

Radon Mitigation Technology

Appendix Documents

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1 Using Smoke Bottles and Micromanometers to Determine Pressure Field Extension

Introduction

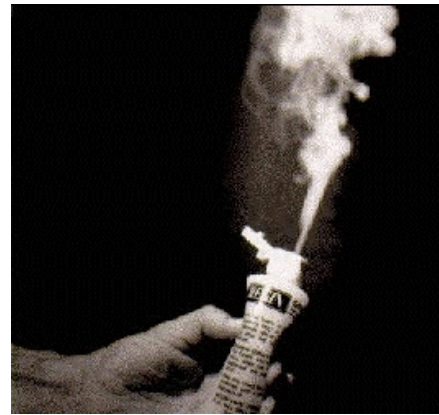
Since ASD systems create vacuums under the foundation there are a number of situations where you want to be able to measure the impact of your system, either qualitatively using a smoke bottle, or quantitatively using a micromanometer. You can also use these devices to measure pressure differentials across the shell of a building to see the impact of increasing make-up air, or in the case of large buildings or schools, which classrooms are under negative pressure due to an unbalanced HVAC system.

1.1 Using a Smoke Bottle

Smoke bottles are devices that create a visible smoke. It is recommended that you use a non-thermal type, where the smoke is not generated through a combustion process where the smoke is warm and would rise due to its heat rather than follow the direction of air flow.

Most smoke bottles are made of Teflon and are filled with titanium tetra chloride; such that when they are squeezed the vapor enters the air and reacts with the moisture in the air, forming a non-thermal hydrochloric acid mist.

- *DO NOT SQUIRT THIS IN YOUR EYES!*
- *Be very careful where you squirt the mist as it can corrode materials*
- *Store the bottle inside a tightly closed container so it does not leak out and damage your other tools.*



1.1.1 Steps for using smoke bottle on pilot holes drilled through a slab:

1. Find a gap along a floor to wall joint, or if necessary, drill a small 3/8-inch hole through the slab.
2. Shine a flashlight at the hole.
3. Hold the end of the bottle near the hole and ***gently*** squeeze it. Remember you want to observe which way the air currents are moving (up or down). If you squeeze it hard, like the picture above, you will only see the force of your squeezing the bottle and make a mess as well.
4. Observe the direction of smoke:
 - If the smoke comes up the hole after squeezing a little down it that means soil gases (including radon) are coming into the building.
 - If the smoke goes down the hole (for example when you have your system or diagnostic vacuum cleaner operating) the subgrade is at negative pressure relative to the building and radon is not likely to come up at that region of the slab.

1.1.2 Interpreting Results When Doing Vacuum Cleaner Diagnostics

Smoke bottles are easy to use devices and certainly a must tool for mitigators. However, they don't always tell you what you want to know when conducting a pressure field extension test when doing vacuum cleaner diagnostics.

For example:

- If the smoke rises up a hole when your vacuum is off and reverses direction when the vacuum cleaner is on, you clearly know you can pull a vacuum to the region of the slab you are testing.
- If on the other hand the smoke rises with the vacuum cleaner both on and off, it does not necessarily mean you are not having an effect in that area. That is, you might be reducing the pressure under the slab, but not enough to for it to go negative. The only way you can see a decrease in positive pressure is by using a micromanometer. Remember your final system will almost always work better than your diagnostics indicate because during the system installation, you will be able to seal slab openings or dig out a nice suction pit, both of which improve pressure field extension.

1.1.3 Other uses of smoke bottles:

Finding gaps in slabs or sump lids that should be caulked

- Finding gaps in sheeting of sub-membrane systems that should be sealed.
- Quickly identifying which rooms are negative relative to a hallway, or even if the entire building is negative relative to the outside.
- Determining if combustion appliances are backdrafting

1.1.4 Other comments on Smoke Bottles

- Be careful with them
- Get the material data sheets for chemicals and follow precautions
- Once filled, they last forever. You will probably lose them before you run out of chemical.
- Do not leave them where children can find them and play with them.
- Some occupants are sensitive to chemicals and you should always ask before using them.

1.2 Micromanometers

Micromanometers are an essential tool for the serious mitigator who is faced with challenging houses and especially if designing systems for large buildings. They are used for the following primary purposes:

- Measuring sub-slab pressures
- Measuring air flow in system or air flow in diagnostic vacuum cleaner tests when used in conjunction with a pitot tube.



To be useable in both of these applications they should be able to sense pressure differentials (both positive and negative) to 0.001 inch of water column. Meters of this sensitivity will likely cost approximately \$500.

Note devices will measure either in units of inches of water column or pascals. Either is fine, but note the following conversion:

0.001 inch of water column = 0.249 pascals, or
1 pascal = 0.004 inches of water column

1.2.1 Using a Micromanometer for Sub-slab Measurements

The steps for using a micromanometer for air flow measurements are described in the Air Flow Measurement section. When using the device for measuring sub-slab measurements when doing diagnostics follow these steps:

1. Drill a 3/8-inch hole in the location where you want to measure. Be sure you drill down into the sub-grade.
2. Remove dust from around hole.
3. Connect a tube to the negative port of the meter and leave the other port open to the room air.
4. But a small amount of plumbers putty around the end of the tube that will be used to temporarily seal your tube to the floor.(don't plug tube).
5. Place the micromanometer on the floor next to hole.
6. Zero out the meter BEFORE you place the tube in the hole.
7. Place the tube into the hole (no need to shove it all the way down.
8. Squeeze plumbers putty down firmly so air will not leak into hole and affect reading.
9. Take hands off tube and observe reading.
 - negative number means vacuum under the slab
 - Positive number means positive pressure under the slab
10. Turn on the vacuum cleaner without removing the tube
11. Observe reading.
12. If you do more than one pilot hole measurement, it is best to take the measurements at each hole (with vacuum on and vacuum off) before proceeding to the next test location.

1.2.2 Interpreting Results When Doing Vacuum Cleaner Diagnostics

First, when using these devices, you need to be aware of what is going on in the building. If a person turns on a bathroom exhaust fan elsewhere in the building or a gust of wind comes up during the measurement, these factors can influence your reading and perhaps mislead you. Here are some simple guidances on interpretation.

- If the reading goes from a positive to a negative when you turn on your vacuum system, you clearly are having an influence in the region of the slab you are measuring
- If on the other hand there is no change at all, you are not having an effect and you perhaps should reconsider your suction point location or look to see if, perhaps a grade beam is interfering with the draw of air under the slab; or perhaps there are too many

leaks in the floor or wall that is providing all the air your vacuum can handle and therefore it cannot reach the region you are measuring. This would be a good time to drill another test hole or even seal some openings.

- If the sub grade is positive with the vacuum cleaner is off, for example at +0.020 in W.C. but when the vacuum cleaner is on it is reduced but not to a negative number (say, +0.005) your shop vacuum is having an effect in the test region. Turn your shop-vac on and off several times to verify results. What this means is that your system can influence that region of the slab when installed, provided you seal openings and dig out a large enough pit. Remember diagnostics typically underestimate performance of ASD system. It is the ability of a micromanometer to measure influence as described in this example, which makes it a valuable diagnostic tool.

2 Determining Air Flows in a Pipe

Introduction

There are several occasions where you would want to measure air flow:

1. Air flow in your finished ASD system (EPA Radon Mitigation Standards section 17.2 require measurement of either air flows or suction being created by system).
2. Air flow of Heat Recovery Systems to be able balance intakes and exhausts (EPA Radon Mitigation Standards section 14.8.5)
3. Air flow in suction wand of vacuum cleaner when doing sub-slab diagnostics.

Although there are a number of devices available to do this, the most commonly used are Pitot tubes and Anemometers. Both of these devices measures air velocity in terms of feet or meters per minute. Once you determine how fast the air is moving in the pipe you simply multiply the velocity times the cross sectional area of the pipe (in corresponding units of either square feet or square meters) the product is the volumetric air flow rate in units of cubic feet per minute (CFM) or Cubic Meters per minute.

Example:

If the air velocity in 4-inch pipe is 550 feet per minute, what is the air flow rate?

The cross-sectional area of the pipe is determined by the following formula:

$$\text{Area} = \pi r^2,$$

where

$$\Pi = 3.143$$

R = radius of pipe (one half the diameter of the pipe)

The superscript 2, means that the radius is multiplied by itself (i.e., squared)

In our example of a 4-inch pipe the radius will be assumed to be 2-inches (note the exact inside diameters can be obtained from pipe specifications), therefore

$$\text{Area} = 3.143 \times 2^2, \text{ or } 3.143 \times 4 = 12.572 \text{ square inches}$$

Note that our measurement is in units of square feet so we must convert the cross-sectional area to square feet (there are 144 square inches in a square foot) as follows:

$$\text{Area} = 12.572 \text{ square inches} / 144 \text{ sq in/sq ft.} = .087306 \text{ square feet}$$

To now get the volumetric flow rate, multiply the velocity times the cross-sectional area

$$\text{Flow} = 550 \text{ feet/minute} \times 0.087306 \text{ square feet} = 48 \text{ CFM}$$

Of course the question is how you determine the velocity-*read on!*

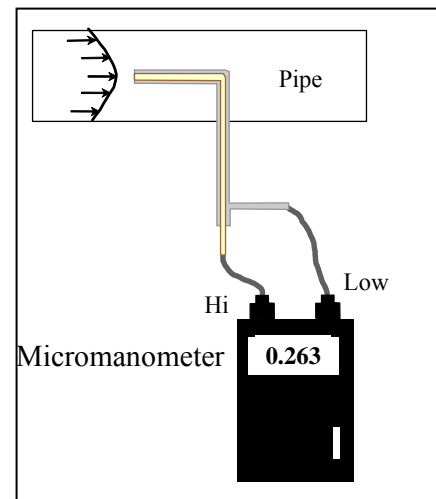
2.1 Using a Pitot Tube to Determine Air Velocities

A pitot tube is a relatively inexpensive device (\$30-\$40) that can be used in conjunction with a pressure differential device, such as the same micromanometer you use to measure sub-slab pressures.

A pitot tube is the same device that is used to measure the speed of a plane and comes in a variety of sizes, but for radon mitigation purposes a small one that is roughly 3/16-inch in diameter with an insertion length of 1 ½ inches works very well.

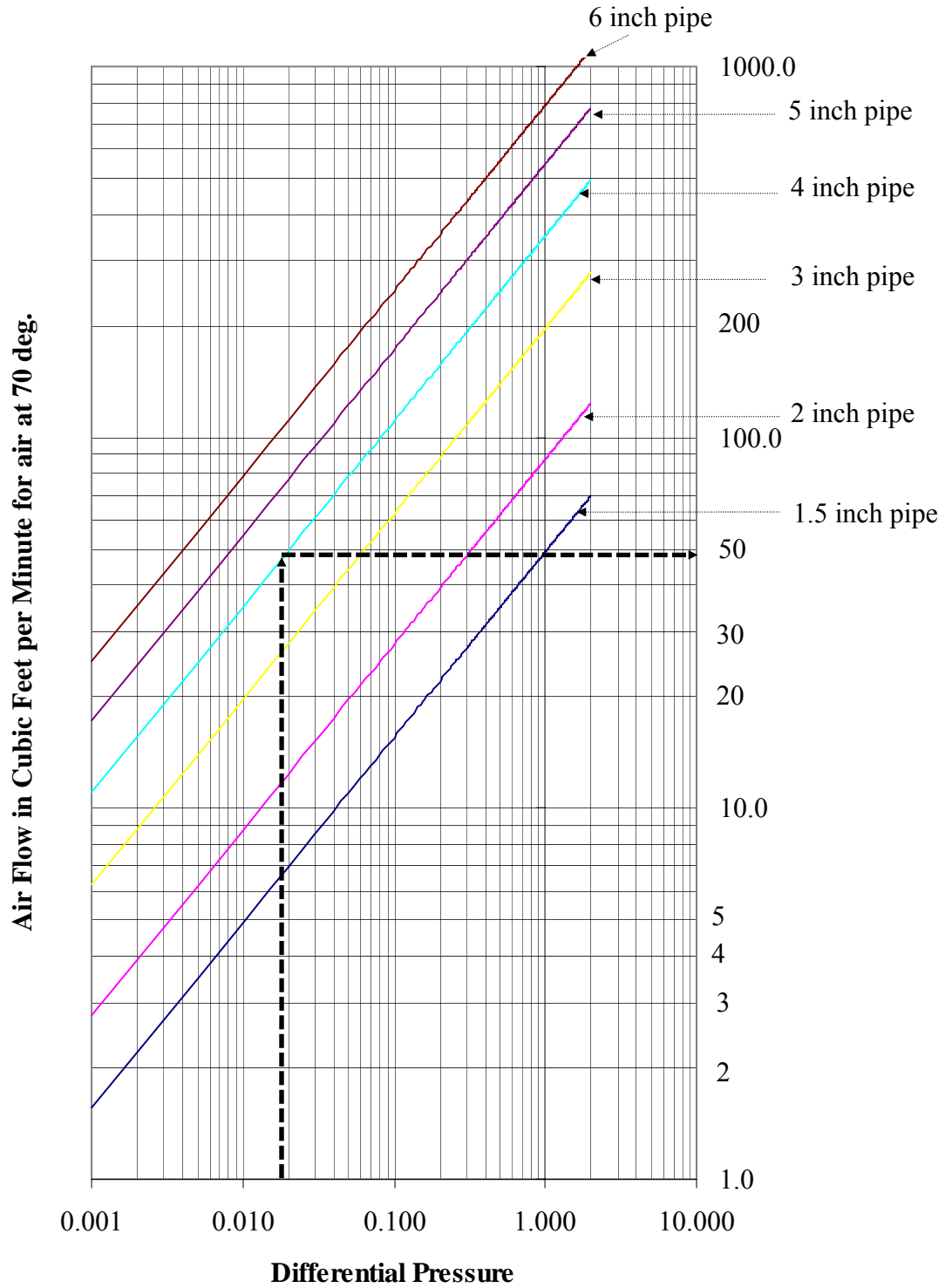
It is essentially a tube within a tube, which when directed into the air stream the pressure of the air hitting it causes a pressure into the tube that is proportional to the air flow rate (it is like holding your hand out the car window-the faster you are traveling the more the wind is pushing your hand back). There is another tube outside of the main one that has holes in it, to be able to measure the pressure inside of the pipe, which when this pressure is also measured, the difference between the direct pressure and the interior pipe pressure is due to the velocity of the air. Here are the steps to take:

1. Connect the fittings on your pitot tube to your micromanometer (or U-tube manometer), with the interior tube connected to the “High” side of your manometer and the outer tube to the low or reference port.
2. Drill a hole in your pipe large enough to insert your tube into.
3. Insert the tube so the end is in the center of the pipe for starters.
4. Turn the tube so it is parallel to the wall of the pipe and directly into the air stream.
5. Look at your manometer and turn the tube so you are getting the maximum reading for the point (this will indicate that you have it pointed directly into the oncoming air).
6. Write down the reading. Note that since the air may be turbulent inside the readings will bounce around, but watch it and take an average.
7. Repeat the measurement, halfway between the center of the pipe and the opposite pipe wall to you.
8. Repeat the measurement, halfway between the center of the pipe and the closest pipe wall to you
9. Average all three readings.



Once you have the average of your readings, you can use the calibration chart that came with your pitot tube to obtain the air velocity. Then simply use that number and knowing the cross-sectional area of the pipe you measured the velocity within, you can determine the flow rate (see preceding discussion).

You can also use the chart below, which allows you to determine the air flow directly from the micromanometer readings without having to do as much math, which saves a lot of time in the field.



Example: A micromanometer reading of 0.019 in a 4inch pipe was obtained. The flow is 48 CFM

2.2 Using an Anemometer

An anemometer is also a velocity measuring device. However, it typically uses a hot wire to heat up an airstream and then measures the temperature air stream downstream of the heated wire. The temperature measured is a function of the amount of air passing by the hot wire. These cost a few hundred dollars, but are very convenient when measuring air flows in ducts of HRV systems. They are also very easy to use and most models display the air velocity without the need for calibration charts. Here are the steps to take:

1. Drill a hole larger enough to insert the tip of the anemometer.
2. Insert probe to center of pipe and note measurement.
3. Repeat the measurement, halfway between the center of the pipe and the opposite pipe wall to you.
4. Repeat the measurement, halfway between the center of the pipe and the closest pipe wall to you
5. Average all three readings.



Then simply multiply the average of the measurements times the cross-sectional and sectional area of the pipe you measured the velocity within to get the flow rate (see discussion on page 1).

Note that anemometers come with different probe lengths and even telescoping ones that can be used to measure air flow in large ducts. If you use this for large ducts, you will need to make a number of measurements in a systematic way (called a traverse) to get a good average. Most manufacturers provide instructions for doing this.

3 Calculating Energy Costs for Active Soil Depressurization Systems

Introduction

There are three components that make-up operating costs for active soil depressurization systems:

1. Cost of electricity for operating the depressurization fan
2. Energy penalty of air withdrawn from the conditioned space of the home
3. Cost of maintenance (negligible)

Since most fans used for ASD applications have sealed bearings, there is little, if no, maintenance required and therefore can be neglected in the calculation. This leaves the cost of electricity to operate the fan continuously and the energy penalty associated with extracting conditioned air from the living space that is replaced by outdoor air, which may require heating or cooling.

3.1 Calculating Electrical Costs

Fans typically used for ASD systems have name plate ratings of 50 to 150 watts. This is an expression of the amount of power that will be required to operate them.

Nameplate ratings referred to the maximum power draw, which occurs either when the fan first starts, or if the impeller is locked. This allows an electrician to select the correct circuit capacity to install the fan on. This however, is not the actual power consumed by the fan in normal operation, which is typically less than the nameplate reading.

Example:

Let's start with making a conservative assumption that the fan will pull the maximum wattage as indicated on the nameplate.

Let's assume that the nameplate says the fan is rated for 90 watts. Since the fan is to run all the time, this is the amount of power that will be consumed continuously (just like leaving a 90-watt light bulb on constantly).

To determine cost, we need to know the cost of electricity which is typically expressed in terms of \$ per kilowatt-hour or \$/KWH. You can obtain this information from utility bills for your area. For this example assume \$0.08/KWH

Step 1: Determine the KWH for the time period you are interested in; let's say for an annual basis. Simply multiply the watts x the hours of operation:

$$90 \text{ Watts} \times 365 \text{ days/year} \times 24 \text{ hours/day} = 788,400 \text{ watt-hours/year}$$

Step 2: Convert watt-hours to kilo watt hours, by dividing by 1000 (kilo stands for 1000)

$$788,400 \text{ watt-hours/year} / 1000 \text{ watts/kilowatt} = 788.4 \text{ KWH/year}$$

Step 3: Determine costs. Multiply KWH x \$/KWH (Use appropriate cost for your area)

$$788.4 \text{ KWH/year} \times \$0.08/\text{KWH} = \$63.00 / \text{year}$$

3.1.1 Actual Electrical Cost

ASD fans typically draw less power than the nameplate rating is. The amount is a function of the fan design as well as the amount of air you are moving. One can determine this by measuring the amperage being drawn by an operating fan and also knowing what the voltage is that is being supplied to the fan (either 110 volt or 24-volt). One measures amperage with an Amprobe clamped around one of the single wires providing power to the fan.

Step 1: Measure current draw of fan. Let's assume it is 0.6 amps

Step 2: Determine wattage of fan. Multiply current measured (in amps) and multiply it by the voltage of the power supply (determine voltage at the same location as you measured the current). Let's assume it is 110 volts.

$$0.6 \text{ amps} \times 110 \text{ volts} = 66 \text{ watts}$$

Note this is less than the nameplate rating used in the previous example.

Step 3: Using the calculated wattage, perform the same calculations as were done in the previous example.

$$\frac{66 \text{ watts} \times 24 \text{ hr/day} \times 365 \text{ days/year} \times \$0.08/\text{KWH}}{1000 \text{ watts-hours/KWH}} = \$46/\text{year}$$

So as you can see the actual cost is less than what would be assumed by just the nameplate rating. Either from an assumption of a nameplate rating or direct measurement you now can predict the electrical cost. Note that this example was done for an annual operating cost. If one wanted to determine monthly operating cost, merely divide by 12 (number of months in a year).

3.2 Calculating Energy Penalty for Lost Conditioned Air

Sub-slab depressurization systems operate by withdrawing air from beneath the foundation. This creates a vacuum that reverses the direction of airflow between the sub-grade and the slab. The vacuum created in the sub-grade will cause interior conditioned air to be drawn down through the slab, into the system and lost to the outside air. As interior air is lost through the depressurization system, additional outside air will enter the home from above grade and thereby add an additional load on the building's heating or air-conditioning system.

Studies by the U.S. EPA¹ have concluded that on the average, half of the air that passes through an ASD system comes from inside of the home and the other half is from the soil. Of course, caulking and sealing slab joints and edges of membranes in sub-membrane systems will reduce this. EPA has estimated that 30% of the air handled by sub-slab systems installed on a home where floor-to-wall joints have been caulked comes from the interior of the home. Given these assumptions one can estimate the energy penalty resulting from the operation of a sub-slab system.

¹ Radon Reduction Techniques for Detached Houses, Technical Guidance (Second Edition), EPA/625/5-87/019, January 1988.

To perform this calculation one needs to know:

- Air flow rate of ASD system (obtained by measuring airflow in discharge of system or using measurements from vacuum cleaner diagnostics to predict the air flow of a future system)
- Heating degree-days: This is a number that can be obtained from reference books, or the weather service. It is an annualized expression for the difference in temperature between the outdoor air and a constant indoor temperature of 68 degrees Fahrenheit. Obviously the colder the climate, the greater the heating penalty will be.
- Information on heating system:
 - The heat source (gas or electric)
 - The cost of the heat source
 - The furnace efficiency (how much heat is delivered into home as fuel is consumed).

3.2.1 Example:

Assumptions:

1. Volumetric flow rate of SSD system: 60 cfm
2. Heating degree days – 4,208 F° days/year
3. Forced-air furnace, natural-gas fired, 70 percent thermal efficiency
4. Fuel source: gas
5. Gas cost - \$7.00 per 1,000 ft³
6. Heat capacity of air: 0.02 BTU/ft³F°
7. 1 million BTUs are released when 1,000 cu. ft. of gas is burned.

Step 1: Determine volume withdrawn from home

Flow rate of system x percentage from home,

Let's assume that no caulking has been done so 50% of air is coming from home, or:

$$60 \text{ cfm} \times 0.50 = 30 \text{ cfm}$$

Step 2: Calculate annual heating and cooling cost for 30 cfm

A. Heating Cost

Energy required to heat 30 cfm =

$$(30 \text{ cfm}) \times (4208 \text{ heating F}^\circ \text{ days}) \times (0.02 \text{ BTU/ft}^3\text{F}^\circ) \times 1440 \text{ min/day} \\ = 3.6 \text{ million Btu per year}$$

Cost of providing 3.6 million Btu per year =

$$\frac{\$7.00/1,000 \text{ ft}^3}{1 \text{ million Btu}/1,000 \text{ ft}^3} \times \frac{100}{70 \text{ (furnace efficiency)}} \times 3.6 \text{ million BTU} = \$36.30/\text{year}$$

If the system is installed on a home with air conditioning a similar calculation can be performed using Cooling infiltration degree-days.

If one caulked the slab penetrations and then assumed that 30% rather than 50% of the air handled by the system came from the home, the corresponding cost would be \$18 per year.

3.3 Total Cost:

Now that we have the electrical cost and the energy penalty one can determine the overall cost. For example, let's use the measured amperage of the fan as the basis from our first example and also assume that we caulked the basement in our second example.

Electrical Cost:	\$46/year
Energy Penalty:	\$18/year
Total	\$64/year (or \$5.30/month)

Remember these numbers are for these examples and every house will be a little different depending upon how well you seal the system as well as the cost of electricity and fuel source, but overall, these systems have low operating costs.

4 Radon Mitigation Standards Highlights

- Adherence to U.S. EPA Radon Mitigation Standards (October 1993, rev. 4/94) is Mandatory by National and State Certification Programs
- Mandated by the Indoor Radon Abatement Act of 1988.
- Required element of National Radon Proficiency Program.
- April 1994 document replaces Interim Mitigation Standards of 12/91.

4.1 RMS Section 6: Implementation

- 6.1 RMS is basis for evaluating system quality.
- 6.2 Listed contractor to personally inspect for compliance.
- 6.3 RMS is basis for evaluating complaints and de-listing process.
- 6.4 “shall” is mandatory, “should” is good practice.

4.2 RMS Section 7: Limitations

- 7.2 Where local codes and RMS differ, local codes shall govern. Deviation should be reported to NEHA within 30 days.
- 7.4 RMS does not apply to systems installed prior to April 1994 unless system undergoes major alterations. Alterations do not include replacement of worn-out equipment.
- 7.6 If research based system is installed which deviates from RMS a performance standard of 4.0 pCi/L shall apply. However, prior permission from state, and/or NEHA must be obtained. Client must also be informed of deviation.
- 7.7 RMS does not apply to radon removal systems for water supplies.

4.3 RMS Sections 8 & 9: Reference Documents and Description of Terms

RMS Section 8 lists reference documents that may be obtained from US EPA regional offices.

RMS Section 9 defines terms used throughout.

4.4 RMS Section 10: General Practices

RMS Section 10 includes general conditions and requirements for contractual considerations.

- 10.1 Shall review measurement results as basis for selecting mitigation strategy.
- 10.2 “Citizen’s Guide” is basis for interpreting health effects and offers other appropriate documents (state).
- 10.3 Temporary Systems
 - Shall be replaced with permanent system within 30 days, unless home undergoing significant renovations
 - Shall be labeled as temporary system
 - Date, name, phone #, NRPP RMT #
 - Legible from 3 feet

10.4 Client Exposure to Solvents. If materials containing organic solvents are to be used (caulk, glue etc.):

- Shall inform client of need for ventilation during and after application.
- -MSD sheets a good idea to present.
- Shall ventilate according to manufacturers recommendations.

4.5 RMS Section 11: Building Investigation

11.1 A visual inspection shall be conducted prior to initiating work:

- Large entry points.
- HVAC system review and implications.
- Diagnostics recommended but not required.
- Back-draft test recommended prior to work but required at conclusion.

11.3 Back-draft Test

- Close: windows, doors, fireplace & stove dampers.
- Open or turn on: HVAC supplies & returns, exhaust and distribution fans, and combustion appliances except device to be tested.
- Wait 5 minutes: turn on appliance to be tested and see if smoke stops spilling from flue opening within 5 minutes.

11.5 Shall develop sketch of building with:

- Building foundation, bearing walls
- Drain fixtures, HVAC system
- Should include system layout
- Shall be finalized after installation and included with documentation for client

4.6 RMS Section 12: Worker Health and Safety

Contractors shall comply with:

- OSHA
- State and local standards and regulations
- Requirements of RMS

12.2.1 Shall inform workers of radon risks

12.2.2 Shall have worker protection plan on file unless sole proprietor

12.2.3 Shall ensure safety equipment on site

12.2.4 Shall use grounded electrical tools

12.2.5 Shall safely install ladders

12.2.6 Work area shall be ventilated to protect from radon, dusts, fumes, etc.

- Reduce radon to less than 0.3 WL or 30 pCi/L

- Respirators shall be used if ventilation is impractical or radon cannot be reduced below target levels
- Respirators to conform to NIOSH Guide

12.2.7 ABC fire extinguishers when using flames or high temperatures (OSHA CFR 29 1926)

- Worker Exposure Records
 - Radon exposure assumptions
 - Highest pre-mitigation reading available (or actual on-site grab samples)
 - If converting Rn to WL, ER = 0.5
 - Time employees on job site without respirator
 - Maximum 12 month exposure is 4 WLM
- Asbestos & MSD Sheets

12.2.9 Where suspected friable asbestos containing materials are in work area, work shall not occur until a trained or accredited person determines that work complies with regulations.

12.2.10 Contractor shall provide MSD sheets for materials to be used to employees.

4.7 RMS Section 13: System Design

13.1 Shall be integral and permanent part of house.

13.2 Shall avoid creating other hazards.

13.3 Shall maximize Rn reduction and minimize impact on energy cost, comfort, and noise.

13.4 Shall be designed to comply with applicable laws and building codes.

4.8 RMS Section 14: System Installation

14.1.1 Follow applicable codes.

14.1.2 Obtain necessary building permits.

14.1.3 Follow plumbing codes when cutting building framing.

14.1.4 Use fire barriers of ratings consistent with firewall when penetrations are made.

14.1.5 Should use submersible sump pumps.

14.2.1 Permanently seal joints except where maintenance may require access (sump lids and toilet bases). In this case make air tight.

14.2.2 Should insulate where appropriate.

14.2.3,4 Independently secure pipe as follows:

Vertical: 1 hanger per 8 feet

Horizontal: 1 hanger per 6 feet

14.2.6 Shall be installed to prevent accumulation of condensate

Drain back to suction point

14.2.7 Shall not block access to windows, doors, or mechanical equipment

- Attachments to mechanical systems (e.g. sumps) should be easily removable for maintenance
- Radon Vent Pipe Discharge
- Applies to discharge points of fan powered ASD and BWD systems. Discharge points shall be:
 - Above eave of roof (rake edge on gable end OK)
 - 10 feet above ground level
 - 10 feet from any opening that is on a plane less than 2 feet below discharge point
 - 10 feet includes around obstacles and corners

Radon Vent Fan

14.3.1 Shall be well sealed to prevent leakage.

14.3.2 Shall be adequately designed for system.

14.3.3 Shall not be installed below ground or in or beneath conditioned spaces of home.

- Good: outdoors, unoccupied attics, garages without occupied spaces above.
- Bad: indoors, crawls, garages below living spaces.

14.3.4 Prevent condensate build-up (vertical)

14.3.5 Rated for location (e.g. outdoors)

14.3.6 Mount to reduce vibration

14.3.7 Mount to facilitate removal

14.3.8 Intakes to be screened on crawl space and building pressurization systems along with homeowner advisement for periodic cleaning.

14.5.1 Sump pits that permit entry or loss of conditioned air shall be sealed.

- Must not be sealed in a manner that prevents entry of drainage water.

14.5.2 Vent pipe penetrations at suction points shall be permanently sealed.

- Block tops and cracks shall be sealed in a BWD

14.5.4 Floor to wall joints and perimeter canal drains shall be sealed.

- If opening is greater than 1/2 inch, backing to be used
- Water drainage feature of channels to be maintained
- Other cracks should be sealed
- Inaccessible openings and cracks not sealed shall be disclosed to client

14.5.5 Baseboard systems to be sealed.

14.5.6 Seams in sub-membrane sheeting to shall be overlapped 12 in. and should be sealed.

- Should seal edges to foundation wall (good idea).

14.5.7 In combination basement crawl homes where SSD is used but SMD is not, the crawl shall be sealed off from basement-access door gasketed.

14.5.8 When crawl space depressurization is employed (I.e. pulling air from crawl without the use of a membrane).

- All openings through sub-flooring to be sealed with appropriate materials.
- Inaccessible non-sealed openings to be disclosed.
- Caution! Watch out for back-drafting.
- Electrical Requirements
 - Conform to code.
 - Do not run wiring through radon vent pipe.
 - Maximum plugged cord length: 6 feet.
 - Plugged cord may not penetrate wall.
 - Hard wire exterior fans.
 - Cannot > 50% of circuit or use one 80% loaded.
 - Disconnects or plug-ins required.

14.5.8 (cont)

- Drain Installation
- Check valves on soak-aways for DTD systems.
- Trap condensate drains that drain directly to soil.
- Perimeter channel drains should be sealed to maintain drainage capability.
- If open sump is only means for surface water to enter and lid is to be installed, a drain trap shall be installed in the lid to allow for water entry to sump.

14.8.1-4: HVAC Installations

- HVAC system modifications should be reviewed
- Crawl vents installed should be non-operable and utility lines in cold climates be freeze protected
- HRVs shall not be installed in areas of friable asbestos (should apply to all ventilation systems)
- HRV interior supply and exhausts to be 12 ft apart, and exterior ports to be 10 ft apart (can be low)

14.8.5 Contractor shall verify that HRV supply and return airflows are balanced. They shall also advise client of maintenance requirements on filters etc.

14.8.6 All interior and exterior intake and exhaust vent for HRV systems shall be screened.

4.9 RMS Section 15: Materials

- UL listed or equivalent
- Minimum sch. 20 pipe indoors and sch. 40 outdoors & garages
- Pipe fittings match pipe
- Pipe joints cleaned and glued with proper glue
- Urethane, grout, foams for permanent sealing
- Non-permanent caulks or gaskets for non-permanent sealing
- Mil or 3 mil X-lam and treated wood in crawls

4.10 RMS Section 16: Monitoring and Labeling

16.1 All ASD and BWD systems to have performance or failure indicator. (Good idea on HRVs etc.)

16.2 Electrical monitors not to be on switched circuit, or battery operated unless equipped with low battery indicator.

16.3 Mechanical monitors (manometers) to be marked as to operating range and initial reading.

16.4 System description label to be placed on system, or electrical panel, or prominent location:

- Legible from 3 feet: “Radon Reduction System”
- Installer’s name, phone number, NRPP RMT#, date of installation, advisory of re-testing every 2 years
- All exposed visible interior piping to be labeled at each floor level: “Radon Reduction System”

16.5 Label circuit in panel: “Radon System:

4.11 RMS Section 17: Post-Mitigation Testing

17.1 Check integrity of system after installation

17.2 Check system airflows or suction for design compliance

17.3 Immediately after installation of ASD or BWD system perform back-draft test. If concerns arise shut-off system and have condition corrected. (This is a good procedure for all radon systems especially HRVs and crawl depressurizations.)

17.4 A post-mitigation test shall be conducted either by contractor, client, or 3rd party:

- Using a certified device.
- Not before 24 hours and within 30 days.
- Shall recommend independent 3rd party NEHA certified tester.

17.5 Shall recommend re-testing every 2 years or if major renovations are undertaken.

4.12 RMS Section 18: Contracts and Documentation

- Recommend providing prior to initiating work:
 - Certification ID Number
 - Scope of work and estimate of completion time.
 - Statement of know hazards involved (chemicals, etc.)
 - System maintenance requirements
 - Estimate of installation and operating costs
 - Warranty and guarantee conditions
- Recommend that the following records be kept for 3 years:
 - Investigation summary
 - Pre and post mitigation test data
 - Copies of contracts and warranties
 - Narrative or pictorial description of installed system
 - Health and safety data should be retained for 20 years
- Required Client Information
 - Building permits
 - Investigation summary
 - Pre-& post mitigation test data
 - Contract/warranty copy
 - System description
 - Deviations from RMS
 - Operation/maintenance procedures
 - Actions to take when monitor indicates system failure
 - Name, phone#, NEHA ID#
 - State Radon Office #

5 Additional Explanation for Complex Online Questions

5.1 Worker Protection Question 1

Based upon the following work periods in homes where sequential short-term measurements had been previously conducted, what is the assumed accumulative exposure for this four day period? (Use assumptions from the EPA Radon Mitigation Standards)

Monday for 4 hours in a house previously measured at 10 pCi/L and 50 pCi/L.

Tuesday for 7 hours in a house previously measured at 12pCi/L and 8 pCi/L.

Wednesday for 8 hours in a house previously measured at 6pCi/L and 7 pCi/L.

Thursday for 6 hours in a house previously measured at 5pCi/L and 8 pCi/L.

Remember to:

- use highest radon measurement rather than the lower or an average (be conservative)
- convert radon measurement to working levels, and according to EPA RMS use a 50% EF
 $WL = Rn \times 0.5/100$
- Calculate each exposure individually rather than using average exposures, etc.
- Calculate WL-Hours by multiplying WL x hours spent
- Calculate WLM by dividing WL-Hours by 170 hours within a month

Calculations that are either correct or would have led to a wrong answer

	Radon	WL	Hours	WL hours	WLM	
Monday	50	0.250	4	1	0.006	Correct Way
Tuesday	12	0.060	7	0.42	0.002	
Wednesday	7	0.035	8	0.28	0.002	
Thursday	8	0.040	6	0.24	<u>0.001</u>	
					0.011	
	Radon		Hours	WL hours	WLM	
Monday	30	0.150	4	0.6	0.004	Wrong Used average of each pair of radon measurements
Tuesday	10	0.050	7	0.35	0.002	
Wednesday	7	0.035	8	0.28	0.002	
Thursday	8	0.040	6	0.24	<u>0.001</u>	
					0.009	
	Radon	WL	Hours	WL hours	WLM	
Monday	50		4	200	1.176	Wrong Forgot to convert radon to WL
Tuesday	12		7	84	0.494	
Wednesday	7		8	56	0.329	
Thursday	8		6	48	<u>0.282</u>	
					2.281	
	Radon	WL	Hours	WL hours	WLM	
Monday	50	0.250	4			Wrong Used total hours and average of all radon exposures Calculate WLM for each individual exposure then add
Tuesday	12	0.060	7			
Wednesday	7	0.035	8			
Thursday	8	0.040	6			
	19.25	0.096	25	2.40625	0.014	

Note that in the case of the 50 pCi/L, if you could not have ventilated it to less than 30 pCi/L respirator protection would have been required, per the EPA RMS.

5.2 Worker Protection Question 2

While installing a radon mitigation system, Worker A spent 6 hours in 0.12 working level (WL) and 8 hours in 0.08 WL, and Worker B spent 5 hours in 0.25 WL and 4 hours in 0.12 WL. Which one of the following statements correctly describes the amount of radon decay progeny exposure received by Workers A and B?

$$\text{WLM} = \text{Sum of WL} \times \text{hours} / 170$$

Worker A				
	WL	Hours	WL hours	WLM
Exposure 1	0.120	6	0.72	0.004
Exposure 2	0.080	8	0.64	0.004
				<hr/> 0.008
Worker B				
	WL	Hours	WL hours	WLM
Exposure 1	0.250	5	1.25	0.007
Exposure 2	0.120	4	0.48	0.003
				<hr/> 0.010

Since the calculated amount for Worker B is greater than Worker A, Worker B is the correct answer.

5.3 Worker Protection Question 3

In 1 month, a radon mitigation worker has performed mitigation projects for 20 days, has worked an average of 10 hours per day, and has an average exposure of 0.34 WL. What is this worker's cumulative exposure in working level months (WLM)?

$$\text{WLM} = \text{Sum of WL} \times \text{hours} / 170$$

$$= \frac{0.34 \times 20 \text{ days} \times 10 \text{ hours per day}}{170 \text{ hours per working month}} = \mathbf{0.4 \text{ WLM}}$$

5.4 Worker Protection Question 4

What average radon working environment can a radon worker be in without exceeding the EPA's Radon Mitigation Standards maximum annual exposures for radon decay products? Assume an 8 hour workday, 50 weeks per year.

- First we must remember that one should not exceed 4 WLM/year
- Rearrange our normal equation to solve for WL since we already know the total WLM which is 4 WLM

$WLM = WL \times \text{hours} / 170 \text{ hours}$, rearranges to:

$$WL = \frac{WLM \times 170}{\text{Hours}}$$

- We also know the number of hours to be worked from the question which is 50 weeks x 40 hours per week = 2000 hours.
- Now substitute what we know into the equation:

$$WL = \frac{4 \text{ WLM} \times 170}{2000 \text{ hours}} = 0.34WL$$

- Using our Equilibrium Equation we learned in the measurement course

$$\text{Radon} = \frac{WL \times 100}{ER} = \frac{0.34 \times 100}{0.5} = \mathbf{68 \text{ pCi/L}}$$

Note that had we used an equilibrium ratio of 100% as would be appropriate for OSHA calculations, our answer would have been 34 pCi/L. EPA uses 50%, so remember this for the test and consider being more conservative in your recordkeeping by using 100%.

In either event, 34 or 68 pCi/L is pretty hard to average in a mitigation contractor's career, which means that it will be difficult to exceed the 4 WLM guidance. However it is still prudent to exercise caution by ventilating your work areas.

5.5 RMS Question

Prior to installing a 150-Watt/120-Volt mitigation fan on an existing 15-amp household circuit, an EPA-listed contractor must verify that the total connected load on that circuit (excluding fan) does not exceed:

- First one cannot have a circuit loaded more than 80% after installation of the fan.
- Since the circuit is a 15 amp circuit the max load would be:

$$15 \times 0.8 = 12 \text{ amps}$$

- The mitigation fan is a 150 watt fan on a 120 volt circuit.
- We learned that watts can be calculated with the following formula:

$$\text{Volts} \times \text{Amps},$$

- If we rearrange this equation the amps drawn by our fan will be:

$$\text{Amps} = \frac{\text{Watts}}{\text{Volts}} = \frac{150}{120} = 1.25 \text{ amps}$$

As calculated above, the max load on the circuit cannot exceed 12 amps. Therefore if the fan pulls 1.25 amps the other loads on the circuit cannot exceed:

Max existing load on circuit before fan = 12 amps – 1.25 amps = **10.75 amps**

5.6 Operating Costs Question 1

A sub-slab depressurization (SSD) system is proposed operating a 93-watt fan at 250 cubic feet per minute (cfm). Local electrical costs are \$0.06/kilowatt hour. Which of the following statements is a proper representation of total annual energy costs?

$$93 \text{ watts} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{1 \text{ KW}}{1000 \text{ watts}} \times \frac{\$0.06}{\text{KWH}} = \$48.80 \text{ per year}$$

5.7 Operating Costs Question 2

If the cost of electricity is \$0.04/kWh, the approximate monthly savings in operating a 180-watt versus a 90-watt fan would be:

180 watt fan:

$$180 \text{ watts} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{30 \text{ days}}{\text{month}} \times \frac{1 \text{ KW}}{1000 \text{ watts}} \times \frac{\$0.04}{\text{KWH}} = \$5.18/\text{month}$$

60 watt fan:

$$60 \text{ watts} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{30 \text{ days}}{\text{month}} \times \frac{1 \text{ KW}}{1000 \text{ watts}} \times \frac{\$0.04}{\text{KWH}} = \$1.73/\text{month}$$

$$\text{Savings per month} = \$5.18 - \$1.73 = \mathbf{\$3.45/\text{month}}$$

5.8 Operating Costs Question 3

An ASD system has a fan which is plugged into a 120V outlet and pulls 0.40 amps, running continuously. What is the annual electrical cost, if electricity costs \$0.085/kilowatt hour?

- In this question you are not given the wattage of the fan, so you must first calculate this:

$$\text{Watts} = \text{Volts} \times \text{Amps} = 120\text{V} \times 0.4\text{amps} = 48\text{watts}$$

$$48 \text{ watts} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{1 \text{ KW}}{1000 \text{ watts}} \times \frac{\$0.085}{\text{KWH}} = \mathbf{\$35.74/\text{year}}$$

5.9 Ventilation Question 1

A slab-on-grade house has 2000 square feet of slab living area, and standard 8-foot ceilings. The estimated air exchange rate, calculated from blower door testing, is 0.5 air change per hour. It is desired to reduce the radon from 8 to 2 pCi/L using an air-to-air heat exchanger. Assume that the exchanger works simply by dilution of the indoor radon (i.e., not by house pressurization effects). What approximate exchanger capacity will be required?

$$\text{ACH FINAL} = \frac{\text{Initial Radon}}{\text{Desired Radon}} \times \text{ACH Initial} = \frac{8}{2} \times 0.5 = 2$$

$$\text{ACH HRV} = \text{ACH FINAL} - \text{ACH Initial} = 2 - .5 = 1.5$$

$$\text{Volume HRV} = \text{ACH HRV} \times \text{House Volume} = 1.5 \times 2000 \text{ sq ft} \times 8\text{ft} = 24,000 \text{ CFH}$$

CFH is cubic feet per hour, convert to cubic feet per minute

$$24,000 \text{ CFH} / 60 \text{ minutes per hour} = 400 \text{ CFM}$$

- Remember if you calculate a number which does not exactly match an HRV size, pick the next largest size (capacity).
- In this case, choose the one that is **425 CFM**

5.10 Ventilation Question 2

A small (750-square-foot) single-story slab-on-grade home with an 8-foot ceiling shows an initial radon level of 12 pCi/L. A blower door measurement indicates 0.5 air changes per hour (ach) of natural ventilation. How large an air exchanger would be needed to reduce the radon level to 2 pCi/L, by dilution alone?

$$\text{ACF Final} = \frac{\text{Initial Radon}}{\text{Desired Radon}} \times \text{ACH Initial} = \frac{12}{2} \times 0.5 = 3$$

$$\text{ACH HRV} = \text{ACH Final} - \text{ACH Initial} = 3 - .5 = 2.5$$

$$\text{Volume HRV} = \text{ACH HRV} \times \text{House volume} = 2.5 \times 750 \text{ sq ft} \times 8 \text{ ft} = 15,000 \text{ CFH}$$

$$15,000 \text{ CFH} / 60 \text{ minutes per hour} = \mathbf{250 \text{ cfm}}$$

5.11 Ventilation Question 3

The natural ventilation rate in a house is 0.8 air change per hour (ach) and the radon level is 10 pCi/L. To what value must the ventilation rate be increased, in order to lower the radon level to 2.5 pCi/L? [Assume that radon reduction is due solely to dilution by outdoor air that contains no radon.]

- In this question all we need to do is determine what the Final ACH will need to be. That is they are not asking how much the HRV needs to add, just what the air exchange rate will be after you are done.

$$\text{ACF Final} = \frac{\text{Initial Radon}}{\text{Desired Radon}} \times \text{ACH Initial} = \frac{10}{2.5} \times 0.8 = \mathbf{3.2 \text{ ACH}}$$

5.12 Ventilation Question 4

Which of the following is the air-exchange rate per hour in a 12,000 cubic foot building with both an infiltration rate of 100 cubic feet per minute and an exfiltration rate of 100 cubic feet per minute?

- The amount of air being exchanged per hour is:
 $100 \text{ cfm} \times 60 \text{ minutes/hour} = 6000 \text{ CFH}$
- The air exchange rate is the number of house volumes exchanged with the outdoors per hour, therefore

$$\text{ACH} = 6000/12,000 = \mathbf{0.5 \text{ ACH}}$$

5.13 Diagnostics Question 1

*During vacuum cleaner diagnostics to simulate active soil (ASD) system performance, the following data are obtained: Velocity of air: 2100 fpm; Inside diameter of pipe where measurement is taken: 1.5 inches. What is the airflow rate in cfm? [(*pi = 3.14)]*

- The 1.5 inch pipe would likely be a pipe connected to the inlet of your shop-vac. Note that the 1.5 inches is the diameter. The radius (r) would be half that, or 0.75 inches. The air velocity was given as 2100 feet per minute (fpm)
- Air flow = velocity x cross-sectional area of pipe.
- Cross sectional area = $\pi r^2 = 3.14 \times 0.75^2 = 3.14 \times 0.75 \times 0.75 = 1.766$ square inches
- Convert to square feet = $1.766 \text{ sq in.} / 144 \text{ sq inches per sq ft.} = 0.012265$ sq ft
- Get volume by now using first formula above
Air flow = $2100 \text{ fpm} \times 0.012265 = \mathbf{25.8 \text{ cfm (cubic feet per minute)}}$.

5.14 Diagnostics Question 2

If a radon system is moving 87 cubic feet per minute through a 4-inch pipe (area = 0.0872 square foot) and the air is moving at 1000 feet per minute, approximately how fast will the same amount of air flow through a 2-inch x 3-inch downspout?

If a radon system is moving 87 cubic feet per minute through a 4-inch pipe (area = 0.0872 square foot) and the air is moving at 1000 feet per minute, approximately how fast will the same amount of air flow through a 2-inch x 3-inch downspout?

You can do this two ways:

- One way to do this is to calculate the velocity in the downspout:
Velocity = flow/cross-sectional area.
Cross sectional area = 2 in. x 3 in. = 6 sq in
Convert to square feet: $6 \text{ sq in} / 144 \text{ sq in/sq ft} = 0.04167$ sq ft.
Use formula above
Velocity = flow/cross-sectional area = $87 \text{ CFM} / .04167 = 2,087$
(which essentially **2,100** feet per minute)
- You can also multiply the 1,000 fpm velocity given you by the ratio of the two cross sectional areas:
 $1000 \text{ fpm} \times \frac{0.0872 \text{ sq ft}}{0.04167 \text{ sq ft}} = 2,092 \text{ fpm}$ which is also essentially **2,100** feet per minute

6 Calculating Pressure Drop in Radon Vent Pipes and Sizing Fans for Sub-Slab Depressurization Systems (Supplement)

Introduction

Typical active soil depressurization systems designed and installed in homes are fairly simple and do not require extensive design calculations to size them. Most vent systems in homes are a minimum of 3 inches in diameter and commonly 4 inches in diameter. Fans used to supply the required vacuum typically have the capability of generating approximately one inch of water column vacuum while being able to move 100 cubic feet per minute of air (cfm).

However, there may be situations where highly compacted soils may be encountered where different fan characteristics may be needed. There may also be situations where loose soils allow large amounts of air to be provided to the fan.

The following discussion and example provides a methodology for optimizing vent pipe size and fan characteristics.

6.1 Friction Loss

Friction loss is the term used to describe the resistance to airflow that a pipe can present. The more air that moves through the piping system, the more “friction” generated. It is important to realize that in order to achieve a vacuum beneath a slab in a sub-slab-depressurization system one has to remove air from beneath the foundation at a faster rate than it can be supplied from the soil and from above grade.

The friction loss or resistance to the flow of air increases as:

- The pipe diameter is decreased
As the pipe diameter decreases, the air has to squeeze through a smaller area. This factor has a very large effect on friction
- The length of pipe is increased
The longer the pipe run is, the more surface area is presented to air for friction. This is typically not as significant of a factor as is the pipe diameter.
- The number of fittings (elbows, and tees) is increased
As air turns a corner, there is a lot of turbulence and hence friction loss. Fittings can cause significant amounts of friction and air noise.

6.2 Equivalent Length of Pipe

Tables are used in estimating the amount of friction or loss of vacuum. To use these tables one needs to know the actual length of pipe used and the amount of friction caused by fittings. The term *equivalent length* refers to the length of straight pipe which would cause the same amount of friction as would a fitting. This is determined by using factors based upon the type of fitting and are expressed in a dimensionless term called the L over D ratio (L/D).

The L/D ratio can be multiplied by the diameter of the pipe to determine the equivalent length of pipe that would cause the same friction as the fitting.

Example: The L/D ratio for a 90-degree short radius elbow (as commonly used in radon mitigation systems) is 30.

In the case of a 3-inch pipe where the inside diameter of the schedule 40 pipe is 0.256 feet, multiplying the L/D ratio by the diameter yields:

$$0.256 \times 30 = 7.7 \text{ feet}$$

Or in other words, adding one elbow adds as much resistance to airflow as does an additional 7.7 foot length of 3 inch pipe.

Similarly, a four inch 90 degree elbow would add as much resistance to airflow as does an additional 10-foot length of 4-inch pipe

$$0.336 \times 30 = 10.08 \text{ feet}$$

6.2.1 Determining Equivalent Length of Pipe in a Proposed System (Example)

As an example, assume that you have performed your vacuum cleaner diagnostics and determined a good suction point and a preferred routing of the vent pipe. Add up the straight length of pipe and the number of fittings needed for the system. For the purpose of illustrating the approach assume that you will need:

- 49 feet of actual pipe (both above and below fan)
- Two 45 degree elbows
- Three 90 degree elbows.

The first step is to determine the actual and equivalent length of pipe. Let's also assume that you are trying to decide if a three-inch pipe or a four-inch pipe is needed. The following two tables are used to determine this for each pipe size.

Figure 1 Equivalent Length 4-inch system

Item	L/D Ratio	x	Pipe dia. (feet)	=	Equiv. length	x	Quantity	=	Sub-total
Pipe	1				1		49		49
45's	16		.336		5.376		2		11
90's	30		.336		10.08		3		30
							Total =		<u>90</u>

Figure 2 Equivalent Length for 3-inch system

Item	L/D Ratio	x	Pipe dia. (feet)	=	Equiv. length	x	Quantity	=	Sub-total
Pipe	1				1		49		49
45's	16		.256		4.096		2		8
90's	30		.256		7.68		3		23
							Total =		<u>80</u>

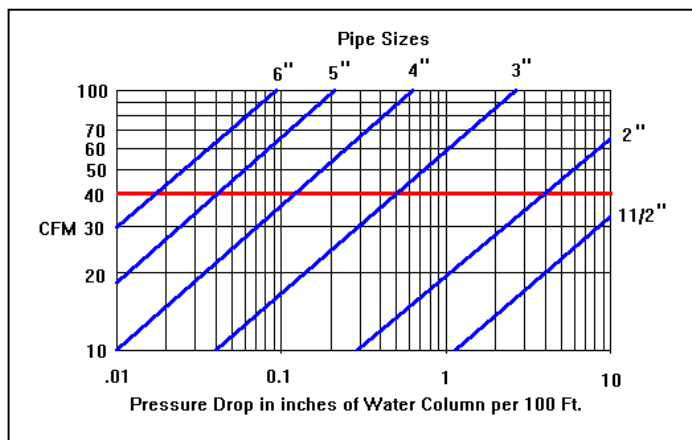
6.3 Determining Actual Friction Loss

The actual friction loss, or the amount of the vacuum lost at the suction point due to the resistance to airflow, can be determined from published tables (a copy is at the end of this document). To determine the amount of vacuum lost from the fan system one needs to know the:

- Equivalent length of pipe
As calculated above
- The amount of air that needs to be handled by the system
Determined by measuring the air flow when you performed the vacuum cleaner diagnostics

Let's assume that for the example system, you measured 40 cfm on the suction side of your vacuum cleaner. The illustration below shows the portion of the friction loss table that is applicable to this range of air flows. The chart is a log-log scale. The airflow is along the vertical axis, the diagonal lines represent different pipe sizes and the friction loss expressed in inches of water column per 100 feet of pipe can be found on the horizontal axis. By finding the intersection of the desired airflow and the proposed pipe size one can trace a line down to the horizontal axis to determine the estimated friction loss.

Figure 3 Friction Loss



At 40 cfm the following friction losses would be developed for the following pipe sizes:

- 6 inch.: 0.018 in/100 feet
- 4 inch.: 0.13 in/100 feet
- 3 inch.: 0.5 in/100 feet

Note how dramatically the friction loss increases as the pipe diameter is decreased.

To determine the actual vacuum that would be lost from the depressurization fan, one needs to factor in the actual equivalent length of the proposed system. This is simply done by multiplying the total equivalent length of pipe by the friction factor obtained from the friction table for the proposed pipe size. Returning to our example:

Four inch pipe:

$$90 \text{ feet of equivalent pipe} \times 0.13 \text{ in/100 ft} = 0.117 \text{ inches of water column lost}$$

Three inch pipe:

$$80 \text{ feet of equivalent pipe} \times 0.5 \text{ in/100 ft} = 0.40 \text{ inches of water column lost}$$

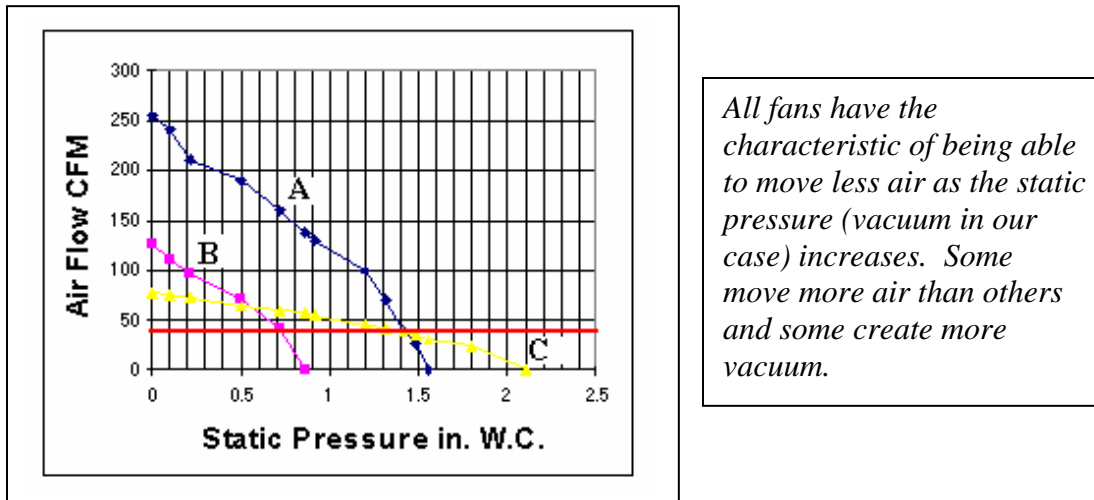
The resultant numbers can be subtracted from the vacuum that can be produced by the fan to determine the vacuum that will be exerted at the suction point. Since we are concerned about

both the vacuum exerted at the suction point we now need to integrate this into our calculations the fan itself.

6.4 Fan Curves

Each type of fan or blower has different capabilities of moving different amounts of air at different static heads (difference in pressure between the suction and the discharge of the fan). These characteristics can be illustrated on graphs called fan curves. The graph below shows the curves for three fans.

Figure 4 Fan Curves



By drawing a line horizontally across the fan curve at the air flow rate that was determined from our vacuum cleaner diagnostics one can determine the amount of vacuum that can be developed by a fan at that air flow.

In our example, the airflow determined from diagnostics was 40 cfm. From the chart we can determine that the maximum vacuum developed by the fans (prior to accounting for pipe friction losses):

Fan	DP at 40 cfm (inches of water column)
A	1.4
B	0.7
C	1.3

6.5 Determining Vacuum at Suction Point

Now we can pull everything together to determine the various configurations of pipe size and fan size to provide the most cost-effective installation. First, one has to assume how much vacuum is needed at the suction point. The experience of many mitigation contractors is that one should not plan to have any less than 0.5 inches of water column at the suction point after accounting for the loss of vacuum created by the piping system.

To determine the vacuum at the suction point one simply subtracts the friction loss created by the proposed piping system from the vacuum produced by the fan at the desired air flow rate. Returning to our example:

Three inch system

Fan	DP developed by fan (From fan curve) (inches WC)	-	Friction Loss imposed by pipe (from calculations) (inches WC)	=	Vacuum at Suction Point (inches WC)
A	1.4	-	0.4	=	1.00
B	0.7	-	0.4	=	0.30
C	1.3	-	0.4	=	0.90

In our example the combination of Fan A or Fan C with three-inch pipe would appear to work-provided the airflow required to reduce the radon truly is 40 cfm. The use of Fan B with the three-inch system would not be advised since the actual vacuum at the suction point would be less than 0.5 inches of vacuum.

Four inch system

Fan	DP developed by fan (From fan curve) (inches WC)	-	Friction Loss imposed by pipe (from calculations) (inches WC)	=	Vacuum at Suction Point (inches WC)
A	1.4	-	0.117	=	1.28
B	0.7	-	0.117	=	0.58
C	1.3	-	0.117	=	1.18

In our example the combination of any of the three fans with four-inch pipe would appear to work-provided the airflow required to reduce the radon truly is 40 cfm.

After determining which combinations of pipe and fans will work, the decision then becomes one of economics and ease of installation.

6.6 Impact of Excess Air Flows:

The previous example was based upon the assumption that 40 cfm was the amount of air that had to be removed in order to accomplish the appropriate radon reduction. This number was determined from measuring the suction wand of a vacuum cleaner during diagnostics. When the actual system is installed you will dig a pit which will make it easier for air to be removed from beneath the slab. This will allow more air. It could also be that your vacuum cleaner was volume limited and once again the actual airflow handled by the system will be in excess of what was measured during diagnostics.

This is not a trivial concern!

To illustrate this, all of the previous calculations have been repeated using an airflow rate of 60 cfm rather than 40 cfm. The table below illustrates the impact:

Three inch system at 60 cfm

Fan	DP developed by fan (From fan curve) (inches WC)	-	Friction Loss imposed by pipe (from calculations) (inches WC)	=	Vacuum at Suction Point (inches WC)
A	1.35	-	0.8	=	.55
B	0.5	-	0.8	=	-0.3
C	.4	-	0.8	=	-0.4

Four inch system at 60 cfm

Fan	DP developed by fan (From fan curve) (inches WC)	-	Friction Loss imposed by pipe (from calculations) (inches WC)	=	Vacuum at Suction Point (inches WC)
A	1.35	-	0.225	=	1.125
B	0.5	-	0.225	=	0.275
C	.4	-	0.225	=	0.175

By reviewing the two tables one can see that Fan B and C would not work with a three-inch system if 60 cfm had to be handled. Fan A is marginal. However, if the system is enlarged to 4-inch pipe one can see that Fan A is preferred.

Since many ASD systems commonly handle airflow in the range of 40 cfm to 100 cfm, one can see why 4-inch pipe is so common. If one uses three inch pipe, it could be overcome during periods of high winds, or if the soil dries causing opening pores to form through which more air can flow. Alternatively, one can seal floor to wall joints and other slab penetrations to reduce the air that the system would have to handle.

6.7 Summary

Calculations can be made to determine restrictions to airflow and thereby optimize pipe and fan systems. The example shown is a simple one, but points out why 4-inch piping systems are common for mitigating radon in homes, or if in doubt install larger pipe sizes.

The same methodology is used for sizing radon systems in large buildings.

7 Heat Recovery Ventilators

7.1 Sizing

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 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 rate of the home after the HRV is added, expressed in air changes per hour (ACH)

R1= the initial radon reading

R2= the desired or final radon concentration

7.1.1 Determining ACH1:

The additional ventilation (air changes per hour) that will be needed 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 determine the amount of air needed to depressurize a house to 0.2 inches of water column (50 pascals). Dividing this measured amount of air by 20 approximates the average ventilation rate to obtain ACH1.

The dilution equation above is an oversimplification of the dynamics that occur in a structure, since the natural ventilation rate is highly variable. If the entire volume within a home is utilized in calculating the additional ventilation needed, 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.

7.2 Example

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

$$\text{ACH1} = 0.5$$

$$\text{R1} = 8.0$$

$$\text{R2} = 3.0$$

- Using the simple dilution formula:

$$\text{ACH2} = \text{ACH1} \times \text{R1/R2}$$

$$\text{ACH2} = 0.5 \times (8/3) = 1.33 \text{ ACH}$$

- The capacity of the HRV must be sufficient to increase the air changes per hour from the current 0.5 ACH to the desired 1.33 ACH, so simply subtract the two numbers:

$$\text{ACH HRV} = 1.33 - 0.5 = 0.83 \text{ ACH}$$

- To determine the volumetric flow, multiply this times the volume of the house (each house will be different)

$$\text{HRV Flow Rate} = \text{ACH HRV} \times \text{Volume of house}$$

$$\text{Volume of House} = \text{Area} \times \text{ceiling height}$$

In our example,

- Volume of house = 2000 square feet x ceiling height of 8 feet = 2,000 x 8 = 16,000 square feet
- Therefore the HRV must supply the following amount of air,
- HRV Flow Rate = 0.83 x 16,000 = 13,280 cubic feet per hour.
- Convert this to cubic feet per minute by dividing by 60 minutes within an hour,
- HRV Flow rate = 13,280/60 = 221 CFM**

Since HRVs have fixed air delivery rates from the manufacturer, select a size that can deliver an amount of air, equal to or greater than the amount calculated.

7.3 Calculating Simple Air Exchange Rates

You might also want to be able to calculate simple rates of air exchange prior to adding an HRV. This is very simply done by multiplying the air exchange rate by the house volume.

Example: What is the amount of air being exchanged to the outside, expressed in cfm (cubic feet per minute) in a 3,000 square foot house with 10 foot ceilings, where a blower door indicated an air exchange rate of 0.15?

$$\text{Volume of House} = 3000 \times 10 = 30,000 \text{ cubic feet}$$

$$\text{Air exchange} = 30,000 \text{ cubic feet} \times 0.15 \text{ ACH} = 4500 \text{ cubic feet/hour}$$

$$4,500 \text{ cubic feet per hour} / 60 \text{ minutes per hour} = \mathbf{75 \text{ cfm}}$$

7.4 Calculating Energy Costs for HRVs:

Although not a skill needed for passing a certification exam, it might be helpful to know how to calculate energy costs, when an HRV is installed. The following five pages have been extracted from the US EPA's Radon Reduction techniques for Detached Homes (2nd edition), which describe how this can be accomplished along with an example.