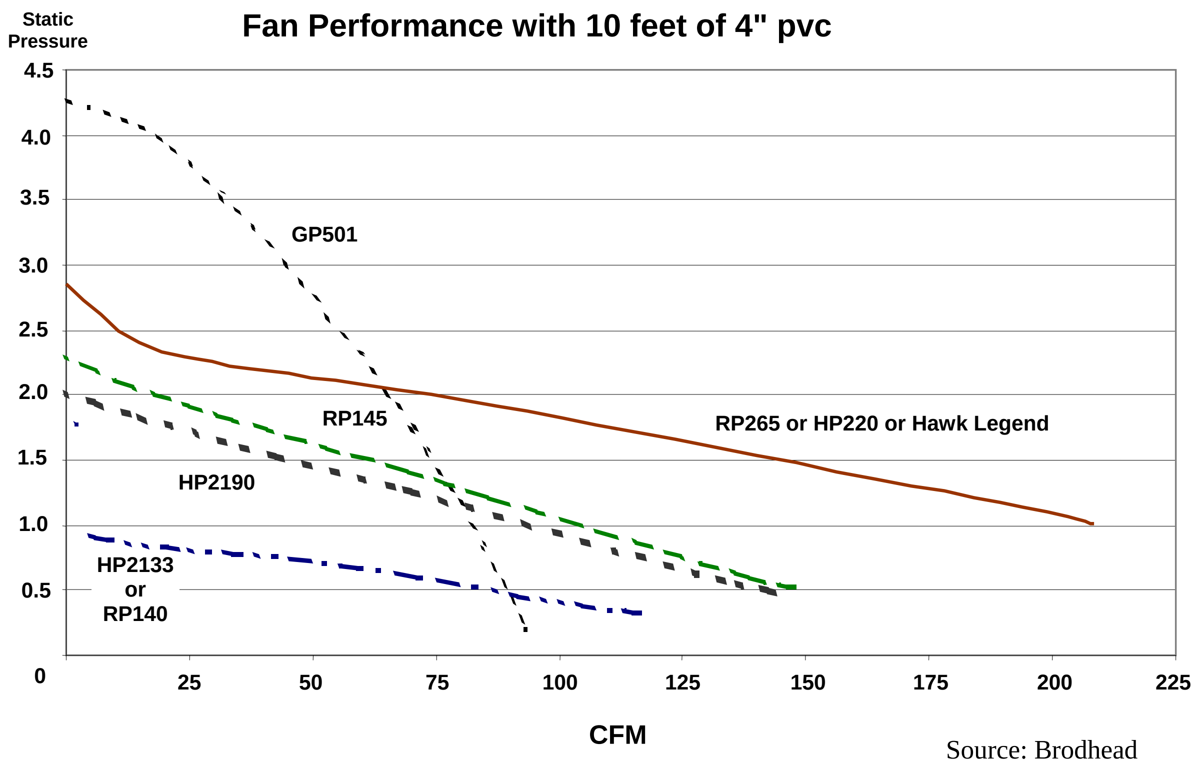
FRICTION LOSS IN INCHES OF WATER PER 100 FT



Source: Brodhead

Performance curves for some typical radon fans

Radon Equipment & Supplies

Energy Conservatory - MN 612 827-1117 energyconservatory.com
Festa Radon Technologies - PA 800 806-7866
Infiltec - VA 888 349-7236 infiltec.com
Obar Systems - NJ 800 949-6227
Radon Away - MA 800 767-3703 radonaway.com
Radon Supplies NA - NJ 888 800-5955 radonsupplies.com
RCI - IN 800 523-2084 radoncontrol.com

Radon Trade Association

AARST (American Association of Radon Scientists and Technologists)
866 772-2778 aarst.org

Radon Certifying Agencies

NEHA (National Environmental Health Assoc) 800 269-4174 radongas.org
NRSB (National Radon Safety Board) 866 329-3474 nrsb.org

Radon in Water Manufacturers

BGC, CN - Airaider 203 357-9117 wateraeration.com
Felder Industries, NH - Mitigator Model 800 405-1107
NEEP Systems, NH - Clearadon 603 298-7061 neepsystems.com

Activated Carbon Detectors (AC) & Electret Ion Chamber (EIC)

Air Chek - NC – (AC) 800 247-2435 airchek.com
Rad Elec – MD - (EIC) 800 526-5482 radelec.com
RTCA - NY – (AC) 800 457-2366 rtca.com

Continuous Radon Monitors

Accustar - AL 888 580-9596 accustarlabs.com
Femto-TECH - OH 937 746-4427 femto-tech.com
Sun Nuclear - FL 321 259-6862 sunnuclear.com
Pylon - Canada 613 226-7920 pylonelectronics.com

Alpha Track Detectors

REM - IL 888 580-9596 accustarlabs.com
Landauer - IL 800 323-8830 landauerinc.com

Radon Chamber

Bowser & Morner - Ohio 937 236-8805 ext 248 bowser-morner.com

Low Voltage Cut Off Box