Unit 4. Mitigation Systems

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Objectives

O4.01 Identify the radon mitigation techniques for the three approaches to mitigation listed

Active Soil Depressurization systems, ASD (controlling transport by pressure-driven entry)

Sealing (controlling entry pathways)

Ventilation (controlling accumulation of radon and radon decay products

[1]*/***Compare the relative efficiency of these common radon reductionmethods.

Note: Controlling the radon source as a mitigation technique is rare.

04.02 ***Identify the criteria for selecting appropriate materials and system components to be used when installing different mitigation systems.

04.03 ***Design and install active soil depressurization systems, ASD.

a. Identify the conditions that can increase or decrease the effectiveness of an active soil depressurization system.

b. Explain the relationship between a pressure field, soil permeability and soil gas flow in the field.

c. Select the appropriate number of suction points and ductwork sizes for a depressurization system for given situations.

d. Select the appropriate fans, installation locations and ductwork routing for active soil depressurization systems.

e. Define and prevent radon gas re-entrainment.

f. Identify soil types or conditions that require an increase in the pressure field of an active soil depressurization system.

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1 *These objectives are only for radon measurement specialists.

**These objectives are only for radon mitigation specialists.

***These objectives are only for mitigation applicants.

g. **Given hypothetical situations, determine which pressurization method or active soil depressurization method (block-wall, drain tile, sub-membrane, sub-slab depressurization or combination system) would perform best. When determining this, consider all of the following:

- purposes
- advantages and disadvantages
- conditions.

04.04 ***Design and perform sealing.

a. Identify the most appropriate places and materials for sealing.

b. Increase the efficiency of active soil depressurization systems by sealing floor and block wall openings, cracks and sumps and explain why sealing increases the efficiency of the system.

c. Describe the method for sealing canal drains and other large joints and openings.

04.05 ***Design and install ventilation systems.

a. Describe the application of the isolation and ventilation method to crawl spaces and the effect of ductwork in the crawl space.

b. Evaluate measurement and house data to determine when to use increased ventilation to reduce radon concentrations.

c. Identify the advantages and disadvantages of increasing ventilation to reduce radon concentrations.

d. Identify three techniques to increase ventilation.

e. Increase ventilation using each of these three techniques.

f. Identify the correct placement of system components to achieve proper airflow and minimum re-entrainment for a powered ventilation system installation.

04.06 ***Identify the installation requirements in the Florida Standard for Mitigation of Radon in Existing Buildings (Chapter 9B-53, Florida Administrative Code).

I. Overview

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 in most houses can cost effectively be reduced. Methods which reduce or defeat the factors that cause the entry and accumulation of radon are referred to as "mitigation" techniques. The challenge confronting the mitigator is not whether the radon can be reduced, but rather how to do so without compromising the aesthetics, the integrity of the building, and the health and safety of the occupants and workers, as well as providing the mitigation at reasonable costs.

This unit discusses mitigation techniques for reducing radon concentrations from soil gas entry as well as entry from diffusion and building material emanation. (Unit Six addresses reducing radon that enters from water sources.) It provides the mitigator with basic information for understanding and applying the techniques typically employed in the industry. The implementation of these techniques certainly requires a thorough working knowledge of building and construction practice, and more detailed guidance can be obtained in the EPA publication, "Radon Reduction Techniques for Existing Detached Houses" (Technical Guidance Third Edition). This introductory section provides background on the objectives of radon control and on mitigation approaches to address categories of the radon problem. Subsequent sections discuss specific mitigation techniques in greater detail, while the last section in this unit describes proficiency evaluation and standards for the professional radon mitigator.

Although some recently developed techniques are not discussed in this unit, this does not mean that such techniques are not useful, but rather that insufficient experience has been gained to generalize about their applicability and the conditions necessary for successful use. Consequently, the professional mitigator is encouraged to stay current with developing trends through relevant symposia and technical journals (see "References" at the end of this unit).

A. Goal of Radon Mitigation: To What Level Should the Radon be Reduced?

The Federal Indoor Radon Abatement Act of 1988 stated that the goal for radon mitigation should be that indoor radon concentrations should approach or equal outdoor radon concentrations. Although the outdoor concentration can vary depending on local factors, typical ambient outdoor radon concentrations average range from 0.1 to 0.4 pCi/L (Ref. 19). 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 cost of installation and operation, as well as the willingness of the client to absorb those costs for the incremental radon reduction. The "phasing" portion of this unit discusses this in more detail.

Historically, industry practice has been to design a radon reduction system that reduces the radon 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 guideline of 4.0 pCi/L generally precipitate action, either 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 guideline. It should be

further noted that levels below 4 pCi/L still present a risk, and further reduction of the radon levels may diminish the health risk to the occupant.

B. General Approaches to Radon Mitigation

Control strategies to reduce elevated radon levels in a building are selected to attack one or more of the following factors (discussed in Unit Two) that contribute to the problem:

- **Sources** of radon in the soil surrounding the house (or infrequently in the building materials or water supply).
- **Transport mechanisms** that drive radon into a building: usually pressure differences across the outer shell of the substructure that pull radon in from the soil; or, less importantly, diffusion of radon from an area of high concentration to the building interior.
- **Radon entry pathways** or openings through which radon from the soil can be drawn into the building.
- **Accumulation** of radon and radon decay products within the building.

Radon control techniques could be categorized as (1) those that inhibit (or prohibit) radon from entering the occupied space by addressing the first three items in the list above, and (2) those that remove radon (and its progeny) after it is already present in the air of the occupied space by treating the last item on the list. Introductory descriptions of generic mitigation strategies grouped according to each of the four factors above follow.

1. Controlling the Radon Source

Although the radon source is typically in the native soil (which contains small concentrations of uranium and radium), there have been incidents where high radium- content soils have been imported as fill beneath and around the structure or used as aggregate in the building materials. In rare cases where extremely high radium-content soils have been encountered (approximately 100 picoCuries of radium per gram of soil), actual soil excavation from around and beneath the structure has been used. Removal is possible because the source is isolated, but even in that case the costs would be extremely high. Most of these high radium-content soils have been caused by mill tailings or by-product materials from the uranium production industry. Their use has been well documented by the Department of Energy through activities mandated by the Uranium Mill Tailings Recovery Act (UMTRA). Areas in which these soils are found in or around homes are very localized and well known by local health agencies, and by and large, they do not enter into the vast majority of radon mitigation applications. In general, removal of soils around a house is not a practical or economically feasible approach, except in very unusual situations (Ref. 2). However, the professional mitigator should be aware of these isolated situations.

Emanation of radon from building materials within the structure (such as granite countertops and rock fireplaces) certainly can be of concern if one is attempting to reduce radon to ambient levels. Emanation rates are not only a function of the radium content of the material, but also of the porosity and surface area of the material itself. For example, although a rock fireplace may appear to be a physically large surface, its 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 gravel-sized rock in the soil beneath the home). Furthermore, the rock on the fireplace is certainly not as permeable for

radon transport as would be the void space around crushed rock. Consequently, the relatively slow mass transfer of radon from a low radium-containing building material (3 to 4 pCi/gram), such as a rock fireplace, can generally be dissipated with natural, or slightly enhanced, building ventilation rather than by physical removal.

2. *Controlling Transport by Pressure-Driven Entry*

Many of the mitigation techniques that cause the greatest reduction in indoor radon levels are directed at reversing the driving force caused by negative pressures at the bottom of buildings. These techniques aim to cause the soil/materials surrounding the substructure to be at a lower pressure than the inside of the substructure, thereby reversing the normal air flow: building air now flows into the soil.

The most widely applied approach to changing the pressure-driven entry is called Active Soil Depressurization (ASD). Active Soil Depressurization is a technique that creates a partial vacuum beneath the structure that is greater than the partial vacuum applied to the soil by the building. ASD systems can be installed in a variety of ways, but have common elements consisting of vacuum-producing blowers or fans connected to a pipe which draws gases from the underlying soil. The radon is thus drawn to the collector and exhausted to a safe location outside the home (Figure 4-1).

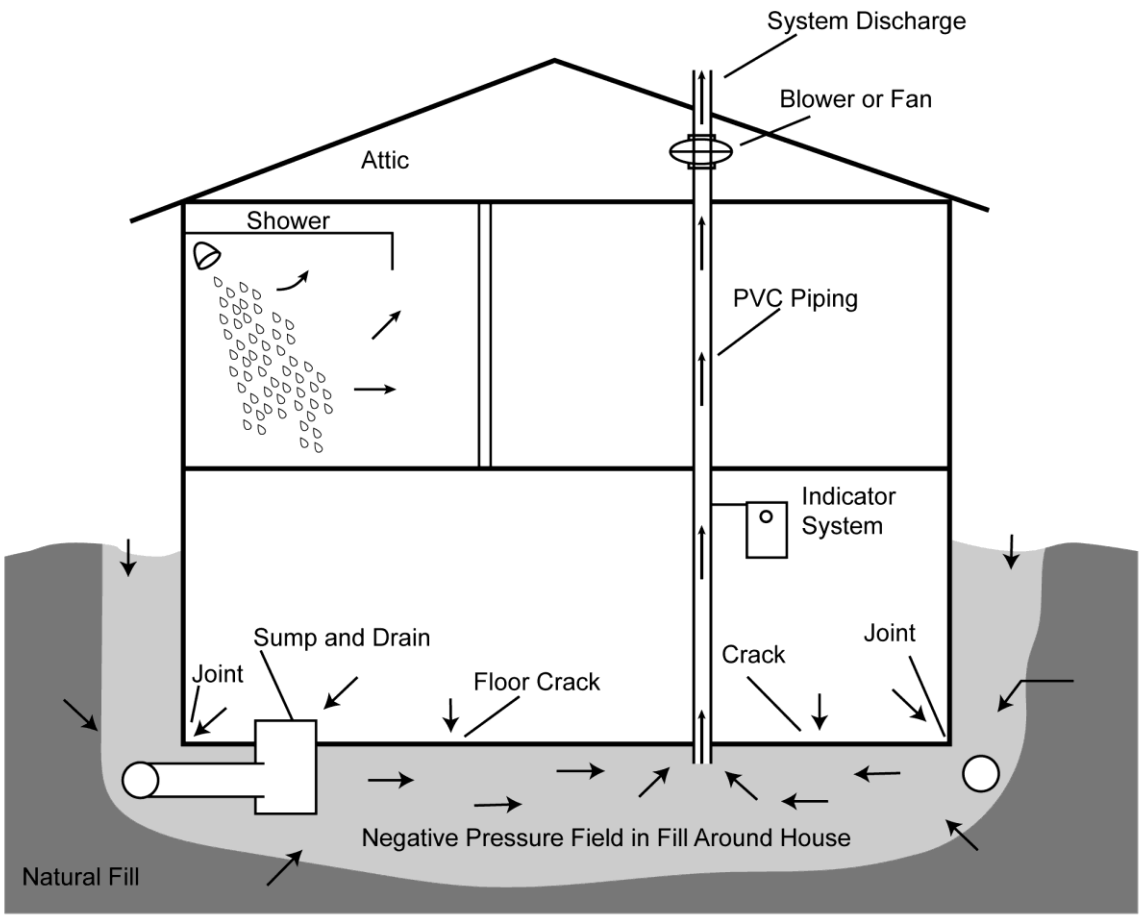


Figure 4-1. Active Sub-Slab Depressurization System, Source: EPA

Arrows indicate the direction of air flow with Active Soil Depressurization. Note that if radon also enters the home via well water, this system may have less of an effect on indoor radon concentrations. Arrows indicate that the negative pressure field beneath the slab caused by the system has reversed the normal direction of soil gas flow into the house.

Several variations of ASD systems exist:

- Sub-slab depressurization (**SSD, SSV or SSS**),
- Drain tile depressurization (**DTD**),
- Sub-membrane depressurization (**SMD**),
- Block-wall depressurization (**BWD**), and
- A combination of the above systems.

Their applicability (with certain design adaptations) is almost universal. Research indicate that 91% of basement homes and 81% of slab-on-grade homes are mitigated with a combination of ASD and entry point sealing (Ref. 12). Consequently, a significant portion of this unit will be devoted to ASD systems.

To complicate matters somewhat, it should be noted that while pressure-reversal may be the primary reason for the success of these systems, other beneficial processes may be involved. Since the systems also tend to increase the air flow through the soil (or block wall, drain tile, etc.), radon concentrations in these areas are reduced by dilution. Consequently, any soil gas that still enters the building will contain less radon. In addition, the lower radon concentration in the area adjacent to the building will result in a small concentration gradient-thus, less diffusion into the building.

Other, less frequently used techniques achieve the pressure reversal by using a fan to pressurize the entire building or the substructure alone. The use of this approach indicate that the reduction of indoor radon levels is variable, due to the greater difficulty in maintaining pressurization inside the structure.

In rare instances, diffusion of radon from material that contains an earth-based substance (e.g., rock in a fireplace, aggregate in concrete) can be reduced by applying a sealant or membrane to the surface that is resistant to radon diffusion. This is seldom done in practice, because of the generally small contribution to indoor radon levels by diffusion, but is mentioned here for completeness.

3. Controlling the Radon Entry Pathways

In addition to a radon source and a driving force, there must also be openings into the structure through which the gas can enter. Cracks and joints with widths less than 1/16th of an inch (1.6 mm) shall be repaired by the application of an elastomeric material capable of withstanding at least a 25 percent extension and extending at least 4 inches beyond the length and width of the crack. Theoretically, radon entry could be significantly reduced (other than diffusion through the substructure surfaces in contact with the soil, which is typically minor) if all the openings could be sealed. In practice, by sealing some openings, the soil gas (and radon) entry rate will increase through the unsealed openings, partially offsetting the entry eliminated through the sealed opening. Additionally, even when an opening is accessible, a perfect seal is often not achievable. Furthermore, with the shifting of a structure due to aging, settling, and other causes, new openings are many openings in a home's construction to be reasonably accessed for sealing. While sealing of cracks and openings by itself has

proven to be a poor stand-alone technique, it usually improves the performance of ASD systems by enhancing the negative pressure field in the soil around the substructure.

4. Controlling the Accumulation of Radon and Radon Decay Products

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 enters, the lower the final radon concentration will be because radon is mixed with this air. If the pressures in a structure and the source strength of radon are not changed, the addition of fresh outside air will decrease concentrations of radon and radon decay products. The method of adding ventilation is generally an effective control technique only in houses with low to moderate indoor radon levels. Above that, the amount of ventilation necessary to lower radon below EPA's 4 pCi/L guideline will probably cause a moisture and mold problem, discomfort and excessive energy use and cost.

Decreasing radon and decay product concentrations can be accomplished by simply allowing more natural ventilation through window and door openings. Ventilation with outdoor air can be boosted by a fan that either blows air into the building or exhausts air from the building. Blowing air into the house has the added benefit of pressurizing the home and thereby reducing or eliminating the pressure-related driving force for soil gas entry. Mechanically exhausting air from the building will increase ventilation rates, but may also increase radon entry from the soil by further depressurization of the building. The relationship between the change in ventilation rates and change in radon entry rates is unique to each building and may result in indoor radon levels being lower, higher, or not changed at all. Both supplying and exhausting fresh, unconditioned, outdoor air can have a detrimental effect on the comfort level and operating costs of the house, and may be considered as temporary measures.

The energy penalty associated with additional ventilation can be reduced by utilizing a heat transfer mechanism. These systems are generally referred to as heat recovery ventilators (**HRV**) or air to air heat exchangers (**AAHX**), when heat from exhaust air is recovered in fresh, outdoor supply air. Although generally not as cost-effective as ASD systems in reducing radon levels in excess of 12 pCi/L, they have the added benefit of dealing with other indoor air quality problems in addition to achieving moderate radon reductions. As will be seen later, they are generally more complex and often entail higher operating costs, especially if heat recovery techniques are not properly employed.

Air cleaning devices are available to remove radon, decay products, or-both from the indoor air and have occasionally been used as temporary mitigation techniques or where other techniques have not been suitable or effective. They are available as stand- alone units or may be incorporated into the air handling sections of beating, ventilation, and cooling equipment. The processes by which they remove radon or RDPs are various, but may include high efficiency panel filtration, charcoal filtration beds, and electrostatic precipitation. Relatively little documentation is available on the effectiveness of these devices in an occupied environment, their long-term durability and effectiveness, and, for those that remove decay products, on any reduction in health risk associated with removing certain sizes of RDPs.

C. Sequence of Procedures to Perform Radon Mitigation

Below is a basic sequence of procedures that is often followed in the selection, design, installation, and evaluation of radon mitigation systems. This list is intended as a framework for the student and to provide a perspective on the large amount of information to be presented in the remainder of this unit and Unit Five.

- Inspect the building, while considering appropriate mitigation strategies.
- Based on the building inspection, decide whether investigatory tests and measurements are necessary to provide design information.
- If necessary, perform the diagnostic tests and measurements.
- Select and design mitigation system(s), using information gathered during building investigation.
- Install mitigation system(s).
- Evaluate system performance, by performing post-mitigation radon and system measurements.
- If system performance is unsatisfactory, test and measure, design and install needed modifications/additions to the system.
- Re-evaluate system performance.
- Repeat procedures 1 through 6, as required.

II. Specific Techniques for Reducing Pressure-Driven Entry

This is the first of several sections that discuss in more detail the operation concepts, design considerations, installation details, and documented performance of specific mitigation techniques.

A. Theory of Active Soil Depressurization Techniques

Soil gas is drawn indoors primarily by the lower air pressure in the house compared to that of the soil. To reduce radon-bearing soil gas from entering the house, a small fan (with associated piping) can be used to withdraw radon directly from the soil (see Figure 4-1). This reduces air pressure at the soil/house interface, which reverses the pressure gradient, and thus reduces the entry of radon. It also causes air to flow through foundation cracks and holes, out of the house, and into the soil, thus reversing the direction of flow. All of the methods creating suction (a negative pressure) around the house are referred to as Active Soil Depressurization (ASD). Figure 4-1 illustrates a typical soil depressurization system using SSD. There are several components to such a system, including a fan (blower), a pipe (duct) system, suction points, sealing, labeling and a warning (indicator) system.

Soil depressurization systems have proven to be reliable and successful in a large proportion of buildings and are usually 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 (SSD).

- Interior and exterior footing drains (DTD).
- Sump holes.
- Concrete block basement and stem walls ("frost walls") (BWD).
- Floor/wall perimeter cracks.
- Membranes placed on bare earth floors in crawl spaces and unpaved basement (SMD).

The key to 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 best if that negative pressure field extends under the entire floor and up the cores of the hollow block or up the outside of the foundation. Ideally, this negative pressure field needs to be stronger than the competing low interior pressures generated by the building under worst case conditions for year-round reduction (e.g., mid-winter in the Northern United States). However, in practice, this goal is sometimes not practically attainable. The mitigation system may still be effective if it is successfully controlling indoor radon levels (possibly due to ventilation of the soil induced by the system).

B. Basic Design Considerations in Active Soil Depressurization (ASD) - Using Sub-Slab Depressurization (SSD) as an Example

Many of the basic principles for designing any ASD system (SSD, BWD, DID, SMD) are presented in the following section which features SSD as the mitigation technique. General design considerations for the other systems (fan selection, pipe sizing, etc.) can be referenced to this section. System-specific details are discussed in the appropriate section.

The basic design procedures for most ASD systems will involve the following:

- Specification of the number and location of suction points necessary to provide adequate pressure reversal. Very often this is based solely on the mitigator's thorough inspection of the building and his/her experience with similarly constructed houses on similar soils. However, the mitigator may require additional information beyond a visual inspection and may perform certain tests and measurements that characterize a number of factors (e.g., tightness of material below the slab, the extension of pressure fields in this material, and the presence of barriers below the slab). These tests and measurements are described in more detail in Unit Five.
- Selection of the appropriate mitigation system components including fans and piping. Once again, most mitigators select system fans and piping based on previous experience. However, if a mitigator is attempting to optimize component sizing (for example, to minimize installed costs or energy usage); is faced with unknown construction or soil details; or is designing a complex system, the mitigator may perform tests and measurements to predict the pressure and air flow requirements to be met by the system components. These measurement procedures are also discussed in Unit Five.
- Design of the system layout.
- Consideration of safety factors involved in operating the system.

- Evaluation of mitigation system performance, at least by simple indoor radon measurements, or by additional measurements of the system's pressure and flow characteristics.

1. Developing a Negative Pressure Field

Development of a pressure field is critical to the success of any soil depressurization mitigation approach. The number and location of suction points required for this technique depends on the ability to extend the negative pressure field around and under the foundation. Depending on the ease of the extension, a single suction point will be sufficient. As illustrated in Figure 4-2, the following hypothetical situation describes these design considerations.

The best possible situation for creating a uniform negative pressure field is a tightly sealed box with nothing in it to resist airflow. 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 the walls of the box will be the maximum that the fan can produce.

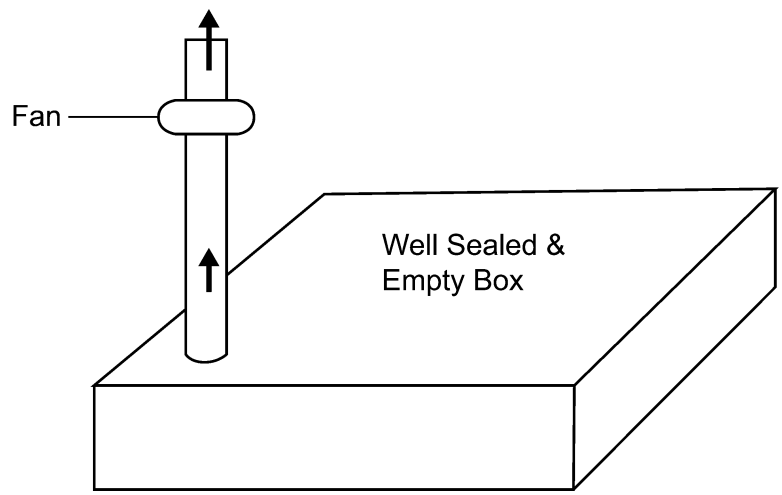


Figure 4-2. Empty Box Simulating Large Void Below Floor Slab - No Leakage, Source: Brennan

If a hole is opened in the box, the pressure will be reduced because more air is being supplied to the blower. Also, as shown in Figure 4-3 the pressure field will no longer extend uniformly throughout the box. If the hole is near the suction point, there may be very little pressure field extension past the hole, "short-circuiting" the pressure field. If the large hole is closed and small air leaks are made at each corner of the box, a fairly uniform pressure field will develop. The closing of this hole and its effect on the elimination of short circuiting is the same effect that floor crack sealing has on an ASD system.

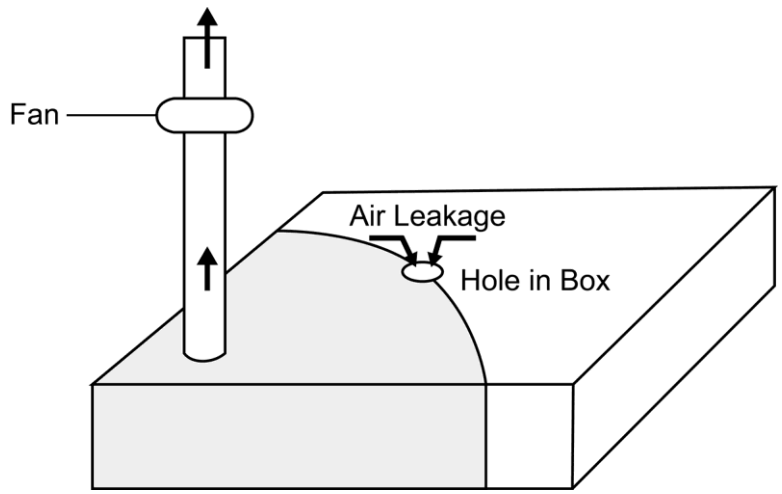


Figure 4-3. Empty Box Simulating Large Void Beneath Slab – with Air Leak, Source: Brennan

If the box is next filled with a permeable soil and a hole made at the end corner furthest from the suction point, 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 characteristics of the box contents, and the size and location of any air leaks into the box (see Figure 4-4).

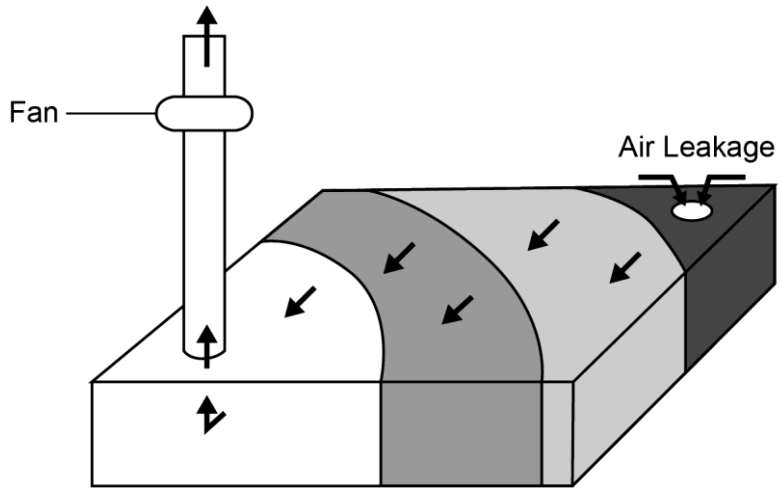


Figure 4-4. Box With Soil Simulating Soil Beneath Slab-With Leak, Source: Brennan

If the box is filled with sand, the negative pressure field will be even stronger near the suction point and weaker near the air leaks, because the sand generally creates more resistance to air flow than does a permeable soil. The pressure field distribution in this example can be improved by adding more suction points (Figure 4-5). It can also be improved by having a network of perforated pipe throughout the sand in the box and connecting it to the suction point, which may already exist as a water drainage system or may be installed during new home construction.

For a house, the surrounding soil, bedrock, and the materials used in the foundation and drainage systems determine how easily a pressure field can be distributed around a foundation. Loose soils, water drainage systems, gravel under slabs, hollow core concrete block walls, and areas where the soil has settled under slabs all have the potential of extending negative pressure fields with few suction points. In contrast, tight soils, slabs poured on solid bedrock, foundations without drainage systems, and footings under slabs are significant barriers to extending a negative pressure field.

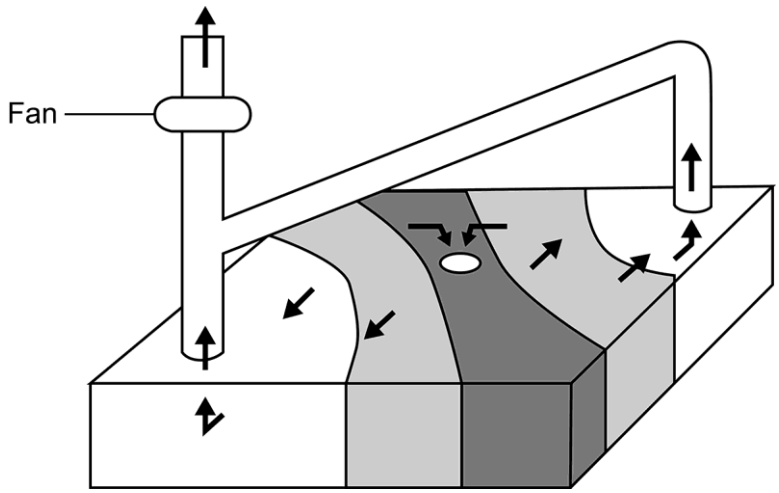


Figure 4-5. Box Simulating Sand Beneath Slab-Two Suction Points, Source: Brennan

2. Number and Location of Suction Points

As illustrated with the boxes filled with soil, the number of suction points necessary to fully extend a negative pressure field beneath a slab depends on the porosity or permeability of the material beneath the slab. This can depend on several things:

- Type of fill beneath the slab.
- Compaction and consistency of the soil conditions.
- Continuity of footings beneath the slab (as may be the case for a bearing wall unless set with pads and posts).

The best locations for suction points will depend not only upon where the best pressure field extension can be achieved, but where a good location can be found to conceal and route the piping system. These decisions are based on a careful examination of the structure and may require that some diagnostic measurements be performed.

In areas of the country where footings are at least 18 inches below outside grade or deeper, one of the better locations for a pressure field extension is right next to the interior of the outside wall. This is because the soil is generally less compacted than in the center and the soil was disturbed when the footings were dug. Frequently, the soil beneath the slab will settle and, since the slab is often on top of a spread footing (which does not allow the concrete near the wall to settle with the soil), a void space is found (see Figure 4-6). A suction point located in this void space may facilitate extension of a negative pressure field completely around the perimeter of the slab. This can provide excellent negative pressure field extension throughout the slab area, while also applying the greatest suction to the floor wall joint

that is often the major radon entry point. This location often makes routing and concealment of the duct work easier than a suction point located in the center of a room.

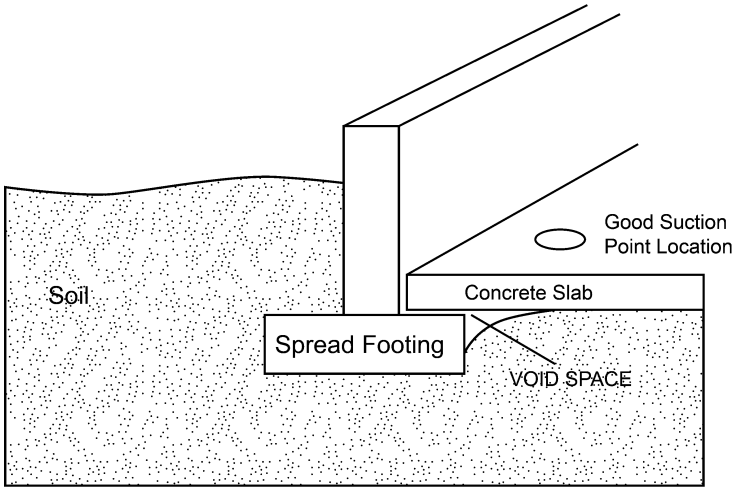
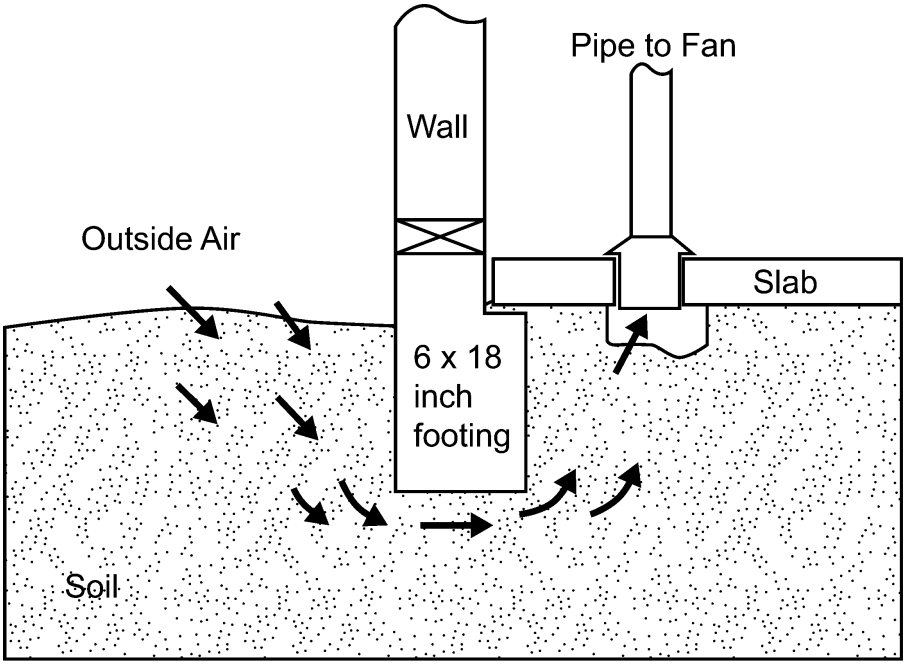


Figure 4-6. Void Space along Spread Footings, Source: Kladder

In parts of the country where building foundations are not as deep, such as the Southwest and Southeast, a location next to an exterior wall in slab-on-grade houses may be detrimental. In cases such as these, the negative pressure field extension could be defeated by pulling too much air from outside, rather than from beneath the slab. Here a more centrally located point may be recommended (Figure 4-7).

Figure 4-7. Potential Impact or Shallow Footings on Perimeter Suction Point Locations, Source: Kladder



Continuous footings or grade beams running beneath a center portion of the slab can disrupt a negative pressure field. To obtain negative pressures under all parts of the slab, it may be necessary to place suction points on both sides of such a footing (see Figure 4-8).

One possible way to reduce the need for ·multiple suction points in soils with poor pressure field extension is to locate a suction hole near an under-slab utility line, being **careful** to avoid breaking the line when drilling. Since the trench for the line is generally not well compacted, a vacuum applied on or near this trench may extend along and out from the trench. This trench will also generally extend under and beyond a grade beam or bearing wall foundation, which can allow for a reasonable suction field on the opposite side of the beam (see Figure 4-9).

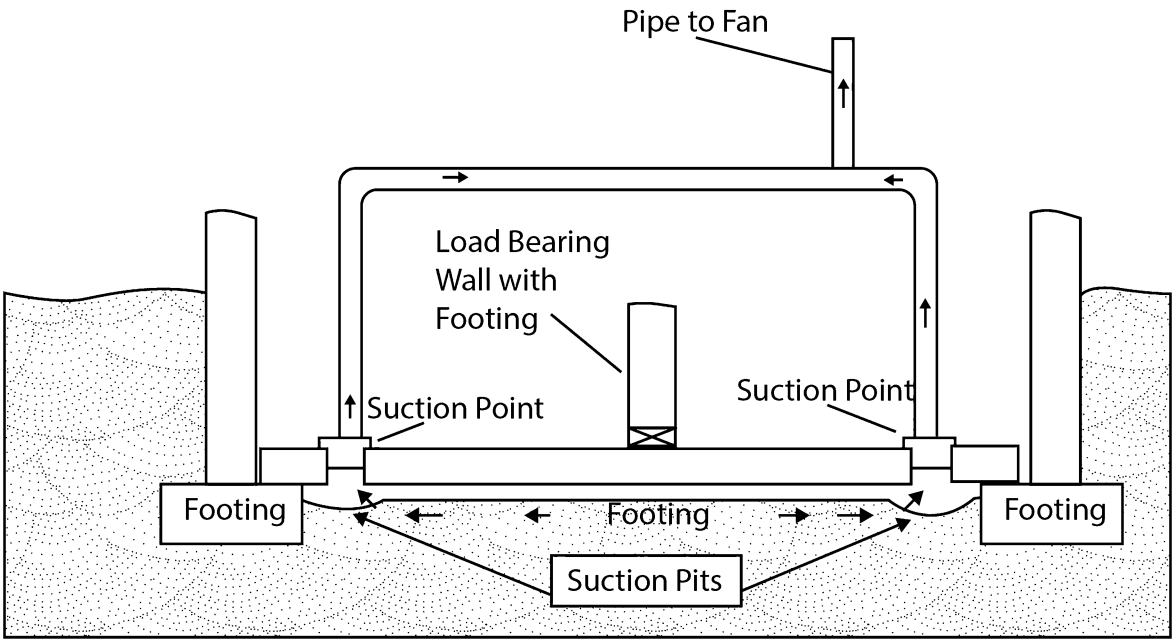


Figure 4-8. Creating a Negative Pressure Field on Either Side or a Footing or Grade Beam, Source: Kladder

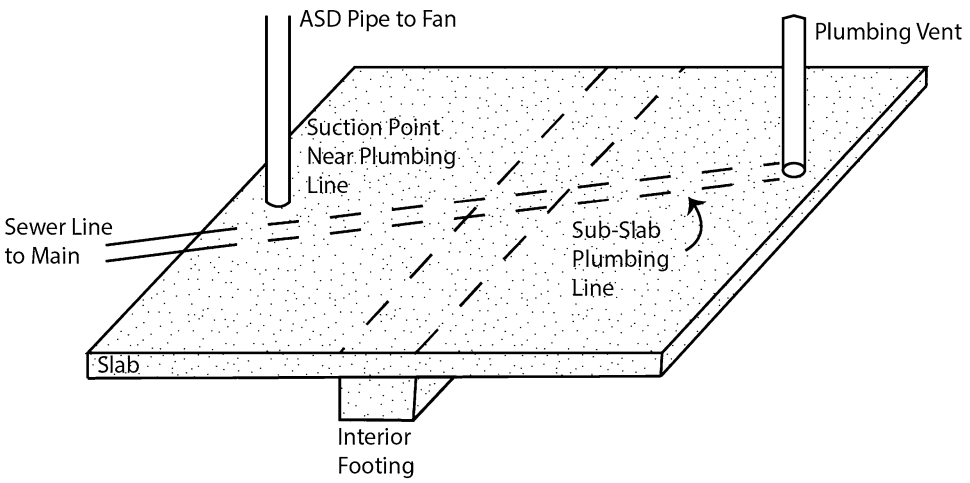


Figure 4-9. Placement or Suction Point Near Plumbing Trenches Can Help Distribute Negative Pressure Field and Span Grade Beams or Intermediate Footings, Source: Kladder

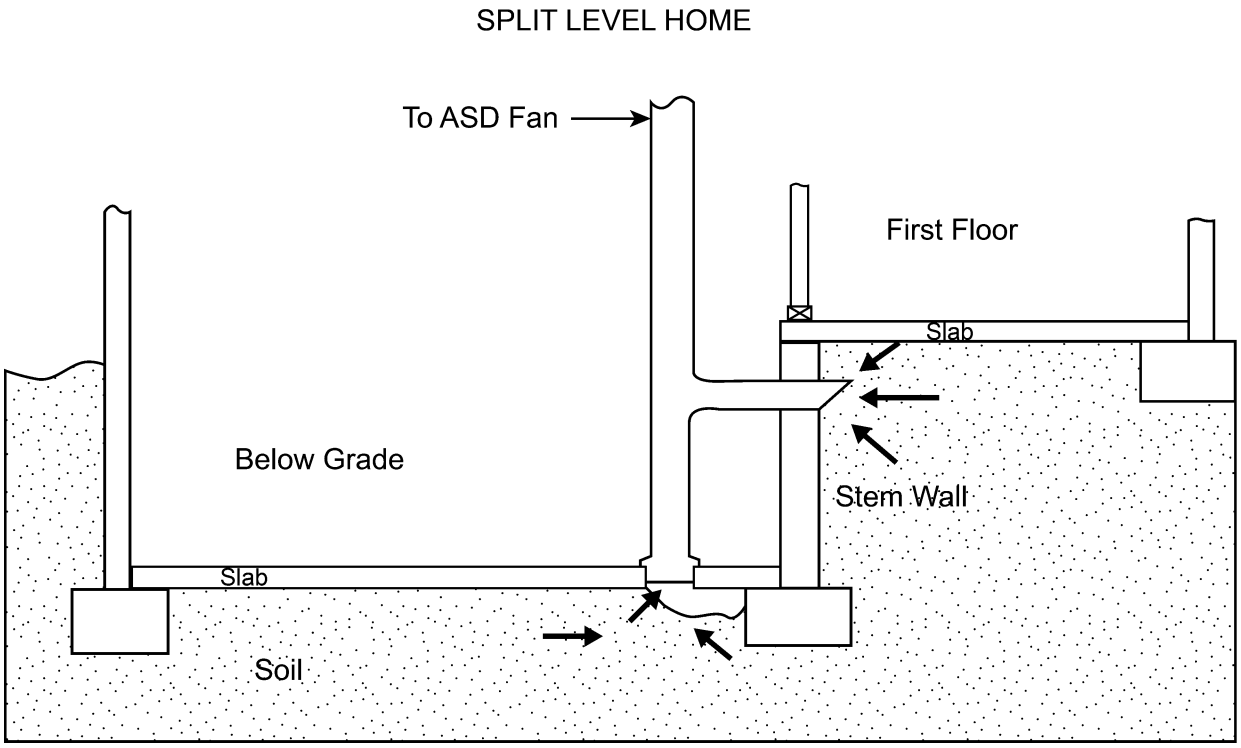


Figure 4-10. Possible Suction Point Layout For Split Level Home. Both Suction Points Are Tied to Common Fan System, Source: Kladder

Split-level homes with two different but adjacent levels, both slab-on-grade, may need sub-slab depressurization techniques applied to both levels. In this case, it is often advantageous to create a suction on the lower floor near the stem wall. Pulling a vacuum on the stem wall generally creates a good negative pressure field along the entire wall and beneath upper slab, since that area generally has

loose, non-compacted soil behind it. This approach can eliminate the need for a second fan installation and confine the piping to an area of the home that is less likely to be finished (Figure 4-10)

3. Selection and Sizing of the System Fan

There are a variety of commercially available fan designs suitable for the radon industry. The keys to proper selection are interrelated: an awareness of the amount of suction to be applied to the under slab, and the amount of air to be withdrawn in order to achieve the desired vacuum. To understand the dynamics involved, several important fan characteristics are first discussed.

Fan Curves

Fan curves are graphic representations of how much air a fan will move given various pressure conditions, e.g., resistance to air flow. One axis of the graph is static pressure, while the other axis is the volumetric air flow, typically expressed in cubic feet of air per minute (CFM). A point on the curve is used to read the vacuum developed by the fan at a given air flow (or vice-versa). 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. To get a perspective on these units, consider the following example:

A glass filled with water contains a drinking straw. One can drink from the glass by sucking on the straw, thus creating a vacuum. When this vacuum on the straw is created, the water rises up the straw to the mouth which is, for example, 2 inches above the water level in the glass. A vacuum is thus created on the end of the straw equal to 2 inches of water column (2 in. W.C. - see Figure 4-11).

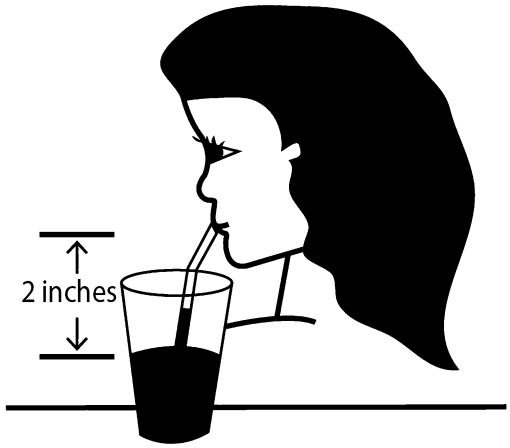


Figure 4-11. Static Suction Pressure of 2 inches of Water Column (W.C.), Source: Kladder

If the straw is removed from the water and sucked on, one is able to feel air move through the straw. In fact, it is very easy to do this with little suction force on the straw. If, however, one began pinching off the straw, greater and greater suction pressures would have to be applied to draw the same amount of air through the straw. The same type of situation occurs if one blows through the straw. The more resistance to flow (pinching off the straw), the less air one can move through the straw without exerting a greater force on the straw.

Fan curves express the relationship between pressure and air flow in quantitative terms like the example above, with one exception. Generally, a fan cannot increase or decrease the force it exerts, as a person can in the example above. A fan or blower can only increase suction as air flow decreases, as defined by its performance curve. Therefore, when available air flow decreases, as in the case of pinching off the straw, the vacuum increases, just as it would on a sub-slab suction system working on a tightly compacted soil. Conversely, when the available air increases as it would in loose soils and large sub-slab aggregate and leaky slabs, the air flow of the fan would increase, but the suction pressure would decrease. Whereas different fans have different characteristics, they all act similarly, in that their suction capacity decreases with available air volume. The rate of decrease, however, depends on the fan design.

Fan Sizing

From the preceding discussion, we see that selecting the proper fan depends on estimating the pressures and air flows required to make radon control successful. These pressures and flows, in turn, depend not only on the soil and slab characteristics, but also on other components in the system (e.g., piping, fire dampers, and rain caps). While the pressure drops associated with the piping and other standard components can be calculated (see later discussion), the pressure and flow characteristics of the soil and slab may need to be determined by taking measurements (Unit Five).

Consider two, identically sized slabs, one on tight soil and the other on loose soil. To develop identical negative pressure fields beneath both slabs, the fan servicing the tight soil slab (which would not have much air available to it) would not require a high volumetric capacity but, because of the higher resistance of the soil to air flow, would require a high suction capability. In contrast, the fan drawing on the loose soil (which would have a lot of free air available and less resistance to flow) needs the characteristics of high volumetric flow and low vacuum.

If the low volume, high vacuum fan was incorrectly installed on the loose soil slab, then the volumetric capacity of the fan would be exceeded and the sub-slab vacuum field would not extend far from the suction point. Similarly, if the high volume, low vacuum fan was incorrectly installed on the tight soil, the resistance to flow would be greater than the vacuum capability of the fan, limiting the field of negative pressure to just around the suction point. Obviously, it is essential to select a fan suited to the conditions under which it must operate. Figure 4-12 demonstrates how one may need different capacity or vacuum producing fans for different types of sub-slab aggregate. This data was obtained from measurements performed on a 1 foot by 1 foot by 10-foot box. It presents a conservative approximation of what dynamics are involved in sub-slab soils. Figure 4-13 and Tables 4-1 and 4-2 provide information for a comparison of the characteristics of different fans. while Table 4-3 presents a guide to the number of SSD suction points, pipe penetrations, and fan capacities typically encountered.

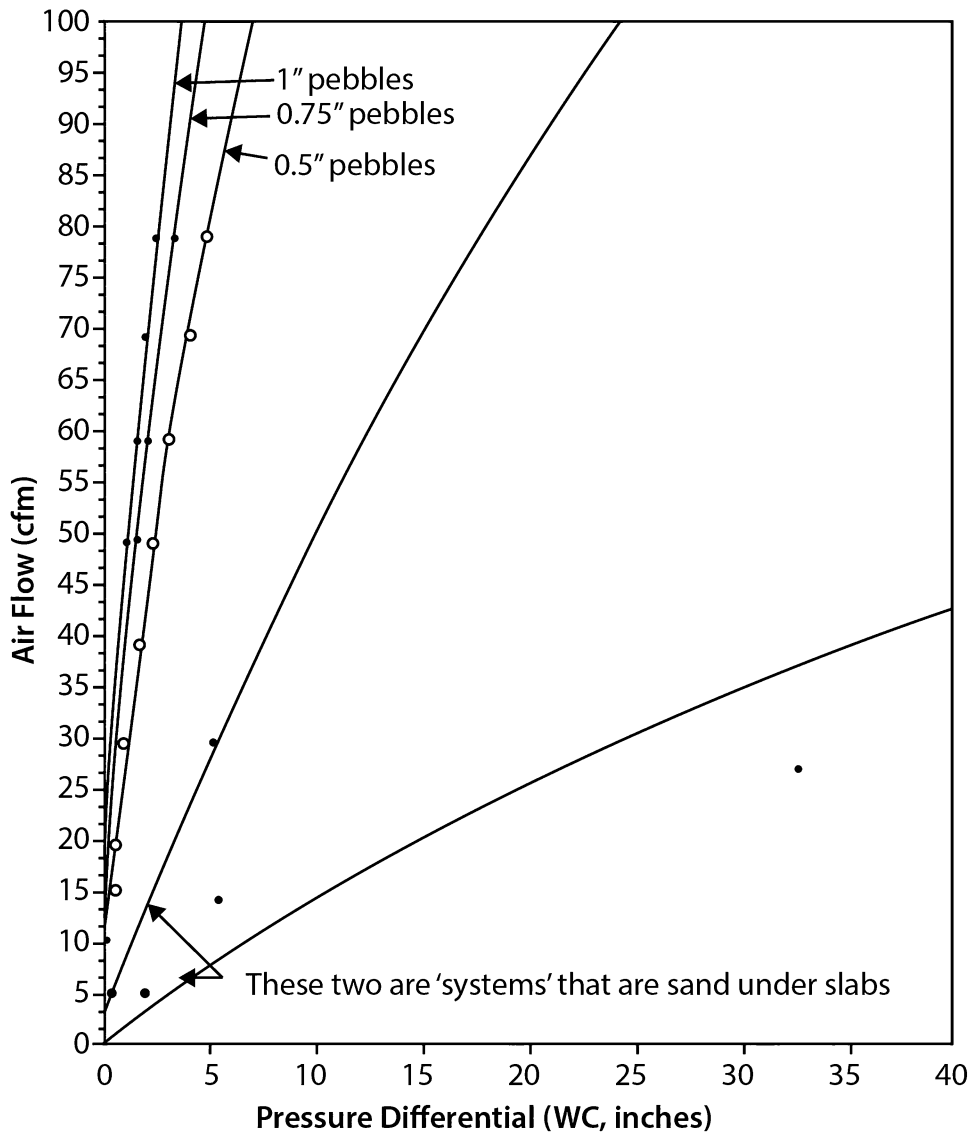


Figure 4-12. System Curves for Different Aggregates, Source: Camroden Associates

It is also important to note that any fan will create a larger suction field, or have a better radon removal efficiency, if less extraneous air needs to be handled. Caulking and sealing entry points (such as floor-wall joints, large floor cracks, open sumps, and floor drains) improves efficiency, reducing the amount of house air (that is drawn down 'beneath the slab) that has to be removed to maintain the negative pressure field. Furthermore, a reduction in the amount of conditioned inside air that is drawn down beneath the slab would diminish the additional load on the home's beating or air- conditioning systems. As much as half of the air handled by an ASD can come from inside the home (Ref. 4). Caulking and sealing, therefore, not only improves radon reduction but is also an energy conservation measure. If enough entry point leaks are sealed, it may be possible to select a smaller fan that can handle the new pressure and flow conditions, or the power rating of the original fan could be reduced because it is moving a smaller volume (the power rating curves for some of the fans typically used increase as the flow rate increases). In either case, additional energy savings will result.

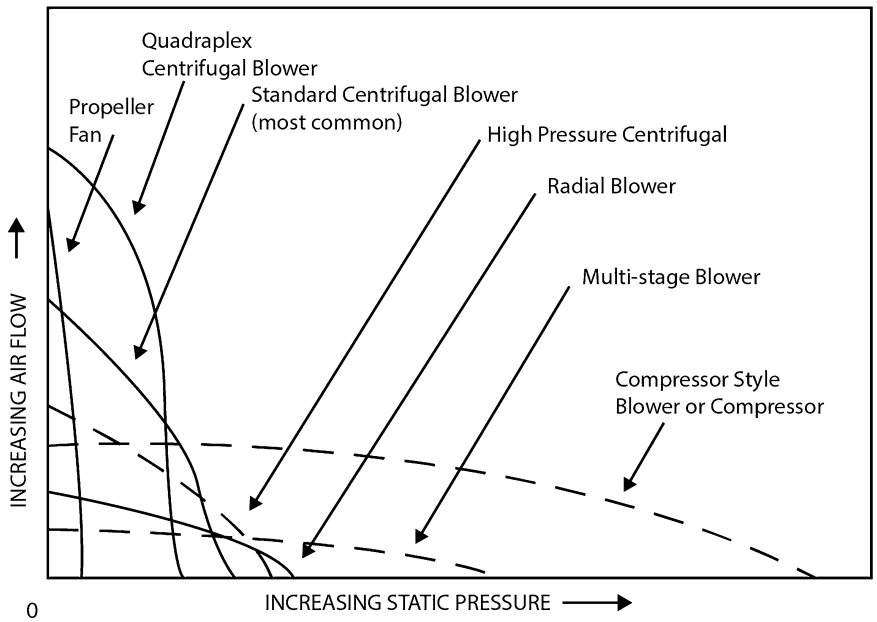


Figure 4-13. Fan Characteristics, Source: Kooltronics

Furthermore, a large amount of interior air drawn into an ASD system could back draft a combustion appliance and cause a significant health hazard to the occupants. Sealing in this case may be a requirement to prevent this situation rather than an enhancement for energy savings or radon reduction.

Another consideration in fan sizing is ensuring that the fan has sufficient capacity to overcome the negative pressures that may be greater at times of the year different from those when the initial design and installation work was performed. Sufficient air flow capacity should also be in reserve for the possibility of greater air flows occurring at other time periods when the condition of the soil around the building may change and allow more outside air to enter the system (ground drying, thawing, cracking). It is accepted practice, therefore, to size the fan for tasks that generally fall within the mid-range of its performance curve, thereby allowing both reserve flow and suction capacity. This does not necessarily create an energy penalty depending on the fan power rating curve.

Other considerations for fan selection include:

- Noise,
- Service life,
- Maintenance requirements,
- Ease of installation and replacement,
- Availability of replacement fans and fan parts,
- Positive pressure leaks,
- Impact of other soil gases,
- Moisture resistance, and
- Electrical rating.

Fan ID	Max Watts	Horse Power	Fitting Diameter	RPM	CFM @ 0 in. W.G.	CFM @ 1 in.W.G.	Max Suction (in W.G.)
K4	-	1/40	4	2800	122	-	0.75
R100	50	-	4	2900	124	-	0.75
F100	70	-	4	2500	160	60	1
K4XL	-	1/20	4	2450	170	50	1.5
F125	70	1/30	5	2500	205	-	-
K5	-	1/40	5	2800	158	-	0.75
T1	-	1/40	5	2800	158	-	0.75
R125	50	-	5	2900	146	-	0.75
F150	90	1/20	6	2500	270	110	1.0
KT150	90	1/20	6	2500	270	110	1.0
K6	-	1/20	6	2150	270	110	1.0
T2	-	1/20	6	2150	270	110	1.0
R150	90	-	6	2350	270	102	1.0
F160	100	1/15	6	2150	361	122	1.0
KT160	100	1/15	6	2150	361	122	1.0
K6XL	-	-	6	2150	360	122	1.0
F200	100	1/15	8	2150	410	135	1.0
K8	-	1/15	8	2150	410	135	1.0
T3A	-	1/15	8	2150	410	135	1.0
R200	125	-	8	2800	541	324	2.0

The above table is intended only as an example of some of the types of fans that have been used in the radon mitigation field. This list is not intended to be a comprehensive listing compilation of fans suitable for this purpose nor is an endorsement of these particular fans. The fan identifiers are as follows:

Table 4-1. Examples of In-Line Duct Fans Which Have Been Marketed for Radon Mitigation

The above table is intended only as an example of some of the types of fans that have been used in the radon mitigation field. This list is not intended to be a comprehensive listing compilation of fans suitable for this purpose nor is an endorsement of these particular fans. The fan identifiers arc as follows:

F = Fantech, K = Kanalkakt, R = Rosenberg. KT = KT Ventures, T -= Kanaflakt

(Ref. 30 & manufacturing data)

Manufacturer	Fan I.D.	Max Watts	Flow (CFM) @ 0 inches W.G.	Suctions at Alternative Flows In. W.G. @ CFM
Pelican	S-3 Blower	210	27	10" @ 22 cfm 26" @ 0 cfm
Dynavac	Standard	--	60	30" @ 20 CFM
Dynavac	High Vacuum	--	55	40" @ 20 CFM
Dynavac	High Flow	--	115	15" @ 45 CFM

Table 4-2. Performance Characteristics of Some High Suction Fans Used in Radon Mitigation Applications Requiring High Vacuum and Low Air Flow.

Material Under Slab	Pipe Diameter (inches)	Number of Suction Points	Suction Point Location	Blower Suction (inches W.C.)	Blower Volume CFM
Large Aggregate continuous through out	4 to 6*	1	Where convenient	.75 to 2	50 to 240
Pea gravel continuous through out	4	1	Where convenient	1.5 to 2	100 to 150
Fractured granite continuous through out	4	1	Perimeter of slab	1.5 to 2	100
Fractured granite or pea gravel with footing for bearing wall through center	4	2	Near perimeter of slab on either side of center footing	1.5 to 2	100 to 150
Air gap beneath slab generally on perimeter where fill is settled	4	1 to 2	Over air gap	1.5 to 2	100 to 150
Coarse sand	3	2 to 4	Slab edge, perimeter wall	5 to 10	60 to 100
Fine, tightly compacted sand	1.5 to 2	2 to 4	Slab edge, and where necessary	20 to 30	30 to 50

***** 6" or larger pipes may occasionally be necessary for pipe manifolds in large buildings with multiple suction points and high flow rates.

Table 4-3. Guidance for Number of Suction Points and Blower Type for SSD Systems

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 fan noise than any other aspect of a functional ASD system.

Typically, in-line style fans are used on ASD systems. Neoprene or rubber couplings are used to attach the fan to the piping and are excellent for isolating the fan vibration, as well as for easy removal for maintenance. It is also a good idea to utilize non-metallic strapping or rubber feet when supporting a fan or as standoffs from a building member to prevent Vibration feeding back into the house.

Some of the higher vacuum blowers generally run at higher speeds, which may require mufflers or sound enclosures to dampen the noise. Noise from the piping system itself will be discussed in a later section.

Fan Service Life

Given the constant generation of radon in the underlying soil, the fan should be capable of operating in a continuous mode, with a life expectancy comparable to any other major household appliance. Most in-line duct fans being utilized in the industry have a life expectancy projected at 15 years (Ref. 24).

Unfortunately, if one bas properly isolated the fan and designed the piping system to minimize the noise transmission in the living space, a homeowner may be unable to notice when the system stops running. Also, in some cases, a failure can occur even though the fan appears to operate normally. For this reason, the EPA Radon Mitigation Standards require an audible or visual warning device (beyond listening to the fan) on all active radon mitigation systems that positively indicates proper, continuing performance of the system fan.

Positive Pressure Side Leaks and Fan Location

The ASD system extracts the air from beneath the slab where radon is most highly concentrated. Any leakage which occurs from the fan housing or the piping system can contaminate the indoor air, if the leak is at a location inside the occupied space of the house. Most fans with sheet-metal housings are not designed to handle gases considered to be hazardous to health; their housing and electrical junction boxes, therefore, are not well sealed When considering a particular fan or blower, the mitigator must be aware of the leakage potential and either select an alternative piece of equipment or modify the selected fan accordingly. Modification should not be made if it would void warranties and/or electrical classification.

The need to avoid exhaust leaks into the living area is felt to be so great that the EPA Radon Mitigation Standards require that ASD fans not be located within the conditioned (heated/cooled) space of the house.

This means that the fan can be:

- Outside,
- In an attic that is not open into the house or is not occupied itself, or

- In a garage, or other structure that is separated from the house and is not a living space, or under a living space.

Fans should never be located in crawl spaces. Since the house can exert a negative pressure on the crawl space, fan leaks in crawl spaces can cause additional radon to enter a home. Therefore, crawl-space locations are no longer allowed for ASD fans, (see "Mitigation Standards" at the end of this chapter).

Impact of Methane and Other Soil Gases

As an ASD system removes radon gas from the soil beneath and or around a home, it also removes other soil gases, such as moisture, air, and methane. In some instances, this removal process can be beneficial, but it can also present particular operational and safety concerns.

It is also possible to withdraw other soil gases from the underlying soil, such as methane, by ASD systems. 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. Removal and venting of this methane could be perceived as a benefit to the homeowner. However, methane is a highly flammable gas and, in areas where appreciable amounts exist, an active sub-slab system can create a concentrated methane-air stream, where the methane content can approach or even exceed the lower explosive limit. Blowers typically used in the radon industry are not designed for this type of service, and an electrical or a static spark inside the piping system could ignite the methane-air stream. Mitigators should be aware of this when installing systems in areas close to old landfills.

Moisture Resistance

The air withdrawn from beneath the slab is typically at the average annual temperature of the ground beneath the home (which is often the annual average air temperature). The amount of water vapor in the soil air depends upon the soil moisture, plumbing leaks, the height of the water table, or other nearby sources of water. Very often this air is at, or just below, the dew point-the temperature at which the air becomes saturated and produces condensed droplets of water. Since piping systems may be routed through an air-conditioned air space, outdoors, or through a non-heated space, the pipe could be cooled below dew point of the air in the pipe, which will cause moisture to condense on the inside of the pipe.

When condensation begins to occur, the droplets can coalesce and run down the inside of the piping and collect in low spots. To prevent damage, fans or blowers should be moisture-resistant in their internal construction. In-line fans or blowers should be mounted vertically so that the condensate does not collect in the fan housing. This is not a trivial point, since under the right conditions (even the arid southwest), quantities as much as ½ or more gallons of water a day have been collected.

Electrical Classifications

At this time, the electrical and plumbing code agencies have not determined a specific hazard classification for radon gas. However, there are several applicable codes for fan and blower installations, regardless of their use.

Specifically, a fan motor and associated wiring must be rated for the environment in which they are being installed. For example, a fan installed outside the home should be rated for wet, external environments (e.g., National Electrical Manufacturer's Association - NEMA 9) and, unless low-voltage systems are being utilized, external wiring should be in water-tight conduits and connected to a circuit fitted with a ground-fault interrupter. Regardless of the installed location, the fan should normally have an electrical disconnect within eyesight of the motor. A circuit breaker labelled radon mitigation system may also be used as the disconnect. This disconnect is typically a switch on the 110 volt supply or an insulated quick-coupling on low-voltage systems. Some areas have allowed fans with standard plug cords to be installed, with the plug functioning as the disconnect in an indoor application such as an attic or garage. Using cords as a means for disconnect is falling out of favor (and is certainly not permissible if the fan is outside of the home), as radon mitigation systems are being viewed more and more as permanently operating building components.

4. Selection, Sizing, and Layout of System Piping

Apart from the fan selection and installation there are several aspects of the installation of the piping system itself that can affect the performance and durability of the overall system.

Some of those elements are:

- Pipe Sizing,
- Routing,
- Material,
- Noise,
- Suction Point Detail, and
- Moisture.

Pipe Sizing

The effect of soil porosity on air flow resistance was discussed earlier in this unit. A diagnostic method to determine how much air needs to be handled is sometimes useful and is covered in more detail in the next unit. 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 air velocity in the pipe is important in determining the resistance to air flow. At very low velocity ranges, the resistance to flow doubles. However, at higher flow ranges, where most of these applications fall, doubling the velocity will quadruple the resistance. The relationship between velocity and resistance to flow, also called pressure drop, can be derived from Figure 4-14.

For example, if we estimate (perhaps from diagnostic measurements) that a single suction point in a slab with loose soil would extend a negative pressure field fully beneath a slab with a measured flow rate of 25 cfm, it would be prudent to design a system capable of handling 50 cfm. Referring to Figure 4-14, 100 equivalent feet of pipe presents a pressure drop of 0.7 inches of water column if 3 inch pipe is used, and 0.17 inches of water column if 4 inch diameter pipe is used. If a blower with a suction capability of 1 inch at 50 cfm (derived from the blower's fan curve) is installed on the 3 inch system, the resulting suction at the point the system contacted the sub-slab soil would be approximately 0.3 in W.C. (1 in.

W.C. at fan minus 0.7 in. in W.C. pressure loss in 100’ of 3” pipe.) If the same blower is placed on the 4-inch system. the suction at the suction point would be 0.83 (1 in. W.C. at fan minus 0.17 in W.C. pressure loss in 100' of 4" pipe). In this example, one can see that the 4-inch pipe would apply almost three times the suction force to the sub-slab area as would the 3 inch pipe with the exact same fan.

One might question how often 100 feet of pipe is used in a residential situation? It is important to remember that the chart in Figure 4-14 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 length. This has to be calculated for each fitting and is also a function of its size. Pressure drop associated with fittings is given in terms of equivalent length in pipe diameters or a ratio of equivalent length/diameter of pipe (L/D). Multiplying this factor by the diameter of the selected pipe (expressed in feet) will provide an equivalent length of pipe that has the same resistance as the fitting. In this manner, the length of actual pipe and the length of pipe equivalent to the resistance of the fittings can be added to determine the overall resistance to air flow. Table 4-4 and Figure 4-14 provide an example of a calculation of equivalent pipe length for a single point ASD system with the following components:

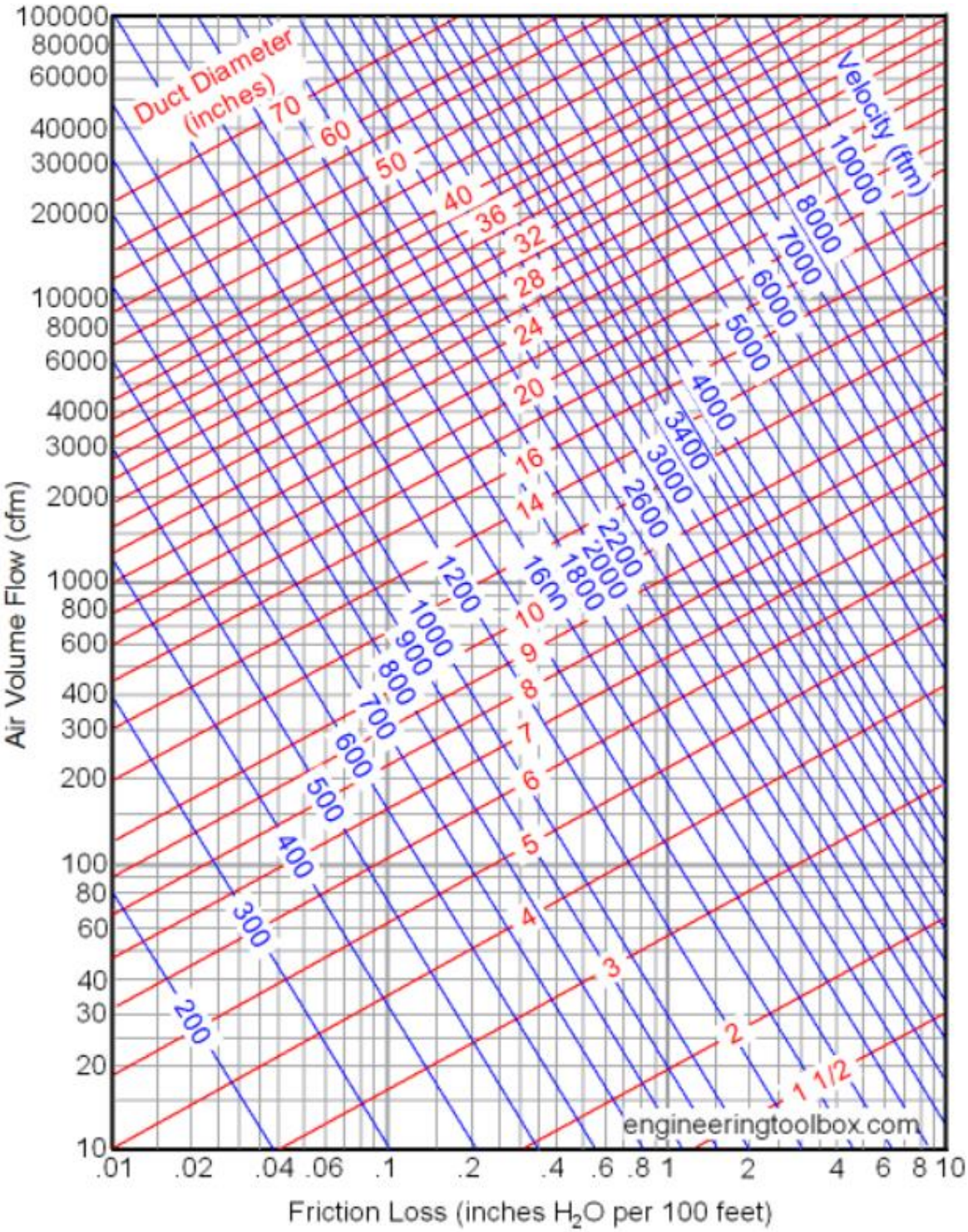


Figure 4-14. Pressure Loss Due to Friction in Ductwork, Source: ASHRAE Fundamentals http://www.engineeringtoolbox.com/

As an example, if the flow is estimated to be 40 cfm, the total pressure drop for 136 ft. of piping would be determined by finding the pressure drop per 100 ft. for a 4-inch pipe and multiplying by the total equivalent feet divided by 100:

$$(0.12 \text{ in. W. C./100 ft.}) \times 136 \text{ ft} = 0.16 \text{ in. of lost vacuum}$$

A couple of lessons can be learned from this example. First, almost two-thirds of the resistance in this particular system is due to the fittings rather than the actual length of pipe. Second, when trying to minimize piping pressure drop one should be as concerned about the discharge as well as the suction piping.

Item	L/D Ratio	Diameter Feet	Equivalent Length (L/D x D)=E	Quantity (Feet or Number of Fittings)	Total Qty x E feet
Suction Side					
Pipe	1	-	-	35	35
45's	16	0.33	5.3	2	10.65
90's	30	0.33	9.9	3	29.9
Discharge Side					
Pipe	1	-	-	10	10
45's	16	0.33	5.3	2	10.65
90's	30	0.33	9.9	2	19.8
Discharge Cap	60	0.33	19.8	1	19.8
				Total	**136 ft**

Table 4-4. Pressure Drop Example Using 4-inch Pipe

As a rule of thumb, some mitigators use the fact that the air velocity in a system should not exceed 700 ft. per minute (61 cfm in a 4-inch pipe). This is due to a concern for excessive pressure drop as well as the noise that the air can create when it passes through the piping. Air velocity in a pipe is calculated by dividing the volumetric flow rate (in cubic feet per minute) by the cross-sectional area of the pipe (in square feet).

In the previous example, the cross-sectional area is calculated as follows:

A (area of a circle) = πr^2

where:

r = radius = diameter/2 or 4 in./2 = 2 in.

π = 3.142 (a constant)

therefore:

A = 3.142x (2 x 2) =12.57 sq. inches

or

A = 12.57 sq. in./144 sq. in./sq. ft. = 0.0873 sq. ft.

therefore,

velocity = 40 dm / 0.0873 = 458 ft. per minute

In Figure 4-14, if a 3-inch diameter pipe had been used rather than a 4 inch, the velocity would have been 814 ft. per minute. This would have caused considerably more pressure drop (approximately 0.6 in. rather than 0.16) and could have caused some additional noise.

Pipes for residential ASD systems are typically 4 inches in diameter. Larger diameter pipes are occasionally used; for example, as a manifold in large buildings with multiple suction points. In cases where very tight soils are encountered or significant sealing has been performed to reduce extraneous air infiltration and hence overall air flow, pipe sizes as low as 1 ½ inch have been effectively used.

The data presented above assumes that the pipe utilized has smooth internal walls. Corrugated style piping can present as much as 75% more resistance to air flow than the typical PVC piping.

The above examples relative to diagnostics and pipe sizing are more rigorous than the situation a mitigator typically encounters in a normal house or in a subdivision with which he/she is familiar. However, use of these methods are often necessary for an inexperienced mitigator, or for an experienced mitigator involved in designing a system for a large home, school, or commercial building or trouble shooting an ineffective system.

Routing of Piping Systems

As explained earlier, typically the best location for a suction point is near an exterior wall. In order to avoid a spread footing. the suction point for the piping system must be an appropriate distance from the wall. The piping above the suction point can be rolled back to the wall. with two 45 degree elbows to allow structural attachment to the wall. Alternate suction point details can be found in Radon Reduction Techniques For Detached Houses (Ref. 30).

Obstacles to pipe routing such as floor joists or support posts may be encountered. These support members should never be altered unless aspects of the building codes are strictly followed. The best course is to reroute the pipe and never to cut a structural member.

Building codes are also very specific when a penetration is made through a fire-rated wall. An example of this would be the routing of a pipe from inside a home to an attached garage. The dividing wall is a fire-rated wall, so the penetration must be made in a manner that does not decrease the fire rating of the wall. This is typically accomplished by utilizing an intumescent wrap and collar (although there has been some recent concern about the degradation of this material over time) where the piping penetrates the wall (other methods are available such as fusible link devices, but may not be as resistant to degradation from moist soil air as is the intumescent wrap external to the pipe). It should also be noted that some ceilings are fire-rated, and caution should be exercised when routing piping into attic spaces (this is especially true in multifamily dwellings and commercial buildings).

Perhaps one of the more challenging aspects of pipe routing is installing it in a manner aesthetically pleasing to the homeowner. Utility/mechanical rooms, unfinished rooms, closets, and plumbing chases are good areas for hidden routing. If one is forced to install piping in finished areas, homeowners generally prefer it to be concealed behind sheet rock or wood paneling.

Moisture

As described earlier, a significant amount of soil moisture can be removed by an ASD system. If the pipe is routed through a space where the temperature is less than the dew-point of the soil-gas condensation can occur within the pipes. One way to minimize this is to insulate the outside of the pipe to reduce this external temperature effect. This is relatively easy to do when the piping is, for example, routed through an unheated attic space. However, when the piping is routed outside, the use of insulation is not as convenient, since it requires a moisture barrier to protect it from the elements.

The most effective method of dealing with moisture is to ensure that the piping is installed in a manner that allows the condensing water droplets to coalesce and run backwards all the way to the suction point. This requires that no traps be built into the system and that all horizontal runs have a slope of at least 1/8 inch per foot. If a water trap is unavoidable, a method for condensate removal still needs to be designed into the system. Two methods are to route a small drain line back to another portion of the suction piping or via a trapped drain line to a condensate pump (drain lines should be the very last alternative, as they can dry out or become plugged with mold and dirt).

Where the pipe is routed through areas of high humidity, it is possible that the interior of the pipe can be cooler than the exterior environment, thus causing condensation or sweating to occur on the exterior of the pipe. If this should occur on the inside of a house, the water can run down the outside of the pipe and drip onto ceilings etc., causing damage. In these situations, the pipe should be carefully wrapped with insulation material that has an external vapor barrier to reduce moisture build up.

The design of the system discharge can also have an effect on potential moisture problems. It is not uncommon to see moisture that is condensed on the inside of the pipe being "spit" out the top of the discharge pipe. Also, homeowners are often concerned about the entry of rain water into a vertical open pipe discharge and want some type of turndown or rain cap to deflect the rain. In areas where very cold temperatures are encountered in the winter months, water being spit out of the end, if collected or

caught on a rain-cap, will freeze and begin to cause an ice dam that can eventually seal off the discharge completely. Generally, for purposes of minimizing ice build-up, as well as minimizing the resistance to air flow (see example above), it is best to direct the exhaust vertically, with no obstructions other than a rodent screen of no less than 1/4 inch mesh screen in the discharge.

Piping Material

Piping systems utilized in ASD systems are almost always PVC, while joints are cleaned and fused with PVC cement. To ensure durability, piping systems that are rated for 125 psi service (ASTM D-1785, D-2665, or F-891-90) are often used. This can include schedule 40 pipe, some lighter weight foam core pipe, and specific grades of sewer and drain pipe. Where piping is routed outside the home, it should be rated against deterioration from ultra-violet radiation from the sun. Although painting can protect the pipe, it generally flakes off easily, thus voiding the protective coating (unless special PVC etching solvents are used to prime it prior to painting). The best approach is to use schedule 40 PVC, metal, or thick wall sewer and drain vent pipe (the same material that plumbers use to run vent stacks).

For some exterior routing applications, it may be more aesthetically pleasing to adapt from round pipe to rectangular pipe, such as oversized down spout, where the piping is routed vertically. This is sometimes done in PVC, but often metal down spout is used, because it can easily be primed and painted to match the building's trim. In such cases, it is required that the down spout be labeled to prevent it from being tied into a rain gutter sometime in the future.

In some instances, where routing is difficult (such as in a pipe chase), flexible piping has been used. Such pipe should be semi-rigid and corrugated. Flexible dryer vent material is very fragile and easily punctured and should never be used for this purpose. Semi-rigid, corrugated piping exhibits a high degree of air flow resistance (70% more than smooth wall PVC), and the next larger size should be used when making a transition from solid pipe to corrugated.

Noise Considerations

When air moves through a pipe, the resistance to air flow creates noise within the pipe: the higher the air flow resistance, the higher the noise created. Areas that create the largest point pressure drop, such as elbows and tees, will also be the largest single-point noise generators. It is a good idea to locate fittings, especially tees, in non-occupied areas whenever possible.

A great amount of air noise is also created at the discharge, where the air enters the atmosphere. It is for this reason, as well as the potential for the exhausted radon to reenter the building, that the discharge point should be located away from building openings. Directing the air stream straight up without the back pressure caused by a rain cap will allow for a quieter system.

As discussed earlier, fans or blowers can vibrate and transmit this noise to the piping system. The key to minimizing this effect is to isolate the fan from the piping system with rubber or neoprene adapters and to isolate the piping from the building itself. This is typically carried out by using non-metallic support straps and rubber pads behind vertical pipe hangers. Also, where piping may pass through a non-fire-rated wall, the use of rubber sleeves over the pipe at the point of penetration can be beneficial.

SSD Suction Point Detail

The way in which the suction is applied to the sub-slab volume is a very critical aspect of the radon reduction system efficiency. Although expedient, merely drilling a hole and inserting a pipe into the soil may yield very poor results. The total volume of soil air being drawn towards the suction pipe is being forced through a progressively smaller cross-sectional area of openings in the material near the pipe (soil, aggregate). This causes the air velocity to increase dramatically, along with the pressure drop, which can become significant near the pipe. If an empty pit is dug around the pipe opening, the air velocity and pressure drop are reduced. Thus, more of the fan's suction capability is available to be distributed over the sub-slab area (i.e., the pressure field is extended). A rule of thumb is to remove about two 5 gallon buckets of soil per hole. The tougher it is to dig, the more critical it is to remove the dirt. Increasing the pit size can have a dramatic effect upon the negative pressure field extension, often to the point of reducing the number of suction points needed, and thereby significantly reducing system cost (Ref. 28).

Figure 4-15 illustrates one of several approaches for installing an SSD suction point. First an oversized hole is drilled, using a coring machine or a hammer-drill. This hole is typically 6 inches in diameter. This larger hole allows for easier access with hand digging tools or specially designed augers. Once the fill has been removed, the hole is left empty and a reducing bushing is inserted into the hole that will adapt from the larger hole size to the pipe size to be run. Expanding foam is placed between the bushing and the concrete. Backer rod and polyurethane caulk could alternatively be used. The bushing flange setting on the concrete is caulked to the concrete to affect an air tight seal. An air leak at the suction point will result in a dramatic loss of sub-slab suction strength. For other suction point connection methods see Ref. 30.

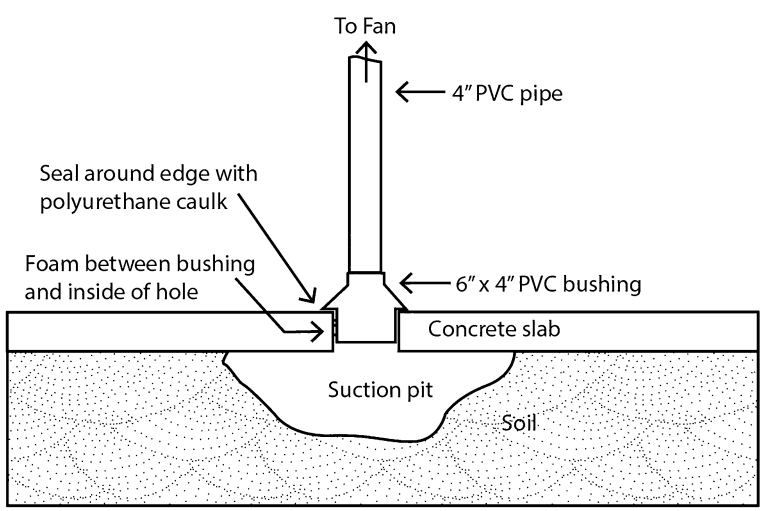


Figure 4-15. Suction Point Detail, Source: Jelinek

5. Safety Considerations

In addition to the normal construction safety concerns with installation and homeowner use, there are a few additional concerns specific to radon soil depressurization systems.

Discharge Point

Concerns about the noise generated from discharge points have already been discussed. However, an even more critical concern is the concentrated radon air stream being exhausted.

Exhaust streams from Active Sub-Slab systems have been measured at levels ranging from less than 100 to several thousand pCi/L. The potential for increased concentrations as a function of low available dilution air causes one to be extremely cautious about discharge location, regardless of measured concentrations. Exhaust streams containing radon can re-enter the building through vents, windows, and even the siding. This is referred to as re-entrainment. Not only is this a health concern, but it has also been the reason for several failed mitigation attempts (Ref. 9).

Consequently, the EPA Radon Mitigation Standards require the following discharge location criteria:

- The discharge point of the system shall be 10 feet or more above ground level.
- The discharge point shall be 10 feet or more from any window, door, or other opening in the structure (e.g., vents, operable skylights, or air intake vents) that are on a plane two feet below the discharge point.
- The discharge shall be 10 feet or more away from any private or public access.
- The discharge point shall be 10 feet or more from any opening into an adjacent building.

It should be noted that violation of these parameters, along with other aspects of the Department of Health, and EPA's Radon Mitigation Standards (contained at the end of this chapter), can result in being de-listed. **This is true even if the client requests such a deviation.**

System Indicators

If the mitigator has done a good job in installing an unobtrusive and quiet system, it may be very difficult for the homeowner to know when it is not operating properly, other than waiting for a radon test result. The EPA Radon Mitigation Standards require that a plainly visible mechanism be installed on these systems that can be easily read and interpreted by the homeowner. There are several acceptable approaches that have been used in the industry.

A differential pressure gauge or differential pressure switch with warning lights or audible alarms can be installed. The gauge or differential switch typically monitors the differential pressure on the suction side of the fan relative to the inside air pressure. This monitoring device should alert the homeowner if the blower malfunctions, or significant air leaks occur in the suction piping. More simply installed, but requiring more interpretation by the homeowner, is the use of U-tube manometer that indicates differential pressure but do not turn on lights or alarms. The sensitivity of the pressure measurement device and the position of its measurement location are critical for detecting small changes in system performance. For example, if a fan is oversized. the measurement point is a few inches below the suction side of the fan, and the floor core is broken off two stories below the fan, the vacuum at the point of measurement may still be sufficient to show normal operating conditions, which is clearly false (see next section on combustion appliance back-drafting).

Installation of volumetric flow sensors have also been utilized as a method of system monitoring. These must be easily interpreted and sensitive to small system changes. The use of a feed-back system, which indicates fan and volumetric flow, is acceptable, provided the sensitivity and function is understood by

homeowners. Simple indications that power is available to the blower (e.g., a light wired in parallel to blower supply lines) would not be acceptable, since the light would still be energized even when the fan burns out.

Devices that sense air flow either directly or indirectly by indicating the current draw on the fan motor offer certain advantages. They are not susceptible to manometer tube plugging and also indicate situations of low flow (pipe plugging) or excess flow (pipe leakage).

System Labelling and Documentation

The Department's Radon Mitigation Standards require that the system be labeled to indicate that the piping and fan are part of a radon mitigation system. The system should be labeled at each location where the system enters a different portion of the home. For example, a system is routed from the basement through the first floor, second floor, and subsequently through the attic to the roof. A label, which is legible from 2 feet away, should be affixed to the piping system in the basement, first floor, second floor, and attic, etc.

Maintenance information and a description of how to operate the system should also be affixed to the system or on a convenient wall or breaker panel. In addition, you should advise the homeowner to engage in biannual radon testing as a further safeguard against system failure. It is also recommended that the homeowner pass this advice (as well as the system documentation) onto future homeowners.

The appendix contains a suggested set of forms, which may be useful for the mitigator to utilize as a checklist to conform with the necessary documentation required by the Radon Certification Program.

Combustion Appliance Back-Drafting

It is important to consider the effect of any building modification on the safety to the occupants. One area of extreme concern when dealing with ASD systems of the type described above, as well as many of the subsequent variations, is the potential for back-drafting of combustion appliances such as hot water heaters, furnaces, fireplaces, etc. When this occurs, the carbon monoxide from these appliances cannot rise-up the flues and an indoor accumulation of this toxic gas can result.

The air that an ASD system can pull out of the house through cracks and openings can cause additional depressurization of the structure, in the same way as an exhaust fan can create more negative pressures in a building. If a vented combustion appliance is located in this space, the negative pressure created by the draft in the flue will compete with the negative building pressure. If the draft pressure in the flue is weak (due, for example, to wind, an improperly-sized flue, or an obstruction in the flue) compared to the negative building pressure, the building can pull air back down the flue-or back-draft the appliance. Thus, the ASD system can make the building pressure more negative so now the appliance draft can no longer compete with the mitigation system.

Whenever a mitigation system is installed and operated, the combustion appliances must be checked for back-drafting before leaving the job-site. There are many rigorous procedures that have been developed for conducting this test. The following method (utilized by the New York State Energy Office (Ref. 14)) is an example of one procedure. Use of this method does not guarantee that back-drafting will not occur subsequent to the test, and the professional mitigator is strongly encouraged to become familiar with more rigorous procedures listed in the references.

- Turn off combustion appliances by either shutting them down or, in the case of a water heater, lowering the set-point. Allow the flue to cool to the touch.
- Turn on all negative pressure-inducing appliances, such as exhaust fans, including the ASD system installed. Shut all windows and doors of the house. The point of this exercise is to simulate, as best as possible, the worst case negative pressures that can occur. Note that if this is performed during the summer months, the temperature-induced stack effect will not be occurring, which is why this method is not fail safe or as rigorous as ones that would use temporarily installed exhaust fans to simulate winter time conditions, as well as those that measure flue temperatures and carbon monoxide.
- Reactivate the combustion appliance(s) to allow all the burners to relight. When the burner is activated, hold a non-thermal, smoke test device (such as a smoke stick) near the flue and observe if the smoke is drawn up the flue. It may take up to 30 seconds for the flue to warm up to where it can draft. Momentary spillage is acceptable, if it does not occur for more than 30 seconds. If the smoke rises up the flue, the system is functioning adequately and the ASD is apparently not causing a back-draft
- If the smoke does not rise, or if spillage occurs for more than 30 seconds a serious condition exists. Repeat the test with the ASD system off, to determine if the other household exhaust systems are causing the problem independent of the ASD system. In any event, inform the homeowner, since you may have just found a life-threatening defect. Most utility companies are acutely aware of this concern and can assist you or the homeowner in correcting the problem. For more rigorous methods consult (References 18, 1, 3).

Evaluation of SSD System Performance

Ordinarily, the performance of a mitigation system is evaluated by measuring the resulting radon levels in the building and by measuring the flows and pressures developed in the system piping after the work is completed. However, there may be situations where the mitigator expected problems with, for example, pressure field extension and would like to have information on the operating characteristics of the system during the mitigation. This information may also be needed if the post-mitigation radon levels have remained elevated.

With the system operating, small 3/8" test holes can be drilled (or utilize previously drilled diagnostic holes) through the slab or wall at locations away from the suction points, and a smoke stick or micro-manometer can be used to determine the negative pressure field extension. If the negative pressure field fails to reach any area of the floor or walls, another suction point could be added or more sealing performed prior to leaving the job site. Whether additional work is to be done prior to re-testing is a judgement call that has to be made by the mitigator, and is also dependent upon the contractual arrangements with the homeowner and the pre-mitigation readings of the home. In some cases, where pre-mitigation radon readings are not extremely elevated (e.g. between 4 and 10 pCi/L), 100% pressure field extension may not be needed to reduce the level to below 4 pCi/L. If time allows, a short-term radon measurement may be prudent before commencing significant additional work. Prior to clean-up, make sure all test holes are sealed.

Generally, the greater the depressurization the better the performance. Any amount of depressurization should theoretically work. However, a weak suction means the system can be easily overcome by house pressures that change during the year due to occupant usage and weather conditions. To determine the effects of this, the pressure field readings described above should be performed with all bathroom and kitchen exhaust fans operating (this would also be an excellent time in which to test the combustion appliances for back-drafting).

Weak pressure fields can be caused by very tight soil beneath the slab or too much air being introduced to the system for the type of fan utilized. To assist in the determination of this, the mitigator should measure the amount of air being exhausted by the system and the suction pressure of the fan and compare it to the fan curves for the fan utilized.

If the SSD air flow is low (5 to 20 cfm) and the negative pressure field is marginal (for example, less than -0.005 in. W.C. at a test hole remote from the suction pipe), some possible reasons may be:

- The piping system has a restriction in it. Check suction and discharge for blockages, trapped water, rags.
- If the negative pressure is fairly strong (-0.20 in. W.C.) near the suction point, but falls off dramatically on the other side of a wall or other architectural feature, there may be a grade beam or an addition to the house that has more compacted fill beneath it than where the suction hole was placed. Add additional suction point(s) into areas of low negative pressure (perhaps a vacuum cleaner suction test in those marginal areas would be of benefit before proceeding (see Unit Five)).
- The suction pit was not enlarged sufficiently.
- The soil is very tight and a higher vacuum fan may be required.

If the air flow is moderate (20 to 30 cfm) and the pressure field is marginal (for example, less than -0.005 in. W.C.) at the far ends of the slab, the first 3 reasons described above should be considered as well as:

- Air leakage is occurring at the far portions of the system. Check floor to wall joints and other plumbing penetrations for areas to seal.

If the air volume is relatively high (above 70 cfm) and the pressure field is marginal, all of the above reasons except the fourth are possible, as well as:

- A large amount of air is leaking into the system near the suction point. Check for openings at floor suction point, adjacent block walls, and tops (see block wall depressurization system description that follows).
- A breach in the suction piping has occurred
- The soil is very permeable, and a great deal of outside air is entering the system. The fan's capacity may not be sufficient to handle this amount of air and a fan with a larger volumetric capacity may be needed.

It should be reiterated that a mitigation system may be successful at reducing indoor radon levels below the EPA guideline and not meet the above criteria for pressure field extension. Therefore, it is usually reasonable to perform the radon measurement before conducting other tests and measurements of system performance.

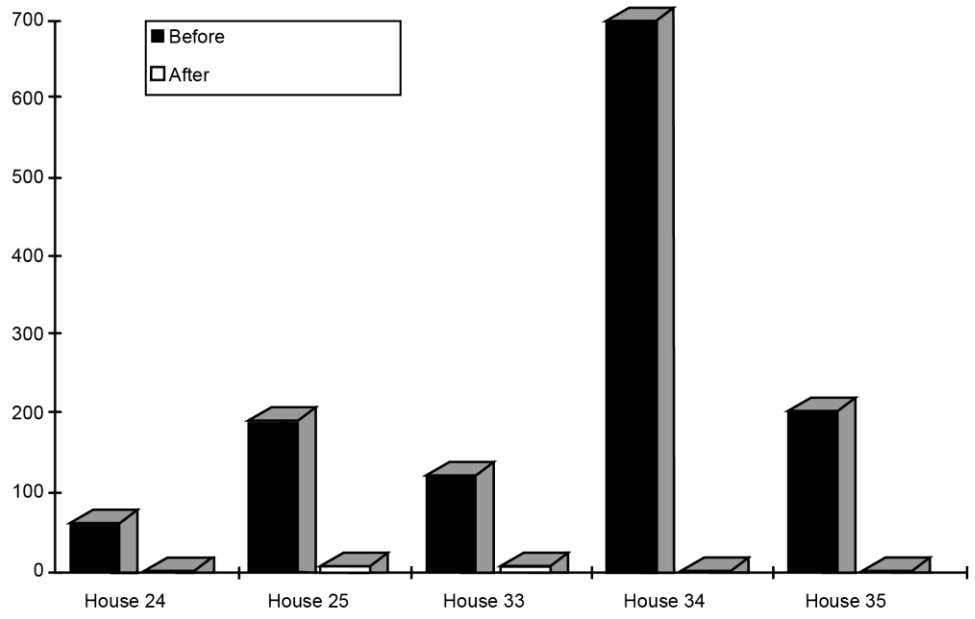
After the system has been installed, the mitigator should arrange, or have the homeowner arrange, for retesting the home for radon. This test should consist of a short-term measurement procedure conducted under closed house conditions, per the protocols described in Unit Three. This test should not commence prior to 24 hours after the completion of the installation. This allows 12 hours for the house to be aired out (concern over odors from caulks and sealants) and 12 hours for the house to reach a new dynamic equilibrium level. The test should be conducted in the same location as the pre-mitigation testing. Assuming sufficient reductions have been achieved as determined by this test, the mitigator should recommend long-term testing to assure proper reductions in the future.

If the post mitigation testing does not reveal proper radon reductions, reassessment will be needed along the lines of the steps described above. Depending upon the location of the fan and system exhaust, it may be necessary to test for re-entrainment of the discharge gases by taking radon grab samples in various locations of the home. If the ASD system appears to be operating properly, alternate entry sources such as water and building materials may also need to be investigated.

Performance of SSD Systems

Sub-slab suction systems have a good record of lowering radon concentrations in existing buildings. Figure 4-16 shows the radon reductions produced by sub-slab installations. Figure 4-17 illustrates the effect of progressive addition of sub-slab suction points in three houses built on tight sand.

Figure 4-16. Results of Active Sub-Slab Depressurization-Measurements - Radon in Air in pCi/L, Source:



EPA/ORD

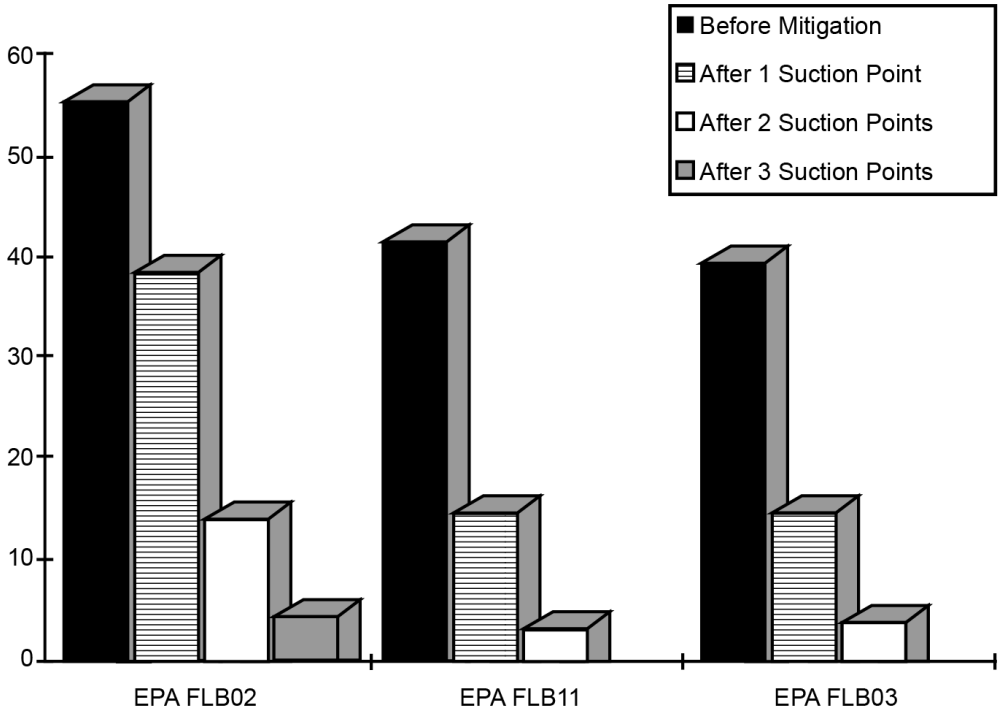


Figure 4-17. Effects of Progressive Addition of Sub-Slab Suction Points in Three Houses - Measurements Are Radon in Air in pCi/L, Source: EPA/ORD

C. Drain Tile Depressurization Systems (DTD)

1. Concept

Homes in areas of high rainfall or run-off are often constructed with some means of collecting and diverting rain (or snow melt) away from the structural foundation. In older homes, this was often carried out with large aggregate in a trench dug around the foundation to a well or off a hillside. This created a path of least resistance for the water to flow through and away from the house. These trench systems have historically been referred to as French Drains. A desire for more effective water removal has caused these peripheral drainage beds to be outfitted with piping to assist in the collection and transport of the water away from the house. These perforated drainage pipes are commonly found around the outside of a house and run away from the house to a low point (daylight end on a hillside) or a gravel-filled well. They can also be routed to a sump inside of the house, typically the basement, where the water is pumped away from the house or into a storm sewer. These drainage pipe systems may also be found under floor slabs on the interior side of the footing.

As discussed in Unit Two, these drainage systems can be excellent conduits for radon-bearing soil gas to enter the home. Also, since they are typically near the footing, they are near the floor to wall joint that is frequently a major radon entry point.

Although these systems can be a radon entry concern, they can also provide an excellent means for collecting the radon gas. Similar to a concrete-floor style or a sub-membrane ASD system, a vacuum can be applied to these drainage pipes to effectively extract the radon from the soil, even if the drain pipe is external to the house (Figure 4-18).

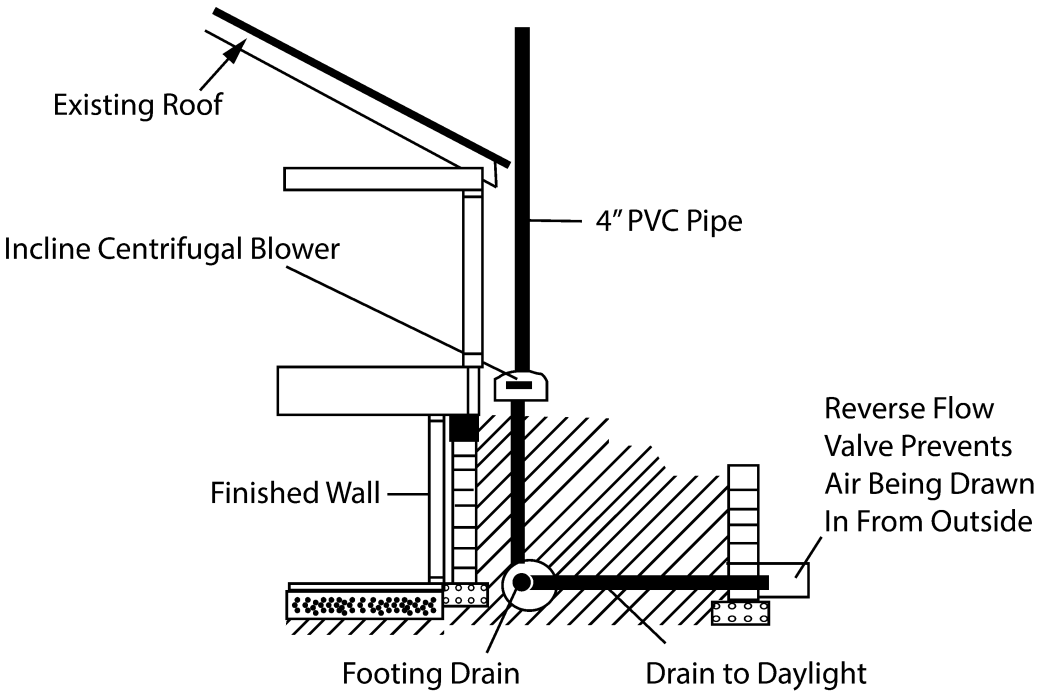


Figure 4-18. Soil Depressurization on Existing Perimeter or French Drains, Source: Brennan

2. Installation Details: Systems with Daylight Drains

In areas of hilly terrain, the drainage piping is typically looped around the house, with a single leg running away from the house towards the downhill slope. The ends of these run-off lines are generally terminated down a hillside, where the water can freely flow out the end, hence the term "daylight end." In areas of extreme slope, the drain may be in a horseshoe configuration, with the closed end of the horseshoe being on the uphill side of the home with two discharge lines going downhill.

For situations where the drainage piping does not enter the home, the drain pipe can be tapped into with a riser brought up to grade level. A blower can be attached to the riser, which will create a vacuum within the drain pipe itself. This approach will create a zone of negative pressure around and under the house, wherever the drain pipe runs. Installing this type of system is accomplished by digging down to the drain pipe, connecting a riser (which will come up in a location that is convenient), and running the fan discharge above the eave line.

Typically, the drain pipe is laid in washed gravel, occasionally above a 4-mil poly strip with a cover of geotechnical filter cloth or some other material over the top. In this case, any cover should be carefully cut, pulled aside, and the gravel collected. After the riser connection is made, the gravel should be replaced and the cover laid back over and repaired. The excavation should be refilled, with attention paid to compacting the fill, so that excessive outside air is not drawn down from the outside to defeat the negative pressure field created. Care should also be taken during excavation to ensure that the soil does not cave in around the installer. Shoring (temporary support used in construction to relieve load from masonry walls) may be needed, per OSHA requirements.

Another aspect of this installation is to treat the open-air ends (daylights) in a manner that restricts outside air flow into the system, while still allowing collected rainfall to exit the system. This is usually achieved with special check valves that opens out with water in the line and closes shut with slight vacuum pressure. These check valves should be of sufficient size to allow for full drain size flow, and ensure that this modification does not restrict the flow of water from the drainage system. This can be done with oversized check-valves or special 45-degree flapper valves. Generally, check valves without spring closures work best in this application. Care must be taken to protect these backflow preventing devices from being physically damaged or blocked with debris.

Some earlier methods for dealing with daylight ends utilized water traps. These are easily plugged by rodents, etc. and can also dry out if not properly maintained by the homeowner. Their use is thus discouraged.

The riser from the foundation drain is typically brought up along the house at a location where it can be concealed behind chimneys or bushes. It is also a good practice to route the riser on the south side of the house, if possible, to minimize freezing in cold climates. The fan is installed outside, with discharge pipe running vertically along the house and above the eave. The piping should be schedule 40 PVC to reduce ultraviolet (sunlight) deterioration. It can also be installed with 3" x 4" down spout that can be painted to match the existing trim.

3. Installation Details: Systems with Sumps

Many foundation-drain-systems are routed to sumps that are internal to the home, where the water is collected and then pumped away from the house. The depressurization system can either be attached to the sump with an appropriate cover, or the sump sealed, and the system connected to the drain tiles remote from the sump. Both approaches work equally well; the choice of which to use is based upon the relative ease of installation. With the need to have the fan outside of the living space, it may be more convenient to install it on the external drain system provided that the depth of excavation is not too large.

Methods for sealing the sump hole depend upon the construction of the sump itself. Newer homes typically have an 18" diameter plastic sump liner, for which pre- molded lids can readily be purchased. For older homes, where the sumps are made from concrete, specialty lids with compression seals can be bolted to the floor with concrete anchors in order to accomplish the seal. Some of these lids are available with sight glasses and connections, should the installer prefer to draw a vacuum on the sump rather than the external piping.

Independent of the type of sump lid that is utilized, accommodation for maintenance of the sump pump must be provided. With that, caulking such as silicone, which can easily be removed, is preferable to polyurethane. If piping is connected to the sump lid, unions or removable couplings should be installed to facilitate removing the lid without damaging the system.

4. Retrofitting Perimeter Drains

The installation of foundation drains on existing homes for radon mitigation is not cost effective compared to other ASD systems. However, excavating at 1 or 2 points underneath the footing or through a stem wall, with the piping routed to a common fan, will essentially accomplishes the same thing as an interior ASD system. This approach works well with slab-on-grade homes where the excavation is relatively easy. The piping connecting one or more of these sub-footing suction points is typically run in non-perforated, corrugated, semi-rigid polyethylene pipe (this allows the soil to shift without breaking the piping). Since rainfall is not expected to accumulate in this pipe, the system can be routed along the outside of the home to a location where the depressurization fan is to be located. The location of the suction points should be determined like those for interior ASD systems. That is, grade beams or other communication barriers should be spanned. Also, where the pipe is inserted under or through the foundation wall, approximately 10 gallons of soil should be removed, with the end of the suction pipe being in the center of the void space. Where the pipe penetrates the foundation wall, a seal utilizing grout or expandable foam should be used to create a seal. Excavated dirt should be compacted when the hole is filled.

5. Fan Selection and Piping

Typical air flow volume on these systems run from 50 CFM to 100 CFM. As discussed earlier about ASD pressure drop, a 4" round pipe or a 3" x 4" rectangular pipe has sufficient free flow area to accomplish this task. Pipe routing should be accomplished with the same criteria described in the ASD section, traps should be avoided and the termination of the piping should be fitted with a rodent screen.

6. Safety Considerations

Foundation Drain Depressurization systems are a form of ASD systems, and have the same safety concerns as described previously.

7. Performance of DTD Systems

The approach to creating a negative pressure field around and under a home by using an existing drain tile is proving to be an extremely cost-effective way of reducing radon. The success of these systems depends upon soil permeability and the integrity of the existing drain installed by others. Figure 4-19 illustrates some typical reductions with this technique.

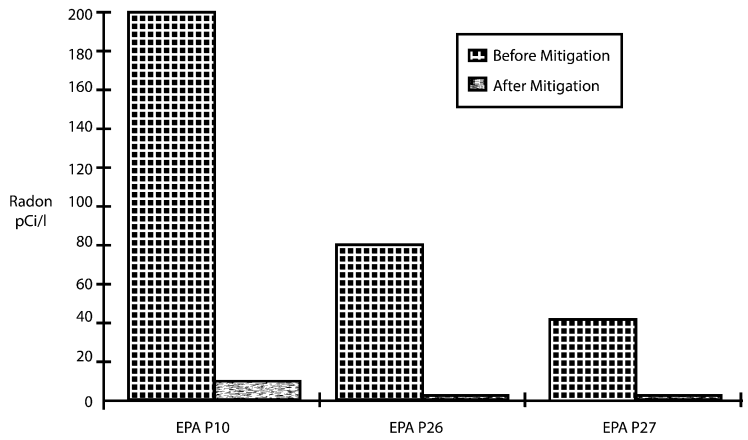


Figure 4-19. Results or Drain-tile Depressurization, Source: EPA/ORD

D. Block Wall Depressurization

1. Concept

Foundation walls are often made of concrete blocks, which can be significant entry points. By applying active depressurization to the block wall, this technique creates a vacuum on the hollow portion of the block wall. The entering radon is thus collected and exhausted outside before it can enter the building (Figure 4-20). It should be noted that, in certain areas of the country, these block walls may be poured solid due to earthquake provisions of the local building codes and therefore block wall depressurization would not be chosen as a mitigation technique.

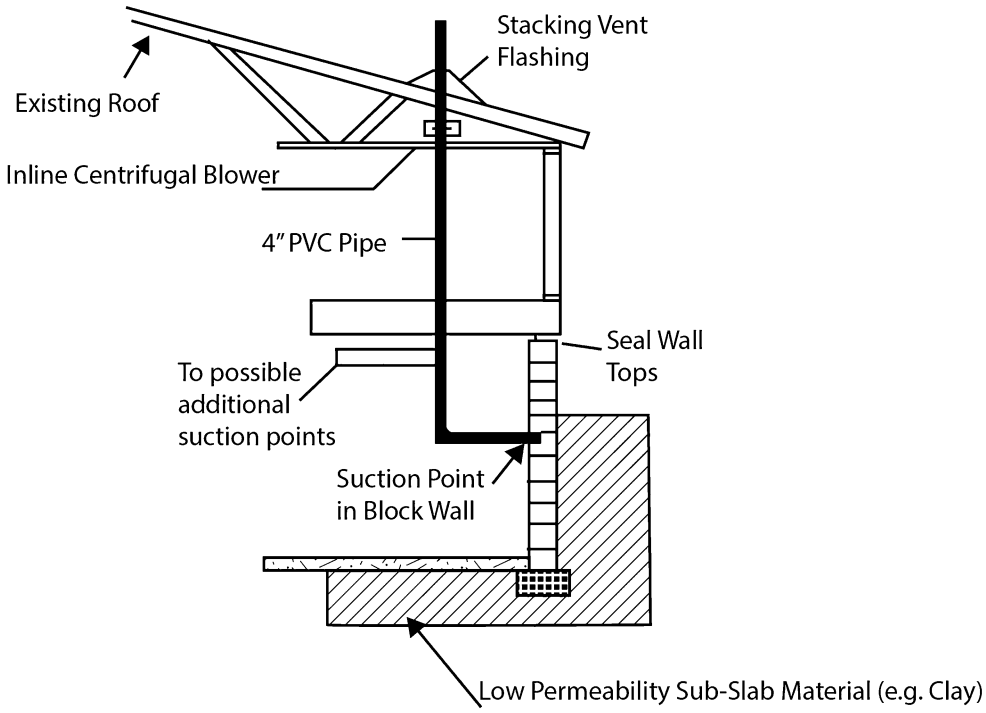


Figure 4-20. Soil Depressurization by Suction Block wall Interior, Source: Brennan

In the same way as grade beams (and other interferences) underneath the slab dictate the number and location of sub-slab suction points for concrete-floor ASD systems, barriers within the block walls can present similar disruptions to extending a negative-pressure field within the block-wall structure.

The interferences commonly found include:

- Pilasters (a portion of the block wall, whose cores are poured solid with concrete or grout top to bottom).
- Lintels over door ways.
- Corners of the basement wall.
- Block cores, which are filled for reinforcing purposes.

Penetrations are made into the hollow core of the basement wall in each of the zones isolated by the barriers described above. PVC pipe is routed from the penetrations to a common fan, which draws a vacuum on the hollow block portions of the walls and exhausts the radon outside. Alternatively, for a basement which may have a water problem, holes may be drilled into the bottom block and a plastic molding installed at the floor to wall joint. This allows for a vacuum to be drawn along the interior perimeter of the wall as well as the floor wall joint via a depressurization fan. This same molding system can also be routed to a sump for water collection, provided that the sump is sealed in the same manner as described in the previous section.

2. Installation Details

One of the key factors in creating a vacuum inside block walls is the amount of block-wall area open to the interior of the home. This large area can defeat the vacuum and affect the cost, performance, and safety aspects of the system. In addition to plumbing penetrations and electrical penetrations, a great deal of attention must be given to the top row of block. Depending upon the construction detail, this top course may be open to the interior of the house. Often a wood sill plate rests on top of this block, which can form a good seal cap if it extends the full width of the block. If the sill plate does not span the upper course, the gap will have to be filled with expanding foam, caulk, or furring strips, depending upon the size of the opening. If this opening is not treated, internal air will be collected and exhausted outside, causing low reduction efficiencies as well as additional cost to heating or air conditioning the home. However, a more serious condition caused by the excessive air loss is potential for back drafting of combustion appliances.

The location of the suction points may be determined using a test fan described in the next unit. However, their actual location is often influenced by the degree of finish in the basement. Therefore, these suction points are often installed in utility rooms and routed overhead to other walls. In situations where one wall does not communicate to an adjacent or opposite wall, a branch suction line may be routed to each of the walls, or a vacuum may be pulled on one wall and "jumpers" used to enable the extension of the negative pressure field to all walls. The jumper generally consists of a 4" elbow with short stub ends that are inserted into two adjoining walls in a corner of the basement. These corner jumpers can often be hidden in closets or other areas that are not visible. This reduces the amount of overhead piping necessary.

Penetrations are made into the hollow core of the basement wall in each of the zones isolated by the barriers described above. PVC pipe is routed from the penetrations to a common duct fan, which draws a vacuum on the hollow block portions of the walls and exhausts the radon outside.

Penetration of the piping in the hollow block is usually achieved by drilling a hole 3/4 inch larger than the outside diameter of the pipe into the block, inserting the pipe a few inches into the block, and sealing the pipe to the block, utilizing non-shrink grout or expanding urethane foam (caution must be exercised in using foams that will expand into the suction pipe. Foams that expand only 5% are best used for this purpose.

Baseboard dewatering systems have also been used to achieve block wall depressurization, while also walls are seldom straight, once these baseboards are installed and before the adhesive has cured, the molding may pull away from the wall, thus requiring follow-up sealing. These moldings are generally, but not always, installed around the entire perimeter of the basement and jointed at a common collection box, where the depressurization piping can be attached and then routed to the fan. Given the difficulty of installing this system in finished basements, it is typically used in applications where the basement is unfinished and may also have need for water control.

3. Fan Selection and Piping

Diagnostics will determine the amount of air to be handled by the depressurization fan. However, since sealing of the top row blocks will be performed as part of the mitigation, it may be difficult to quantify the exact amount of air from the diagnostics. Typically, a 270-cfm fan at 0 in. W.C. is sufficient

to handle most systems. Referring to the previous discussion on electrical costs of fan operations, oversizing this fan will have little consequence on operating costs. Similarly, pipe size is typically 4" if a single wall suction point with jumpers is utilized, or 4" or larger pipe is utilized if multiple wall suction pipes are tied into a single collection pipe.

4. Safety Considerations

Block wall systems are a form of ASD systems and have the same safety concerns as described previously. However, special attention must be paid to back-draft potential with these systems.

5. Performance of BWD Systems

Block-wall depressurization can be very effective, if this is a major entry route. Depressurization of the block wall can also have a beneficial effect upon adjacent radon levels under slabs and crawl spaces. Results of block-wall depressurization in conjunction with good sealing are shown in Figure 4-21.

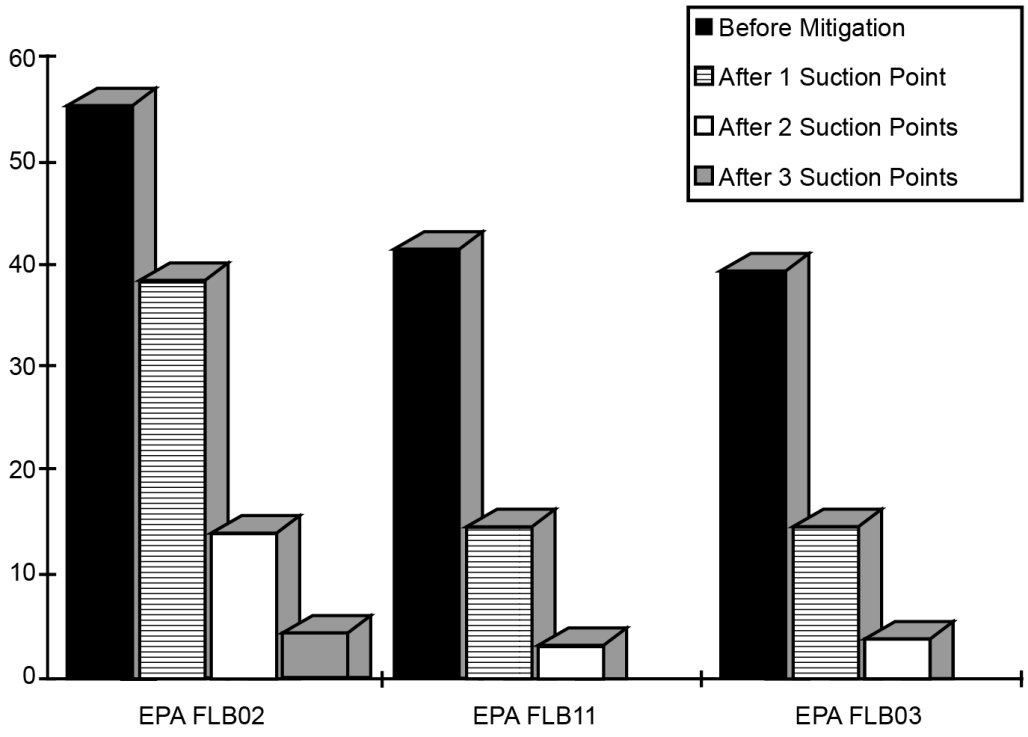


Figure 4-21. Radon Reduction with Block-wall Depressurization, Source: EPA/ORD

E. Sub-Membrane Depressurization: Crawl Spaces and Dirt Floors

Some structures often have a large area of exposed soil as found in a crawl space or an unpaved cellar. As discussed in Unit Two, these open areas can be a significant radon entry point, depending on how

well coupled the living space is to these earthen floored areas. This section applies ASD technology to these situations.

1. Concept

In the same way as a negative pressure field is created beneath a concrete slab in an SSD system, a suction can be pulled beneath a plastic sheet or membrane laid on the exposed dirt area. In this application, the plastic membrane functions as the concrete floor and all design and safety parameters relating to concrete floor SSD systems apply. Conceptually this is shown in Figure 4-22.

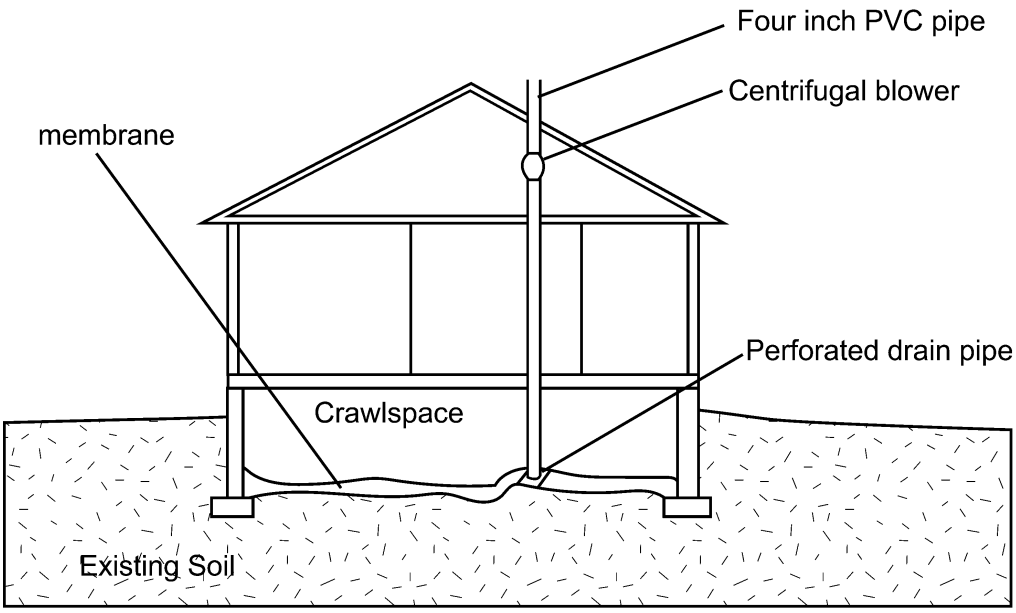


Figure 4-22. Schematic or Sub-Membrane Depressurization, Source: Brennan

2. Installation Details

Materials

The plastic membrane that is laid on the dirt floor area must be sturdy enough to withstand being pulled through what is very often confined spaces. It must also be resistant to punctures that can result from traffic. if the crawl space is used as storage or is accessed for periodic maintenance of utilities.

Typically, the membrane used is a cross-laminated polyethylene membrane that can be obtained in 10 and 20 foot widths as well as in various colors (white makes for very bright crawl space). Since it is laminated, it is very strong for its weight and resists tears. Its nominal thickness is 10 mil. (0.01 inches thick) and is generally satisfactory for crawl-space use.

Standard polyethylene has also been used successfully but, since it can more easily be torn, greater care must be exercised during installation. In some cases, roofing felt is laid down prior to installation to protect the underside of the plastic from punctures from the sharp-edged rocks on the surface of the crawl-space floor. This is especially needed in areas of high traffic. Other materials such as ethylene

propylene diene monomer (EPDM) or roof sheeting have also been used for cases where extremely sharp stones and extremely frequent access may occur. Similarly, poured concrete has been used for this purpose, but is generally not cost effective unless the client intends to use the area for clean storage. Durability of the membrane is an important consideration in this application. Damage can occur to the plastic through normal temperature contractions if it is installed with little or no excess material and sealed to the sidewalls. Damage generally occurs due to traffic or maintenance work that can take place in the crawl spaces (proper homeowner information should be supplied for this instance). The cross-laminated plastic appears to be a strong intermediate material between the standard polyethylene and the EPDM (ethylene propylene diene monomer) rubber.

Surface Preparation

To have a safe work place as well as to improve the long-term durability of the membrane, it is advisable to remove the construction debris often found in these areas (glass, wire, rebar etc.). These areas are often where asbestos-covered ductwork has been routed and/or discarded. In addition, insecticides or termiticides have often been sprayed in these areas. Crawl spaces are often used as "storage" locations for partially used containers of household chemicals that have not been properly discarded. The mitigator should be extremely cautious when working in these areas (see Unit Eight, Worker Health). *Should a mitigator encounter these conditions, work should cease until proper procedures for dealing with these hazards can be implemented.*

Sub-Membrane Depressurization Details

Depressurizing beneath the plastic membrane is carried out in a similar manner to a concrete floor SSD system. This is typically performed in one of two ways.

One method is to lay a perforated pipe the length of the crawl space. This pipe is generally perforated, corrugated polyethylene or rigid PVC pipe with 1/2 in. holes. Either type of pipe is usually laid on top of the soil, which makes the corrugated semi- rigid pipe easier to use on non-level surfaces. It is also a good idea to route the pipe along the ground through a non-traffic or storage section of the crawl space as a convenience to the homeowner. The pipe can be buried, but this generally does not provide any better reduction efficiency than laying the pipe on the surface of the crawl space. Burying the pipe is very labor-intensive, but may be an option if the homeowner plans to concrete the in the future. The perforated pipe is routed to the point where the riser for the sub-membrane depressurization system is to be located, and a transition is made to solid pipe around which the membrane is sealed.

One of many methods that have been successfully used is to install a wood plate (generally a 4 ft. x 4 ft. piece of 1/2-inch pressure-treated plywood) in the center of the area, which is raised off the dirt approximately 2 inches by the use of blocking spaced around the underside of the plywood. The plastic is then laid over this as well as the rest of the crawl space. The riser for the depressurization piping is attached to the plywood in a similar manner to a concrete floor core. The blocking holding the plywood above the ground should be spaced to allow entry of air beneath the board to the suction point.

Installation of the Membrane

The plastic membrane is spread out on the surface of the dirt. Typically, the membrane is secured to the sidewalls of the crawl space using polyurethane caulk, after these are thoroughly cleaned to facilitate

adhesion. This sidewall sealing is carried out for the same reasons as sealing the floor wall joints in a concrete floor suction system. That is, when the system is turned on, air from within the crawl space would be drawn down under the membrane. The introduction of air other than the targeted soil gases puts an additional electrical load on the fan. Furthermore, the exfiltration of interior air through the system can have a detrimental effect on the house by loss of conditioned inside air. Unnecessarily exhausting excess inside air may also affect the draft capabilities of the combustion appliances. For similar reasons, seams in the membrane are typically overlapped about 12 inches with a bead of sealant between the overlapped edges, and further secured with tape to hold the seam together while the balance of the membrane is installed and until the seam glue sets. Similar attention should be paid to any piers and plumbing risers that are encountered in the area, paying close attention that all plumbing clean-outs end up above the membrane.

Attachment to the sidewalls can occur in a variety of methods. Often, if the sidewalls are poured concrete or block, the walls are wire brushed and a thick, even bead of polyurethane caulk is applied to tile wall and the edge of the membrane is smoothed onto the caulking by hand. The membrane will pull down once the depressurization fan is turned on; it is a good idea to leave the membrane loose so it does not pull off the walls before the glue sets. The same polyurethane can be used to seal the seams as well as the membrane to piers and risers.

An alternate method for attachment to the sidewalls is to fasten a furring strip to the walls and attach the membrane to the furring strip by sandwiching it between another strip that is nailed to the first. This technique is especially good for uneven walls, as may be encountered with rock-foundation homes. After the strips are in place, the void spaces behind the first strip can be filled with urethane foam (see Figure 4-23). Whenever utilizing large amounts of chemically-based adhesives and foams in these confined spaces, good ventilation is required.

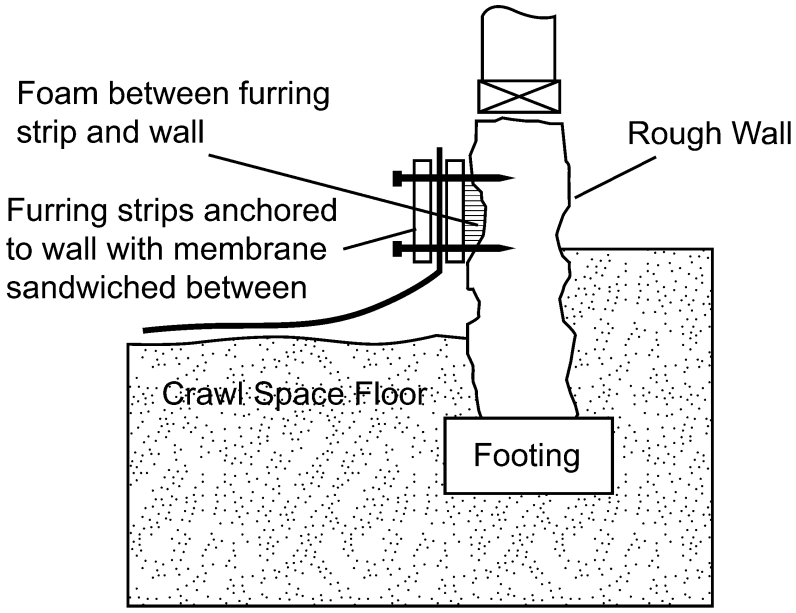
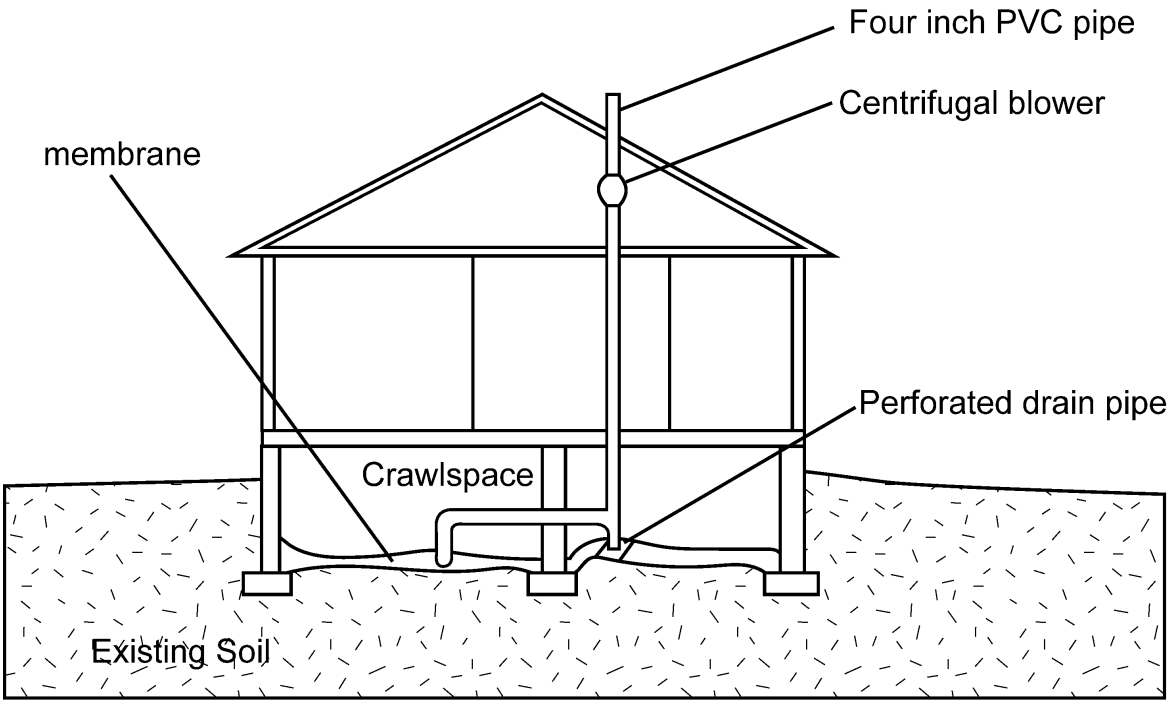


Figure 4-23. Attachment or Membrane to Uneven or Rock Walls, Source: Kladder

In older homes, the crawl space may have dirt along the edges above the foundation walls, or the access to the walls may be less than a person can crawl through. In these cases, an attempt to clear the dirt away should be made. If this is not possible, all areas that can be sealed should be sealed. Leaving a few loose edges may still allow for adequate reductions. Similar to SSD systems where all slab leaks cannot be accessed, some leaks in the plastic may be permissible, provided that this does not cause back drafting of combustion appliances. Sealing all edges and seams has been shown to improve radon reduction efficiencies by as much as 40% and should be done where possible (Ref. 16).

In areas where the joists for the floor above are resting on the dirt, access is not possible. Successful reductions have occurred where the floor is sealed and a vacuum has been drawn from the general crawl area through the sub-flooring above. If this approach is taken for these difficult situations, it should be noted that serious back drafting potential exists, and a large energy penalty for lost interior air can occur (Ref. 11).

In some cases, the crawl space may be broken up by intermediate bearing walls, which require installation of separate depressurization cells. This is similar to the problems encountered with



concrete floor style ASD systems, where suction points have to be added to these areas. This problem can be overcome by running an overhead header with drops to each section, or running the sub-membrane piping in series through each of the cells with non-perforated jumpers rising over the intervening walls (see Figure 4-24).

Figure 4-24. Use or Multiple Suction Points or Areas in Segmented Crawl Space, Source: Brennan

3. Fan Selection and Piping

The flow and pressure characteristics of this technique arc such that the low vacuum (2 in. W.C.), high volume fans are preferred. For the same reason, it is easy to end up with higher air flow rates than with a sub-slab system if care is not taken in sealing the seams and penetrations. Flow rates of 30 to 50 cfm are not uncommon in reasonably well-sealed systems, thus typically allowing for a 4-inch diameter pipe. Like SSD systems, the piping runs must be sloped back to the crawl space areas to ensure that condensed moisture does not fill low spots in the piping. Note that the mitigator should not route through or otherwise render existing crawl space vents inoperable.

In some cases, the installation of a well-sealed membrane with a collection pipe connected to it that is passively vented (without a fan) to the outside has resulted in moderate reductions in homes of moderate radon content (less than 10 pCi/L) (Ref. 5). As discussed later in the phasing section, this may be an intermediate approach, and, should the mitigator choose to take this phased approach, allowances should be made in the design to install the fan and discharge piping per RCP standards if the passive approach is unsuccessful.

4. Safety Considerations

Sub-membrane systems are a form of ASD systems and have the same safety concerns as described previously. That is, all the issues of fan placement, labeling, monitoring, back-drafting, and system discharge mentioned in sub-slab depressurization are of equal concern. The fan cannot be in the crawl space because if it were to leak you will have thousands of picocuries per liter that could come into the home.

5. Performance of SMD Systems

Active SMD systems have performed extremely well, not only for homes that are completely over crawl spaces, but even in crawl spaces where the proximity of the dirt floor to the overhead floor joists have made it impossible to completely seal the sidewalls. Other benefits have been demonstrated by these systems in that they tend to dry up and remove the musty odors that are often associated with these areas, improving the overall indoor-air quality.

SMD systems work extremely well as a stand-alone technique if the entire house is above a crawl space. If the home has a basement and an adjoining crawl space, both a sub-membrane and a sub-slab depressurization system may be needed (Ref. 16). In cases where a good seal between the membrane and the walls has been achieved, a negative pressure field was extended to below the concrete floor without a suction point on the concrete itself. (Also refer to Figure 4-10 to understand how an adjacent crawl space and basement could be handled together, where the membrane would be in place of the concrete of the second level). Figure 4-25 illustrates some results of sub membrane depressurization.

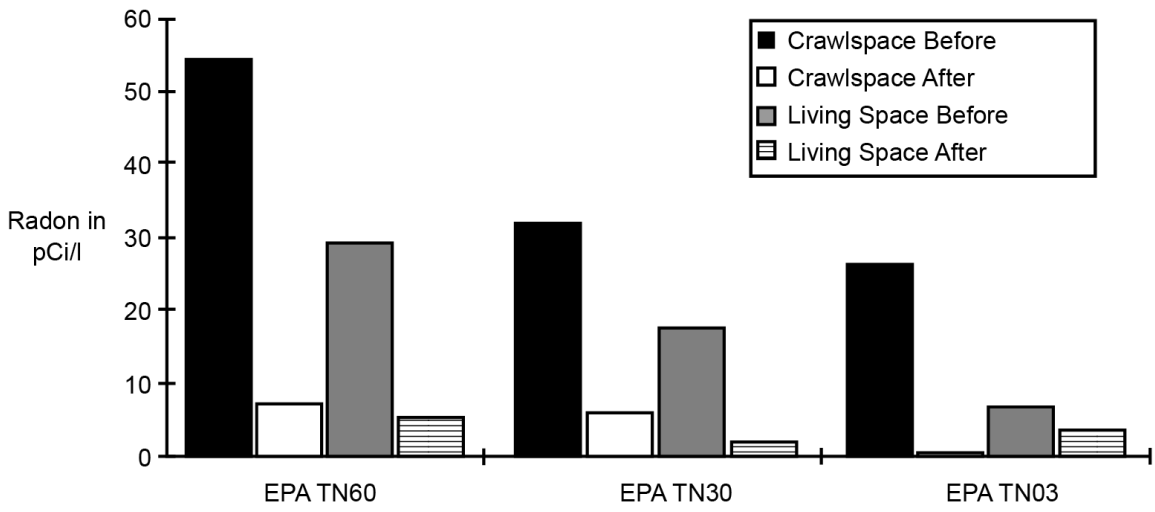


Figure 4-25. Results of Sub-Membrane Depressurization Systems, Source: EPA/ORD

F. Pressurization

1. Concept

Pressurization is a method that reverses the natural pressure gradient to prevent soil gas from entering the building and, less importantly, reduces radon concentrations by dilution. It can be accomplished by applying a positive air pressure to the basement or building, using a blower to pull air from upstairs and blowing it into the basement. This creates a higher air pressure in the basement than outside and causes air to flow through cracks and holes in the basement out into the soil. If there are combustion appliances on the upper floors such as a hot water heater, furnace, or fireplace, basement pressurization is not recommended due to the high potential for back-drafting of those appliances. In this case, alternative methods such as whole house ventilation should be considered.

Basement pressurization should be considered as an alternative for houses that are not compatible with one of the soil depressurization techniques already discussed and have tight basements (tight between the basement and upper level as well as in reference to the building exterior). This method has not been as thoroughly tested as have some of the other techniques covered in this section. Adequate long-term data is not available to show whether basement pressurization will adversely affect energy costs, or whether condensation at the rim joist will occur as basement air is forced out through cracks above grade. Figure 4-26 shows the schematic layout of a basement pressurization system.

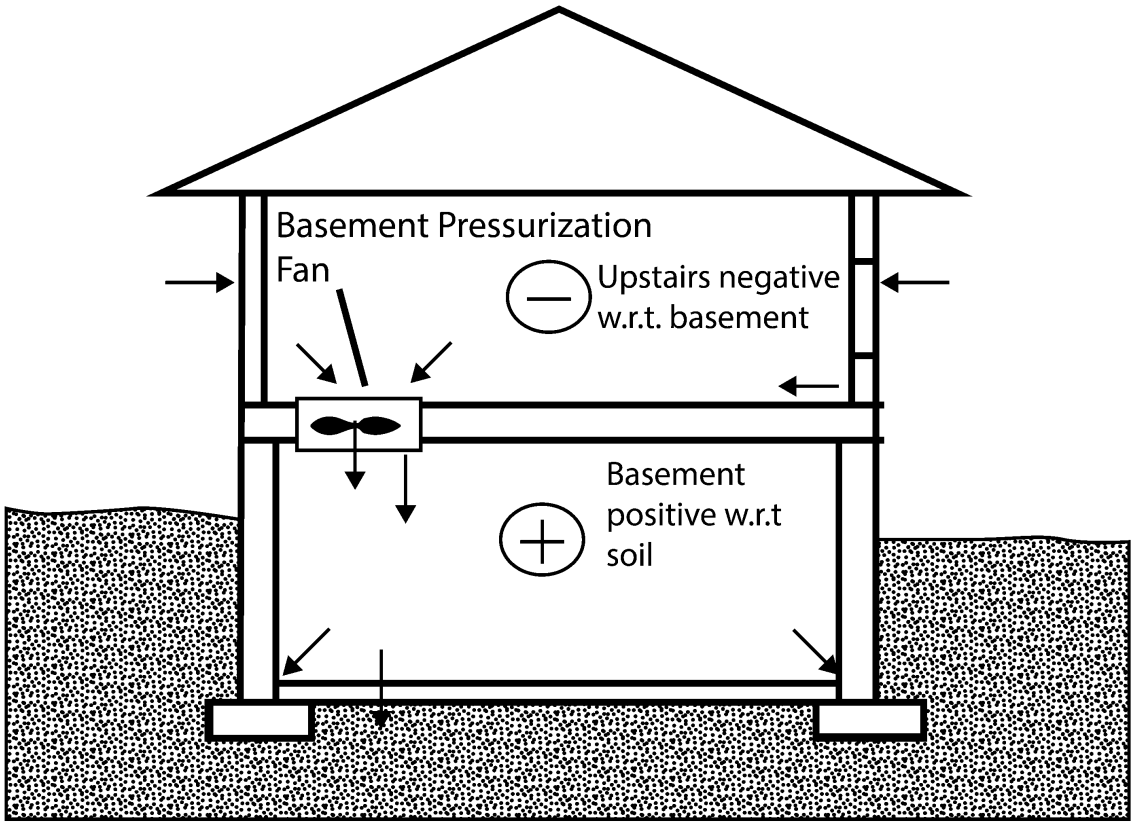


Figure 4-26. Basement Pressurization, Source.: Brennan

Note: The air used to pressurize the basement should not be drawn from garages or from areas of the house that contain combustion devices. This could result in blowing auto exhaust and aromatic hydrocarbons from the garage into the basement or in down drafting of combustion devices.

Suggested locations for the blower are:

- Beneath an upstairs closet that has louvered doors and is located where blower noise would not be a problem.
- In a laundry chute or other pipe-like chase which connects the upstairs and the basement (not an active chimney chase).

For this type of system to be successful, the basement windows and doors must remain closed (e.g., windows and doors are kept closed during the heating or cooling season). Otherwise, the basement will lose positive pressure and soil air will enter. During the summer months, when the windows and doors are open, it may be possible to ventilate the basement passively (e.g., without the pressurization blower).

2. Blower Selection and Installation

The blower should be sized using the results of the basement pressurization fan door test (see Unit Five). Pressurization is not normally selected if it would require greater than a 300 cfm blower to achieve the flow reversal pressure. In addition to flow rate at the specified static pressure, two key features in blower selection are the power consumption (watts) and the amount of noise it makes (decibels or Sones). Try to keep power consumption to less than 100 watts, and noise level below 40 decibels (or about 2 Sones). The blower should be sized to allow for excess capability to cope with extreme conditions, degradation of performance, or building tightness. The power supply should be wired to a smoke alarm, so that current to the blower will be shut off in the event of a fire.

3. Sealing

The following openings should be sealed or weather-stripped to enable pressurization of the basement using the smallest possible airflow from the blower:

- Basement doors leading to the inside and outside of the home: door closure devices, although inconvenient, may be needed.
- Openings through the floor between the basement and upstairs:
  - pockets between studs in walls (draft breaks).
  - electrical and plumbing penetrations.
  - laundry chutes.
- Return air ductwork of a forced air furnace with registers located in the basement may not allow this approach to be feasible.
- Floor drains in basement floors may have to be retrofitted with positive seal traps.

4. Evaluation of Basement Pressurization Performance

If post-mitigation radon levels have not been reduced to a satisfactory level, additional tests and measurements may be necessary. The key concern with pressurization as it relates to radon reduction is whether or not the room to be pressurized or basement have achieved a pressure greater than the pressure in the soil around it. The way this is done is identical to the procedures outlined in the ASD portion of the chapter. That is, holes are drilled through the concrete and pressure measurements are made to determine the strength of the pressure above the concrete. Although not as rigorous, a simpler pressure measurement is to determine the pressure difference between the basement and outdoors above grade. Alternatively, and perhaps additionally, a smoke pencil may be used on floor cracks and plumbing penetrations to ensure that smoke goes down these openings (basement is at positive pressure with respect to the underlying soil). This testing should occur with all doors and

windows closed, with house exhaust fans on, and be repeated with the forced air furnace fan on and off. If insufficient differential pressure is achieved the additional air may be necessary (larger fan).

If the basement is finished with partitions with doors, testing invarious rooms should be conducted with doors open and closed. If separated portions of the basement show positive pressures beneath the slab relative to the basement, then a means for distributing air into these areas may be necessary. This can be accomplished by installing grills on non-fire-rated doors, running air supply ducts, or adjusting furnace registers to those areas.

A key test here, as well as elsewhere, is the determination if this system has affected the ability of the combustion appliances to draft properly. Typically, basement pressurization will boost the draft on combustion appliances in the basement, but can cause serious back-drafting for appliances located upstairs. Basement pressurization is generally not recommended for buildings with vented combustion appliances in the depressurized zone (upstairs).

5. Labeling and Monitoring

It is often difficult to maintain pressure in the basement when so much depends upon the way the occupant operates the house. Success of this technique depends upon labeling system components (this can include doors and windows) and installing a pressure-sensing warning device. This sensor monitors the upstairs/basement pressure differential, and alerts homeowners when the system fails due to blower or sealant failure (open doors).

6. Performance of Basement Pressurization Systems

Basement pressurization can be a highly effective technique, as shown in Figure 4-27 with the results of pressurization in four buildings. However, it does not have as long a history of operation as the soil depressurization methods, and its long-term structural effects and reliability are not known. It is not commonly implemented as a first step approach for radon mitigation. This is primarily due to the difficulty of maintaining pressure. It may be considered as a follow-up technique to ASD to further reduce radon levels.

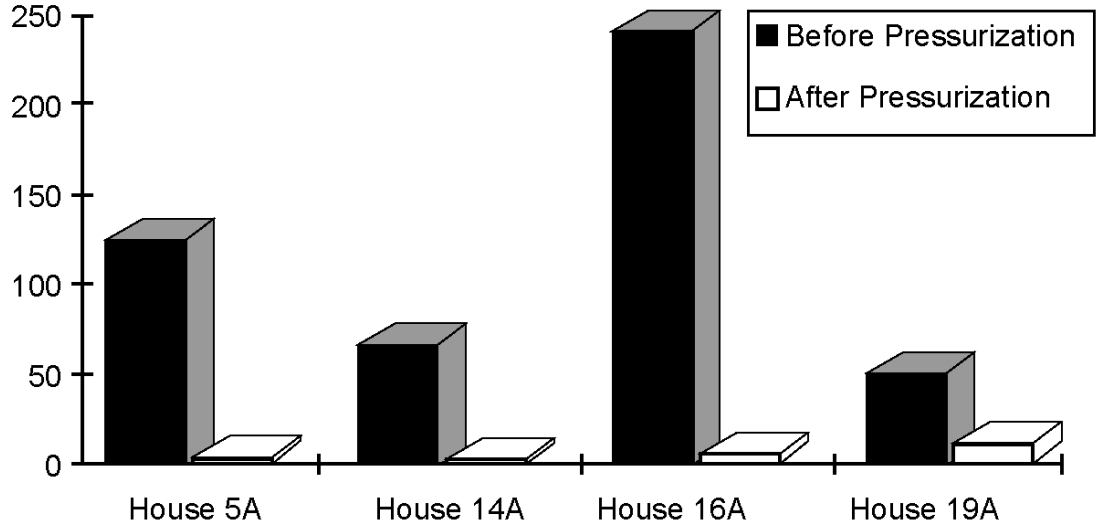


Figure 4-27. Results of Basement Pressurization, Source: LBL

Basement pressurization has also been used in areas where the soils are very tight and several suction points would be needed for an ASD system. This approach can apply a more uniform pressure reversal to the basement interior and reverse the air flow through many inaccessible small openings.

G. Positively Pressurizing Beneath a Slab Floor (SSP)

1. Concept

As an alternative to applying a suction beneath the slab, some success has been encountered with pressurizing the soil beneath the slab. Outside air is forced beneath the slab via the same type of piping and fan system that would be utilized in a normal ASD system. It is believed that two processes are important to the successful operation of this system. First, the positive pressure created in the soil around the substructure tends to keep away radon for a distance. Second, although more soil air than usual is pushed into the house, the outdoor air blown beneath the slab tends to lower the radon concentration in this soil air by dilution (see Figure 4-28).

Generally, the positive pressure technique does not perform as well as depressurization, except where the surrounding is very permeable with low radon levels in the soil air. Advantages to this type of system are that above-the-roof exhaust piping is unnecessary and that the fan can be mounted indoors. A disadvantage is that the incoming air must be filtered to prevent outdoor dust and debris from plugging the sub slab pit and reducing system air flow.

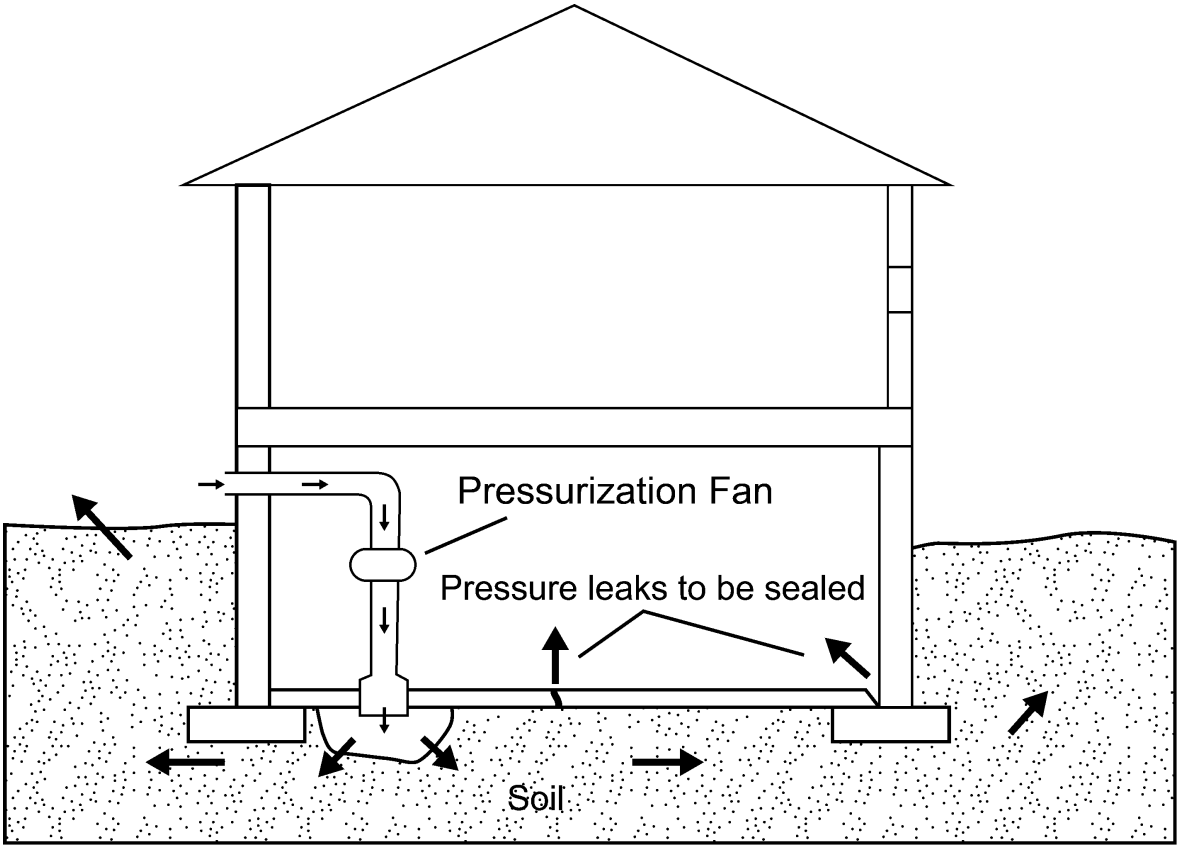


Figure 4-28. Sub-Slab Pressurization, Source: Brennan

These systems are most applicable to situations where the soil beneath the slab is highly permeable, and resistances to air flow around the outside of the home, such as asphalt, concrete aprons, or frost depth does not impede air flow away from under the slab area. Because loose soils are a prerequisite, the larger in-line duct fans are generally utilized.

2. Installation Details

Fresh air is brought in from the outside, from a point near grade level but above snow drift lines. The pipe is routed to a fan, which can be inside the envelope of the home, and then routed to the positive pressure point on the slab. The slab connection detail is performed in the same way as for a typical ASD suction point. The number and location of the pressure points can be determined in the same way as with an ASD system.

Sealing of foundation cracks and openings to reduce radon and soil gases entry rates is more important for this technique than for SSD. The air intake for the system would need to be screened to keep out rodents and filtered to remove outdoor air dust. Regular inspection of the intake screen and filter must be performed by the homeowner to assure adequate air flow.

3. Safety Considerations

Positive sub-slab pressurization requires similar labeling and alarm systems as for any mitigation system. However, because system pressures that are too low (fan failure) or too high (plugged sub-slab pit) could indicate system malfunction, an air flow sensing alarm may be an appropriate alternative to the pressure sensor alarm. Furthermore, specific maintenance requirements for intake duct monitoring must be added to the homeowner's maintenance documentation.

4. Evaluation of SSP System Performance

Immediately after installation, a smoke stick should be used at all slab openings to determine the direction of air flow. If air flow is detected from the under-slab area to the interior of the basement, these should be sealed immediately prior to leaving the home. Since the soil beneath the slab is being pressurized, the potential for forcing radon into the home via small openings in the slab is very high.

Results of this technique have been mixed; an initial, short-term radon spike has been observed in some houses after the system is activated. Therefore, it may be best to postpone post-mitigation radon measurements for at least 24 hours after completion of the installation. Should post- mitigation testing indicate insufficient reduction, areas for sealing should be located and sealed. If additional sealing is still not adequate, then the approach should be abandoned and an appropriate ASD system should be installed.

Also, because external soil conditions may affect the ability for air to escape around the house, follow-up testing in the winter months would be very prudent in addition to recommending long-term testing.

5. Performance of SSP Systems

Figure 4-29 illustrates some early test data comparing sub-slab pressurization versus sub-slab depressurization. In one example, the results were better with sub-slab pressurization and, in other cases. the pressurization approach had no effect or increased the radon levels. This technique has never been observed to increase post-mitigation radon levels above pre-mitigation levels. Due to the varied results, recent research has indicated that soil pressurization may work better than ASD systems where the underlying soil is large, well-drained aggregate. This would be where higher than normal volumetric fans would be needed for adequate ASD negative pressure field extension. Conversely, ASD has outperformed soil pressurization in moderate to low permeability soils (Ref. 30).

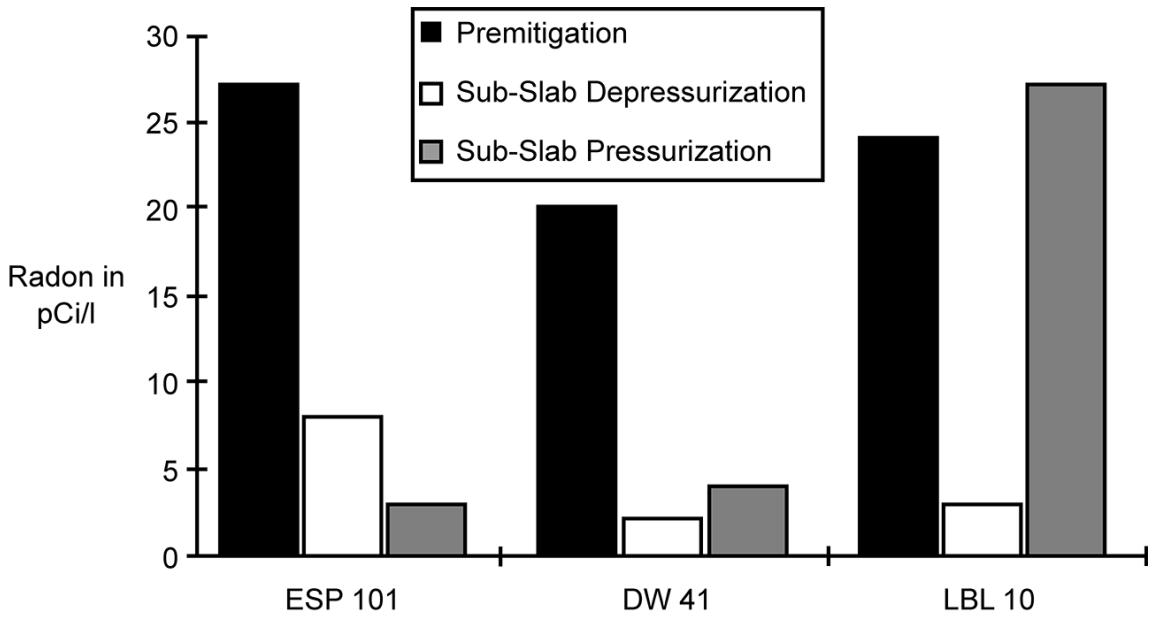


Figure 4-29. Variable Results of Sub-Slab Pressurization and Comparison to Active Sub-Slab Depressurization, Source: EPA/AEERL

H. Manipulation of Crawl Space Pressures

1. Concept

While SMD is the most successfully applied technique in crawl spaces with exposed soil floors, there are situations where an alternative approach must be used. Examples include crawl spaces that are inaccessible because of very low clearance or crawl spaces that are used extensively (e.g., for active storage) and the occupants do not want the soil floor covered. The latter situation may be a common problem in basements with exposed soil floors (e.g., root cellars).

Under normal conditions, the occupied space creates a negative pressure in the crawl space (with respect to the soil) by indirectly warming the crawl space (and developing a small stack effect). More importantly, by openings in the floor to the crawl space that permit some of the negative pressure in the house to be transferred to the crawl space. The negative pressure in crawl spaces acts to pull soil gas and radon from the soil into the crawl space. Diffusion of radon from the soil surface to the crawl space air may also be important for some soils. Since the occupied space is negatively pressurized with respect to the crawl space, the high radon level crawl space air is then drawn into the occupied space through the always-present gaps and openings. Alternative radon control strategies involve altering the pressures between the occupied space, crawl space, and soil so that (1) the pressure coupling between the occupied space and soil is broken, and (2) crawl space radon levels are diluted by additional ventilation air.

The three techniques that have been used are:

- Passive ventilation of the crawl space,
- Depressurization of the crawl space, and
- Pressurization of the crawl space.

A good summary of these techniques is found in Ref. 11. The performance of all techniques benefits from sealing the openings between the occupied space and crawl space. The openings reduce the ability of the techniques to control pressures in the crawl spaces. Large openings can include gaps around electrical, plumbing, and duct penetrations. Duct work that is in the crawl space usually has many openings around poorly fitting sections and plenums. The flooring between the occupied space and crawl space may have numerous small gaps and cracks (especially in older homes with a board subfloor). This situation may make any attempt at sealing very impractical, particularly where the crawl space is inaccessible.

Moisture condensation on cool crawl space surfaces may be increased by these techniques under certain climatic conditions. This would result from the introduction of moist air into the crawl space from outdoors or the occupied spaces.

2. Passive Ventilation

In Florida, crawl spaces are required by code to have ventilation, usually provided by vent openings in the side wall of the crawl space. These vents can diminish the negative pressure in the crawl space and can increase the ventilation rate (if natural driving forces, such as wind, are present) to dilute the radon concentrations in the crawl space. In cold climates, insulation may need to be added to the underside of the floor to the occupied space to reduce heat loss, and pipes may need to be protected from freezing. The indoor radon reduction with this technique is variable, ranging from significant reductions to below 4 pCi/L to no reductions at all. The results depend on the size and location of vents, the presence of natural driving forces for ventilation, and the operation of the house (including the use of heating and cooling air handling equipment in the crawl space which can depressurize a crawl space through leaks in the return duct work, and distribute radon from the crawl space to the occupied space).

3. Depressurization of the Crawl Space

By using a fan to pull air from the crawl space, the crawl space can be depressurized with respect to the occupied spaces. Although the additional negative pressure often increases radon entry into the crawl space, the pressure reversal across the floor to the occupied space keeps the radon-laden crawl space air from entering the occupied space. In fact, house air now enters the crawl space through various holes and openings and can comprise a significant portion of the air exhausted by the fan. The amount of depressurization (with respect to the occupied spaces) only needs to be large enough to overcome any pressures imposed on the floor by the house. In contrast to the space below a slab, the negative pressure field in a crawl space (which has relatively little resistance to air flow) is very uniform-even when a single suction pipe is used for a very large space. Only in buildings with separate crawl spaces may there be a concern about large reductions in the negative pressure field.

The fan equipment, piping, and system layout common to other ASD systems are usually appropriate for crawl space depressurization systems. Depending on the leakage between the crawl space and

outdoors and between the crawl space and the occupied space, the exhaust flow rate typically ranges from 50 cfm to 150 cfm. As for other ASD systems, the amount of conditioned air removed from the occupied space (through the floor to the crawl space) can determine the increase in the heating and/or cooling load of the building, and the likelihood of back-drafting vented combustion appliances in the occupied space. Of course, any vented combustion appliances in the crawl space will be even more susceptible to back-drafting. Indicating alarms should be based on a flow sensor in the depressurization pipe, since crawl space pressures will be lower than what can be practically sensed with affordable pressure sensors.

Crawl space depressurization can be very effective at reducing indoor radon levels. It is the most effective control technique for crawl spaces after SMD, with reductions of up to 96% of indoor radon levels.

4. Pressurization of the Crawl Space

This technique is seldom used, except in research and demonstration projects, and will be described only briefly. In concept, it is very like basement pressurization techniques. A fan blows air (from outdoors, occupied spaces, enclosed porches, etc.-but not garages) into the crawl space to pressurize the space with respect to the soil. The pressure reversal keeps soil gas (and radon) from entering the crawl space-causing crawl space (and occupied space) radon levels to be lowered. Although the flow rate of crawl space air into the occupied space is increased (unless many of the holes and openings have been sealed), the overall flow rate of radon has been reduced. There has been some concern that this technique may increase the rate at which other crawl space pollutants (bio-aerosols, termiticides, etc.) are forced into the occupied space.

The flow and pressure demands on the system are very like those for crawl space depressurization. Therefore, system components are typical of those for other ASD systems. Pipe routing will be different depending on where the air is drawn from to pressurize the crawl space. If the temperature of this air can drop below freezing, then precautions should be taken to prevent freezing of water pipes and to avoid cold house floors. When the pressurizing air stream is withdrawn from a zone with a vented combustion appliance, back-drafting becomes a possibility. Indicating alarms should be flow sensors like those recommended for crawl space depressurization.

Few data are available on the radon reductions from this technique. Large reductions (greater than 90%) have been reported for several houses (Ref. 25) while in other houses, indoor levels remain above 4 pCi/L after installation of the system. While none of the pressure manipulation techniques for crawl spaces directly reduce the diffusion of radon from the soil, only crawl space pressurization can force more radon from this diffusion into the occupied spaces. This process may explain the poor radon reductions mentioned above for some houses.

III. Sealing the Radon Entry Pathways

By itself, sealing of radon entry points usually has limited impact on indoor radon levels. Sealing is most often used in conjunction with ASD techniques to improve distribution of the pressure field surrounding the structure. In this application, it can dramatically enhance the performance of mitigation systems. The effort to seal some openings that are difficult to access or that are numerous but very small must be weighed against the benefits. In many cases, small openings can be left

unsealed without seriously affecting either radon entry or the performance of ASD. In other cases, the building owner/occupants may decide that the disruption resulting from sealing in a finished area is not worth the benefit.

1. Cracks

Small Cracks

Generally small cracks should be sealed if it appears that they are interfering with the operation of an ASD technique. There are many caulks available today from retailers and commercial suppliers for sealing openings in concrete and mortar. Gaps that are good candidates for caulk-type sealants are 1/8" to 1/2" in width.

Essential characteristics of caulks used for sealing cracks for preventing radon entry are:

- Long life.
- Good adhesion and cohesion.
- Easy surface preparation.
- Good elasticity.

Regardless of the type of caulk used, the key to the durability of any caulking job is the quality of the surface preparation and the geometry of the caulk profile. A clean surface is necessary. This can be achieved by a good brushing with a wire brush, with the removed dirt vacuumed up. This is generally the approach used in sealing crawl-space membranes to solid concrete walls. However, in the case of small floor cracks, the crack must be ground out with a hand grinder in order to assure a good clean surface. If this is done, the mitigator must wear a suitable respirator to avoid dust and silicosis.

To have a strong caulk joint, the caulk must be able to flex as the concrete moves with the expansion and contraction of the soil beneath it. To allow the needed flexibility, a two-point bond rather than a three-point bond needs to occur. For example, in a ground-out crack, the caulk should bond to each side of the crack but not at the bottom of the crack. To assure that the caulk does not adhere to the bottom of the crack, a bond breaker should be used. Bond breakers can be in the form of tapes, or a small amount of dirt left in the bottom of the groove. In the case of floor to wall joints, the caulk should be bound to both the floor and the wall but have a bond break at the floor to wall joint intersection. Where floors are poured right up to the wall, a bond breaker tape can be used. In the case where expansion joints are between the floor and the wall, the expansion joint serves as the bond breaker. Furthermore, in sealing floor cracks, the crack should be ground out sufficiently, such that the resultant caulk will be twice as wide in the groove as the groove is deep. The same ratio also applies to floor to wall joints.

Gun-grade urethane caulk, as opposed to flowable caulks, has become the work horse of the industry. It can be obtained in 11 oz. sized tube form for small jobs, or can be purchased as two part formulations that can be mixed and applied with special guns and power caulkers. These caulks have shown excellent durability when applied correctly (Ref. 21). The term gun grade refers to caulk that is relatively thick and must be worked into a joint. The caulk can be applied directly from the nozzle on the tube and then worked or smoothed with a putty knife (the end of a spent tube of caulk

makes a good finishing tool). As caulks must contain a solvent to make them workable, and as they are very sticky, one should avoid contact with the skin for safety and convenience reasons.

Flowable urethane sealants have the same properties as gun grade caulks, but are sold in a flowable formulations. These are also referred to as "self-leveling" caulks. These products, available in one-part (tube) and two-part (gallon size) formulations, can be poured (flowed) into cracks and control joints. Although they will flow into cracks, they will also drain through large cracks or openings and fail to create a seal. In cases where deep cracks occur, gun grade may be preferable by itself or applied as a thin bead at the bottom of the crack with self-leveling poured on top of it. The advantage of self-leveling is that it can quickly be applied and produces a very professional looking job when cured.

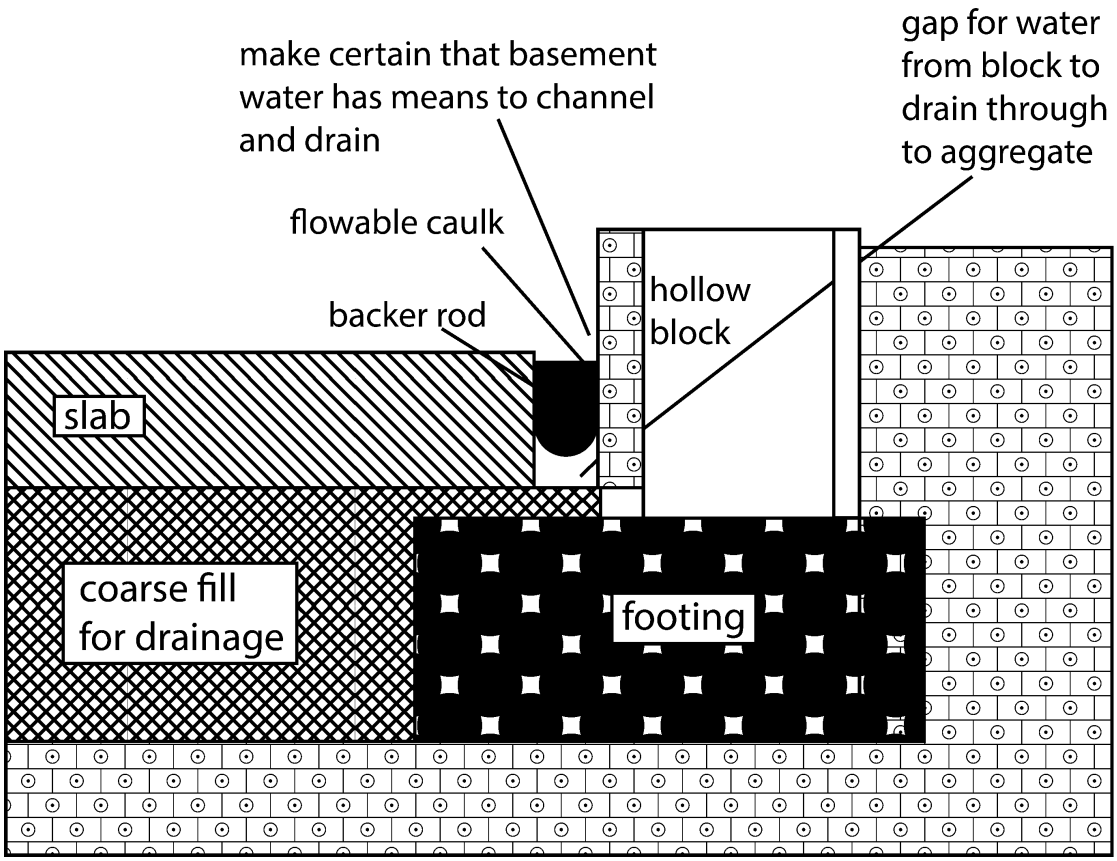
Silicone caulks are not generally recommended for concrete, mortar, or block, because they tend to have poor adhesive qualities. However, silicones might be used where a removable caulk is needed, such as at a floor drain, or around a toilet where access for maintenance will be required. Silicones are good "gasketing" materials and perform well when compressed between surfaces (e.g. between a sump cover and a floor).

Canal Drains and Other Large Joints

These large openings probably should be sealed as standard procedure for any mitigation job. Left open, they can constitute major radon entry pathways and can significantly degrade the performance of an ASD technique. Flowable urethane has many advantages for sealing the perimeter edge where a canal drain exists. Figure 4-30 illustrates a means for sealing canal drains (also known as "French drains").

Begin by installing backer rod (flexible, closed cell foam strip) in the drain. The backer rod comes in sizes from 1/4" to 2" wide. Larger sizes of backer rod can be saw- ripped into half circles and installed with the flat side up, about 1/2" down into the drain channel. On top of this, squeeze flowable urethane from quart tubes or pour two-part flowable urethane (a garden sprinkling can with the head cut off works well) in an even layer about 1/8" to 1/4" thick over the backer rod. Smaller sizes of backer rod can also be used to fill larger floor cracks before applying urethane sealant.

This method leaves an air space below the backer rod for some water migration to take place from the base of the foundation into the sub-floor. This space also serves as an added air channel, to extend the



pressure field of a sub-slab ventilation system.

Figure 4-30. Sealing a Canal Drain or Large Floor to Wall Joint, Source: Brennan

One must make sure that the purpose of the channel to remove water from the basement has not been violated by virtue of caulking this joint. The 1/4"' channel above the sealant will act as a small trough for condensation and minor foundation weeping. Identify and fix any serious foundation wall leaks or there may be water problems after the first rain.

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. Similar caution needs to be exercised with regards to impacting occupants of the house. Always make sure homeowners aware of planned use of caulks and other materials to determine if they are sensitive to the chemicals contained. Have material safety data sheets available for employees as well as homeowners.

Expansion Joints

In areas where expansive soils exist, expansion joints are placed between the floor slab and the foundation walls. The expansion material is a half inch wide, fibrous board that is fastened to the foundation wall and the concrete slab is poured up against it. This construction technique allows the slab to move more easily, should the underlying soil swell due to a change in moisture content. This technique is generally accompanied by control joints in the slab, where the slab has been weakened along straight lines by forming a groove in the concrete before it has set, or with a concrete saw, after it has cured. The expansion joints can be a major leakage area and attention should be given to sealing these wherever feasible.

Expansion joints can be brushed clean and caulked over with a gun grade polyurethane caulk applied in generous quantities. The caulk should bridge the expansion joint such that at least 1/4 inch of concrete on the wall and floor is covered. This allows reasonable movement of the slab without breaking the bond. If the expansion material is more than 3/8 of an inch above the surface of the concrete, it should be cut down with a knife. Never try to pound the expansion joint down, as it will later rise and break the caulking bond (Figure 4-31).

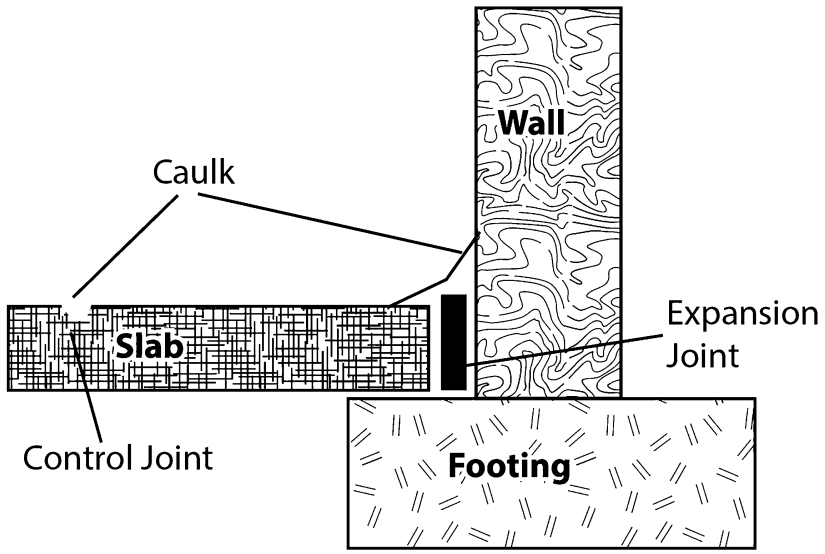


Figure 4-31 Sealing of Floor/Wall Expansion Joints and Control Joints, Source: Jelinek

In sealing expansion joints, gun grade rather than flowable polyurethane works best since it will not flow through gaps that are often found on either side of the expansion joint or run onto the floor.

2. Holes

As with canal drains and other large joints, most large holes that penetrate foundation surfaces (and serve no functional purpose) should be sealed.

Large Openings

Urethane foam sealants are useful for sealing holes that are too large to be caulked. These have good bonding characteristics and work well at filling hard-to-reach, odd-shaped spaces. The major drawback in using these sealants is the difficulty of determining the success of sealing attempted in concealed or hard-to-get-at spaces. Both single-part and two-part urethane foams are available. Single-part comes in disposable, single-use, 2 lb. cans, which require a gun to apply but are reusable and dispense only the amount needed, and in 10-pound cylinders, which include a 5-foot hose and a brass valve nozzle. The foam collapses if it is worked with after application.

Two-part urethane foams have separate hoses connected to two separate cylinders. The hoses are connected to a paint-type spray gun with a replaceable mixing head nozzle. The foam is sprayed out of the gun as with a paint sprayer. The two-part foam sets up hard in minutes compared to the 1/2 hour to 12 hour drying time of the single-part foams. These foams are messy, so avoid putting foam where it is not wanted.

Note: Gloves and eye protection should be worn while using the urethane foams. Respirators should be worn if adequate ventilation cannot be maintained.

Mortar can also be used to fill holes. Non-shrink grout must be used here to avoid the cracks that can occur when other types of grout cure and shrink. This method is often used for sealing penetrations into block walls.

Hydraulic or expanding cement is another option, but it requires quick work due to setting within minutes.

Sump Holes

In addition to closing a radon entry location, sump holes are often sealed as part of drain tile depressurization systems. In these cases, the sump acts as a suction plenum and is maintained at a negative pressure. Sump pump holes can be sealed with 3/4" pressure-treated plywood, metal, or heavy plastic sheeting, and specially made sump covers and gaskets. Whatever method is used, the cover should be strong enough to hold a person's weight and be screwed and sealed to the floor.

To avoid moisture warping the plywood, include a vapor barrier paint or sheet on the underside of the plywood or use a heavy plastic sheet. If the sump pump is a high-boy type, it will have to be replaced with a submersible unit. Some sump holes are designed so that water collecting on the floor can drain towards and into the hole. If this is the case, a means for getting this water to the sump must be preserved. This can be done by setting a plastic lid below the top surface of the concrete with a trapped floor drain in it, or installing a new trapped floor drain adjacent to the pit with sub-slab plumbing going to the sump below the cover. Use silicone caulk when the lid is caulked to the floor, so that it can removed for inspection or emergency draining.

Sump covers can be fabricated from many durable plastic materials (PVC, fiberglass, and polypropylene sheet). Some units are now manufactured specifically for radon control. They offer a variety of features, including holes for anchors, gaskets, view ports, fittings for sump pump discharge pipes, electrical power lines, and sump hole depressurization pipes.

Floor Drains

Usually, only those floor drains that are attached to pipes that open directly to the soil (for example, a dry well) are radon entry locations. To determine if a floor drain is a potential entry location, a radon grab sample measurement could be made in the drain, or soil gas movement out of the drain could be detected using chemical smoke. If required, there are many ways to seal a floor drain. One method is to retrofit with a proprietary drain insert. These small retrofit units fit into existing drains and seal with a weighted ring trap or a small rubber ball if the water trap dries out. Sometimes a drain is chopped out of the floor and a full-scale water trap installed. This is substantially more expensive than the retrofit water trap, but is a more permanent installation. Some mitigators pour antifreeze into the water trap to extend evaporation time.

Block Tops

One difficult sealing application is the open cores at the top of block foundation walls. Although the top of the foundation is not always easily accessible, sealing may be necessary so that the pressure field from a BWD, or even an SSD system may be extended up into the wall.

There are four sealant choices for the top of block walls:

- Urethane foam,
- Mortar,
- Extruded styrene foam or lumber caulked to the block and the existing sill plate, and
- Urethane caulk, if the gap is small enough.

To prevent the foam from falling through the cores before it sets, a non-combustible backing material should be used. The two-part foams tend to expand and cure faster than the one part foams and would be the preferred choice of foam in this application. Figure 4-32 illustrates use of these methods in sealing open block tops.

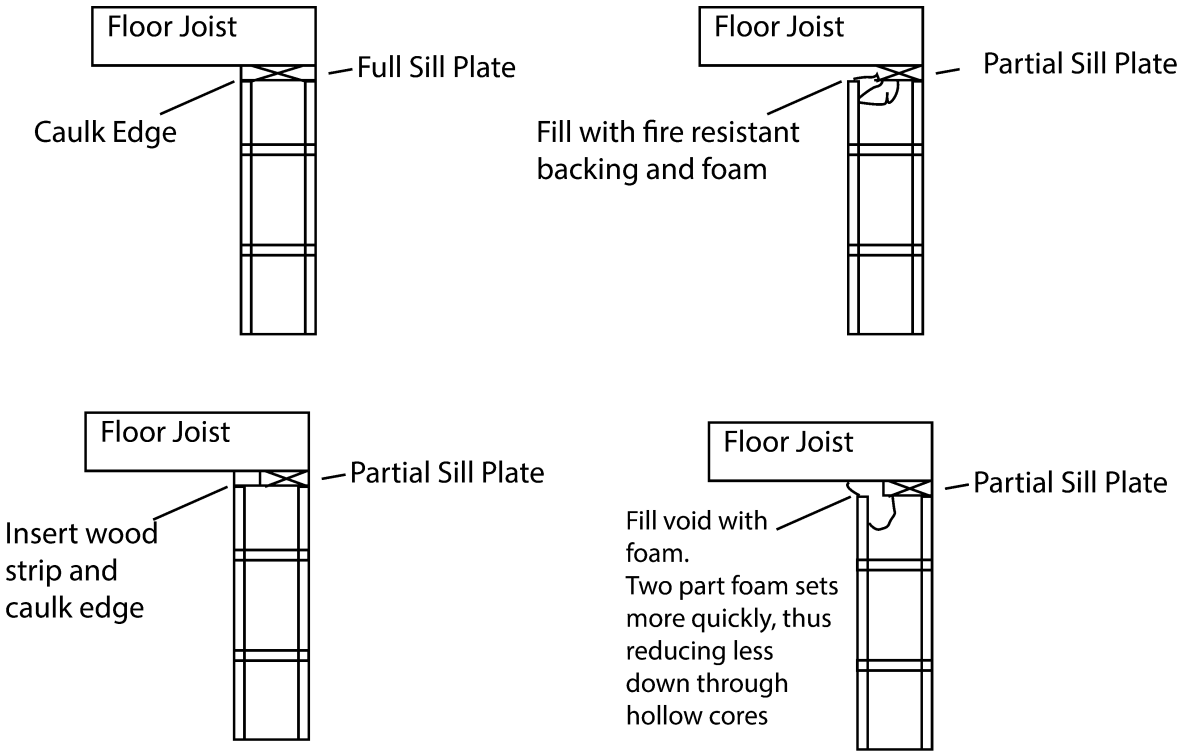


Figure 4-32. Sealing Tops of Hollow Block Walls, Source: Brennan

If the block tops are difficult to reach, or the block cores need to be sealed in the middle of a block wall, the above options will not work. An alternative is to drill a small hole into all the cores of the blocks that must be sealed, and shoot a 2- or 3-second burst of the two-part urethane foam into the cores and between each block.

This technique is tedious, but workable, and is the only possibility for such situations as:

- Brick or stone veneer atop course of open core block.
- Finished interior walls, which limit access to the open block tops (blocks must be sealed from the outside of the house).
- Block-wall construction from footing to eave.

Holes in Block Walls

Holes in block walls can be sealed with urethane foam or caulk over backer rod. Fractures in the wall can be sealed with caulk, but be sure to check closely for signs of water leakage, since caulks will not hold well against hydrostatic water pressure.

Unfortunately, the best way to seal a leak is from outside the foundation. Some waterproofing companies have had success with patching leaks in poured walls using hydraulic cement. A better, though costlier, solution is to cut a channel from the leak down into the sub-floor and surface seal the channel with fiber tape and hydraulic cement.

Other Holes

The large open cavities in the slab floor under bathtubs or shower stalls can have a negative impact on the pressure field extension of an SSD system. These openings are intentionally created when the slab is poured to permit access to plumbing components. If it is believed that the opening is hindering an SSD system, then a removable seal (in the event of future repairs) can be accomplished with 2-part urethane foam. Unfortunately, it may be necessary to cut an opening in the adjoining wall to gain access to the cavity.

Condensate drains from air conditioning coils are occasionally set up to empty into an open floor hole. A condensation pump should be used instead, and the hole sealed with backer rod and caulk. Alternatively, the condensation line can be routed to a wet-trapped drain.

Hollow metal support columns (lally columns) for the main girder and oil tank legs are other hidden entries. Drill two small holes in the columns and shoot foam in one hole until it comes out of the second hole.

Sometimes a furnace or a well water tank is supported on open concrete blocks that sit on the dirt. Sometimes the furnace cabinet sets above a square opening where the concrete was not poured. These areas can either be foamed or filled with non-shrink mortar.

Exposed Soil

Occasionally, areas of exposed soil may be encountered. These areas may be larger than a hole and be a significant part of a crawl space or basement floor. The areas may be closed with a concrete or mortar patch (depending on size) and urethane sealant applied at the edge where the new patch meets the original slab. If the area is large, it may be appropriate to cover it with a membrane and apply a suction beneath the membrane (see SMD).

3. Porous Surfaces

If the block foundation wall is a major contributing radon source, it may be necessary to seal the porous block surface to extend or enhance the vacuum from a block wall or sub-floor suction system. Any good foundation waterproofing paint or sealer will close up the porous surface of the block face. Keep in mind that several coats may be required to fill all the small pinholes, especially over cinder blocks.

Pressurize the basement with a fan while the wall is being coated: this forces the coating into the block wall. If basement pressurization is not possible, open all the windows and doors to neutralize the negative pressure usually found in basements.

Note: Do not blow air through a basement if there is friable asbestos present.

New radon-resistant paints for both floors and walls are now on the market. In making a selection, determine if the objective is to seal gross leaks to enhance a vacuum, or to create a perfect surface seal to block radon transmission without the use of a fan.

4. Performance

The use of sealing alone has not proven to be a good, long-term, stand-alone solution. Figure 4-33 illustrates the unreliability of this approach alone. Sealing entry routes is done primarily to enhance the performance of other mitigation techniques.

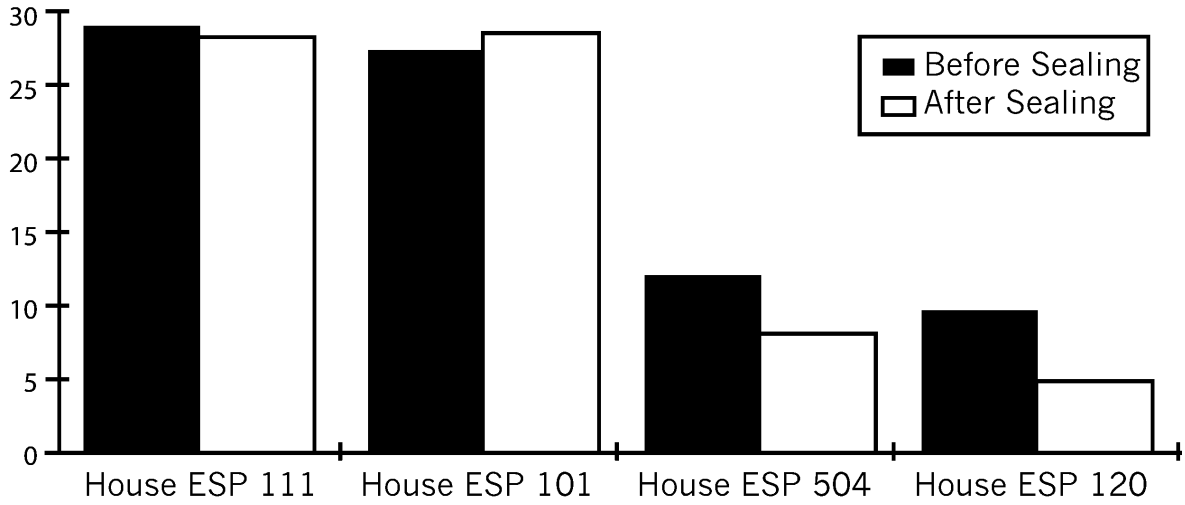


Figure 4-33. Radon Reduction Results Using Caulking and Sealing Only, Source: LBL

IV. Reducing the Accumulation of Radon Using Ventilation or Slight Positive Pressurization

Most cases of elevated indoor radon levels can be improved by increasing the ventilation rate through balanced supply and exhaust flows or supply-only flow.

There are several practical limitations to providing additional ventilation:

- Greater energy costs to heat (and cool) the additional ventilation air, and to operate the ventilation fan (if one is used).
- Comfort problems associated with moving air.
- Possibly increased noise levels caused by fans and moving air.

Because relatively large ventilation rates are required to control high radon levels successfully, the practical limitations restrict the use of ventilation techniques to houses with low to moderate radon levels (less than 20 pCi/L). Consequently, ventilation techniques may be the most appropriate mitigation approach for dealing with radon entry resulting from diffusion or emanation from building materials.

Increased ventilation falls into one of three categories:

- Mechanically powered ventilation that supplies fresh outside air to the house with no means for heat recovery.
- Mechanically powered ventilation that exhausts and supplies fresh outside air to the house with means for heat recovery.
- Passive ventilation.

The use of ventilation as a radon mitigation approach can also address other indoor air quality concerns such as:

- Humidity,
- Odors,
- Combustion byproducts, and
- Bio-effluents.

A. Mechanically Powered Ventilation

When powered ventilation is used, it can be in the form of exhaust only, supply only, or a combination of both.

- Exhausting air from the house applies negative pressure and increases the radon source. The results of this approach are unpredictable: it could produce some radon reductions, no radon reductions, or even an increase in radon concentrations. It is consequently not a recommended approach.
- Blowing air into the house tends to pressurize it, or at least reduce the negative pressures from normal exhaust flows. This tends to lower radon levels and might lead to radon reductions higher than expected from dilution effects alone. In heating climates, blowing un-tempered air into the house may increase the risk of moisture problems in the building shell.
- If ventilation air is supplied and exhausted from a structure at equal rates (with separate fans) to provide balanced flow, then no additional pressures (positive or negative) are created within the building. In this situation, it is expected that the radon concentration will go down in proportion to the increase in ventilation rate.

1. Mechanically Powered Ventilation Without Heat Recovery

One technique for supplying dilution air without heat recovery is to supply make-up air passively to the return air side of the heating or air-conditioning distribution system (Figure 4-34).

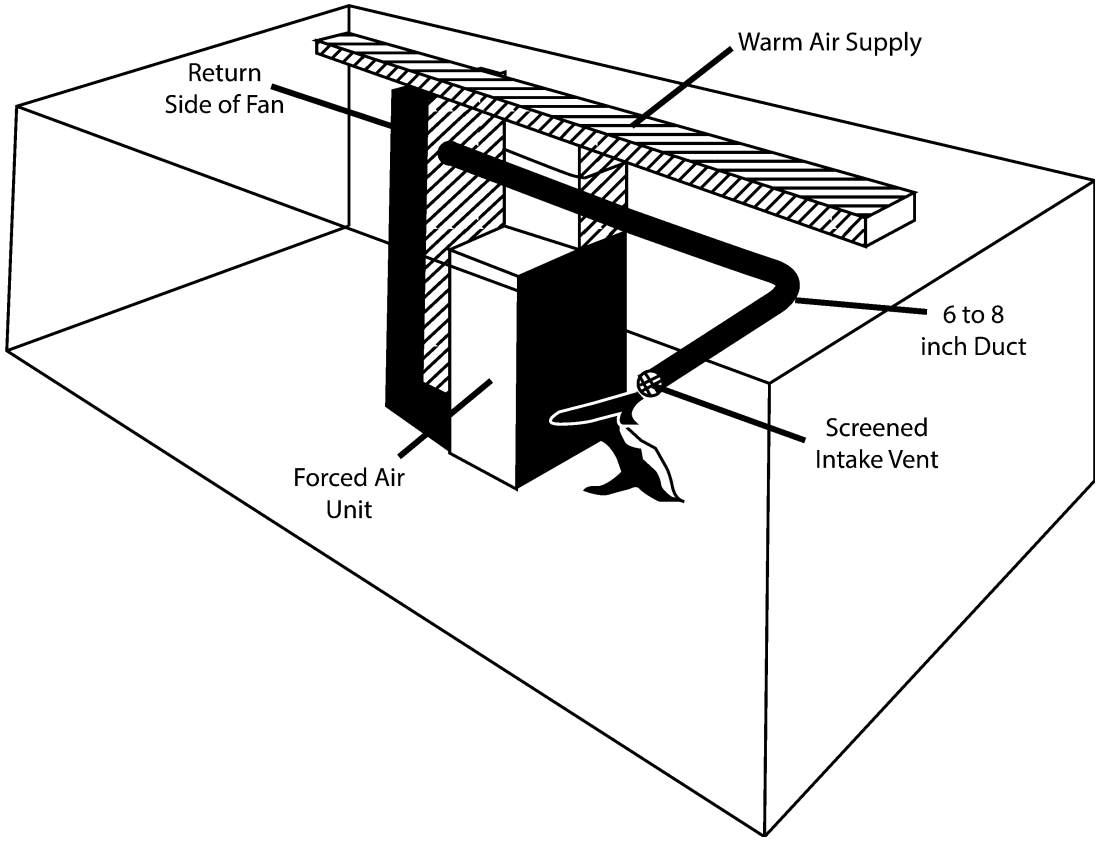


Figure 4 -34. Passive Air Make-up to House via Return Air Duct or Furnace/Air- Conditioner, Source: Brennan

Note: there is no booster fan on this air make-up line.

A typical installation would simply run a 6-inch insulated pipe from the outside air to the return air duct. When the distribution fan is not running, fresh air enters only in response to pressure differentials between inside and outside air and attempts to equalize pressure differentials. With the distribution fan running, make-up air is drawn in – the amount varies depending on the installation, but 100 cfm is representative (Ref. 13). The heating unit preheats this air and distributes it to the house. This small amount of air will probably not turn the house from negative to positive pressure, but will reduce the negative pressure on the building (Ref. 27). The makeup air is warmed by the heating unit and is only drawn in when the heating unit is running.

2. Heat Recovery Ventilation – Balanced and Unbalanced Flow

Heat recovery ventilators (HRV) are designed to bring in the same amount of air that they are exhausting. The incoming airstream is preheated by the outgoing airstream. This helps keep the energy penalty low and reduces comfort problems. Figure 4-35 presents the schematic layout of an HRV system being utilized for whole house ventilation.

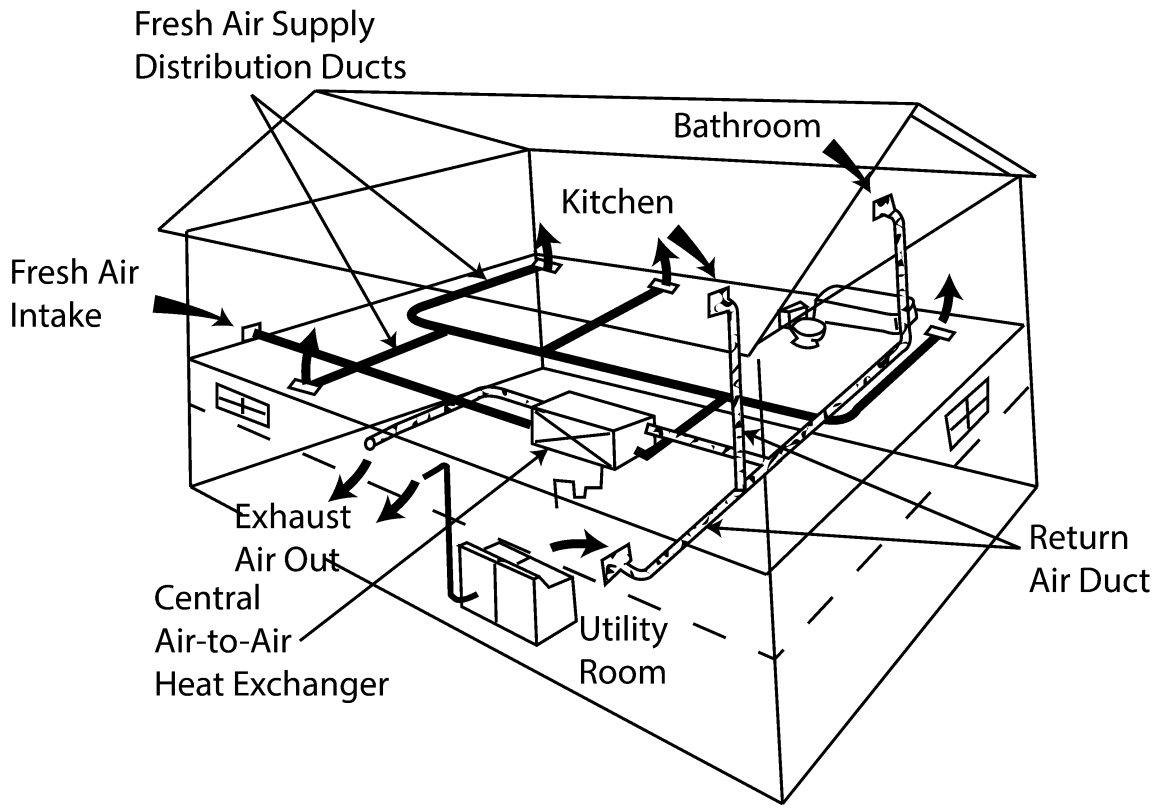


Figure 4-35. Layout of a Whole House Air to Air Heat Exchanger, Source: Air Exchange

This balanced flow should have no impact on the basement pressure. Therefore, the influx of radon by infiltration should remain the same. With a balanced flow, radon gas reduction occurs only through dilution. The pollutant concentration will be reduced by the inverse of the ventilation increase. In other words, if the ventilation is doubled, the pollutant is halved. If the ventilation is increased by a factor of 10, the pollutant is decreased to 1/10 or 10 percent of the original amount, resulting in a 90-percent reduction. Unless the basement is very small or extremely tight, increasing the ventilation 10 times requires the introduction of a lot of fresh air. If a basement is large or already leaky, it will be very difficult to make a significant difference with ventilation.

Greater radon reductions may be achieved by unbalancing the airstreams of the heat recovery ventilator to allow more air in than is being exhausted. However, this reduces the unit's energy recovery efficiency.

3. Design Considerations for Heat Recovery Ventilation

The major design concern is locating the fresh air supply(ies) and stale air returns, to ensure a thorough sweep of the entire space. Ductwork that may restrict airflow should be avoided. Place the outside grilles at least 12 feet apart to avoid contaminating the outdoor air entering the system. The unit should be sized correctly by not having to ventilate more than is required. Ensure that the intake grille does not become obstructed by leaves or dirt, and that the homeowner is well informed about the unit's maintenance requirements.

Note: Heat recovery ventilation systems should be designed and installed only by qualified air handling professionals; to prevent the occurrence of inefficiency of heat recovery and equipment and duct noise problems. HRV manufacturers frequently offer design services at nominal cost.

Note that it is very easy for heat recovery units to go out of balance, due to wind changes on the outside grilles or pressure changes in the building. It is worth the trouble to use an in-line pitot tube and installed dampers in both exterior duct lines, to facilitate measurement and balance of the flows.

Typically, heat recovery ventilators (HRV) are sized assuming that dilution is the principal reduction mechanism. The equation for calculating the additional ventilation that is necessary for a desired final radon concentration is:

$$ACH2 = ACH1 \times R1 / R2$$

where:

ACH1 = the initial ventilation rate (air changes per hour) due to natural ventilation in the home under the conditions that produced the initial radon reading

ACH2 = the final overall ventilation of the home after the HRV is added, expressed in air changes per hour

R1 = the initial radon reading

R2 = the desired or final radon concentration

The additional ventilation (air changes per hour) that will need to be introduced by the HRV will be the difference between ACH1 and ACH2. The flow rate (cfm) required of the HRV will be the difference between ACH1 and ACH2 multiplied by the volume of the house. The initial ventilation rate for the house (ACH1) can be estimated by using a blower door to measure the leakage area of the building, and then applying a mathematical model, local weather conditions; and special features of the house and surroundings. Or the blower door can be used to determine the ventilation rate at 0.2 inches W.C. (50 pascals) of pressure (or depressurization), which when divided by 20, approximates the average natural ventilation rate.

The above equation is an over-simplification of the dynamics that occur within a structure, since the natural ventilation of a home is highly variable. If the entire volume of the house is utilized in calculating the additional ventilation necessary, and the ventilation provided by the HRV is isolated to the high radon zones of the building, the resultant sizing is conservative for radon reduction.

Example:

A 2,000-square foot house with 8 ft. ceilings has been measured at 8 pCi/L utilizing a year-long alpha track device. Furthermore, blower door testing has determined that the house has a natural ventilation rate of 0.5 air changes per hour. If the homeowner desires the radon to be reduced to 3 pCi/L, what should the capacity of the HRV be?

ACH1 = 0.5

R1 = 8.0

R2 = 3.0

Substituting into the above equation, the following results are obtained:

ACH2 = 0.5 x (8/3) = 1.33 ACH

The capacity of the HRV needs to increase the ACH from what it was originally to the new value of 1.33 or:

HRV-Supplied Additional Ventilation = 1.33-0.5 = 0.8 ACH

HRVs are not sold in units of ACH, since this number is house-specific and must be converted to cubic feet per minute delivered by the HRV.

HRV Flow Rate = ACH needed x house volume/60 min. per hour

= 0.8 x (8 ft x 2000 ft^2) / 60 min. per hour = 222 cfm

Most HRVs are sold with integral blowers, in increments of 100, 200, 400 or, 1,000 cfm. In this example, the 400-cfm unit would be an appropriate choice. Although this may seem to be significantly oversized, one must consider pressure drop losses in the air distribution duct work. Once the system is installed, the air flow can be reduced by means of dampers. This will improve the heat recovery efficiency of the unit, due to the increase in residence time on the heat transfer media. Radon reduction efficiency can be improved utilizing these systems, by appropriate placement of duct work. As discussed in Unit Two, radon concentrations are usually higher in the lower portion of the house, especially in the case of a basement. Therefore, installing the HRV in a manner that concentrates the dilution effects in the lower level will have a larger impact on radon concentrations than if it was distributed throughout the entire house. Although this increases the radon reduction, it does not take full advantage of the beneficial effects of distributing fresh air throughout the house. A rule of thumb is that in homes in excess of 8 pCi/L, the ventilation should be isolated to the lower level. Those below 8 pCi/L can be installed in a whole house manner.

When installing a HRV to impact the whole house, it is best to have the stale air pick-up located near the floor in the lowest portion of the house. This will collect most of the high radon-containing air and exhaust it outside. Simultaneously, fresh air is brought in from the outside, passed through the HRV, and distributed to the upper portion of the house. However, the location of the stale air pick-up should not be in a zone that can be isolated from the fresh supply air discharge, so that the pick-up does not create more negative pressure in the low level of the house and increase radon entry.

Mitigation of the supply air to the pick-up (return) will occur if open doorways or stairwells are present from one zone to the next. If there are no openings, then passive diffusers should be installed either on walls or doors separating the zones.

When installing a HRV in an isolated manner in a basement, it is generally better to have the stale air pick-up located near the floor and at one end of the room. The fresh air supply should be located at the opposite end of the room. This technique will essentially sweep air to the pick-up point and thereby increase radon capture. The distribution of the fresh air can be accomplished via its own independent duct work or inserted into the return air plenum of the furnace or air conditioner. The latter is often preferable so that when the heating/cooling system is operating, the fresh supply air can be further conditioned to a comfortable temperature. Because the HRV runs continuously and the heating/cooling equipment usually operates intermittently, there may be periods when the supplied air's temperature may be uncomfortable. Therefore, it is important to consider the supply air discharge locations carefully to avoid an uncomfortable draft blowing directly on the occupants.

HRV exhaust of stale air will be relatively low in radon concentration compared to ASD systems that were discussed earlier. Therefore, the exhaust point does not need to be above the eave line, but should be at least 7 feet away from any building opening. Furthermore, the location of the exhaust and the fresh air entry point should be at least 12 feet away from each other and preferably on opposite sides of the building. Since the fresh air make up is going to be supplied to the breathing space of the home, care should be taken that it is not located in an area that can accumulate noxious fumes, such as near car ports, garages; or gas meters. The intake for fresh air make up should be screened to prevent bugs and debris from entering the system. This intake must be regularly cleaned and maintained by the homeowner.

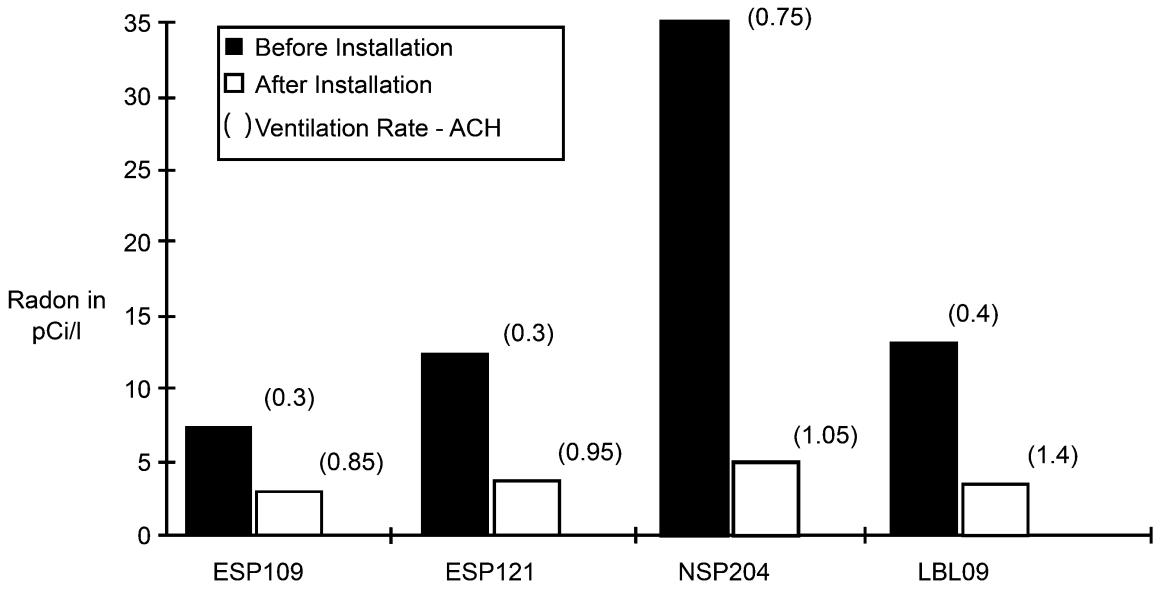
One of the techniques used to increase the radon reduction effects of these systems is to balance the system in a manner that supplies more air than is exhausted. This applies a slightly positive pressure on the house, thereby reducing the driving force which pulls radon into the structure. If this is done, one should be aware that there is a significant energy penalty in the operation of the home, which should be calculated and presented to the customer. The mitigator should also determine that the existing heating or cooling capacity of the home can handle the additional heating or cooling load presented by these systems in either balanced or unbalanced modes.

Consideration should also be given to the impact that these systems will have on the humidity of the home. HRVs that utilize a solid core heat transfer media tend to reduce humidity in cold climates. Conversely, the same type of units will increase the humidity in warm climates where air conditioning is utilized. HRVs that utilize rotating heat wheels have less of an impact on humidity due to moisture retention that occurs on the wheel. Although the moisture retention is an asset, it can cause problems during periods of extremely cold weather. In very cold weather, the water can freeze and bind the wheel to the point of mechanical failure. For systems with solid cores, very cold outdoor air can freeze the core so that air flow is restricted or completely obstructed. In climates where this can occur, additional indicators and/or freeze protection devices must be added to the system.

Duct work utilized with these systems is typically insulated with l" fiberglass and vapor barriers to prevent condensation on the outside of the duct work. Typical duct sizes are 7" or greater, depending upon size of the unit and the need to minimize air noise in the ducts.

4. Performance of Balanced Ventilation (HRV) Systems

In houses with typical ventilation rates, heat recovery ventilators can typically be expected to make a 30 to 80 percent reduction in radon concentrations. Representative changes in radon levels and ventilation rates are shown for four houses in Figure 4-36 (Ref. 25). Radon reduction follows the expected behavior, except for house NSP204 where the much greater reduction is due to an



improvement in the supply and return air distribution systems.

Figure 4-36. Radon Reductions from Use of HRVs in Four Houses, Source: Turk

HRVs are generally not recommended for homes more than 12 pCi/L and are typically more expensive to install and operate than ASD systems. Consequently, these are generally installed when other indoor-air quality problems exist (in addition to radon) or as a supplemental approach to sub-slab depressurization when very low levels of radon are desired (see phased approach below).

It should be noted that significant air leakage (up to 10% or more) can occur between the stale and fresh air streams in some air-to-air heat exchangers. For stale air with high radon levels, this leakage may cause unacceptably high radon levels in the "fresh" supply air. The HRV manufacturer should be contacted regarding the leakage specification.

B. Naturally Powered Ventilation

Simply put, naturally powered ventilation means opening the windows or doors. In doing so, ensure that windows are opened so that prevailing winds do not depressurize the house, since this might increase the indoor radon levels. Opening all the windows can increase the leakage area of the house by a factor of 10 to 20, and reduce radon concentrations by a factor of 4 to 10 (Ref. 13). This method is only useful when the outside weather permits; it is not considered to be a permanent solution to a radon problem.

V. Combination Systems and Phased Approaches

It is often not possible from the diagnostic measurements to determine the total system that is required to reduce radon concentrations sufficiently. This is especially true when there are several major areas for radon entry, such as a block wall, an attached crawl space, and a basement floor. Certainly, a separate design to deal with each of these areas individually would ensure significant reduction. However, this is often more than what is required. For complicated situations, a phased approach is often the most effective and efficient. Generally, the first step is to install a system to treat the largest entry area in a manner that allows easy attachment of another system. After the first system is installed, post mitigation radon measurements can indicate whether an additional system that treats another area needs to be added and incorporated with the first. Often a single fan can be used to drive both systems. This approach allows the homeowner to obtain the most cost-effective system, while still protecting the mitigator with regards to system reduction guarantees.

One example of this is a split-level home, which has a basement and a crawl space open to the basement. One could initially install a sub-membrane depressurization system with a capped tee installed on the SMD piping. The tee could easily be routed to future SSD suction points on the basement floor, if post mitigation testing did not show sufficient radon reductions.

For example, to achieve very low, final indoor radon concentrations may require the combined reductions of several mitigation systems. An ASD system could be installed as the first phase, with basement pressurization or ventilation installed as an additional system. This approach may also be necessary, for instance, in a building with poor pressure field extension where an SSD system does not reduce radon levels below the 4 pCi/L guidelines. In this case, a modest amount of additional ventilation may be sufficient to further reduce radon levels below 4 pCi/L.

Obviously, there are many permutations of phased approaches. Their successful use depends upon the time available for satisfactory radon reductions (i.e. real estate transactions). Economics also comes into play, if long distances for travel to the site and testing costs can negate what savings may have been generated by the phasing approach.

State of Florida Department of Health

Bureau of Environmental Health, Radon Program

NOTE TO STUDENTS

August 2012

Radon Proficiency Programs

UNIT THREE,

VIII, NATIONAL CERTIFICATION PROGRAM,

Pages 37 through 43.

Privatized Radon Proficiency Programs

The U.S. EPA's Radon Proficiency Program was discontinued in September 1998. The National Environmental Health Association, NEHA, and the National Radon Safety Board, NRSB, were providing services that are like the previous EPA program. On March 30, 2001, the U.S. EPA issued letters to both organizations regarding the status of these programs. NEHA no longer manages the program and is now the National Radon Proficiency Program (NRPP) and NRSB are recognized.

This information may be viewed on their web page:

https://www.epa.gov/sites/production/files/2015-11/documents/20090512-09-p-0151.pdf

Additional information may be found on the CD accompanying this manual.

VI. Radon Contractors Proficiency Program

EPA established the Radon Contractor Proficiency (RPP) Program in 1989 to evaluate the proficiency of radon mitigators of residential homes and provide information to the public on proficient mitigators. The RPP Program is a voluntary program consisting of several elements that collectively help to ensure the proficiency of radon mitigation contractors and the quality of mitigation services offered to the public.

These program elements are:

- Training,
- An examination,
- The proficiency report,
- Radon mitigation standards, and
- Biennial re-examination.

The mitigator should be aware that certain states have instigated certification programs for mitigators, testers, and consultants. The requirements to become certified or listed within a specific state may require only EPA, RCP, and RMP listing but may have additional requirements as well. The professional should check with state and local health officials to determine local requirements.

A. Training

EPA requires all participants in the RPP Program to complete at least two days of EPA-approved, hands on training. Only EPA-approved training will be recognized. You must complete this training before you take the RPP Program National Radon Proficiency Examination. Approved training is offered by EPA's Regional Radon Training Centers (RRTCs), States, and private providers.

While only two days of hands-on training are required, EPA recommends that one take at least four days of training if no other radon mitigation training bas been obtained. The Agency has developed a comprehensive four-day training program, Radon Technology for Mitigators (RTM), offered by the RRTCs, that satisfies the hands-on training requirement.

There are four EPA Regional Radon Training Centers (RRTCs):

Midwest Universities Radon Consortium

(University of Minnesota, Kansas State University, University of Illinois-Chicago)

University of Minnesota

1985 Buford Avenue (240)

St. Paul, MN 55108-6136

(612) 624-8747 Fax (612) 625-3113

Eastern Regional Radon Training Center

Rutgers University

Bldg. 4087, Livingston Campus

New Brunswick. NJ 08903

(908) 445-2582 Fax (908) 445-4918

Western Regional Radon Training Center

University of Colorado at Colorado Springs

1420 Austin Bluffs Parkway

Colorado Springs, CO 80933

(800) 513-8332 Fax (719) 593-3013

EPA strongly recommends annual continuing education for all radon mitigators to improve mitigation skills, increase knowledge, improve business capabilities, and keep current with new developments in the field. Over a two-year period, a mitigator should devote 16 hours to coursework, conferences, symposia, workshop seminars, or other radon related continuing education. Recommended topics for continuing education include:

- New technology/developments,
- HVAC and radon mitigation,
- Radon in schools and large buildings,
- Strategies for hard-to-mitigate houses,
- Better business administration,
- Worker health and safety,
- Advanced diagnostics,
- Troubleshooting mitigation systems, and
- Epidemiology and radon risk analysis.

B. The Examination

The examination can only be taken after you have completed the required training. Upon passing the examination and meeting all program requirements, your name will be added to the RPP Program Proficiency Report, and you will be issued a RCP identification card, valid for two years.

The examination is given at the four Regional Radon Training Centers and their satellite locations on a periodic basis, generally following a monthly schedule. State governments also administer the examination on national examination dates, which are noted in the insert. Please consult the insert as you complete Section V of your application (Selection of Exam Date).

When you arrive to take the examination, you must present a photo ID (driver's license or passport) to gain entrance. You must also give the Exam proctor two 2" x 2"

(passport size) photos of yourself. These photos will be used to produce an identification card, which will be sent to you once you have met the program requirements.

Once your test has been scored, you will be informed by letter of your performance. If you fail the examination, you may re-take it at any other scheduled time.

C. The Proficiency Report

After successfully completing the Program requirements, you will be listed in the National RPP Program Proficiency Report. The Proficiency Report is issued to States, EPA Regional Offices, and public health organizations. The Report will be used to refer the public to you. An individual's name appearing on this Report may also serve other functions: for example, a number of States have developed, or are developing, certification programs for mitigation contractors. A requirement for State certification may include successful completion of the RPP Program.

An individual listed in the Report has met the requirements of the RPP Program and has demonstrated a minimum level of radon mitigation capability. An individual whose name appears in the Proficiency Report may not misrepresent the meaning of RPP Program participation to the public. Being listed in the Proficiency Report means that you (not your company) have met the requirements of the Program and have demonstrated an understanding of radon and radon reduction methods. The RPP Program does not accredit mitigation contractors, nor does it certify, recommend, or endorse participating individuals; however, it does approve radon mitigators. Below are suggested phrases appropriate for advertising:

- [Individual's name] meets EPA requirements for radon mitigation.
- [Individual's name] is an EPA-approved radon mitigator.

EPA may determine that a mitigator's actions or performance warrant removal from the Proficiency Report. A mitigator can be removed from the Report for failing to comply with Program requirements or for submitting false or misleading information.

D. Radon Mitigation Standards

Participants in the RPP Program will be required to follow EPA Radon Mitigation Standards when performing radon mitigation work (see **Radon Mitigation Standards**). If not adhered to, mitigators arc subject to being de-listed from the RPP Program and the Proficiency Report. The Department’s radon mitigation standards are replaced the EPA’s Interim Standards. Mitigators will be required to adhere to the final standards when they become available.

The Mitigation Standards set a base level of performance for all RPP Program participants. The Standards require mitigators to follow specific practices related to radon mitigation. They cover such areas as code compliance, installation standards, and pre- and post-mitigation radon measurements. A copy of the latest edition of the Interim Radon Mitigation Standards can be found in the Appendix.

A suggested set of forms can be found in the Appendix that may be useful for the mitigator to utilize as a checklist to conform with the necessary documentation required by the RPP Program.

E. Biennial Re-Examination

To ensure that Radon Proficiency Program participants stay abreast of changes in the radon mitigation field, all contractors listed in the Report must be re-examined every two years. The re-examination is similar to the first examination, but includes new technology, policy standards, protocols, and other developments. Contractors should apply for and take the re-examination prior to the ID card expiration date. No training is required prior to taking the biennial re-examination; however, EPA strongly recommends continuing education on an annual basis to prepare for the re-examination and for your professional development.

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Review Questions (Measurement), Unit 4, Form A

1. The mitigation technique of sealing uses which of the following approaches?

   A. controlling the radon source

   B. controlling transport by pressure-driven entry

   C. controlling radon entry pathways

   D. controlling the accumulation of radon and radon decay product

2. Which of the following BEST describes the use of a natural ventilation system as a radon reduction measure?

   A. It can decrease the leakage area of the house.

   B. It can be an effective temporary measure to use.

   C. It can eliminate radon in a house.

   D. It can work well in all climates.

3. If the effectiveness of mitigation techniques was ranked from high to low, which of the following would be correct?

   A. sealing, ventilation, soil depressurization

   B. soil depressurization, source removal, sealing

   C. soil depressurization, ventilation, sealing

   D. source removal, sealing, ventilation

Answers to Measurement Review Questions

Review Question	Answer	Student Manual, Unit 4, Page Number
04.1	C	5, 63-72
04.2	B	72-73, 81
04.3	C	2-6, 8, 39, 60, 72, 80, 81

Review Questions (Mitigation), Unit 04, Form A

1. If significant radon entry into a 7 pCi/l house cannot be prevented by sealing, which of the following control actions would be the BEST to consider next?

   A. Increase house ventilation and minimize house depressurization.

   B. Monitor indoor concentrations and increase house ventilation.

   C. Monitor indoor concentrations and minimize house depressurization.

   D. Increase house ventilation and remove the soil radium source.

2. An air-conditioned house in South Florida, with a natural ventilation rate of 0.75 air changes per hour (ACH) has a confirmed radon concentration of 10 pCi/L. The homeowner does not want any holes drilled through the slab or foundation. Which design consideration would be violated by installing forced air ventilation which tripled the air exchange rate to reduce radon?

   A. ease of installation

   B. economy of installation

   C. economy of operation

   D. effectiveness of operation

3. When implementing a mitigation system installation, in what order should you do the following activities?

   1. Design the mitigation system.

   2. Procure the tools and materials.

   3. Review the site plans and home evaluation.

   A. 1, 2, 3

   B. 2, 1, 3

   C. 3, 1, 2

   D. 3, 2, 1

4. When installing a active soil depressurization system, why must you make certain tbat the negative pressure side of the system is thoroughly sealed and free of leaks? ·

A. to avoid reducing the sub-slab pressure field

B. to eliminate possible noise in the system

C. to decrease re-entrainment of the soil gas

D. to reduce condensation of the soil moisture

5. Which mitigation system should you choose if only the following facts about a home are available?

   1. The house is of slab-on-grade construction

   2. The slab is poured over block foundation

   3. There is easy access to the exterior perimeter

   4. The owners are concerned about interior damage and system appearance

   5. The interior floor is terrazzo

A. a sub-membrane depressurization (SMD) system

B. a block walls depressurization (BWD) system

C. a sub-slab depressurization (SSD) system

D. a combination of the above systems

6. Which mitigation technique should you use in a home with a high soil gas radon concentration, if the ductwork is hard to seal and is located in the crawlspace?

A. Depressurize under a soil membrane cover

B. Pressurize the crawlspace

C. Replace the ductwork with smaller ducting

D. Vent the crawlspace

7. For a commercial building with elevated radon levels, which of the following is the **LEAST** appropriate adjustment to make?

A. Adjust the heating, ventilating and air-conditioning (HVAC) system to maintain a positive pressure

B. Attempt to locate the radon entry points

C. Check for a ventilation or pressure imbalance

D. Increase the return fan capacity

8. What problem(s) might result from the improper air flow balancing of a heat recovery ventilator (HRV) for a radon mitigation system?

A. increased dust in the house

B. increased noise

C. increased soil gas entry

D. increased system wear

9. What life expectancy should an active soil depressurization (ASD) system fan be projected to provide?

A. length of the installer's guarantee

B. length of the manufacturer's warranty

C. 5 years

D. 15 years

10. How do foundation sealants reduce radon gas concentration?

A. by closing the entry pathways

B. by eliminating the driving force

C. by increasing the ventilation rate

D. by removing the source

Answers to Review Questions, Unit 04

(Mitigation applicants only)

Review Question	Answer	Student Manual, Unit 04, Page Number
04.1	A	5, 63-72, 81
04.2	C	72-73
04.3	C	7
04.4	A	5, 8-10, 37-38
04.5	B	4-5, 43-47
04.6	A	53, 60-63
04.7	D	72-81
04.8	C	73-81
04.9	D	23
04.10	A	63