Minneapolis Blower Door™

Operation Manual

for

Model 3 and Model 4 Systems

The ENERGY CONSERVATORY

DIAGNOSTIC TOOLS TO MEASURE BUILDING PERFORMANCE

Minneapolis Blower Door™

Operation Manual

for

Model 3 and Model 4 Systems

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ENERGY CONSERVATORY WARRANTY

EXPRESS LIMITED WARRANTY:

Seller warrants that this product, under normal use and service as described in the operator's manual, shall be free from defects in workmanship and material for a period of 24 months, or such shorter length of time as may be specified in the operator's manual, from the date of shipment to the Customer.

LIMITATION OF WARRANTY AND LIABILITY:

This limited warranty set forth above is subject to the following exclusions:

a) With respect to any repair services rendered, Seller warrants that the parts repaired or replaced will be free from defects in workmanship and material, under normal use, for a period of 90 days from the date of shipment to the Purchaser.
b) Seller does not provide any warranty on finished goods manufactured by others. Only the original manufacturer's warranty applies.
c) Unless specifically authorized in a separate writing, Seller makes no warranty with respect to, and shall have no liability in connection with, any goods which are incorporated into other products or equipment by the Purchaser.
d) All products returned under warranty shall be at the Purchaser's risk of loss. The Purchaser is responsible for all shipping charges to return the product to The Energy Conservatory. The Energy Conservatory will be responsible for return standard ground shipping charges. The Customer may request and pay for the added cost of expedited return shipping.

The foregoing warranty is in lieu of all other warranties and is subject to the conditions and limitations stated herein. No other express or implied warranty IS PROVIDED, AND THE SELLER DISCLAIMS ANY IMPLIED WARRANTY OF FITNESS for particular purpose or merchantability.

The exclusive remedy of the purchaser FOR ANY BREACH OF WARRANTY shall be the return of the product to the factory or designated location for repair or replacement, or, at the option of The Energy Conservatory, refund of the purchase price.

The Energy Conservatory's maximum liability for any and all losses, injuries or damages (regardless of whether such claims are based on contract, negligence, strict liability or other tort) shall be the purchase price paid for the products. In no event shall the Seller be liable for any special, incidental or consequential damages. The Energy Conservatory shall not be responsible for installation, dismantling, reassembly or reinstallation costs or charges. No action, regardless of form, may be brought against the Seller more than one year after the cause of action has accrued.

The Customer is deemed to have accepted the terms of this Limitation of Warranty and Liability, which contains the complete and exclusive limited warranty of the Seller. This Limitation of Warranty and Liability may not be amended or modified, nor may any of its terms be waived except by a writing signed by an authorized representative of the Seller.

TO ARRANGE A REPAIR: Please call The Energy Conservatory at 612-827-1117 before sending any product back for repair or to inquire about warranty coverage. All products returned for repair should include a return shipping address, name and phone number of a contact person concerning this repair, and the purchase date of the equipment.

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Safety Information

Equipment Safety Instructions

1. The Blower Door Fan is a very powerful and potentially dangerous piece of equipment if not used and maintained properly. Carefully examine the fan before each use. If the fan housing, fan guards, blade, controller or cords become damaged, do not operate the fan until repairs have been made. Repairs should only be made by qualified repair personnel.
2. Keep people and pets away from the Blower Door fan when it is operating.
3. Press the power plug firmly into the power receptacle on the Blower Door fan. Failure to do so can cause overheating of the power cord and possible damage.
4. Do not use ungrounded outlets or adapter plugs. Never remove or modify the grounding prong.
5. Do not operate the Blower Door fan if the motor, controller or any of the electrical connections are wet.
6. Disconnect the power plug from the Blower Door fan receptacle before making any adjustments to the fan motor, blades or electrical components.
7. Do not reverse the Blower Door fan (using the flow direction switch) while the blades are turning. Turn off the fan and wait for it to come to a complete stop before reversing the flow direction.
8. Do not run the Blower Door fan for long periods of time in reverse.

Other Important Safety Instructions

9. For long-term operation, such as maintaining building pressure while air-sealing, use a Flow Ring whenever possible to ensure proper cooling of the Blower Door fan motor. This is especially important in warmer weather. In particular, do not operate the fan for long periods of time on low speed with open fan.
10. If the motor gets too hot, it may experience a shut-down due to the thermal overload protection. If this happens, turn off the controller so that the fan does not restart unexpectedly after it cools down.
11. Adjust all combustion appliances so they do not turn on during the test. This is commonly done by temporarily turning off power to the appliance, or setting the appliance to the "Pilot" setting. If combustion appliances turn on during a depressurization test, it is possible for flames to be sucked out of the combustion air inlet (flame rollout). This is a fire hazard and can possibly result in high CO levels.
12. If there are attached spaces (e.g. townhouses) that could contain a vented combustion appliance, either adjust those appliances to prevent them from turning on during the test, or be sure that the attached spaces are not depressurized or pressurized when the Blower Door is operating.
13. Be sure that fires in fireplaces and woodstoves are completely out before conducting a test. Take precautions to prevent ashes from being sucked into the building during the test. In most cases it will be necessary to either tape doors shut, clean out the ashes, and/or cover the ashes with newspaper.
14. Be sure you have returned the building to its original condition before leaving. This includes turning the thermostat and water heater temperature controls to their original setting. Always check to see that furnace, water heater and gas fireplace pilot lights have not been blown out during the Blower Door test - re-light them if necessary. Remove any temporary seals from fireplaces or other openings sealed during the test.
15. If combustion safety problems are found, tenants and building owners should be notified immediately and steps taken to correct the problem including notifying a professional heating contractor if basic remedial actions are not available. Remember, the presence of elevated levels of carbon monoxide in ambient building air or in combustion products is a potentially life threatening situation. Air sealing work should not be undertaken until existing combustion safety problems are resolved, or unless air sealing is itself being used as a remedial action

Chapter 1 Introduction

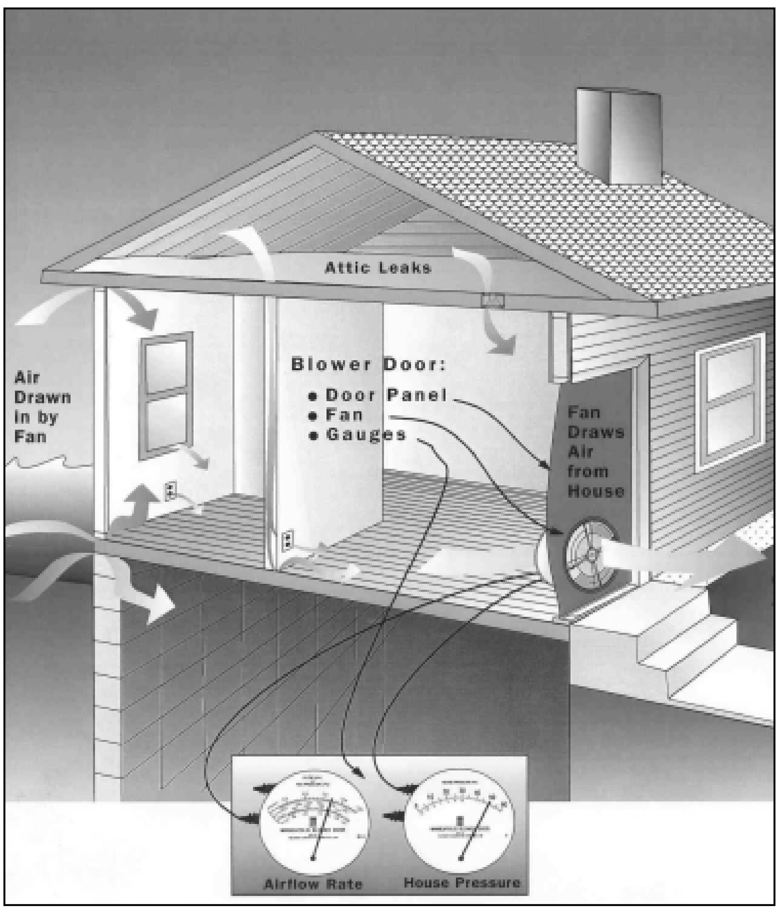
1.1 What is a Blower Door?

The Blower Door is a diagnostic tool designed to measure the airtightness of buildings and to help locate air leakage sites. Building airtightness measurements are used for a variety of purposes including:

- Documenting the construction airtightness of buildings.
- Estimating natural infiltration rates in houses.
- Measuring and documenting the effectiveness of airsealing activities.
- Measuring duct leakage in forced air distribution systems.

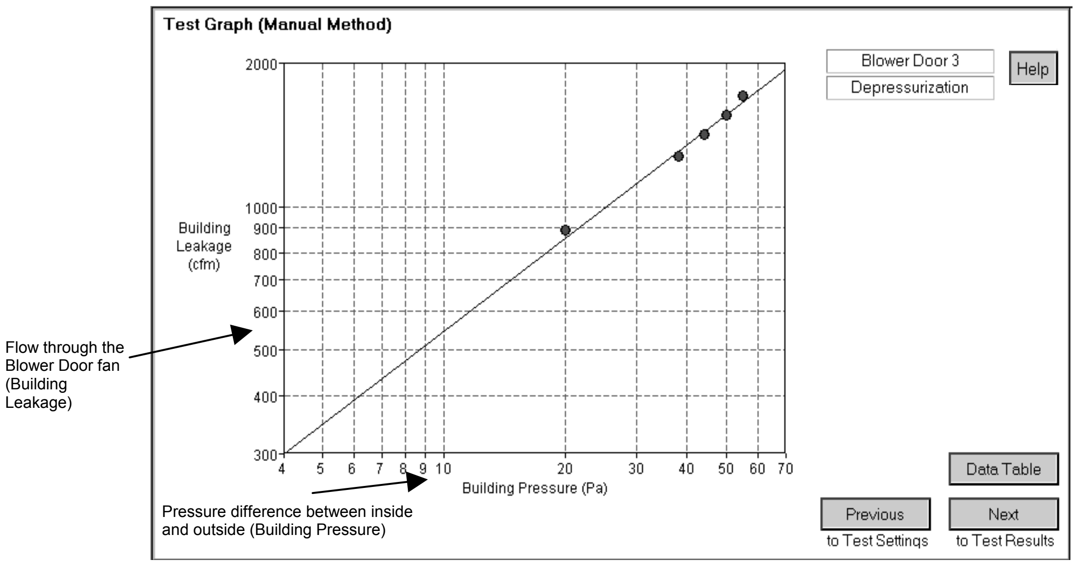
The Blower Door consists of a powerful, calibrated fan that is temporarily sealed into an exterior doorway. The fan blows air into or out of the building to create a slight pressure difference between inside and outside. This pressure difference forces air through all holes and penetrations in the exterior envelope. By simultaneously measuring the air flow through the fan and its effect on the air pressure in the building, the Blower Door system measures the airtightness of the entire building envelope. The tighter the building (e.g. fewer holes), the less air you need from the Blower Door fan to create a change in building pressure.

Figure 1: Blower Door Depressurization Test



A typical Blower Door test will include a series of fan flow measurements at a variety of building pressures ranging from 60 Pascals to 15 Pascals (one Pascal (Pa) equals approximately 0.004 inches of water column). Tests are conducted at these relatively high pressures to mitigate the effects of wind and stack effect pressures on the test results. Sometimes a simple "one-point" test is conducted where the building is tested at a single pressure (typically 50 Pascals). This is done when a quick assessment of airtightness is needed, and there is no need to calculate leakage areas (i.e. estimate the cumulative size of the hole in the building envelope).

Figure 2: Graph of Blower Door Test Data



It takes about 20 minutes to set-up a Blower Door, conduct a test, and document the airtightness of a building. In addition to assessing the overall airtightness level of the building envelope, the Blower Door can be used to estimate the amount of leakage between the conditioned space of the building and attached structural components such as garages, attics and crawlspaces. It can also be used to estimate the amount of outside leakage in forced air duct systems. And because the Blower Door forces air through all holes and penetrations that are connected to outside, these problem spots are easier to find using chemical smoke, an infrared camera or simply feeling with your hand. The airtightness measurement can also help you assess the potential for backdrafting of natural draft combustion appliances by exhaust fans and other mechanical devices, and help determine the need for mechanical ventilation in the house.

1.2 Air Leakage Basics

To properly utilize the diagnostic capabilities of your Blower Door, it is important to understand the basic dynamics of air leakage in buildings. For air leakage (infiltration or exfiltration) to occur, there must be both a hole or crack, and a driving force (pressure difference) to push the air through the hole. The five most common driving forces which operate in buildings are:

1.2.a Stack Effect:

Stack effect is the tendency for warm buoyant air to rise and leak out the top of the building and be replaced by colder outside air entering the bottom of the building (**note:** when outside air is warmer than inside air, this process is reversed). In winter, the stack effect creates a small positive pressure at the top of the building and small negative pressures at the bottom of the building. Stack effect pressures are a function of the temperature difference between inside and outside, the height of the building, and are strongest in the winter and very weak in the summer. Stack induced air leakage accounts for the largest portion of infiltration in most buildings.

1.2.b Wind Pressure:

Wind blowing on a building will cause outside air to enter on the windward side of the building and leave on the leeward side. Wind causes negative pressures in the building on the windward side and positive pressures on the leeward side. At exposed sites in windy climates, wind pressure can be a major driving force for air leakage.

1.2.c Point Source Exhaust or Supply Devices:

Chimneys for combustion appliances and exhaust fans (e.g. kitchen and bath fans) push air out of the building when they are operating. Air leaving the building from these devices causes a negative pressure in the building which draws outside air into holes and cracks in the building envelope. Supply fans (e.g. positive pressure ventilation fan) deliver air into the building creating a positive pressure which pushes inside air out of the building through holes and cracks in the building envelope. (The interaction of ventilation fans on building air leakage and pressures is discussed in Chapter 10)

1.2.d Duct Leakage to the Outside:

Leaks in forced air duct systems (to the outside) create pressures which increase air leakage in buildings. Leaks in supply ducts act like exhaust fans causing negative building pressures. Leaks in return ducts act like supply fans creating positive pressures in buildings. (Duct leakage and duct leakage diagnostics are discussed in more detail in Chapter 9).

1.2.e Door Closure Coupled with Forced Air Duct Systems:

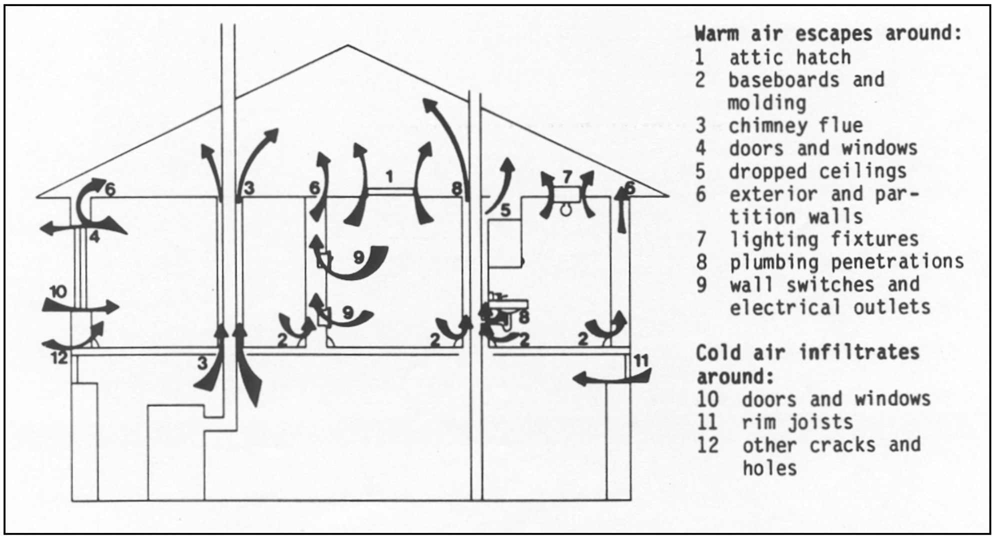
Research has shown that in buildings with forced air duct systems, imbalances between supply and return ducts can dramatically increase air leakage. For example, a study conducted in Florida showed that infiltration rates in many houses were doubled whenever the HVAC system fan was operating due to pressures caused by door closure. In the Florida houses, closing of bedroom doors created large duct imbalances by effectively cutting off the bedroom supply registers from the central return registers located in the main part of the house. (Duct leakage and duct leakage diagnostics are discussed in more detail in Chapter 9)

1.3 Common Air Leakage Sites

Common air leakage sites are shown in Figure 3 below. Notice how as warm air rises due to the stack effect, it tends to escape through cracks and holes near the top of the building. This escaping air causes a slight negative pressure at the bottom of the building which pulls in cold air through holes in the lower level. Air sealing activities should usually begin at the top of the building because this is where the largest positive pressures exist and where many of the largest leakage sites (and potential condensation problems) can be found.

The next most important location of leaks is in the lowest part of the building. The bottom of the building is subject to the largest negative pressures, which induces cold air infiltration. Importantly, if spillage prone natural draft combustion appliances are present, do not seal lower level building leaks unless you have first addressed leaks in the attic or top part of the building. Sealing only lower level leakage areas while leaving large high level leaks could create large enough negative pressures to cause combustion appliance backdrafting.

Figure 3: Common Air Leakage Sites



In addition to these common leakage sites, there can also be large leakage paths associated with hidden construction details such as attached porches, cantilevered floors and overhangs. Figures 4 - 6 show a number of potentially important leakage paths which are often overlooked by crews using traditional weatherization techniques. Use of densely blown cellulose insulation or other barrier-type air sealing techniques at these key junctures often result in dramatic air leakage reductions.

Figure 4: Hidden Construction Details

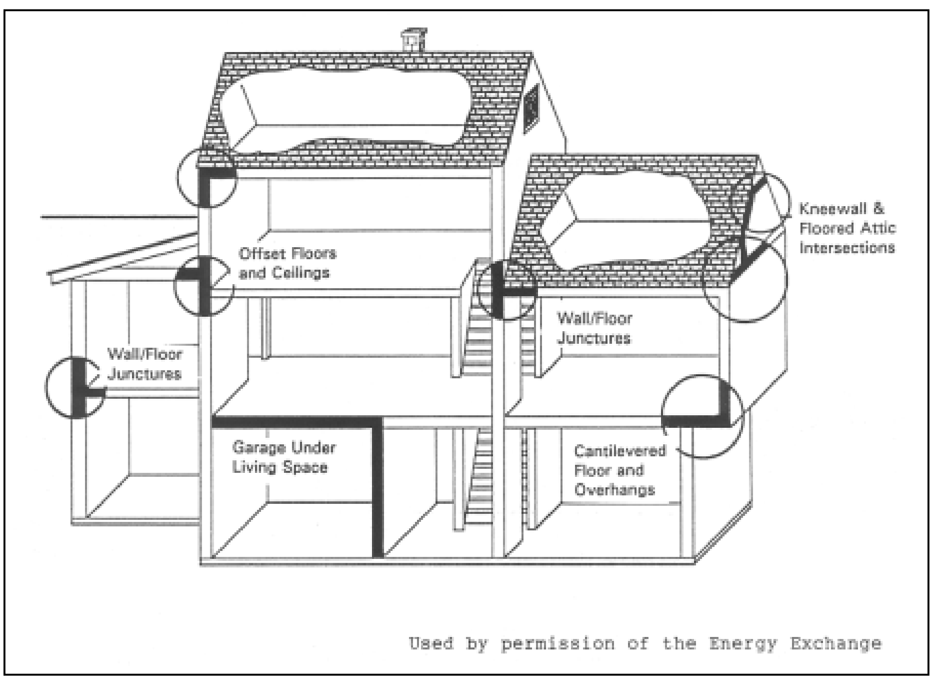


Figure 5: Leak from Attached Porch

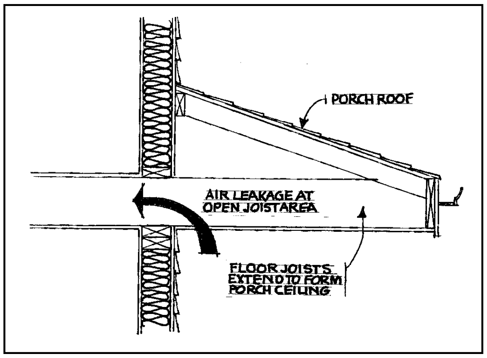
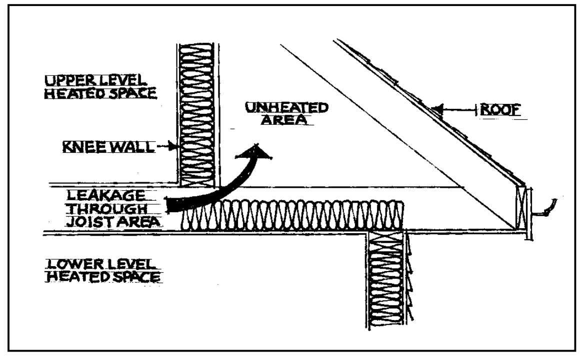


Figure 6: Common Kneewall Leak



Forced air system ductwork can also be a major air leakage site. Even small leaks in ductwork can result in significant air leakage due to the high pressures found in ducts whenever the heating or cooling system is operating. More information on duct leakage can be found in Chapter 9.

Chapter 2 System Components

This Manual includes operating instructions for the following models of Minneapolis Blower Door:

- Model 3/110V System
- Model 3/230 System
- Model 4/230V System (CE labeled fan and controller)

Both the Model 3 and Model 4 Minneapolis Blower Door systems are comprised of three separate components:

1. Blower Door Fan
2. Accessory Case with Test Instrumentation (building pressure and fan flow gauges), Fan Speed Controller and Nylon Door Panel
3. The Adjustable Aluminum Door Frame

While the Blower Door fan motor, flow sensor and speed controller vary slightly between the three different Minneapolis Blower Door systems, the other system components are identical.

Optional Windows based software (TECTITE™) is also available to help you document and analyze Blower Door test results.

2.1 Blower Door Fan

The Blower Door fan consists of a molded urethane fan housing with a 3/4 h.p. permanent split capacitor AC motor. Air flow through the fan is determined by measuring the pressure at the flow sensor which is attached to the end of the motor. Under normal operating conditions, air is pulled into the inlet side of the fan and exits through the exhaust side (a metal fan guard is bolted to the exhaust side of the fan). Although the Model 3 fan motor is reversible, air flow can only be measured when air is exhausting through the exhaust side of the fan.

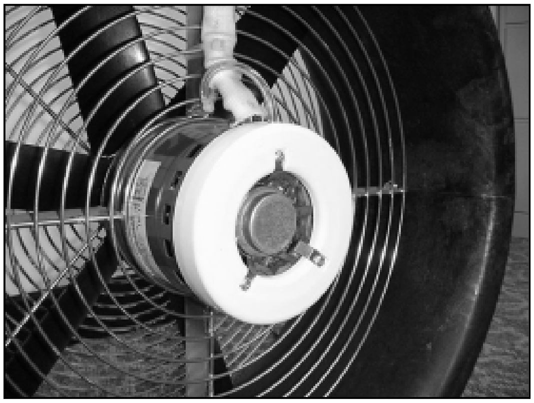
The Blower Door fan can accurately measure airflow over a wide range of flow rates using a series of calibrated Flow Rings which are attached to the inlet of the fan. The standard Minneapolis Blower Door system comes with 2 Flow Rings (A and B) capable of measuring flows as low as 300 Cubic Feet per Minute (cfm). Optional Rings C, D and E are available which allows flow measurements as low as 100, 40 and 15 cfm respectively.

Model 3 Fan with Rings A and B

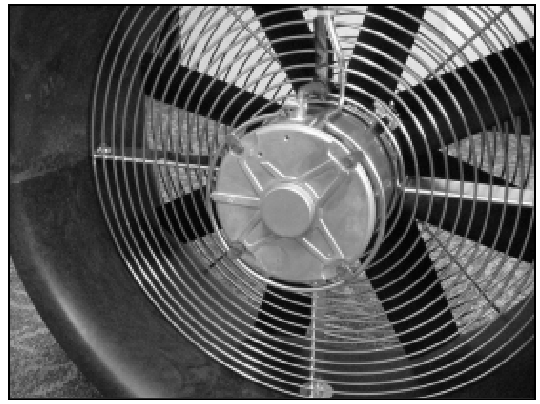
Optional Rings C, D and E

The main distinguishing feature between the Model 3 and Model 4 fans is the shape of the flow sensor attached to the fan motor. Model 3 fans (both 110V and 230V) use a round white plastic flow sensor, while the Model 4 fan uses a flow sensor manufactured out of stainless steel tubing.

Model 3 Fan and Flow Sensor



Model 4 Fan and Flow Sensor



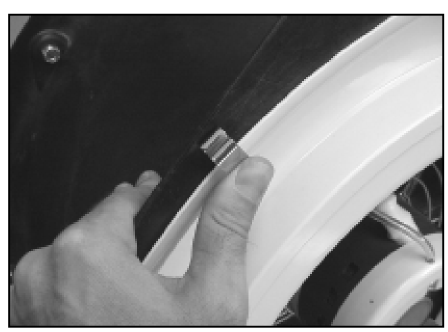
2.1.a Determining Fan Flow and Using the Flow Rings:

Fan pressure readings from the flow sensor are easily converted to fan flow readings by using a Flow Conversion Table (see Appendix B), by reading flow directly from the Blower Door gauge(s), or through the use of the TECTITE Blower Door Test Analysis Software. The Blower Door fan has 6 different flow capacity ranges depending on the configuration of Flow Rings on the fan inlet. Table 1 below show the approximate flow range of the Blower Door fan under each of the 6 inlet configuration. The greatest accuracy in fan flow readings will always be achieved by installing the Flow Ring with the smallest opening area, while still providing the necessary fan flow. Importantly, when taking Blower Door measurements, stand at least 12 inches from the side of the fan inlet. Standing directly in front of the fan may affect the flow readings and result in erroneous measurements.

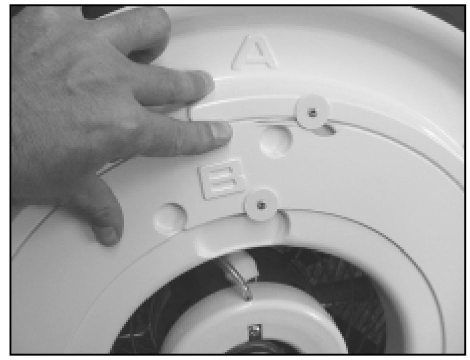
Table 1: Fan Flow Ranges

Fan Configuration	Flow Range (cfm) for Model 3 Fan	Flow Range (cfm) for Model 4 Fan
Open (no Flow Ring)	6,300 - 2,400	4,800 - 2,000
Ring A	3,000 - 900	2,500 - 800
Ring B	1,000 - 300	900 - 240
Ring C	400 - 100	260 - 60
Ring D	125 - 40	125 - 40
Ring E	50 - 15	50 - 15

To install **Flow Ring A** on the fan, snap the 4 hooked spring clips attached to Ring A onto the inlet flange of the fan.



To Install **Flow Ring B**, place Ring B in the center of Ring A so that the 3 notches on the outside of Ring B line up with the 3 washers on Ring A. Be sure that the finger holes on Ring B are located on the top of the Ring (12 o'clock) before attaching it to Ring A. While gently pushing Ring B against Ring A, turn Ring B clockwise until it is securely fastened in place.



In addition to Flow Rings A and B, the standard Minneapolis Blower Door comes with a solid circular **No-Flow Plate** to seal off the fan opening. The No-Flow Plate is attached to Ring B in the same manner that Ring B attaches to Ring A.

The No-Flow Plate and Rings A and B can be removed separately, or all 3 pieces can be removed at the same time by releasing the 4 snap clips holding Ring A to the fan housing.

Installation and use of optional Flow Rings C, D and E are discussed in Appendix C.

2.2 Test Instrumentation (Pressure and Fan Flow Gauges)

There are three instrumentation options available with the Minneapolis Blower Door; the DG-700 Digital Gauge, the DG-3 Digital Gauge, or the APT System.

2.2.a DG-700 and DG-3 Digital Pressure Gauges:

The DG-700 and DG-3 are differential pressure gauges which measure the pressure difference between either of their ***Input*** pressure taps and its corresponding bottom ***Reference*** pressure tap. Both gauges have two separate measurement channels which allows you to monitor the building pressure and fan pressure (air flow) signals during the Blower Door test (the DG-700 allows for simultaneous display of both channels, while the DG-3 can display one channel at a time). In addition, both gauges are able to directly display air flow through the Blower Door fan (the DG-700 can display fan flow in units of cfm, l/s and m^3/hr). The digital gauge is shipped in a separate padded case which is stored in the Blower Door accessory case. Also included is a black mounting board to which the digital gauge can be attached using the Velcro strips found on the back of the gauge.

The DG-700 can also be used to conduct fully automated Blower Door tests from a user supplied laptop or desktop computer using custom Windows based TECTITE software developed by The Energy Conservatory. The TECTITE software allows the user to select among various airtightness testing procedures, including a cruise control option which maintains the building at any user-defined pressure. When conducting automated tests, the speed of the Blower Door fan is computer controlled while the system simultaneously monitors the building pressure and fan flow using the DG-700's two pressure channels. Test results are recorded, displayed on the screen, and can be saved to a file. **Note:** Automated testing requires the TECTITE software, an upgraded fan speed controller, and special cabling.

DG-700 Pressure Gauge

DG-3 Pressure Gauge

2.2.b Automated Performance Testing System™:

The Automated Performance Testing (APT) system performs fully automated Blower Door tests from a user supplied laptop or desktop computer using TEC's TECTITE software. The TECTITE software allows the user to select among various airtightness testing procedures, including a cruise control option which maintains the building at any user-defined pressure. The APT system automatically adjusts the speed of the Blower Door fan while simultaneously monitoring the building pressure and fan flow using 2 on-board differential pressure channels. Test results are recorded, displayed on the screen, and can be saved to a file.

If the APT system contains more than 2 installed pressure channels, the additional channels can be used to monitor and record pressures in attached zones (e.g. attic or crawlspace) during the automated Blower Door test.

The APT system consists of the following components:

- One Data Acquisition Box (DAB) with 2 to 8 on-board pressure channels and phone jacks for 8 voltage input channels.
- One 6' serial cable (w/ 9 pin connectors) to connect the DAB with your computer.
- One 12V power supply for the DAB.
- A modified Blower Door fan speed controller with a communication jack installed into one side of the controller box, and a fan control cable to connect the controller to the DAB.
- One CD containing the TECTITE software.

The Data Acquisition Box (DAB) comes fastened to a black plastic mounting board. The mounting board may also contain two electrical outlets which can be used to power the Blower Door fan, DAB or a lap-top computer.

Note: When using an APT system, only automated Blower Door testing can be conducted because the APT's DAB does not have a built-in display. Manual testing must be done with a DG-700 or DG-3 gauge.

2.3 Fan Speed Controllers

Model 3 and Model 4 Blower Door fans are supplied with a speed controller. Fan speed is adjusted using the adjustment knob on the face of the speed controller. Model 3 Blower Door systems come with the fan speed controller clipped onto the black mounting board supplied with the system. The Model 3 controller can be removed from the mounting board by sliding the controller clip off the board.

The Model 4 fan speed controller will either be attached to a mounitng board (system with DG-700 gauge), or simply have an attachment clamp connected directly on the back of the speed controller box (system with APT system).

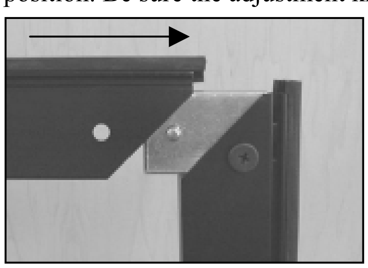
Model 3 Speed Controller

Model 4 Speed Controller

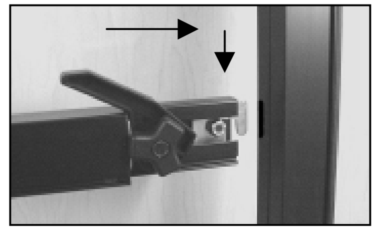
2.4 Adjustable Aluminum Door Frame

The adjustable aluminum door frame (and nylon panel) is used to seal the fan into an exterior doorway. The door frame is adjustable to fit any typical size residential door opening. The aluminum frame consists of 5 separate pieces which are shipped in a hard-shelled plastic or cloth frame case. The two longest frame pieces make up the vertical sides of the door frame, while the two remaining shorter frame pieces make up the top and bottom. The cross bar has a hook on either end of the bar. The frame was designed to be quickly assembled and broken down to simplify storage and transport. If desired, the frame can be transported completely assembled.

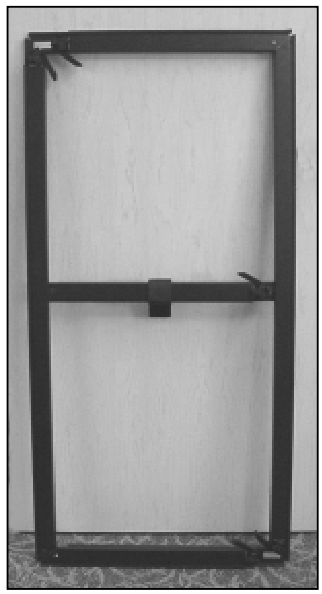
To assemble the frame, remove one long and one short frame piece from the case. Disengage the cam levers on each piece by flipping the cam lever to the relaxed position. Be sure the adjustment knobs have been tightened so that the frame piece does not extend as you put the frame together. Snap the two pieces together by sliding one end of the short piece over one corner block on the long frame piece. You will need to push in the round bullet on the corner block as you slide the pieces together. The round bullet will snap into the hole located on the short frame piece. Assemble all four sides of the frame together in this manner. Be sure that the cam levers and adjustment knobs are all on the same side of the frame as you assemble the pieces.



Now remove the cross bar from the frame case. The hooks at each end of the middle bar will fit into one set of slots which are found on the inside edges of the vertical frame pieces. To insert the middle frame bar, first loosen the adjustment knobs on the cross bar and the top and bottom frame pieces. With the frame adjusted to its smallest size and the cam levers and knobs facing you, insert one hook into the 2nd slot from the top on one side of the frame. Extend the middle bar and insert the second hook on the other side of the frame. Push the middle bar down so that the hooks are fully set into the slots.



Assembled Aluminum Frame



2.5 TECTITE Blower Door Test Software (Optional)

TECTITE is a Blower Door test analysis program for Windows operating systems. The TECTITE program can be used to calculate and display airtightness test results from manually collected Blower Door test data. In addition, TECTITE can be used along with a DG-700 gauge or APT System to conduct fully automated building airtightness tests.

2.5.a TECTITE Features:

- Easy data entry of all test data and building information.
- Calculation and display of airtightness test results including CFM50, air changes per hour, leakage areas, estimated annual and design natural infiltration rates, and estimated cost of air leakage.
- Airtightness test results are calculated using the CGSB 149.10-M86 test Standard.
- Estimated annual infiltration rates are calculated using ASHRAE Standards 119 and 136.
- Built-in report generator and file storage features.
- TECTITE lets you print your company logo directly on the reports.
- Compatible with both Model 3 and Model 4 Blower Door Systems.
- Automates Blower Door testing when used with a DG-700 gauge or APT system.

Note: If you purchased TECTITE, the program CD contains a separate software operation manual. A 30 day demonstration copy of TECTITE is available from The Energy Conservatory's website at *www.energyconservatory.com*.

Chapter 3 Installing the Blower Door for Depressurization Testing

The following instructions are for conducting building **depressurization** tests (i.e. blowing air out of the building). Depressurization testing is the most common method for taking Blower Door measurements.

One of the primary reasons depressurization testing is the most commonly used test method is that back-draft dampers in exhaust fans and dryers will be pulled closed during the test. Because back-draft dampers are typically shut most of the time, leakage from these devices should generally not be included in the results of a Blower Door test.

Information on how and why to conduct Blower Door **pressurization** tests (i.e. blowing air into the building) is discussed in Chapter 7.

3.1 Door Frame and Panel Installation

3.1.a Where To Install The Door Frame?

- It is always best to install the Blower Door system in an exterior doorway of a large open room.
- Try to avoid installing the fan in a doorway where there are stairways or major obstructions to air flow very close (1-5 feet) to the fan inlet. See Appendix A for additional information on obstructions to air flow.
- If the doorway leads to a porch or garage, make sure this space is open to the outside by opening doors and/or windows.
- The door frame is almost always installed from the inside of the building and may be installed in place of the prime door, the storm door, or anywhere in between.
- Always open the inside door and outside storm door as much as possible during the test to prevent restrictions to airflow.

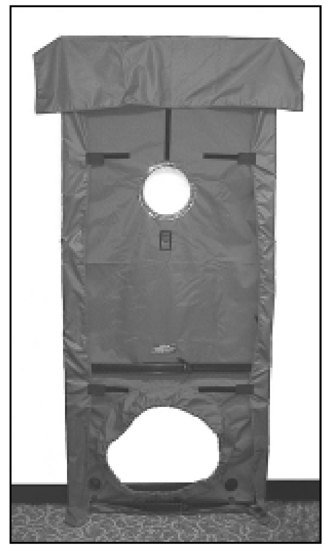
3.1.b Installing the Aluminum Frame:

The first step is to fit the adjustable frame loosely in the door opening. Adjust the width of the frame by loosening the three knobs on the top, middle and bottom frame pieces and sliding the sides apart. The side frame weatherstripping should be touching the sides of the door jam opening, but should be easily removed. Retighten the knobs.

Now loosen the knobs on the 2 vertical frame pieces and slide the frame up to the top of the door opening. Retighten the vertical frame piece knobs.

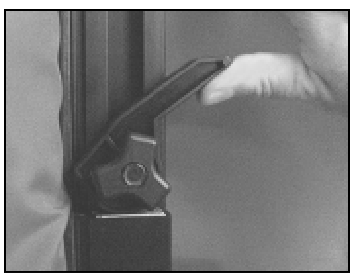
Remove the frame from the door opening and set it up against a wall. Take the nylon panel out of the accessory case and drape the top of the panel over the top of the frame. Use the long Velcro strip at the top of the panel to hold the panel over the top frame piece.

Use the two Velcro tabs at the bottom of the panel to secure the panel around the bottom piece of the frame. Once the bottom tabs are attached, readjust the top Velcro strip to remove any slack and tighten the panel vertically over the frame.



Now pull both sides of the panel tightly around the frame and secure the panel with the 4 side Velcro tabs. The frame and panel should now look like the picture to the right.

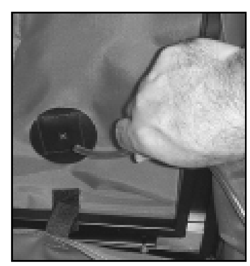
You are now ready to fit the frame and panel into the door opening and secure it in place. Lift the frame and panel assembly and insert it into the doorway and up against the door stop. Once the frame is firmly pushed up against the door stop, release the top Velcro strip and 4 side Velcro tabs. If necessary, re-adjust the frame so it fits snugly in the door opening, being sure to re-tighten the 5 adjustment knobs.



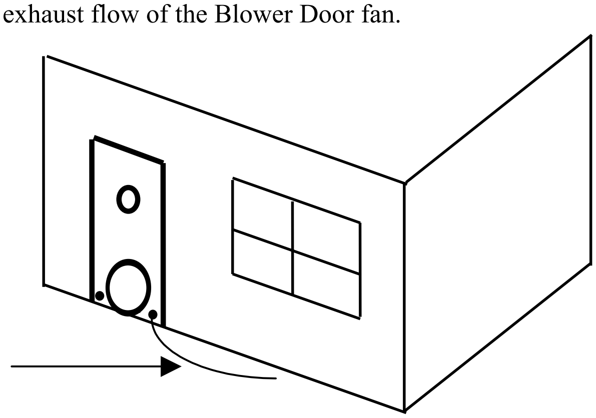
Now engage the five cam levers so that the frame is secured tightly into the opening. These cam levers provide the final tightening in the door opening.

Note: If the frame does not fit tightly, disengage the cam levers, re-adjust the frame to fit tighter in the opening, and then re-engage the cam levers.

3.2 Installing the Outside Building Pressure Tubing



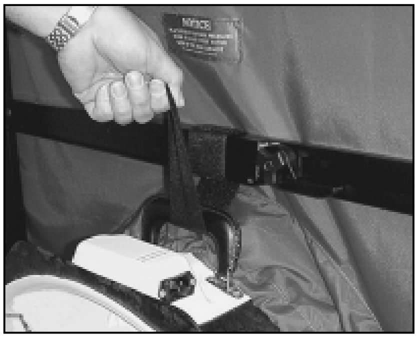
Run approximately 3 - 5 feet of one end of the green tubing outside through one of the patches in the bottom corners of the nylon panel. Be sure the outside end of the tubing will be placed well away from the exhaust flow of the Blower Door fan.



Outside pressure tubing should be placed away from fan exhaust.

3.3 Installing the Blower Door Fan

Place the fan, with the Flow Rings and no-flow plate installed, in line with the large hole in the door panel. The exhaust side of the fan should be facing the door panel. Now tip the fan forward with one hand while you stretch the elastic panel collar over the exhaust flange of the fan. The elastic panel collar should fit snugly around the fan with the collar resting in the gap between the two sides of the electrical box.



The fan is held in place and stabilized by the Velcro strap attached to the aluminum frame cross bar. Slip the Velcro strap through the fan handle and loop it up and back around the cross bar. Pull the strap tight so that it is holding most of the weight of the fan. The Velcro strap can now be attached to itself.

3.4 Attaching the Gauge Mounting Board

The black mounting board for the DG-700, DG-3, or the APT Data Acquisition Box can be attached to any door by using the C-clamp connected to the back of the board. The mounting board can also be easily attached to a horizontal surface (book shelf or desk top) by rotating the clamp 90 degrees before securing the board. In addition, the mounting board can be attached to the gauge hanger bar which comes with the adjustable aluminum door frame. To use this option, connect the gauge hanger bar to either side of the aluminum frame by inserting the hook into one of the remaining slots on the side of the frame. You can now tighten the mounting board clamp onto the hanger bar.

3.5 Gauge Tubing Connections for Depressurization Testing

The Minneapolis Blower Door system comes with 2 pieces of color coded tubing - a 15 foot length of green tubing for measuring building pressure, and a 10 foot length of red tubing to measure fan pressure and flow. Connect the remaining end of the green tubing (the other end should be running outside through the nylon panel) and one end of the red tubing to the gauge(s) as shown below:

3.5.a DG-700 Gauge:

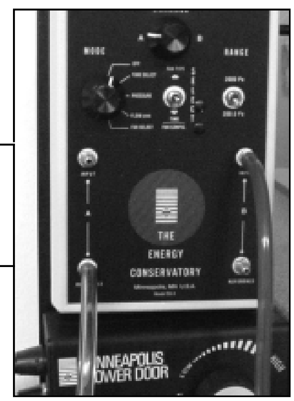
Connect the **Red** tubing to the Channel B Input tap. ***Channel B is used to measure Fan pressure and flow.***

Connect the **Green** tubing to the Channel A Reference tap. ***Channel A is used to measure building pressure with reference to outside.***

3.5.b DG-3 Gauge:

Connect the **Red** tubing to the Channel B Input tap. ***Channel B is used to measure Fan pressure and flow.***

Connect the **Green** tubing to the Channel A Reference tap. ***Channel A is used to measure building pressure with reference to outside.***



3.5.c APT System:

APT-2

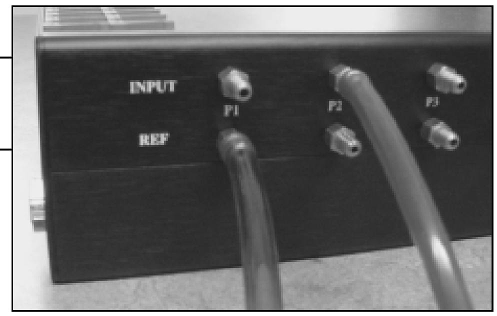
Connect the **Red** tubing to the Channel P2 Input tap. ***Channel P2 is used to measure fan pressure and flow.***

Connect the **Green** tubing to the Channel P1 Reference tap. ***Channel P1 is used to measure building pressure with reference to outside.***

APT-3 through 8

Connect the **Red** tubing to the Channel P2 Input tap. ***Channel P2 is used to measure fan pressure and flow.***

Connect the **Green** tubing to the Channel P1 Reference tap. ***Channel P1 is used to measure building pressure with reference to outside.***



Note: See the APT manual for information on measuring zone pressures with installed pressure channels P3 through P8.

3.6 Electrical and Tubing Connections to the Fan

3.6.a Electrical Connections:

Insert the female plug from the fan speed controller into the receptacle located on the fan electrical box. **Make sure that the plug is pushed completely into the receptacle - overheating of the plug or receptacle can result if not installed correctly.** The remaining cord (power cord) should be plugged into a power outlet that is compatible with the Voltage of the fan motor. Be sure the fan controller knob is turned all the way counter clockwise to the "off" position before plugging into the power outlet.

If you are using a Model 3 fan, check that the fan direction switch is in the proper position. The fan direction switch (located on the fan electrical box) determines the air flow direction. In order to measure air flow during a Blower Door test, air must flow through the fan inlet and out the exhaust side of the fan.

Note: The Model 4 fan motor is not reversible.

3.6.b Connecting Tubing to the Fan:

The remaining end of the red tubing should now be connected to the pressure tap on the Blower Door fan electrical box.

Chapter 4 Setting Up the Building for Testing

After installing the Blower Door system, you will need to set up the building for the airtightness test. This typically includes closing adjustable openings and preparing combustion appliances and exhaust fans. The following preparations are appropriate when using the Blower Door to determine retrofit airsealing potential, weatherization effectiveness or estimating natural infiltration rates. If the purpose of the Blower Door test is to document construction airtightness quality for new houses, additional preparation may be needed (see Testing For New Construction below). If you are using the Blower Door to estimate duct leakage, see Chapter 9 for set up procedures. Your program guidelines may require you to prepare the building differently than described below.

Note: The building set-up and test procedures contained within this manual are recommended specifically by The Energy Conservatory. These procedures generally conform to the Canadian General Standards Board (CGSB) standard CGSB-149.10-M86 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method", and American Society for Testing and Materials (ASTM) standard E779-87 "Standard Test Method for Determining the Air Leakage Rate by Fan Pressurization". However, our procedures include options and recommendations that are not contained within the CGSB and ASTM standards. If you need to perform a Blower Door airtightness test that exactly meets the CGSB or ASTM test procedures, you should obtain a copy of these standards directly from CGSB or ASTM.

4.1 Adjustable Openings

- Close all storm and prime windows.
- Close all exterior doors and interior attic or crawlspace hatches which are connected to conditioned spaces. Also close exterior crawl space hatches and vents if they are normally closed most of the year.
- Open all interior doors to rooms that are conditioned. The object here is to treat the entire building as one conditioned space and to subject all of the leaks in the building to the same pressure difference. Because few house basements can be completely sealed from the house and usually some conditioning of the basement is desirable, they are typically included as conditioned space.
- Tape plastic over window air conditioners if they appear to be a source of air leakage into the building and they are typically removed during a large part of the year.

4.2 Combustion Appliance/Exhaust Devices

- Adjust all combustion appliances so they do not turn on during the test. This is commonly done by temporarily turning off power to the appliance, or setting the appliance to the "Pilot" setting. ***Note:*** *If combustion appliances turn on during a depressurization test, it is possible for flames to be sucked out of the combustion air inlet (flame rollout). This is a fire hazard and can possibly result in high CO levels.*
- If there are attached spaces (e.g. townhouses) that could contain a vented combustion appliance, either adjust those appliances to prevent them from turning on during the test, or be sure that the attached spaces are not depressurized or pressurized when the Blower Door is operating.
- Be sure that fires in fireplaces and woodstoves are completely out. Take precautions to prevent ashes from being sucked into the building during the test. In most cases it will be necessary to either tape doors shut, clean out the ashes, and/or cover the ashes with newspaper.
- Turn off all exhaust fans, vented dryers, air conditioners, ventilation system fans and air handler fans.

4.3 Testing For New Construction

If the Bower Door test is being performed to document construction quality for new houses, it is common practice to temporarily seal all intentional openings in the building envelope (such as dryer exhaust, ventilation system intake or exhaust, or a chimney for a furnace or water heater). Sealing intentional openings is typically not done on existing houses as part of residential retrofit weatherization programs.

Chapter 5 Conducting a Blower Door Depressurization Test

The following instructions assume you are conducting a depressurization test and have set up the Blower Door system and building as outlined in Chapters 3 and 4 above. These instructions cover manual test operation using the DG-700 and DG-3 Digital Pressure Gauges. If you are using the DG-700 or APT System to conduct an automated Blower Door test, follow the test instructions contained in the TECTITE Software Users Guide (available from the TECTITE Help menu). Information on how and why to conduct Blower Door pressurization tests (i.e. blowing air into the building) is discussed in Chapter 7.

5.1 Choosing a Test Procedure

The two most common Blower Door test procedures used to assess overall building airtightness are the ***One-Point Test*** and the ***Multi-Point Test***. The *One-Point Test* utilizes a single measurement of fan flow needed to create a 50 Pascal change in building pressure. The *One-Point Test* provides a quick and simple way to measure building airtightness without the need to have a computer to analyze the Blower Door test data (although a computer program like TECTITE can still be useful to generate reports and store data).

The *Multi-Point Test* procedure involves testing the building over a range of pressures (typically 60 Pascals down to 15 Pascals) and analyzing the data using a Blower Door test analysis computer program (e.g. TECTITE). When conducting a *Multi-Point Test*, we generally recommend that the building be tested at 8 different target pressures between 60 Pa and 15 Pa. For example, a common set of target building pressures includes 60 Pa, 50 Pa, 40 Pa, 35 Pa, 30 Pa, 25 Pa, 20 Pa and 15 Pa. Other target pressures may be used as long as they cover a variety of building pressures between 60 Pa and 15 Pa. Making multiple measurements allows some of the errors introduced by fluctuating pressures and operator error to be averaged out over several measurements, thus increasing test accuracy. In addition, a *Multi-Point Test* allows the operator to estimate the leakage area of the building (i.e. estimate the cumulative size of the hole in the building envelope). Leakage area values are used in detailed infiltration models and can be a useful way to express the results of the Blower Door test.

5.2 Depressurization Test Procedures Using the DG-700

The following test procedures cover use of the DG-700 for both *One-Point Tests* and *Multi-Point Tests*.

a) Turn on the DG-700 and place it in the proper Mode:

- *DG-700: One-Point Test*

Turn on the gauge by pressing the **ON/OFF** button. Press the **MODE** button twice to put the gauge into the **PR/ FL @50** mode. In this specialized test mode, **Channel A** is used to measure building pressure while **Channel B** is used to display estimated building leakage at a test pressure of 50 Pascals (CFM50). The leakage estimate shown on **Channel B** is determined by mathematically adjusting the actual air flow from the Blower Door fan to a test pressure of 50 Pascals, using the real-time **Channel A** building pressure reading and a Can't Reach Fifty (CRF) factor. CRF factors are discussed later in this Chapter.

- *DG-700: Multi-Point Test*

Turn on the gauge by pressing the **ON/OFF** button. Press the **MODE** button once to put the gauge into the **PR/ FL** mode. The **PR/ FL** mode is a multi-purpose mode used to measure a test pressure on **Channel A** while simultaneously measuring air flow from the Blower Door fan on **Channel B**.

b) Measure the baseline building pressure (same for both *One-Point* and *Multi-Point Tests*).

When conducting a Blower Door test, we want to measure the change in building pressure caused by air flowing through the Blower Door fan. In order to measure this change accurately, we need to account for any existing pressures on the building caused by stack, wind and other driving forces. This existing building pressure is called the "baseline building pressure".

The DG-700 has a built-in baseline measurement procedure which allows the user to quickly measure and record the baseline pressure on **Channel A**, and then display the baseline adjusted pressure. This feature makes it possible to “zero out” the baseline building pressure on **Channel A**, and display the actual change in building pressure caused by the Blower Door fan.

With the fan sealed off, begin a baseline building pressure reading from **Channel A** by pressing the **BASELINE** button. The word “BASELINE” will begin to flash in the **Channel A** display indicating that the baseline feature has been initiated. Press **START** to start the baseline measurement. During a baseline measurement, **Channel A** will display a long-term average baseline pressure reading while **Channel B** is used as a timer in seconds to show the elapsed measurement time. When you are satisfied with the baseline measurement, press the **ENTER** button to accept and enter the baseline reading into the gauge. The **Channel A** display will now show an **ADJ** icon to indicate that it is displaying a baseline adjusted building pressure value. **Note**: Once a baseline measurement has been taken and entered into the gauge (i.e. ADJ appears below the **Channel A** reading), a new baseline measurement procedure can be initiated by pressing the **BASELINE** button.

c) Choose a Flow Ring for the Blower Door fan (same for both *One-Point* and *Multi-Point Tests*).

Fan Configuration	Flow Range (cfm) for Model 3 Fan
Open (no Flow Ring)	6,300 - 2,400
Ring A	3,000 - 900
Ring B	1,000 - 300
Ring C	300 - 100

Remove the No-Flow Plate from the Blower Door fan and install the Flow Ring which you think best matches the needed fan flow. Installation of Flow Rings will depend on the tightness level of the building stock being tested. For example, for relatively leaky buildings (greater than 3,000 CFM50), you will want to start the test using the Open Fan configuration (i.e. no Flow Rings installed). As you test tighter buildings, you will need to install Flow Rings A or B. Refer to the Table to the right for approximate flow ranges of the fan using the various Flow Rings configurations. Don't worry if you guess wrong and start the test with the incorrect Flow Ring - you can change the Fan Configuration during the test procedure.

d) Enter the selected Flow Ring into the Gauge (same for both *One-Point* and *Multi-Point Tests*).

In order for the DG-700 to properly display fan flow, you need to input the Blower Door fan model and selected Flow Ring into the gauge. Check, and adjust if necessary, the selected test Device (i.e. fan) and Configuration (i.e. Flow Ring) shown in the upper part of the gauge display to match the fan and Flow Ring used in the test.

Press the **DEVICE** button to change the selected Blower Door fan.

Device Icon	
BD 3	Model 3 110V fan
BD 3 220	Model 3 220V fan
BD 4	Model 4 220V fan

Once the fan is selected, the configuration of the fan can be selected by pressing the **CONFIG** button. The currently selected Flow Ring configuration is shown in the Config section of the gauge display.

Config Icon		**Config Icon**	
OPEN	No Flow Ring	**C3**	Ring C
A1	Ring A	**D**	Ring D
B2	Ring B	**E**	Ring E

Also be sure that **Channel B** is showing the proper air flow units for your test (this should typically be set to **CFM**). Units can be changed by pressing the **UNITS** button.

e) Turn on the fan for an initial inspection (same for both *One-Point* and *Multi-Point Tests*).

Turn on the Blower Door fan by slowly turning the fan controller clockwise. As the fan speed increases, the building depressurization displayed on **Channel A** should also increase. As you increase the fan speed, you will be increasing the pressure difference between the building and outside resulting in increased pressure exerted on the aluminum door frame installed in the door opening. If you did not properly install the door frame, the frame may pop out of the doorway at higher building pressures (over 30 Pascals). If this happens, simply reinstall the frame more securely. When installed properly, the frame will easily stay in place during the entire test procedure. Before making measurements, you may want to quickly walk around the building with the fan producing about 30 Pascals of building pressure to check for any problems such as windows or doors blown open or blowing ashes from a fire place or wood stove.

f) Make final adjustments to the Blower Door fan:

- *DG-700: One-Point Test*

Continue to increase the fan speed until the building depressurization shown on **Channel A** is between –45 and –55 Pascals. Do not waste time adjusting and re-adjusting the fan speed control to achieve a test pressure of exactly -50 Pascals – just get close to the target pressure and make your measurement. As long you are using the **PR/ FL @50** mode and the test pressure displayed on **Channel A** is within 5 Pascals of the -50 Pascal target pressure, any errors introduced by estimating the leakage on **Channel B** will typically be very small (less than 1%).

Channel B will now display the *One-Point* CFM50 leakage estimate. If the leakage estimate is fluctuating more than desired, try changing the Time Averaging setting on the gauge by pressing the **TIME AVG** button and choosing the ***5*** or ***10*** second or ***Long-term*** averaging period. Once you are satisfied with the reading, press the **HOLD** key on the gauge to temporarily freeze the display. Record the CFM50 test reading on a Test Form (see Appendix D). Turn off the fan. Press **HOLD** again to unfreeze the gauge display.

(If "------" or "LO" appear on **Channel B**, see below).

Whenever "**-----**" or "**LO**" appears on **Channel B** in the **PR/ FL @ 50** mode, the DG-700 can not calculate a reliable leakage estimate. The messages "**-----**" and "**LO**" appear on **Channel B** under the following three conditions:

- "**-----**" is continuously displayed when the building test pressure from **Channel A** is below a minimum value of 10 Pascals. Estimating leakage results when the test pressure is below this value may result in unacceptably large errors. If possible, install a larger Flow Ring or remove the Flow Rings to generate more fan flow.
- "**LO**" is continuously displayed when there is negligible air flow through the test device.
- "**LO**" alternates with a flow reading when the air flow reading through the device is unreliable (i.e. you are trying to measure a flow outside of the calibrated range of the test device in its current configuration). If possible, you should change the test device configuration to match the flow rate being measured (e.g. install a Flow Ring or a smaller Flow Ring).

Note: If you change the Flow Rings on the fan, be sure to change the Configuration setting on the gauge to match the installed Ring.

- *DG-700: Multi-Point Test*

Increase the fan speed until you achieve the highest target building pressure (e.g. -60 Pascals) on **Channel A.** The fan flow needed to create this building pressure can be read directly from **Channel B**. Press the **HOLD** key to temporarily freeze the display. Record the test readings (building pressure and fan flow) on a Test Form (see Appendix D). Press **HOLD** again to unfreeze the display.

Now reduce the fan speed until the building pressure equals the next target pressure (e.g. -50 Pa). Once again record the test readings on a Test Form. Continue this procedure for each of the remaining target pressures. Turn off the fan when the final set of readings are completed.

Enter the test readings into the TECTITE software to generate you final test results. **Note:** Enter a baseline pressure value of 0 into the TECTITE Manual Data Entry Screen because you "zeroed out" the baseline pressure using the DG-700's built-in baseline feature.

(If "LO" appears on **Channel B**, see below).

Whenever "**LO**" appears on **Channel B** in the **PR/ FL** Mode, the DG-700 can not display a reliable fan flow reading. The message "**LO**" appears on **Channel B** under the following two conditions:

- "**LO**" is continuously displayed when there is negligible air flow through the test device.
- "**LO**" alternates with a flow reading when the air flow reading through the device is unreliable (i.e. you are trying to measure a flow outside of the calibrated range of the test device in its current configuration). If possible, you should change the test device configuration to match the flow rate being measured (e.g. install a Flow Ring or a smaller Flow Ring).

Note: If you change the Flow Rings on the fan, be sure to change the Configuration setting on the gauge to match the installed Ring.

5.3 Depressurization Test Procedures Using the DG-3

The following test procedures cover use of the DG-3 for both *One-Point Tests* and *Multi-Point Tests*.

a) Turn on the DG-3 and put it into the proper Mode (same for both *One-Point* and *Multi-Point Tests*).

Turn the **CHANNEL** knob to **A**, turn the **MODE** switch to ***Pressure***, and put the **RANGE** switch in the ***Low Range*** position (***200.0*** Pa).

b) Measure the baseline building pressure (same for both *One-Point* and *Multi-Point Tests*).

When conducting a Blower Door test, we want to measure the change in building pressure caused by air flowing through the Blower Door fan. In order to measure this change accurately, we need to account for any existing pressures on the building caused by stack, wind and other driving forces. This existing building pressure is called the "baseline building pressure".

When using the DG-3 gauge, we need to measure and record the actual baseline building pressure (see Appendix D for a sample test recording form). Baseline building pressure is read from **Channel A** of the gauge. With the fan sealed off, record the baseline building pressure on a Test Form, including the sign of the reading (i.e. negative or positive reading). If the pressure is fluctuating too much to determine the reading, try changing the Time Averaging setting on the gauge by turning the **Mode Switch** to ***Time Select***, choosing the ***5*** or ***10*** second or ***L***ong-term average, and then return the **Mode Switch** to the ***Pressure*** setting.

Note: If you will be using the TECTITE software, the measured baseline building pressure will need to be entered into the program's Data Table.

c) Choose a Flow Ring for the Blower Door fan (same for both *One-Point* and *Multi-Point Tests*).

Fan Configuration	Flow Range (cfm) for Model 3 Fan
Open (no Flow Ring)	6,300 - 2,400
Ring A	3,000 - 900
Ring B	1,000 - 300
Ring C	300 - 100

Remove the No-Flow Plate and install the Flow Ring which you think best matches the needed fan flow. Installation of Flow Rings will depend on the tightness level of the building stock being tested. For example, for relatively leaky buildings (greater than 3,000 CFM50), you will want to start the test using the Open Fan configuration (i.e. no Flow Rings installed). As you test tighter buildings, you will need to install Flow Rings A or B. Refer to the Table to the right for approximate flow ranges of the fan using the various Flow Rings configurations. Don't worry if you guess wrong and start the test with the incorrect Flow Ring - you can change the Fan Configuration during the test procedure.

d) Enter the selected Flow Ring into the Gauge (same for both *One-Point* and *Multi-Point Tests*).

In order for the DG-3 to properly display fan flow, you need to input the Blower Door fan model and selected Flow Ring into the gauge. To select the fan type and fan configuration being used in your test, first turn the **MODE** knob to the ***Fan Select*** position. The gauge display will show "-SEL" to indicate that a fan type and fan configuration have not yet been selected. The fan type can be selected by toggling the **SELECT** Switch up. The fan configuration can be selected by toggling the **SELECT** switch down.

If the Display Shows	Description
-SEL	Begin fan type selection by toggling the **SELECT** switch up once.
3-0	This indicates that you have chosen the Model 3 Minneapolis Blower Door fan, and that the fan is in the "Open" inlet configuration (i.e. no Flow Rings installed). To change the fan inlet configuration for the Model 3 Blower Door fan, toggle the **SELECT** switch down.
3-1	Model 3 Blower Door fan with Ring A installed.
3-2	Model 3 Blower Door fan with Ring B installed.
3-3	Model 3 Blower Door fan with Ring C installed.
3-4	Model 3 Blower Door fan with Ring D installed.
3-5	Model 3 Blower Door fan with Ring E installed.

To change the fan type to the Model 4 Blower Door fan, toggle the **SELECT** switch up twice (DG-3E gauge only).

4-0	This indicates that you have chosen the Model 4 Minneapolis Blower Door fan, and that the fan is in the "Open" inlet configuration (i.e. no Flow Rings installed). To change the fan inlet configuration for the Model 4 Blower Door fan, toggle the **SELECT** switch down.
4-1	Model 4 Blower Door fan with Ring A installed.
4-2	Model 4 Blower Door fan with Ring B installed.
4-3	Model 4 Blower Door fan with Ring C installed.
4-4	Model 4 Blower Door fan with Ring D installed.
4-5	Model 4 Blower Door fan with Ring E installed.

Once you have input the fan configuration, turn the **MODE** knob back to ***Pressure,*** and then flip the **RANGE** switch to the ***2000*** setting (***High Range***).

e) Turn on the fan for an initial inspection (same for both *One-Point* and *Multi-Point Tests*).

With the **CHANNEL** knob set to **Channel A**, turn on the Blower Door fan by slowly turning the fan controller clockwise. As the fan speed increases, building pressure indicated on **Channel A** should also increase. As you increase the fan speed, you will be increasing the pressure difference between the building and outside resulting in increased pressure exerted on the aluminum door frame installed in the door opening. If you did not properly install the door frame, the frame may pop out of the doorway at higher building pressures (over 30 Pascals). If this happens, simply reinstall the frame more securely. When installed properly, the frame will easily stay in place during the entire test procedure. Before making measurements, you may want to quickly walk around the building with the fan producing about 30 Pascals of building pressure to check for any problems such as windows or doors blown open or blowing ashes from a fire place or wood stove.

f) Make final adjustments to the Blower Door fan:

- *DG-3: One-Point Test*

Increase fan speed until the building is depressurized by 50 Pascals from the baseline pressure measured in section **b)** above (i.e. change the building pressure by 50 Pa from the baseline building pressure). In order to do this, you first need to calculate a new adjusted target test pressure to shoot for. This is done by manually adding the measured baseline building pressure to the target depressurization.

> ***Example****: If the measured building baseline pressure was negative 2 Pascals (-2 Pa), the new target test pressure becomes (-2 + (-50)) or -52. In other words, you will need to depressurize the building to -52 Pascals for your One-Point Test. The main point to remember is that we want to change building pressure by 50 Pascals from the starting point (baseline) pressure.*
>
> ***Note****: If you are using the DG-3 and the TECTITE software program, it is not necessary to adjust the target pressure of -50 Pascals for your One-Point Test because the baseline building pressure can simply be entered into the TECTITE Data Table.*

After adjusting the fan speed to depressurize the building by 50 Pascals, turn the **CHANNEL** knob to **Channel B**, and turn the **MODE** switch to ***Flow***. The gauge will now display the *One-Point* CFM50 leakage result for the building. If the gauge display is fluctuating too much to determine the reading, try changing the Time Averaging setting on the gauge by turning the **MODE** Switch to ***Time Select***, choosing the ***5*** or ***10*** second or ***Long-term*** average, and then returning to the ***Flow*** mode. Record the CFM50 test reading on a Test Form (see Appendix D). Turn off the fan.

(If the CFM flow reading on **Channel B** is blinking, see below):

- The CFM flow reading on **Channel B** will blink when the air flow reading through the fan is unreliable (i.e. you are trying to measure a flow outside of the calibrated range of the test device in its current configuration). If possible, you should change the fan configuration to match the flow rate being measured (e.g. install a Flow Ring or a smaller Flow Ring).
- If you change Flow Rings, be sure to use the **Fan Select** feature to update the gauge with the new Flow Ring installed before reconducting the test.

- *DG-3: Multi-Point Test*

Increase the fan speed until you achieve the highest target building pressure (e.g. -60 Pascals) on **Channel A.** Now determine the air flow through the fan needed to create this building pressure by first turning the **CHANNEL** switch to **Channel B**, and then turning the **MODE** knob to the ***Flow*** position. The gauge will now display the flow through the fan. Record the test readings (building pressure and fan flow) on a Test Form (see Appendix D).

Turn the **CHANNEL** switch back to **Channel A** and then turn the **MODE** knob back to the ***Pressure*** setting. Now reduce the fan speed until the building pressure equals the next target pressure (e.g. -50 Pa). Once again determine the air flow from **Channel B** and record the test readings on a Test Form. Continue this procedure for each of the remaining target pressures. Turn off the fan when the final set of readings are completed.

Enter the test readings into the TECTITE software to generate your final test results.

(If the CFM flow reading on **Channel B** is blinking, see below):

- The CFM flow reading on **Channel B** will blink when the air flow reading through the fan is unreliable (i.e. you are trying to measure a flow outside of the calibrated range of the test device in its current configuration). If possible, you should change the fan configuration to match the flow rate being measured (e.g. install a Flow Ring or a smaller Flow Ring).
- If you change Flow Rings, be sure to use the **Fan Select** feature to update the gauge with the new Flow Ring installed before reconducting the test.

5.4 Using the Can't Reach 50 Factors (*One-Point Tests*)

If you were performing a *One-Point Test* and the Blower Door fan was unable to depressurize the building by approximately 50 Pascals because one of the Flow Rings was installed, remove the Ring and repeat the test (removing the Flow Ring will increase the maximum air flow available from the fan). If you were not able to depressurize the building by approximately 50 Pascals (with the "Open Fan" running at full speed) because the building is extremely leaky, use the following instructions:

- *For DG-700 Users:*

No adjustments to the test procedure above are necessary other than to make sure the gauge was in the **PR/ FL @50** mode during the *One-Point Test*. If you can not achieve the target test pressure of 50 Pascals because the building is extremely leaky, a CFM50 leakage estimate will automatically be displayed on **Channel B**. The leakage estimate shown on **Channel B** is determined by continuously adjusting the measured air flow from the Blower Door fan to a test pressure of 50 Pascals, using the real-time **Channel A** building pressure reading and the Can't Reach Fifty Factors shown in Table 2 below.

- *For DG-3 Users:*

Take your *One-Point Test* reading at the highest achievable building pressure. Now manually use Table 2 below to estimate the amount of air flow through the Blower Door fan it would take to reach the target pressure. To use Table 2, determine the flow required to maintain the highest achievable building pressure listed in the Table. Multiply this flow by the corresponding "Can't Reach Fifty (CRF) Factor" to estimate flow that would be required to maintain a 50 Pascal building pressure.

Table 2: Can't Reach Fifty Factors

Building Pressure (Pa)	CRF Factor	Building Pressure (Pa)	CRF Factor
48	1.03	28	1.46
46	1.06	26	1.53
44	1.09	24	1.61
42	1.12	22	1.71
40	1.16	20	1.81
38	1.20	18	1.94
36	1.24	16	2.10
34	1.28	14	2.29
32	1.34	12	2.53
30	1.39	10	2.85

<u>*Example:*</u> *With the fan running full speed, you are able to achieve a building pressure of 28 Pascals with a measured fan flow of 5,600 cfm. The corresponding CRF Factor for a building pressure of 28 Pascals is 1.46. The estimated flow needed to achieve the target pressure of 50 Pascals is 5,600 x 1.46 = 8,176 cfm.*

$$\textbf{Can't Reach Fifty Factor} = \left\{ \frac{\textbf{50}}{\textbf{Current Test Pressure (Pa) (Channel A)}} \right\}^{\textbf{0.65}}$$

Note: The TECTITE program automatically applies the CRF Factors to *One-Point Test* data.

5.4.a Potential Errors In One-Point CFM50 Estimate from Using the CRF Factors:

Table 3 below show the potential errors in the *One-Point* CFM50 leakage estimates from using the CRF factors. There are two main sources of error:

- The actual test pressure (**Channel A**) not being equal to the target pressure of 50 Pascals.
- The actual exponent of the leaks being measured differing from the assumed exponent of 0.65.

Table 3: Error in *One-Point* Leakage Estimate from CRF factors

Test Pressure in Pa (Channel A)	Actual exponent "n" 0.5	0.55	0.6	0.65	0.7	0.75
10	21.4%	14.9%	7.7%	0.0%	-8.4%	-17.5%
15	16.5%	11.3%	5.8%	0.0%	-6.2%	-12.8%
20	12.8%	8.8%	4.5%	0.0%	-4.7%	-9.6%
25	9.9%	6.7%	3.4%	0.0%	-3.5%	-7.2%
30	7.4%	5.0%	2.5%	0.0%	-2.6%	-5.2%
35	5.2%	3.5%	1.8%	0.0%	-1.8%	-3.6%
40	3.3%	2.2%	1.1%	0.0%	-1.1%	-2.3%
45	1.6%	1.0%	0.5%	0.0%	-0.5%	-1.1%
50	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
55	-1.4%	-1.0%	-0.5%	0.0%	0.5%	0.9%
60	-2.8%	-1.8%	-0.9%	0.0%	0.9%	1.8%
65	-4.0%	-2.7%	-1.3%	0.0%	1.3%	2.6%

For example, Table 3 shows that for a *One-Point* 50 Pa Blower Door building airtightness test, a 2.5% error would be introduced if the leakage estimate was determined at an actual test pressure of 30 Pa (**Channel A**), and the actual exponent of the leaks was 0.60 rather than the assumed value of 0.65.

5.5 Unable to Reach a Target Building Pressure During a Multi-Point Test?

If the Blower Door fan was unable to achieve the highest target building pressure (e.g. 60 Pascals) because one of the Flow Rings was installed, remove the Ring and repeat the test. If you were not able to reach the highest target pressure with the "Open Fan" running at full speed because the building is extremely leaky, take your first set of test readings the highest achievable building pressure. Continue your test by using the remaining target pressures which are less than the highest achievable pressure.

5.6 Testing in Windy Weather

During strong or gusty winds, building pressure readings can vary significantly. As wind gusts contact a building, the actual pressures within the building will change (10 to 20 Pa changes are common in windy weather). Under these conditions, you will need to spend more time watching the gauges to determine the "best" reading. Use of the time-averaging functions can help stabilize readings in windy conditions.

While conducting a multi-point Blower Door test over a wide range of building pressures will tend to even out some of the error introduced from moderate wind fluctuations, significant wind related error can still exist. Under very windy conditions, it is sometimes impossible to manually collect accurate and repeatable test data. Under these conditions, conducting an automated test using a DG-700 or APT system may be the only way to collect accurate and repeatable test results. During an automated test hundreds of simultaneous measurements of building pressure and fan flow are quickly collected greatly reducing the variability of tests results due to wind.

5.7 Before Leaving the Building

Be sure you have returned the building to its original condition before leaving. This includes turning the thermostat and water heater temperature controls to their original setting. Always check to see that furnace, water heater and gas fireplace pilot lights have not been blown out during the Blower Door test - re-light them if necessary. Remove any temporary seals from fireplaces, woodstoves or other openings sealed during the test. In addition, combustion safety tests (see Chapter 10) should usually be performed before leaving the house.

Chapter 6 Basic Test Results

Basic test results from a *One-Point Test* can be manually calculated to provide a quick assessment of the airtightness of the building. For more complicated calculation procedures including analysis of *Multi-Point Test* data, calculated physical leakage areas, estimated natural infiltration rates (including design infiltration rates), estimated cost of air leakage and ventilation guidelines, we recommend that you use the TECTITE program.

6.1 Basic Airtightness Test Results

Airtightness test results can be presented in a number of standardized formats.

6.1.a Air Leakage at 50 Pascals:

- *CFM50:*

CFM50 is the airflow (in cubic feet per minute) from the Blower Door fan needed to create a change in building pressure of 50 Pascals (0.2 inches of water column). A 50 Pascal pressure is roughly equivalent to the pressure generated by a 20 mph wind blowing on the building from all directions. CFM50 is the most commonly used measure of building airtightness and gives a quick indication of the total air leakage in the building envelope. When conducting a *One-Point Test* at 50 Pascals of building pressure, you are directly measuring CFM50.

Note: *Air Leakage at 50 Pa* can also be presented in units of liters per second (l/s), or cubic meters per second (m^3/s).

As a point of reference, an old uninsulated two-story Victorian style wood framed house in Minneapolis would likely produce a CFM50 test result in the range of 4,000 to 8,000 - quite leaky. A new modern house built to a strict airtightness standard would likely produce a test result in the 600 to 1,000 CFM50 range - quite airtight - in fact tight enough that a mechanical ventilation system would be needed to maintain good indoor air quality.

The airtightness of existing homes can vary dramatically based on the construction style, age and region. Below are airtightness test results from a few field tests of new and existing homes around the United States.

	Average CFM50
64 New Houses in Minnesota (1984)	1390
22 New Houses in Arizona (1994)	1959
18 New Houses North Carolina (1990)	1987
19 Existing Houses in Arkansas (low-income weatherization)	3071
6,711 Existing Houses in Ohio (low-income weatherization)	4451

- *Percent Reduction in CFM50:*

Performing a *One-Point* CFM50 test before and after airtightening work will allow you to determine the reduction in building airtightness. Reductions in CFM50 as large as 40 to 50 percent are often achieved in high level weatherization programs working on leaky houses. To determine the percent reduction in CFM50, subtract the after-tightening test result from the before-tightening test result. Divide this difference by the before-tightening result and multiply by 100.

$$\% \text{ Reduction} = \frac{\text{CFM50 (before)} - \text{CFM50 (after)}}{\text{CFM50 (before)}} \times 100$$

6.1.b Normalizing Air Leakage for the Size of the House:

In order to compare the relative tightness of buildings, it is useful to adjust (or normalize) the results for the size of the building. This allows easy comparison of various size buildings with each other, or with program standards. There are many aspects of building size which can be used to normalize including volume, floor area and surface area of the building envelope.

- *Air Change per Hour at 50 Pascals (ACH50):*

One way to compare different size buildings is to compare the measured *Air Leakage at 50 Pascals* (e.g. CFM50) to the conditioned interior volume of the building. *Air Change per Hour at 50 Pa* or (ACH50) is calculated by multiplying CFM50 by 60 to get air flow per hour, and dividing the result by the volume of the building. ACH50 tells us how many times per hour the entire volume of air in the building is replaced when the building envelope is subjected to a 50 Pascal pressure.

Note: If you included the basement of a house in the Blower Door test, (i.e. opened the door between the basement and house during the test) we recommend that you include the basement in your volume calculation.

$$\text{ACH50} = \frac{\text{CFM50} \times 60}{\text{Building Volume (cubic feet)}}$$

Many airtightness test standards for new houses have specified a maximum allowable ACH50 leakage rate. Some examples are listed below.

Example ACH50 Airtightness Standards in New Construction

	ACH50
Canadian R-2000 *	1.5
Alaska Craftsman Home *	1.5
Sweden *	3.0

* Mechanical Ventilation is required.

The airtightness of existing homes can vary dramatically based on the construction style, age and region. Below are results expressed in ACH50 from a few field tests of new and existing homes around the country.

Measured Field Test Results

	Average ACH50 Pa
64 New Houses in Minnesota (1984)	3.7
129 New Electric Homes in Pacific NW (1987-88)	5.6
134 New Electric Homes in Pacific NW (1980-87)	9.3
98 Existing Homes in Florida	12.7

- *Air Leakage at 50 Pascals per Unit of Floor Area:*

This parameter is calculated by dividing the measured *Air Leakage at 50 Pascals* (e.g. CFM50) by the floor area of the building. Floor area is sometimes used to normalize leakage because floor area is an easily determined number often known by the occupant.

$$\text{CFM50 per Square Foot of Floor Area} = \frac{\text{CFM50}}{\text{Square Feet of Floor Area}}$$

- *Air Leakage at 50 Pascals per Unit of Above Grade Surface Area (Minneapolis Leakage Ratio):*

Also known as the *Minneapolis Leakage Ratio* (MLR), this is the measured *Air Leakage at 50 Pascals* (e.g. CFM50) divided by the above grade surface area of the building. MLR is a useful method of adjusting the leakage rate by the amount of envelope surface through which air leakage can occur. The MLR has been particularly useful for weatherization crews working on wood frame buildings. Experience to date has shown that for uninsulated wood frame houses with a MLR above 1.0, very large cost-effective reductions in house leakage can often be achieved by using dense-pack cellulose insulation techniques and airsealing other large hidden construction openings. In houses with a calculated MLR in the 0.5 to 1.0 range, it is often more difficult to achieve economical improvements in airtightness.

$$\text{Minneapolis Leakage Ratio} = \frac{\text{CFM50}}{\text{Square Feet of Above Grade Surface Area}}$$

Note: When calculating Above Grade Surface Area, we recommend including all surfaces separating the conditioned space of the building from unconditioned spaces (e.g. exterior walls, floors over unheated and vented crawlspaces, surfaces separating the building and the attic).

6.2 Optional Correction for Air Density

To increase the accuracy of either a *One-Point Test* or a *Multi-Point Test*, the fan flow measurements can be corrected for differences in air density caused by air temperature. During a depressurization test, the Blower Door system is measuring the air flow through the Blower Door fan. But what we really want to know is the air flow coming back into the building through air leaks. When the inside and outside temperature are different, the air flow leaving the building through the fan is actually different from the air flow back into the building (due to differences in air density). In extreme weather conditions, this difference in air flow can be as great as 10 percent. If you wish to manually adjust your test results for differences in air density, a table of air density correction factors can be found in Appendix H.

Note: If you are using the TECTITE program, corrections for air density are made automatically.

6.3 Additional Test Result Options (requires use of TECTITE software)

6.3.a Leakage Areas:

Once the leakage rate of the building has been measured, it is often useful to estimate the cumulative size of all leaks or holes in the building's air barrier. The estimated leakage areas provide us with a way to visualize the physical size of the measured holes in the building. In addition, leakage areas are used in infiltration models to estimate the building's natural infiltration rates (i.e. the air change rate under natural weather conditions – see Estimating Natural Infiltration Rates below). In order to accurately estimate leakage areas, it is best to conduct a *Multi-Point* Blower Door test over a range of building pressures (60 Pa to 15 Pa).

Typically, two separate leakage area estimates are calculated based on differing assumptions about the physical shape and behavior of the leaks. These two leakage areas are compatible with the two most commonly used infiltration models.

- **Equivalent Leakage Area (EqLA):** EqLA is defined by Canadian researchers at the Canadian National Research Council as the area of a sharp edged orifice (a sharp round hole cut in a thin plate) that would leak the same amount of air as the building does at a pressure of 10 Pascals. The EqLA is used in the AIM infiltration model (which is used in the HOT2000 simulation program).

- **Effective Leakage Area (ELA):** ELA was developed by Lawrence Berkeley Laboratory (LBL) and is used in their infiltration model. The Effective Leakage Area is defined as the area of a special nozzle shaped hole (similar to the inlet of your Blower Door fan) that would leak the same amount of air as the building does at a pressure of 4 Pascals.

Note: The calculated **EqLA** will typically be about 2 times as large as the ELA. When using leakage area calculations to demonstrate physical changes in building airtightness, we recommend using the **EqLA** measurement. Typically, **EqLA** more closely approximates physical changes in building airtightness. For example, if you performed a Blower Door test, and then opened a window to create a 50 square inch hole and repeated the test, the estimated **EqLA** for the building will have increased by approximately 50 square inches from the initial test results.

6.3.b Estimated Natural Infiltration Rates:

Estimating the natural infiltration rate of a building is an important step in evaluating indoor air quality and the possible need for mechanical ventilation. Blower Doors do not directly measure the natural infiltration rates of buildings. Rather, they measure the building leakage rate at pressures significantly greater than those normally generated by natural forces (i.e. wind and stack effect). Blower Door measurements are taken at high pressures because these measurements are highly repeatable and are less subject to large variations due to changes in wind speed and direction. In addition, during a Blower Door test all leaks in the building are subjected to approximately the same pressure and they are leaking in the same direction.

In essence, a Blower Door test measures the cumulative hole size, or leakage area, in the building's air barrier (see Leakage Areas above). From this measurement of leakage area, estimates of natural infiltration rates can be made using mathematical infiltration models. The TECTITE software uses the calculation procedure contained in the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) Standard 136-1993 to estimate the average annual natural infiltration rate for purposes of evaluating indoor air quality and the need for mechanical ventilation.

Notes on Estimated Annual Infiltration Rates:

- Daily and seasonal naturally occurring air change rates will vary dramatically from the estimated annual average rate due to changes in weather conditions (i.e. wind and outside temperature).

- The physical location of the holes in the building air barrier compared to the assumptions used in the infiltration model will cause actual annual average infiltration rates to vary from the estimated values. Research done in the Pacific Northwest on a large sample of houses suggests that estimated infiltration rates for an individual house (based on a Blower Door test) may vary by as much as a factor of two when compared to tracer gas tests - one of the most accurate methods of measuring actual infiltration rates.

- The annual average infiltration estimates from ASHRAE Standard 136-1993 should be used only for evaluating detached single-family dwellings, and are not appropriate for use in estimating peak pollutant levels or energy loss due to infiltration. If any of the building leakage is located in the forced air distribution system, actual air leakage rates may be much greater than the estimates provided here. Duct leaks result in much greater air leakage because they are subjected to much higher pressures than typical building leaks. The ASHRAE 136 standard assumes that 1/4 of the building leakage is in the ceiling, 1/4 is in the floor, 1/2 is in the walls, and that leaks are uniformly distributed.

6.3.c Mechanical Ventilation Guideline:

It is possible, even easy in the case of new construction or when air sealing work is done by trained, skilled contractors, to increase the airtightness of a house to the point where natural air change rates (from air leakage) may not provide adequate ventilation rates to maintain acceptable indoor air quality. To help evaluate the need for mechanical ventilation in buildings, national ventilation guidelines have been established by ASHRAE. The recommended whole building mechanical ventilation rate presented in this version of TECTITE is based on ASHRAE Standard 62.2-2003, and is only appropriate for low-rise residential structures.

Recommended Whole Building Mechanical Ventilation Rate: This value is the recommended whole building ventilation rate to be supplied on a continuous basis using a mechanical ventilation system. The recommended mechanical ventilation rate is based on 7.5 CFM per person (or number of bedrooms plus one – whichever is greater), plus 1 CFM per 100 square feet of floor area. This guideline assumes that in addition to the mechanical ventilation, natural infiltration is providing 2 CFM per 100 square feet of floor area..

For buildings where the estimated annual natural infiltration rate (based on the Blower Door test) is greater than 2 CFM per 100 square feet of floor area, the recommended mechanical ventilation rate is reduced to provide ventilation credit for excess infiltration. In these cases, the recommended mechanical ventilation rate is reduced by the following amount:

0.5 x (estimated annual natural infiltration rate (CFM) – 0.02 CFM x sq. ft. of floor area)

Notes on Ventilation Guidelines:

- ASHRAE Standard 62.2-2003 also contains requirements for local kitchen and bathroom mechanical exhaust systems. These local exhaust systems may be incorporated into a whole building ventilation strategy. Consult Standard 62.2-2003 for more information on ventilation strategies and specific requirements and exceptions contained in the Standard.

- Compliance with the ventilation guideline does not guarantee that a moisture or indoor air quality (IAQ) problem will not develop. Many factors contribute to indoor air quality including ventilation rates, sources and locations of pollutants, and occupant behavior. Additional testing (including combustion safety testing) is needed to fully evaluate air quality in buildings. In many cases, a combination of pollutant source control and mechanical ventilation will be required in order to ensure adequate indoor air quality.

- Previous versions of TECTITE used ASHRAE Standard 62-1989 to determine an annual ventilation guideline. The Standard 62-1989 guideline (which was superceded by Standard 62.2-2003) was based on 15 CFM per person or 0.35 Air Changes per Hour (whichever was greater).

6.3.d Estimated Cost of Air Leakage:

The TECTITE program estimates the annual cost associated with measured air leakage, both for heating and cooling. The equations used to calculate the annual cost for air leakage are:

$$\text{Annual Heating Cost} = \frac{26 \times \text{HDD} \times \text{Fuel Price} \times \text{CFM50}}{\text{N} \times \text{Seasonal Efficiency}} \times 0.6$$

- HDD is the annual base 65 F heating degree days for the building location.
- The Fuel Price is the cost of fuel in dollars per Btu.
- N is the Energy Climate Factor from the Climate Information Screen (adjusted for wind shielding and building height). See Appendix E for more information.
- Seasonal Efficiency is the AFUE rating of the heating system.

$$\text{Annual Cooling Cost} = \frac{.026 \times \text{CDD} \times \text{Fuel Price} \times \text{CFM50}}{\text{N} \times \text{SEER}}$$

- CDD is the base 70 F cooling degree days for the building location.
- The Fuel Price is the cost of electricity in dollars per kwh.
- N is the Energy Climate Factor from the Climate Screen (adjusted for wind shielding and building height). See Appendix E for more information.
- SEER is the SEER rating for the air conditioner.

Note: Cooling Cost procedure is based on sensible loads only. In hot humid climates, latent loads due to air leakage can be greater than the sensible loads which are estimated by this procedure.

Chapter 7 Pressurization Testing

Blower Door airtightness measurements are typically performed with the building depressurized relative to the outdoors (i.e. the Blower Door fan exhausting air out of the building). However, under certain conditions it is necessary to conduct a Blower Door test by pressurizing the building. For example, if a Blower Door test is being conducted where there is a fire in a fireplace or woodstove, pressurization testing should be performed to prevent smoke from being drawn into the building through the fireplace. Pressurization testing may also be used to avoid pulling known pollutants into the building during the test procedure (e.g. mold from walls or crawlspaces). In addition, some testing procedures (ASTM E779-87) recommend that both depressurization and pressurization tests be performed, and then averaged to determine building airtightness.

7.1 Gauge Set-Up For Pressurization Measurements

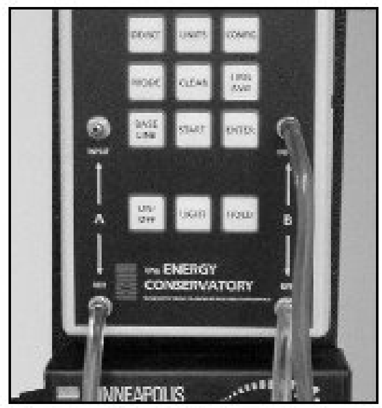
Gauges should be set-up inside the building using the following procedures.

7.1.a DG-700 Gauge:

Connect the **Red** tubing to the **Channel B Input** tap. The other end of the Red tubing should be connected to pressure tap on the Blower Door fan electrical box.

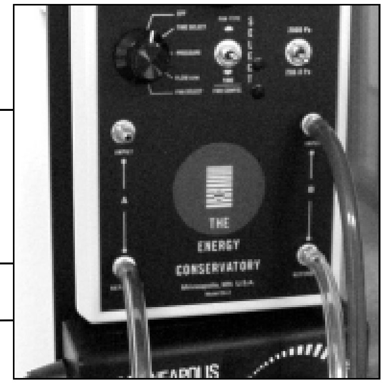
Connect the **Green** tubing to the **Channel A Reference** tap. The other end of the Green tubing should be run to the outside (see Chapter 3 instructions for installing the Outside Building Pressure Tubing).

Connect one end of the extra 30 foot clear tubing (stored in the accessory case) to the **Channel B Reference** tap, and run the other end of the tubing to the outside, through the open patch at the bottom of the nylon panel. The end of this tubing should be placed next to the side of the fan, but not in the fan's airstream. *



* If it is calm outside during the test, you can use the Green tubing as the outside reference hose for both the building and fan. Use a "T" connector along with short pieces of tubing to connect the Green hose to both Reference taps on **Channel A** and **Channel B**.

7.1.b DG-3 Gauge:



Connect the **Red** tubing to the Channel B Input tap. The other end of the Red tubing should be connected to pressure tap on the Blower Door fan electrical box.

Connect the **Green** tubing to the Channel A Reference tap. The other end of the Green tubing should be run to the <u>outside</u> (see Chapter 3 instructions for installing the Outside Building Pressure Tubing).

Connect one end of the extra 30 foot hose (stored in the accessory case) to the Channel B Reference tap, and run the other end of the hose <u>outside</u>, through the open patch at the bottom of the nylon panel. The end of this hose should be placed next to the side of the fan, but not in the fan's airstream. *

7.1.c APT System:

APT-2

Connect the **Red** tubing to the Channel P2 Input tap. The other end of the Red tubing should be connected to pressure tap on the Blower Door fan electrical box.

Connect the **Green** tubing to the Channel P1 Reference tap. The other end of the Green tubing should be run to the <u>outside</u> (see Chapter 3 instructions for installing the Outside Building Pressure Tubing).

Connect one end of the extra 30 foot hose (stored in the accessory case) to the Channel P2 Reference tap, and run the other end of the hose <u>outside</u>, through the open patch at the bottom of the nylon panel. The end of this hose should be placed next to the side of the fan, but not in the fan's airstream. *

APT-3 through 8

Connect the **Red** tubing to the Channel P2 Input tap. The other end of the Red tubing should be connected to pressure tap on the Blower Door fan electrical box.

Connect the **Green** tubing to the Channel P1 Reference tap. The other end of the Green tubing should be run to the outside (see Chapter 3 instructions for installing the Outside Building Pressure Tubing).

Connect one end of the extra 30 foot hose (stored in the accessory case) to the Channel P2 Reference tap, and run the other end of the hose <u>outside</u>, through the open patch at the bottom of the nylon panel. The end of this hose should be placed next to the side of the fan, but not in the fan's airstream. *

* If it is calm outside during the test, you can use the **Green** tubing as the outside reference hose for both the building and fan. Use a "T" connector along with short pieces of tubing to connect the Green hose to both Reference taps on P1 and P2 (or **Channel A** and **Channel B**).

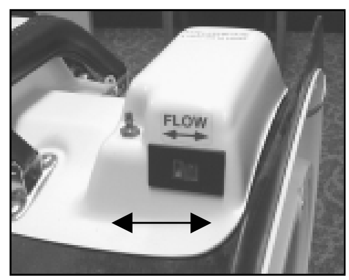
7.2 Fan Set-Up For Pressurization Measurements

When pressurizing the building, the fan should be installed with the inlet side of the fan facing outside, and the exhaust side of the fan inside the building. Keep the fan direction switch in the same position as when you perform depressurization tests - we want to blow air into the building through the exhaust guard. The elastic panel collar should fit snugly around the fan with the collar resting in the gap between the two sides of the electrical box.

The fan is held in place and stabilized by the Velcro strap attached to aluminum frame cross bar. Slip the Velcro strap through the fan handle and loop it up and back around the cross bar. Pull the strap tight so that it is holding most of the weight of the fan.

You are now ready to make your pressurization measurements using the same testing procedures described in Chapter 5.

7.3 Pressurizing the Building to Find Air Leaks (Not Measuring Flow)



If you are using a Model 3 fan and wish to pressurize a building for diagnostic purposes only (e.g. finding duct leaks using a chemical smoke puffer) and do not need to measure the fan flow, use the fan direction switch to blow air directly into the building . The fan direction switch (located on the fan electrical box) determines the air flow direction.

Note 1: Do not reverse the fan direction (by flipping the fan direction switch) when the fan is turning. This could damage the fan motor.

Note 2: The Model 4 fan motor is not reversible.

7.4 Optional Correction for Air Density

Similar to depressurization testing, pressurization fan flow measurements can be adjusted for differences in air density between inside and outside the building. A table of air density correction factors for pressurization testing can be found in Appendix H.

Note: If you are using the TECTITE software, corrections for air density are made automatically

Chapter 8 Finding Air Leaks

There are many techniques that are used to find air leaks with the Blower Door. Air leaks between the interior and exterior of the building often follow long and complicated leakage paths. Typically, the air sealing goal is to find where the leaks cross the "exterior envelope" of the building and to concentrate sealing activities on those areas.

8.1 Using Your Hand

The easiest method and one that is used most often is to depressurize the building and walk around the inside, checking for leaks with your hand. When you are looking for leaks, let the Blower Door fan run at a speed which generates between 20 and 30 Pascals of building pressure. You should get in the habit of always using the same pressure so you will get a good feel for what is a big leak and what is not. An entire room can be checked quickly if there is a door between it and the rest of the house. Standing just outside of the room, close the door most of the way, leaving about a one inch crack. A large blast of air coming through this crack indicates large leaks between that room and the outdoors.

8.2 Using a Chemical Smoke Puffer

In houses, many of the most important leaks are found between the house and the attic or between the house and a ventilated crawlspace. These leaks usually will not be easy to find unless you physically go into the attic or crawlspace. The use of a handheld smoke puffer is often helpful in these areas. With the house depressurized (and the crawlspace or attic access door shut), you can squirt small puffs of smoke toward suspected leakage sites from the attic or crawlspace and watch to see if the smoke gets sucked into the leak. With a piece of tubing attached to the smoke puffer, you can often reach deep into corners or in hard to reach spots. A smoke puffer or a pressure pan is a necessity when looking for leaks in the forced air ductwork (see Chapter 9 on duct leakage testing).

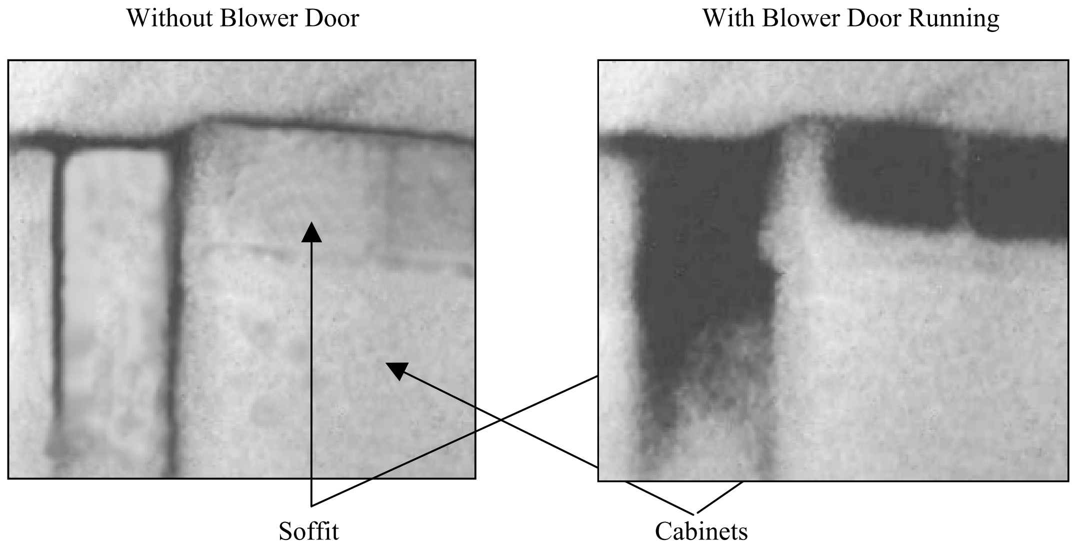
Note: Smoke from the chemical puffer is very corrosive. Do not store the puffer in a closed container with other items, especially tools or gauges.

8.3 Using an Infrared Camera

The ideal technique for finding leaks is to use an infrared scanner with a Blower Door. This procedure usually involves performing two infrared scans from the interior of the building; one before turning on the Blower Door and one after the Blower Door has been depressurizing the building for 5 to 10 minutes. As long as the air being sucked in through the leaks is either warmer or colder than the interior of the house, the area surrounding the leakage path will change temperature and show up on the infrared scanner screen. Even if there is little temperature difference between inside and outside, an infrared scan may still be possible if the attic space has been warmed from solar radiation on the roof or the crawlspace has been cooled from the ground. A temperature difference of about 5 to 10 degrees is sufficient to expose the important leaks. This technique often allows you to find significant leaks without having to enter the attic or crawlspace.

Note: Pressurizing the building and inspecting from the outside can also be useful.

Infrared Images Of Kitchen Soffit



8.4 Diagnosing Series Leakage Paths

Many important air leaks in a building are not direct leaks to the outside. Air leaks often follow complicated paths through building cavities and through unconditioned "zones" (such as attics, crawlspaces or garages) on their way into or out of the building. Attic bypasses, found in many houses, are a good example of a series leak. Air leaving the house first must flow through the ceiling/attic boundary and then through the attic/roof boundary before exiting the house.

Diagnostic procedures have been developed over the past decade to analyze series leakage. These procedures, called zone pressure diagnostics (ZPD), are widely used by weatherization professionals to prioritize airsealing efforts in houses by estimating the amount of air leakage from attached zones (e.g. attics, crawlspaces, garages and basements). ZPD techniques typically combine Blower Door airtightness test results with zone pressure measurements made both before and after an opening or hole has been added to one surface of the zone being tested.

In 2000, the Energy Center of Wisconsin commissioned a study of ZPD techniques and procedures in order to improve the accuracy and reliability of zone leakage estimates. The results of that study, published in 2002, include numerous improvements to both the methodology used to collect ZPD measurements and the calculation procedures used to estimate the magnitude of air leakage from tested zones.

To assist our customers in using ZPD calculation methods, we have developed a simple software program which can be used to quickly perform ZPD calculations using many of the improvements recommended in the Energy Center's study. The ZPD Calculation Utility is comprised of 7 Steps (or screens) which are used to input test information and display test results. The ZPD Calculation Utility program and operation manual are available at no cost from our website (*www.energyconservatory.com*). The ZPD Calculation Utility assumes that the Blower Door test results and zone pressure measurements are being collected using either an Energy Conservatory digital pressure gauge, or as part of an automated Blower Door test using an APT system.

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Chapter 9 Testing for Duct Leakage and Pressure Imbalances

9.1 Duct Leakage Basics

9.1.a Why Is Duct Leakage Important?

Unintentional air leakage in forced air duct systems is now recognized as a major source of energy waste in both new and existing houses. Studies indicate that duct leakage can account for 25% or more of total house energy loss, and in many cases has a greater impact on energy use than air infiltration through the building shell. In many light commercial buildings, duct leakage is the single largest cause of performance and comfort problems.

Here are just a few of the problems resulting from duct leakage:

- Leaks in the supply ductwork cause expensive conditioned air to be dumped directly outside or into the attic or crawlspace rather than delivered to the building.
- Leaks in the return ductwork pull unconditioned air directly into the HVAC system reducing both efficiency and capacity. For example, if 10 percent of the return air for an air conditioning system is pulled from a hot attic (120 F), system efficiency and capacity could be reduced by as much as 30 percent. In humid climates, moist air being drawn into return leaks can overwhelm the dehumidification capacity of air conditioning systems causing buildings to feel clammy even when the air conditioner is running.
- Duct leakage has been found to greatly increase the use of electric strip heaters in heat pumps during the heating season.
- Infiltration rates can increase by 2 or 3 times whenever the air handler is operating.
- Leaks in return ductwork draw air into the building from crawlspaces, garages and attics bringing with it dust, mold spores, insulation fibers and other contaminants.
- Building depressurization from duct leaks and imbalanced duct systems can cause spillage of combustion products (from furnaces, water heaters and fireplaces).

9.1.b Where Does Duct Leakage Occur?

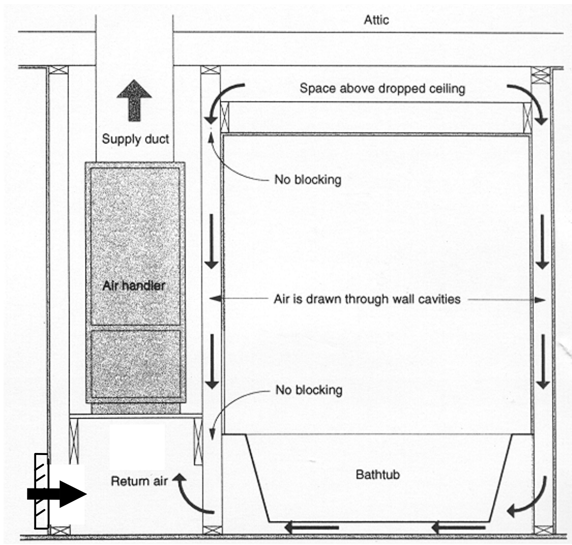
Because the air leaking from ductwork is invisible, most duct leaks go unnoticed by homeowners and HVAC contractors. In addition, ducts are often installed in difficult to reach spots like attics and crawlspaces, or are "buried" inside building cavities making them even more difficult to find. And the hard to find leaks are usually the most important leaks to fix, because they are connected directly to the outside or to a hot attic or humid crawlspace.

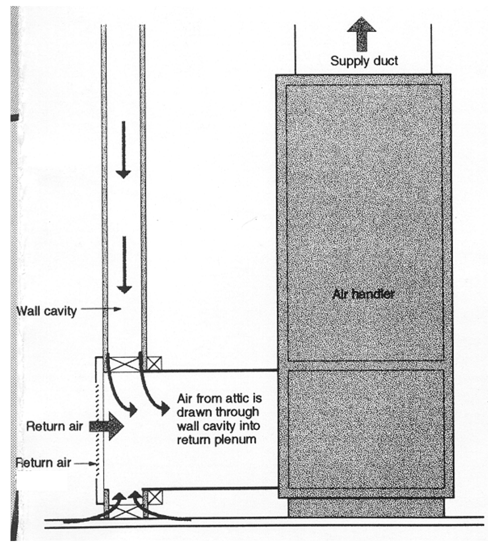
Duct leaks can be caused by a variety of installation and equipment failures including:

- Poorly fitting joints and seams in the ductwork.
- Disconnected or partially disconnected boot connections.
- Holes in duct runs.
- Use of improperly sealed building cavities for supply or return ducts.
- "Platform" return plenums which are connected to unsealed building cavities.
- Poor connections between room registers and register boots.
- Poorly fitting air handler doors, filter doors and air handler cabinets.
- Failed taped joints.

The impact on a particular building will depend on the size of the duct leak, the location of the duct leak and whether or not the leak is connected to the outside.

Example Duct Leakage Problems





9.1.c How Much Can Energy Bills Be Reduced By Sealing Duct Leaks?

Numerous studies conducted by nationally recognized research organizations has shown that testing and sealing leaky distribution systems is one of the most cost-effective energy improvements available in many houses.

A 1991 study in Florida found:

- Air conditioner use was decreased by an average of 17.2% in a sample of 46 houses where comprehensive duct leakage diagnostics and sealing were performed.
- These houses saved an average of $110 per year on cooling bills at a cost of approximately $200 for repairs.

A 1991 study in Arkansas found:

- Duct leaks also waste energy in heating climates. A study of 18 houses showed that a duct leakage repair service saved 21.8% on heating bills by eliminating three-quarters of the duct leakage in the study houses.

In addition to the energy savings, duct leakage repair improved homeowner comfort and reduced callbacks by allowing the HVAC system to work as designed.

9.1.d Duct Leakage to the Outside:

Duct leakage to the outside has the largest impact on HVAC system performance. Duct leakage to the outside commonly results from leaky ductwork running through unconditioned zones (attics, crawlspaces or garages). Most of the duct leakage research studies referenced in this manual have been performed on houses which contain significant portions of the duct system in unconditioned zones. However, significant leakage to the outside can also occur when all ductwork is located within the building envelope. In these cases, leaky ducts passing through wall or floor cavities (or the cavities themselves may be used as supply or return ducts) create a pressure differential between the cavity containing the ductwork and other building cavities indirectly connected to the outside. Air can be forced through these leaks whenever the air handler fan is operating.

9.1.e Duct Leakage to the Inside:

Much less is known about the energy and system efficiency impacts of duct leakage inside the house. A recent study of new houses in Minnesota has shown that the duct systems are very leaky, but that very little of that leakage was connected directly or indirectly to the outside. One of the primary causes of duct leakage in Minnesota houses was found to be very leaky basement return systems which use panned under floor joists as return ductwork. In addition, many of the joints and connections in the sheet metal supply ductwork were leaky. Because almost all of the duct leakage was occurring within the conditioned space of the house, the energy efficiency penalty from this leakage is thought to be much less significant.

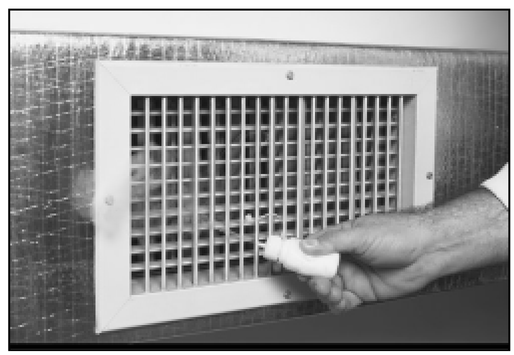
However, the Minnesota study did find that leaky return systems can cause the basement (where the furnace and water heater are located) to depressurize to the point where combustion products from the water heater or furnace would spill into the house. Negative pressures from return leaks can also contribute to increased moisture and radon entry into houses. In addition, many comfort problems were experienced in the summer due to leaks in the supply duct system dumping much of the cool conditioned air into the basement. These problems all suggest that controlling duct leakage to the inside may be just as important as leakage to the outside.

9.2 Finding Duct Leaks to the Outside

There are a number of simple ways to help you pinpoint which duct runs contain major leaks to the outside. Two methods are presented below:

9.2.a Smoke Test:

Turn off the air handler fan, open all registers, remove all filters and open all interior doors. Turn on the Blower Door and pressurize the building to about 25 Pa With Reference To (WTR) outside. With the Blower Door running, go around to all the supply and return registers in the building and squirt a little chemical smoke near the register. If the smoke is vigorously pulled into the register, it indicates that the register is near a large duct leak to the outside. If the smoke lazily moves past the register, little or no outside leakage is near that location.



9.2.b Pressure Pan:

An alternative method for finding duct leaks with the Blower Door can be performed with a gasketed pressure pan and a digital pressure gauge. This method involves placing the pressure pan completely over each register and taking a quick pressure reading while the Blower Door is depressurizing or pressurizing the building by 50 Pascals. A measure of the pressure between a duct run and the room where the duct register is located can often provide a quick and reliable indication of whether significant exterior duct leaks exist in that section of the duct system. The pattern of pressure pan readings often allows for quick identification of major leakage sites. Pressure pan readings can also be used to tell technicians if they have done a good job of air sealing the duct system.

Typical pressure pan readings found in existing buildings with external duct systems are commonly in the 0 - 20 Pa range (with the house depressurized to 50 Pa). However, pressure pan readings up to 50 Pa can be found in cases of catastrophic failure (such as complete disconnects). The higher the pressure pan reading, the more connected (leaking) that part of the duct system is to the outside. Experience to date has shown that in many retrofit applications, pressure pan readings can be brought down to, or below, 1.0 Pa with cost-effective duct sealing techniques.

Pressure pan readings do not measure air flow rates. Rather, the pressure pan reading tells us the degree to which a particular duct run is connected to the outside. Because the pressure pan does not measure leakage rates, it is often necessary to make a direct measurement of duct leakage to the outside in CFM to determine if duct repair is cost effective. Further information on pressure pan testing can be obtained from The Energy Conservatory (the Pressure Pan Manual is available on our website at *www.energyconservatory.com*.

9.3 Estimating Duct Leakage to the Outside With a Blower Door

The following two testing procedures can be used to estimate the amount of leakage directly between the forced air duct system and the outside. **Note:** The leakage rate of a duct system determined using the airtightness test procedures listed in this manual may differ from the leakage rates occurring in the duct system under actual operating conditions. When conducting an airtightness test, all leaks in the ductwork are subjected to approximately the same pressure (i.e. the test pressure). Under actual operating conditions, pressures within the duct system vary considerably with the highest pressure present near the air handler, and the lowest pressures present near the registers. Researchers are working on developing new test procedures which will provide duct leakage measurements under actual operating conditions.

9.3.a Modified Blower Door Subtraction:

Step 1: Conduct "Whole House" Blower Door Depressurization Test

- Set up the building for a standard Blower Door depressurization test.
- Turn the air handler fan off, open all registers and remove all HVAC filters including remote filters.
- Temporarily seal all exterior combustion air intakes and ventilation system air intakes that are connected to the duct system.
- Depressurize the building by 50 Pa With Respect To (WRT) outside (see Chapter 5).
- Record ***Whole House CFM50****,* and turn off the Blower Door.

Step 2: Conduct "Envelope Only" Blower Door Depressurization Test

- Tape off all supply and return registers with Duct Mask temporary register sealing film (available from The Energy Conservatory) or use paper and high quality painters masking tape. Be sure to include any ventilation system supply and return registers that are connected to the forced air duct system.
- Depressurize the building to 50 Pa WRT outside with the Blower Door.
- Record ***Envelope Only CFM50***.

Step 3: Measure Pressure in Duct System with Registers Taped Off

- With the building still depressurized to 50 Pa WRT outside, measure the pressure in the taped off duct system WRT the building. This measurement can be taken at the return or supply plenum using a static pressure probe, or at a supply or return register by punching a small hole through the sealing tape and inserting a pressure tap or hose.

Step 4: Calculate Duct Leakage to the Outside

- Using the pressure measured in Step 3, look up the appropriate correction factor in Table 4 below. This correction is needed to account for any underestimation of duct leakage due to connections between the duct system and the building.
- Calculate Duct Leakage to Outside =

(*Whole House CFM50 - Envelope Only CFM50*) x Subtraction Correction Factor (SCF)

Table 4:

Correction Table For Blower Door Subtraction

House to Duct Pressure (taped off)	Subtraction Correction Factor (SCF)
50	1.00
49	1.09
48	1.14
47	1.19
46	1.24
45	1.29
44	1.34
43	1.39
42	1.44
41	1.49
40	1.54
39	1.60
38	1.65
37	1.71
36	1.78
35	1.84
34	1.91
33	1.98
32	2.06
31	2.14

House to Duct Pressure (taped off)	Subtraction Correction Factor (SCF)
30	2.23
29	2.32
28	2.42
27	2.52
26	2.64
25	2.76
24	2.89
23	3.03
22	3.18
21	3.35
20	3.54
19	3.74
18	3.97
17	4.23
16	4.51
15	4.83
14	5.20
13	5.63
12	6.12
11	6.71

Uncertainty of Duct Leakage Measurements Using Blower Door Subtraction

Because Blower Door Subtraction involves subtraction of two separate Blower Door test results (using the same Blower Door), the accuracy of the duct leakage estimate using this technique is a function of the repeatability of the Blower Door measurements. The example below shows how repeatability errors can affect the accuracy of Blower Door subtraction test results.

Assume you conducted a Blower Door subtraction test with the following results:

- Whole House CFM50 = 3,000
- Envelope Only CFM50 = 2,750
- House to Duct Pressure During Envelope Only Measurement = 45 Pascals
- Correction Factor = 1.29

The estimated duct leakage would be (3,000 - 2,750) * 1.29 = <u>322 cfm</u>

On a day with only slight wind, our experience is that the repeatability of manual Blower Door test is about +/- 3% of the unsealed whole house CFM50 value when using the same gauges for both tests. For the example above, a repeatability error of 3% means we have an error of approximately +/- 90 CFM50 (0.03 x ,3,000 CFM50) in our leakage estimate. We must also apply the correction factor calculated above to the 90 CFM50 error which increases the error to +/- 116 CFM50 (90 x 1.29). Thus our final duct leakage estimate is 322 CFM50 (+/- 116 CFM50). This means the actual leakage in the duct system is somewhere between 206 CFM50 and 438 CFM50, a fairly wide variation in test results.

In very windy weather, repeatability error for a manual Blower Door test will increase to much larger than the 3% shown here. However, if you are using an APT system to conduct your Blower Door test, repeatability errors will typically be reduced below the 3% quoted above, and the APT system will provide you with a estimate of the measurement uncertainty.

9.3.b Flow Hood Method: (Requires use of calibrated flow capture hood)

- Set up the building for a standard Blower Door pressurization test (see Chapter 7).
- Turn the air handler fan off, open all registers and remove all HVAC filters including remote filters.
- Temporarily seal all exterior combustion air intakes and ventilation system air intakes that are connected to the forced air duct system.
- Tape off all supply and return registers, ***except the largest and closest return to the air handler***, with Duct Mask temporary register sealing film (available from The Energy Conservatory) or use paper and high quality painters masking tape. Include all ventilation system registers connected to the forced air duct system.
- Pressurize the building to 50 Pa WRT outside with the Blower Door.
- Place the flow capture hood over the open return register and record the flow going into the return register. This measured flow is an estimate of the CFM50 duct leakage to the outside.

Note: This procedure can also be conducted by depressurizing the building and measuring the air flow coming out of the open return register.

9.4 Unconditioned Spaces Containing Ductwork

When using either duct leakage measurement method described in Section 9.3 above, the unconditioned spaces containing ducts should be as close to outside pressure as possible. Be sure to open all operable vents between the unconditioned space and the outside before conducting the duct leakage test. If the unconditioned space containing ductwork is not well connected to the outside (e.g. unvented crawlspaces or unvented attics) or has very large connections to the house, then the unconditioned space will be at a pressure somewhere between the outside and inside building pressure during the Blower Door test. In this case, the duct leakage measurement will show an artificially low number.

You can measure the degree of connection between an unconditioned space and the outside by measuring the pressure difference between the building and the space during the Blower Door test. If the pressure between the building and the unconditioned space is less than 45 Pa (assuming the building to outside pressure difference is 50 Pa with the Blower Door running), then the duct leakage measurement will be underestimated. The lower the pressure, the greater the underestimation.

9.5 Testing for Pressure Imbalances Caused By Forced Air System Flows

Air handler fans commonly move 500 to 2000 cubic feet of air per minute (CFM). Pressure imbalances within the building can be caused by air hander fan operation if supply and return air flows to each part of the building are not in balance. Pressure imbalances within the building can significantly increase infiltration rates, contribute to radon and moisture entry, create durability problems, and cause potential combustion appliance spillage and backdrafting. Research on combustion appliances has found that very small negative pressures (as low as 3 to 5 Pascals) can cause spillage and backdrafting in natural draft appliances.

Building pressure imbalances can also be caused by duct leakage to the outside. If either the supply or return air ductwork has leaks to the outside, air will be forced through these leaks when the air handler fan is operating. If the leaks are in the supply ducts, building air will be exhausted to the outside through the leaks and this will tend to depressurize the building. If the leaks are in the return system, outside air will be sucked into the leaks and the building will tend to be pressurized. If there are equal amounts of leakage in both the supply and return, no change in building pressure will occur, even though large energy losses may result.

Below are a set of test procedures used to help identify pressure imbalances caused by leaks between the duct system and the outside, and by imbalanced supply and return air flows throughout a building. These tests are very sensitive to wind effects, and on windy days it can be very difficult to get accurate results.

9.5.a Dominant Duct Leak Test:

This test measures whole building pressurization or depressurization caused by duct leakage to the outside during operation of the air handler fan. A pressure change due to duct leakage can cause safety, durability, comfort, and efficiency problems. In some cases, duct repair can cause a problem or make it worse. Diagnosing which side of the system is causing a dominant pressure helps determine a safe and effective treatment strategy.

- Turn off the Blower Door and close off the Blower Door fan opening with the "No-Flow" plate.
- Be sure all exterior doors and windows in the building are closed. Replace all HVAC filters (be sure they are clean). Open all interior doors and check that all exhaust fans and the air handler fan are off.
- Set up a digital gauge to measure the building pressure With Respect To (WRT) outside. The outside pressure hose should be connected to the bottom (Reference) pressure tap on **Channel A** (top tap should be open). Set the gauge Mode to measure pressures.
- Turn on the air handler fan and record the change in building pressure indicated on the gauge.
- Repeat this test several times by turning the air handler on and off for better certainty.

• Greater leakage on the return side of the duct system will typically cause the building to become pressurized since the return ductwork is drawing outside air into the ductwork. In this case, there will be a positive reading on pressure gauge. The size of the pressure change will depend on both the amount of imbalanced duct leakage and the tightness of the building being tested (see Figure 10 in Chapter 10).

- Greater leakage on the supply side of the system will typically cause the building to become depressurized since the supply ductwork is exhausting building air to the outside, just like an exhaust fan. In this case, there will be a negative reading on the pressure gauge. The size of the pressure change will depend on both the amount of imbalanced duct leakage and the tightness of the building being tested (see Figure 10 in Chapter 10).

In cold climates, pressurizing a building to even 1 Pascal could lead to moisture problems caused by forcing warm, moist air into the walls and attic where it can condense on cold surfaces. In warm humid climates, depressurization by 1 Pa can also cause severe moisture problems from warm moist outside air being drawn into the walls where it can condense on the backside of cooled gypsum board. If there are natural draft combustion appliances, or if radon is a problem, depressurizing a building by 1 Pascal may also be a problem.

If there is no change in building pressure, this means that there is either equal supply and return leakage to the outside, no leaks to the outside, or the building itself is too leaky for the duct leakage to create a measurable pressure change.

Note: For APT users, a prototype software program called ONOFF is available to help precisely measure small changes in building or room pressures. The program uses a signal averaging technique which significantly reduces noise, particularly in windy weather, allowing for precise measurement of small pressure changes. Contact The Energy Conservatory for more information.

9.5.b Master Suite Door Closure:

This test measures the effect of closing the master suite door on the pressure in the main body of the building. The master bedroom is often the largest room in a building and can contain multiple supply registers while having no returns. Closing of bedroom doors can restrict the supply air pathway back to the air handler, causing bedrooms to become pressurized while other parts of the building may become depressurized. Repeat this test for other building areas that contain large numbers of registers and can be closed off from the main body of the building with one door (e.g. a basement door when the basement has supply registers).

- Keep the gauge set up to measure the pressure between the main body of the building WRT outside.
- With air handler still running, close the master suite door.
- Record the total pressure difference from the main body of the building WRT outside. (Large impacts from Master Suite Door Closure are most common in single and double return houses.)
- Consider pressure relief if the Master Suite door is frequently closed and causes the pressure in the main body of the building to change by 1 Pascal or more in either direction.

9.5.c All Interior Doors Closed:

This test measures the added effect of closing all interior doors on the pressure in the main body of the building.

- Keep the gauge set up to measure the pressure between the main body of the building WRT outside.
- With the air handler still running, close all interior doors.
- Record the total pressure difference from the main body of the building WRT outside.
- Consider pressure relief if closing all the doors causes the pressure in the main body of the building to change by 2 Pascals or more in either direction.

9.5.d Room to Room Pressures:

This test measures the pressure difference between each room in the building and the main body, with the air handler operating. Excessive pressurization in rooms can create durability problems by driving moisture into walls, ceilings and floors. Excessive depressurization in rooms can pull outside moisture into building components in humid climates. Pressure imbalances can also lead to large increases in building infiltration rates.

- Close all interior doors and walk around the building with a digital pressure gauge.
- Connect tubing to the **Channel A** Input tap and leave the bottom Reference tap open. Set the gauge Mode to measure pressures.
- While standing in the main body of the building, place the hose from the gauge under each door (including the combustion appliance room and/or basement).
- Record the pressure difference from each room WRT the main body.
- Consider pressure relief for any rooms pressurized or depressurized by 3 Pa or more with respect to the main body of the building.

Note: If there are combustion appliances in a depressurized area (i.e. fireplaces, furnace or water heater), their ability to draft properly may be affected. Try to eliminate all depressurization in combustion appliance zones by finding and sealing leaks in the return ducts, plenum, filter access door and air handler cabinet, or by providing pressure relief. See Chapter 10 for more information on Combustion Safety Testing Procedures.

9.6 Other Important Test Procedures

Although not covered in this manual, other important test procedures should be performed whenever repairs and changes are made to the forced air heating and cooling system.

9.6 a Total System Air Flow:

The air flow rate through air handlers is a very important variable in estimating and optimizing the performance of heat pumps, air conditioners and furnaces. Many studies of residential systems have shown low air flow to be a common problem. There are a number of methods to measure total system air flow including the Duct Blaster® pressure matching method, the temperature rise method, system static pressure and fan curve, as well as a new direct flow measuring tool (TrueFlow™ Flow Plate) available from TEC.

Note: Research has shown that in most cases, the temperature rise method and fan curve method are much less accurate than either the Duct Blaster or TrueFlow methods.

9.6.b System Charge:

Having the proper amount of refrigerant installed in a new heat pump or air conditioning system is another critical variable in determining system efficiency, as well the longevity of the system compressor. Numerous studies have shown the incorrect amount of system charge to be a common installation problem.

9.6.c Airflow Balancing:

Verification that proper air flow is being delivered to each room in a building is another important component of a complete system assessment. Air flow rates are commonly measured using a calibrated flow capture hood.

Chapter 10 Combustion Safety Test Procedure

10.1 Overview

Buildings with natural draft combustion appliances should be routinely tested to ensure that the spillage of combustion products into the building is unlikely. Combustion safety testing is critical because of the potential for severe health effects from improperly venting appliances, including carbon monoxide poisoning. Because the goal of Blower Door guided air sealing activities is to reduce the infiltration rate (and subsequent ventilation rate) of the building, contractors need to check that they are not leaving a building with a potential problem.

Spillage of combustion products into the building can be caused by a variety of conditions including:

- Blocked or partially blocked chimneys, vents, or vent connectors.
- Improper equipment installation.
- Cracked heat exchangers.
- Leaks in the venting system (disconnected flue pipes, open cleanout door etc.).
- Low vent temperatures.
- Combustion appliance zone depressurization. As buildings are made tighter, it becomes easier for exhaust fans and forced air system imbalances to create potentially hazardous depressurization conditions.

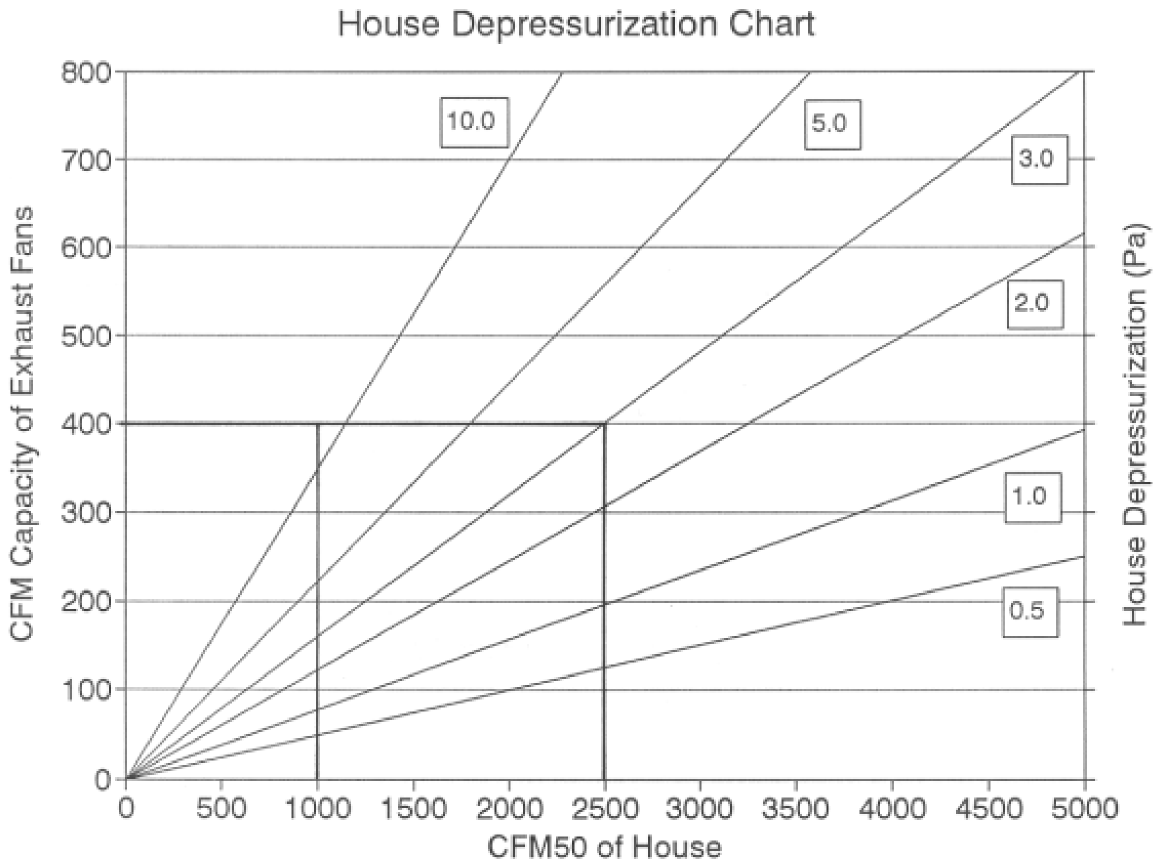
Many cases of improperly venting combustion appliances have been related to depressurization (or negative pressures) in the room that contains the combustion appliance. Depressurization can be caused by exhaust fans, dryers, imbalanced forced air distribution systems, and forced air system duct leakage. As buildings (or combustion appliance rooms) are made tighter, these problems can be made worse, although very leaky buildings can also have venting problems related to depressurization. Figure 10 below estimates the amount of depressurization that can be caused by various exhaust fan flows. For example, from Figure 10 we can see that a 400 cfm exhaust fan will depressurize a 2,500 CFM50 building (or room) to approximately 3 Pascals. That same 400 cfm fan would produce over 10 Pascals of depressurization in a 1,000 CFM50 building.

The presence of code approved combustion air intakes does not ensure that venting problems will not occur. Significant combustion room depressurization is frequently found even after code approved combustion air intakes have been installed. Passive combustion room air intakes typically do not provide sufficient airflow to relieve negative pressures caused by distribution imbalances, duct leakage, or large exhaust appliances. For example, a typical 6" passive inlet can at best supply only about 50 cfm at a 5 Pa negative building pressure. And because passive air intakes are often poorly installed (i.e. many sharp bends, long runs), they typically provide much lower flows than designed. Building codes typically give little or no guidance on how one would design a combustion air opening when competing exhaust appliances are present (the 2000 Minnesota Energy Code is the only code we are aware of to give such guidance).

The only way to be reasonably sure that venting problems will not occur in a building is to perform combustion safety tests. Described below are commonly used test procedures to locate existing or potential combustion safety problems in buildings. **These procedures are offered only as an example of what other organizations in North America typically recommend for testing. The Energy Conservatory assumes no liability for their use, and contractors should have a working knowledge of local codes and practices before attempting to use the procedures outlined below.**

If combustion safety problems are found, tenants and building owners should be notified immediately and steps taken to correct the problem including notifying a professional heating contractor if basic remedial actions are not available. Remember, the presence of elevated levels of carbon monoxide in ambient building air or in combustion products is a potentially life threatening situation. **Air sealing work should not be undertaken until existing combustion safety problems are resolved, or unless air sealing is itself being used as a remedial action.**

Figure 10:



This chart can be used to estimate the amount of house depressurization caused by operating exhaust fans. To use the chart, find the intersection between the airtightness (CFM50) of the house and the cfm capacity of the exhaust fans in question. The amount of depressurization caused by the fan(s) is read off the diagonal house depressurization lines. For example, a 400 cfm kitchen range hood operating in a house with an airtightness level of 2,500 CFM50 would depressurize the house by approximately 3 Pa relative to the outside. This same fan operating in a 1,000 CFM50 house would produce over 10 Pa of depressurization.

Note: This chart was generated by assuming that all houses have a "House Leakage Curve" with an exponent (or slope) of n = 0.65,

10.2 Test Procedures

This procedure is not intended to cover all circumstances you will find in the field. A basic understanding of the dynamic interactions between building pressures, air flow and mechanical system operation is required to fully utilize the procedures presented below. Detailed descriptions of similar test procedures can be found in Reference #4, in Appendix G.

10.2.a Measure Ambient CO Level in Building:

- Zero your digital CO tester outside before entering the building. CO tester should have 1 PPM resolution.
- Measure the ambient CO level in all occupied areas of the building. Be sure to measure ambient CO levels in kitchens and in combustion appliance rooms.
- Investigate any ambient CO levels above 2 ppm. **Note:** Areas close to very busy streets may have ambient CO levels above 2 ppm.
- Maximum CO concentration guidelines: 9 ppm for 8 hour exposure (EPA)
  35 ppm for 1 hour exposure (EPA)
  200 ppm single exposure (OSHA)

CO concentrations at or above these levels requires immediate remedial action.

10.2.b Survey of Combustion Appliances:

- Walk through the building and survey all combustion appliances including furnaces, water heaters, fireplaces, woodstove and auxiliary heating units, dryers and cooking stoves.
- Write down the following information on a survey form:

  - Location, type and input of combustion appliances.
  - Signs of visible deterioration and leaks in flue pipes and connections.
  - Presence of gas leaks, signs of spillage or flame roll-out.
  - Location, size and operable condition of combustion air supply(s).
  - Evidence of rusted interior surfaces of heat exchangers.

Gas or fuel leaks are a very serious safety problem requiring immediate remedial action.

10.2.c Survey of Exhaust Fans:

- Walk through building and note the location and rated capacity (or estimated capacity) of all exhaust fans including kitchen and stove fans, bath fans, dryers, whole house vacuum systems, attic (not whole house) vent fans etc..

10.2.d Measure Worst Case Fan Depressurization:

With this test procedure, the goal is to measure worst case depressurization in all combustion rooms with natural draft appliances and fireplaces. This measurement gives us an indication of the likelihood of exhaust and air handler fans causing the combustion appliances to backdraft and spill. The procedures below measure worst case depressurization under 3 separate operating conditions; running exhaust fans only, running exhaust and air handler fans, and running the air handler fan only. These tests are very sensitive to wind effects, and on windy days it can be very difficult to get accurate results.

Initial Preparation

Close all exterior windows and doors and be sure furnace, water heater and other vented combustion appliances are off. Close all interior doors. Set up a digital gauge to measure the pressure difference of the combustion appliance zone (CAZ) with reference to (WRT) outside on **Channel A**. If using a DG-3 gauge, record the baseline CAZ to outside pressure. If using a DG-700, use the built-in "baseline" feature to measure and record the baseline CAZ to outside pressure on **Channel A**. Once the "baseline" feature has been used with the DG-700, **Channel A** will display the baseline adjusted pressure.

1. Exhaust Fans Only

Turn on all exhaust fans found in the survey above (for dryer, clean out lint filter before turning on). Now determine the worst case position of interior doors with the smoke test below:

> ***Smoke Test:*** While standing in the main body of the building, squirt smoke under each door containing an exhaust fan (except the CAZ currently being tested). If the smoke goes into the room, open the door. If the smoke comes back into the main body of the building, keep the door closed. Now squirt smoke under the CAZ door (while continuing to stand in the main body). If smoke goes into the CAZ, leave the CAZ door shut. If smoke comes back into the main body of the building, open the door.

Measure the depressurization of the CAZ WRT outside caused by turning on the exhaust fans. Depressurization should not exceed the appropriate House Depressurization Limits (HDL) listed below. If it is windy, it is often necessary to turn fans off and on several times to obtain good pressure readings.

> ***Fireplace Zones:*** For Fireplace Zones, repeat the same procedure and measure and record depressurization of fireplace zone WRT outside from exhaust fan operation. Depressurization should not exceed the appropriate HDL listed below.

2. Air Handler and Exhaust Fans

With exhaust fans continuing to run, turn on the air handler fan (note: air handler fan only, do not turn on burner) and close any supply registers in combustion appliance room. For both CAZ and Fireplace Zone tests, re-determine worst case position of all interior doors with the smoke test described above. If cooling is available, be sure air handler fan is running at high speed. Repeat worst case depressurization measurements.

3. Air Handler Fan Only

Turn off all exhaust fans and leave air handler operating (if cooling is available, be sure air handler is running at high speed). For both CAZ and Fireplace Zone tests, re-determine worst case position of all interior doors with the smoke test described above. Repeat worst case depressurization measurements.

> ***If the HDL are exceeded for any of the worst case depressurization tests above, pressure relief is needed***. Pressure relief could include duct system repair, undercutting of doors, installation of transfer grills, eliminating or reducing exhaust fan capacity, or instructing homeowner on safe exhaust fan operation. If negative pressures in the combustion appliance zone (or basement) are a function of return leaks in that area, check for leaks in the return ductwork, plenum, filter access door and air handler cabinet. Pay particular attention to panned under floor joists (used as returns) as they typically have many leaks.

Note: For APT users, a prototype software program called ONOFF is available to help precisely measure small changes in building or room pressures. The program uses a signal averaging technique which significantly reduces noise, particularly in windy weather, allowing for precise measurement of small pressure changes. Contact The Energy Conservatory for more information.

Table 5: House Depressurization Limits (HDL)

Appliance Type	**Depressurization Limit**
Individual natural draft water heater (WH)	2 Pascals
Natural draft WH and natural draft furnace/boiler	3 Pascals
Natural draft WH and Induced Draft (ID) furnace/boiler	5 Pascals
Individual natural draft furnace/boiler	5 Pascals
Individual ID furnace/boiler	15 Pascals
Power vented and sealed combustion appliances	>25 Pascals

Source: *CEE Appliance Safety Test Methods, MAC Part 150 Residential Sound Insulation Program, Mpls, MN.*

10.2.e Spillage Test (natural draft and induced draft appliances):

This test identifies actual spillage of combustion byproducts into the living space under worst case depressurization conditions.

- With building set up in worst case depressurization mode (as specified above), fire up each combustion appliance.
- If appliances are common vented, conduct test on smallest input appliance first, then test with both appliances running.
- When burner lights, check for flame rollout (stand away from burner).
- Check for spillage (using chemical smoke) at the end of the spillage test period (see Table 6 below). For natural draft appliances, spillage is tested at the draft diverter. When an induced draft heating system is vented in common with a natural draft water heater, spillage is checked at the water heater draft divertor. For a single induced draft appliance, spillage is checked at the base of the chimney liner or flue, typically using the drip tee at the bottom of the liner.

Table 6: Spillage Test Period

Appliance Type	**Spillage Test Period (minutes)**
Water heater, gravity furnace and boiler	3.0 minutes
Space heater	2.0 minutes
Furnace	1.0 minutes

Source: *CEE Appliance Safety Test Methods, MAC Part 150 Residential Sound Insulation Program, Mpls, MN.*

- If spillage continues beyond the spillage test period, remove the negative pressure in combustion room by turning off fans and/or opening an exterior window or door.
- Re-check for spillage. If spillage stops, there is a pressure induced spillage problem. If spillage continues, check flue and chimney for obstructions, and check compatibility of appliance BTU input with chimney size.

Spillage of combustion products beyond the spillage test period is a health and safety concern. If the problem is a blocked flue or chimney, or inadequately sized flue or chimney, consult a professional heating contractor. If the problem is pressure induced, provide pressure relief. Re-check for spillage following attempt to provide pressure relief. If spillage continues, contact a professional heating contractor to investigate the problem.

10.2.f Carbon Monoxide Test:

This test measures carbon monoxide levels in all operating combustion appliances.

- After 5 minutes of appliance operation, measure the CO level in the flue products of all combustion appliances.
- CO should be measured before appliance draft diverter, or barometric damper.
- CO levels should be below 100 ppm in all flues.
- For gas stoves, measure CO from oven exhaust port and 3 feet above burners with all burners running. CO level should be below 50 ppm.
- If CO found in gas stove, re-measure ambient kitchen CO after 10 minutes of stove operation.

The presence of CO and spillage requires immediate remedial action.

10.2.g Draft Test (natural draft appliances):

This test measures flue draft pressure in the venting systems of all natural draft combustion appliances under worst case depressurization (not to be done for sealed combustion or induced draft appliances).

- Drill a small hole in the vent pipe approx. 2 feet downstream of the draft divertor or barometric damper. Insert a static pressure probe.
- Measure draft pressure (vent WRT combustion room) with digital pressure gauge after 5 minutes of operation.
- Compare measured draft with minimum draft pressures below:

Table 7: Minimum Draft Pressures

Outside Temp	***Draft Pressure***
Below 10 F	*-2.50 Pa*
20 F	*-2.25 Pa*
40 F	*-1.75 Pa*
60 F	*-1.25 Pa*
80 F	*-0.75 Pa*
Above 90 F	*-0.50 Pa*

Source: *CEE Appliance Safety Test Methods, MAC Part 150 Residential Sound Insulation Program, Mpls, MN.*

If measured draft is below the minimum draft pressure above, check for flue or chimney obstructions, disconnected vents, open chimney cleanout doors etc.. Also remove sources depressurization (e.g. turn off exhaust fans) and test again to determine if CAZ depressurization is contributing to poor draft.

10.2.h Heat Exchanger Integrity Test (Forced Air Only):

This test is used to determine if a crack or hole is present in the furnace heat exchanger. A crack or hole could allow products of combustion into the building, and/or promote carbon monoxide production through flame distortion and impingement. There are 3 main types of tests which can be performed:

1. Flame Distortion Test

This test involves watching the furnace flame when the furnace air handler first turns on. Any distortion of the flame indicates a hole or crack in the heat exchanger. This test can be done in conjunction with the flame rollout component of the spillage test. Another method for conducting a flame distortion test is to slowly extend a match up and down into each combustion chamber with the burner off and the air handler fan on, and watch for movement of the flame head.

2. Blocked Flue Test

With the furnace off, block the flue ports leading from the combustion chamber to the draft diverter or barometric damper. Squirt smoke into the combustion chamber. Turn on the furnace fan and watch to see if the smoke is disturbed when the fan comes on. Smoke movement indicates a hole or crack in the heat exchanger.

3. Tracer Gas Test

A number of testing procedures exist for injecting a tracer gas into the combustion chamber (usually with the furnace fan off) and then measuring or detecting the tracer gas on the warm air side of the heat exchanger.

> ***If any of the above heat exchanger tests provides a positive indication for a cracked heat exchanger, immediate action should be taken to notify the residents of the potential danger, and a professional heating contractor should be contacted to investigate the problem.***

Turn off fans and return appliance controls to their original settings once the test procedures have been completed.

Special thanks to Advanced Energy, Sun Power and the Center for Energy and Environment (CEE) for their work in developing and refining the combustion safety test procedures above.

Appendix A Calibration and Maintenance

A.1 Fan Calibration Parameters

Model 3 (110V) Calibration Parameters:

Fan Configuration	**Calibration Parameters**
Open Fan	Flow (cfm) = 490.2 x (Fan Pressure in Pa)$^{.4945}$
Ring A Installed	Flow (cfm) = 180.7 x (Fan Pressure in Pa)$^{.4948}$
Ring B Installed	Flow (cfm) = 57.2 x (Fan Pressure in Pa)$^{.5065}$
Ring C Installed	Flow (cfm) = 22.34 x (Fan Pressure in Pa)$^{.5048}$

Model 3 (230V) Calibration Parameters:

Fan Configuration	**Calibration Parameters**
Open Fan	Flow (cfm) = 481.6 x (Fan Pressure in Pa)$^{.4947}$
Ring A Installed	Flow (cfm) = 183.53 x (Fan Pressure in Pa)$^{.4961}$
Ring B Installed	Flow (cfm) = 59.22 x (Fan Pressure in Pa)$^{.5023}$
Ring C Installed	Flow (cfm) = 20.51 x (Fan Pressure in Pa)$^{.5217}$

Model 4 (230V) Calibration Parameters:

Fan Configuration	**Calibration Parameters**
Open Fan	Flow (cfm) = 401.84 x (Fan Pressure in Pa)$^{.4993}$
Ring A Installed	Flow (cfm) = 160.35 x (Fan Pressure in Pa)$^{.4959}$
Ring B Installed	Flow (cfm) = 48.43 x (Fan Pressure in Pa)$^{.4967}$
Ring C Installed	Flow (cfm) = 11.89 x (Fan Pressure in Pa)$^{.5084}$

Note: All fan flows indicated on Energy Conservatory gauges or flow tables are corrected to a standard air density of 0.075 lbs/cubic foot, and are not the actual volumetric flow going through the fan. The indicated flows are corrected to standard air density according to the CGSB Standard CAN/CG-SB-149.10-M86. The correction is done in such a way that, for particular types of leaks (where the viscosity of air is negligible and the flow exponent "n" equals 0.5), the indicated flow is independent of barometric pressure. For this type of leak, the indicated flow is the flow that would have been going through the fan if the building had been tested at standard barometric pressure, and indoor and outdoor temperatures were unchanged.

If the actual volumetric flow rate going through the fan is desired, multiply the indicated flow by:

$$\sqrt{\frac{0.075}{\text{actual air density*}}}$$ (where air density is in lb/ft3)

or

$$\sqrt{\frac{1.204}{\text{actual air density*}}}$$ (where air density is in Kg/m3)

* Use the density of air flowing through the fan.

A.2 Issues Affecting Fan Calibration

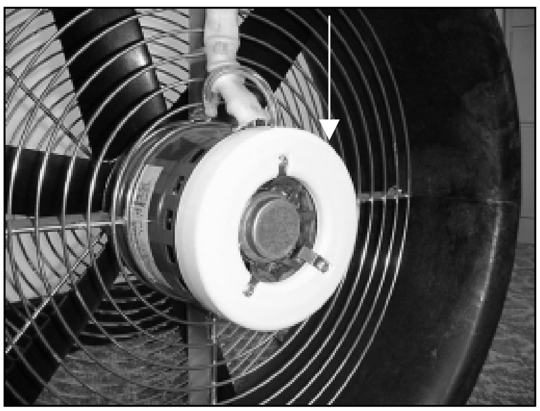
A.2.a Fan Sensor and Motor Position:

Model 3 and Model 4 Blower Door fans maintain their calibration unless physical damage occurs. Conditions which could cause the fan calibration to change are primarily damaged flow sensors, movement of the motor and blades relative to the fan housing, and leaks in the sensor or tubing running from the flow sensor to the fan pressure tap. These conditions are easily detected and should be tested for on a regular basis.

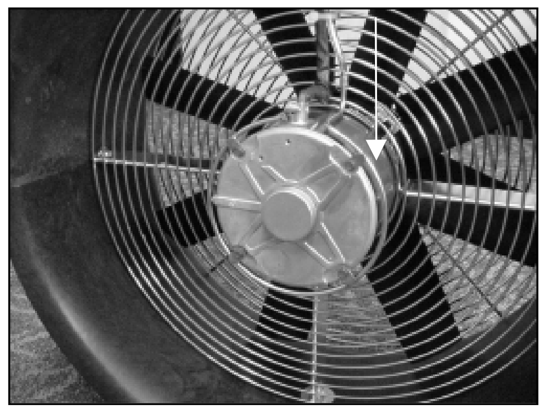
Damaged Blower Door Flow Sensor

Model 3 fans (both 110V and 230V) use a round white plastic flow sensor, while the Model 4 fan uses a flow sensor manufactured out of thin stainless steel tubing. The flow sensors are permanently attached to the end of the fan motor opposite the fan blades.

Model 3 Flow Sensor



Model 4 Flow Sensor



First visually confirm that the sensor is not broken or deformed due to impact. Check that the sensor is firmly attached to the motor. Next, perform a test for leaks in the sensor or the tubing connecting the sensor to the fan pressure tap (this test is easier if you first place the fan in an elevated position such as on a bench top or table.)

Attach a piece of tubing to the pressure tap on the Blower Door fan electrical box. Leave the other end of the tubing open. Find the 4 intentional pin holes in the flow sensor. For the Model 3 flow sensor they are evenly spaced around the outside rim of the sensor - for the Model 4 flow sensor they are evenly spaced on the back side of the sensor. Temporarily seal the 4 holes by covering them with masking tape. Next, create a vacuum in the fan pressure tubing by sucking on the open end. A vacuum in the tubing assures that the flow sensor does not leak. There is a vacuum, if by placing your tongue over the end of the tubing, the tubing sticks to your tongue. Make sure that the vacuum persists for at least 5 seconds. If a vacuum can not be created, contact The Energy Conservatory to further diagnose the sensor leakage problem.

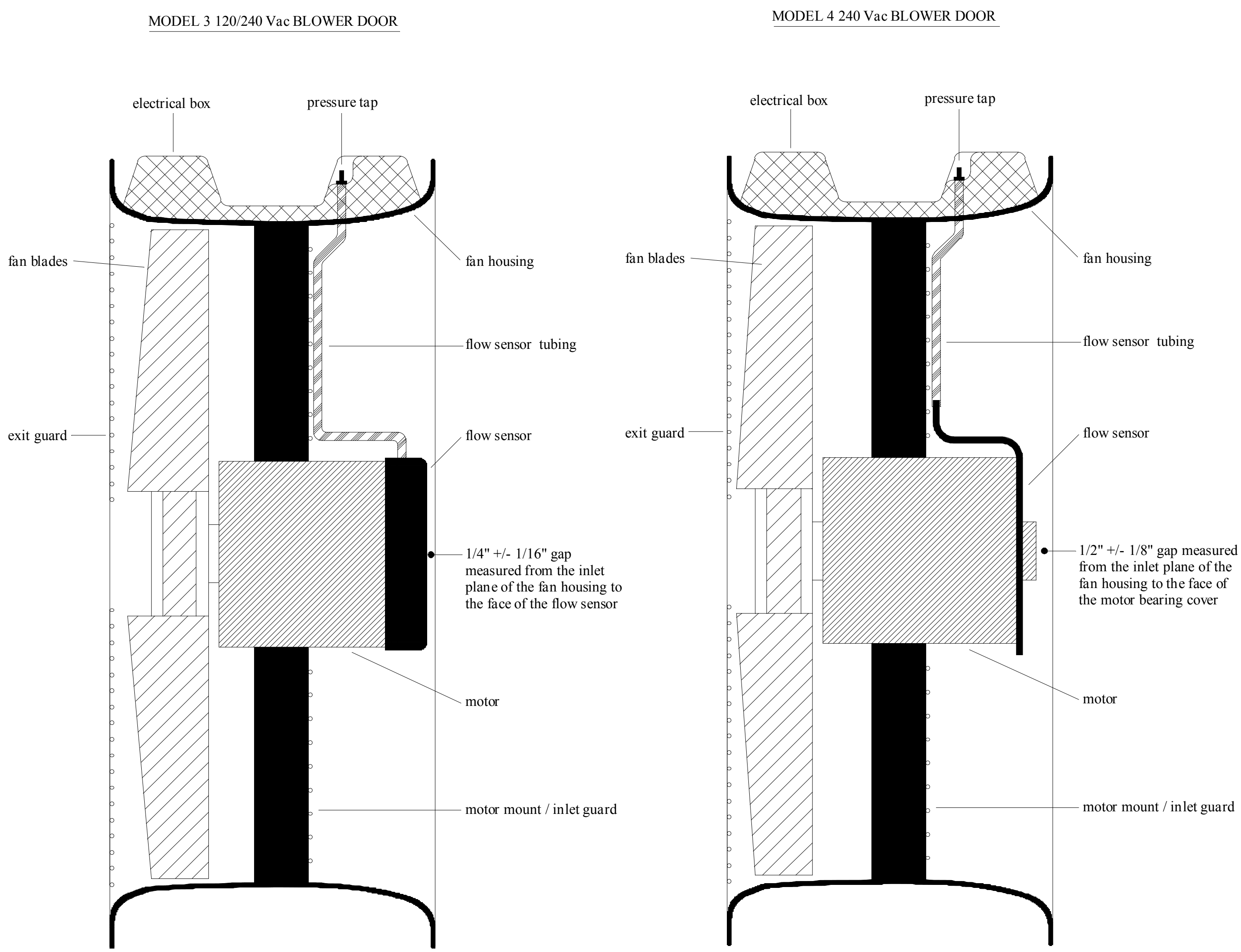
Blower Door Motor Position

If a fan has been dropped, the motor may have shifted from its proper position in the motor mount. This can degrade the fan calibration. To test the motor position, lay the fan on its side with the flow sensor facing up and all Flow Rings removed. Place a straightedge (such as a heavy yardstick on edge) across the inlet of the fan. Use a ruler to measure the following distance and compare this measurement to the appropriate specification.

Model 3 Fan: Measure the distance from the bottom of the straightedge to the face of the flow sensor. This distance should be in the range of 3/16th to 5/16th of an inch. If the motor is not in the proper position, call The Energy Conservatory for further instructions.

Model 4 Fan: Measure the distance from the bottom of the straightedge to the face of the motor bearing cover. This distance should be in the range of 3/8th to 5/8th of an inch. If the motor is not in the proper position, call The Energy Conservatory for further instructions.

Figure 11: Schematic of Blower Door Fans



A.2.b Upstream Air Flow Conditions:

The calibration for all Blower Door fans are slightly sensitive to upstream air flow conditions (e.g. orientation of walls, doors, stairs etc. relative to the fan inlet). This is particularly true when measurements are taken using the "open fan" configuration. As a result, follow these simple rules whenever possible.

- It is always best to install the fan in a doorway leading to a large open room. Try to avoid installing the fan in a doorway where there are stairways or major obstructions to air flow very close (1-5 feet) to the fan inlet.
- If the fan must be installed next to a stairway or major obstruction, it is best to take measurements using one of the Flow Rings and not "open fan".
- Always open the inside door and outside storm door as much as possible during the Blower Door test to prevent restrictions to air flow.

A.2.c Operating Under High Backpressure Conditions:

Note: For most testing applications, backpressure is not a concern and can be ignored.

The term "backpressure" is used to describe the pressure that the Blower Door fan is working against when it is running. Backpressure is determined by measuring the static pressure difference between the air directly upstream of the fan, and the air directly exiting the fan.

Under typical testing applications, the backpressure seen by the fan is simply the test pressure at which the building airtightness measurement is being measured made (e.g. 50 Pascals). However, there are applications where the Blower Door fan could see backpressures that are greater than the test pressure. For example, if the Blower Door fan is exhausting air into a confined area (such as an attached porch), it is possible that the porch area could become pressurized relative to outside creating a backpressure condition that is greater than the test pressure. Although the Blower Door 's flow sensor was designed to be affected as little as possible by variations in backpressure, under certain high backpressure operating conditions (described below) the calibration of the fan can degrade.

Open Fan Configuration, Low Air Flow and High Backpressure

If the Blower Door fan is operated in the open fan configuration (i.e. no Flow Ring), with low air flow (i.e. less than 3,000 cfm), and high backpressure (i.e. greater than 60 Pascals), the flow measurement accuracy of the fan can be diminished.

To avoid this problem:

- If you suspect you are operating under a high backpressure condition, try to measure the backpressure. If the measured backpressure is less than 2 times the fan pressure, then there should not be a problem.
- Always use one of the Flow Rings whenever possible. When Flow Rings are attached to the fan, the fan can reliably measure air flows at higher backpressures.

A.3 Blower Door Fan Maintenance and Safety

There are several maintenance tips and procedures to ensure the proper operation of the Blower Door fan and to avoid any safety risks.

A.3.a Maintenance Checks:

- Examine the motor cooling holes for excessive dust build-up. Use a vacuum with a brush attachment to remove dust, or blow out the dust with compressed air.
- Inspect housing, blades and guards. Especially note clearance of blade tips relative to the fan housing. There should be about 1/4 inch of clearance.
- Inspect electrical wiring and electrical connections on the fan and the fan speed controller.

A.3.b General Operational Notes and Tips:

- Do not reverse the fan (using the flow direction switch) while the blades are turning. Turn off the fan and wait for it to come to a complete stop before reversing the flow direction.
- For long-term operation, such as maintaining house pressure while air-sealing, use a Flow Ring whenever possible to ensure good airflow over the fan. This will minimize the heating of the fan and is especially important in warmer weather. In particular, do not operate the fan for long periods of time on low speed with open fan.
- Do not run the fan for long periods of time in reverse.
- If the motor gets too hot, it may experience a shut-down due to the thermal overload protection. If this happens, make sure to turn off the controller so that the fan does not restart unexpectedly after it cools down.
- Make sure to press the power plug firmly into power receptacle on fan. Failure to do so can cause overheating of the power cord and possible damage.
- Do not use ungrounded outlets or adapter plugs.
- Do not operate if the motor, controller or any of the electrical connections are wet.

The Blower Door Fan is a very powerful and potentially dangerous piece of equipment if not used and maintained properly. Carefully examine the fan before each use. If the fan housing, fan guards, blade, controller or cords become damaged, do not operate the fan until repairs have been made. Keep people and pets away from the fan when it is operating. Contact The Energy Conservatory if there are any unusual noises or vibrations while the fan is running.

A.4 Calibration and Maintenance of Digital Pressure Gauges

A.4.a Digital Gauge Calibration:

Re-calibration of digital pressure gauges is recommended every 12 months. Gauges should be sent back to The Energy Conservatory for re-calibration. It is also a good idea to perform gauge comparisons between calibrations, especially when damage is suspected (e.g. when a gauge has been dropped).

Digital Gauge Comparison

This technique is used to compare the readings of two digital gauges when they are both connected to the same pressure source. When two gauges are being compared, you should expect them to agree within their specifications:

DG-3 Accuracy Specifications:

Low Range:	+/- 1% of reading or 0.2 Pa, whichever is larger (0-200.0 Pa)
High Range:	+/- 1% of reading or 2 Pa, whichever is larger (0-800 Pa)
	+/- 2% of reading (800-1,000 Pa)

DG-700 Accuracy Specifications:

+/- 1% of reading or 0.15 Pa, whichever is greater (0-1,250 Pa)

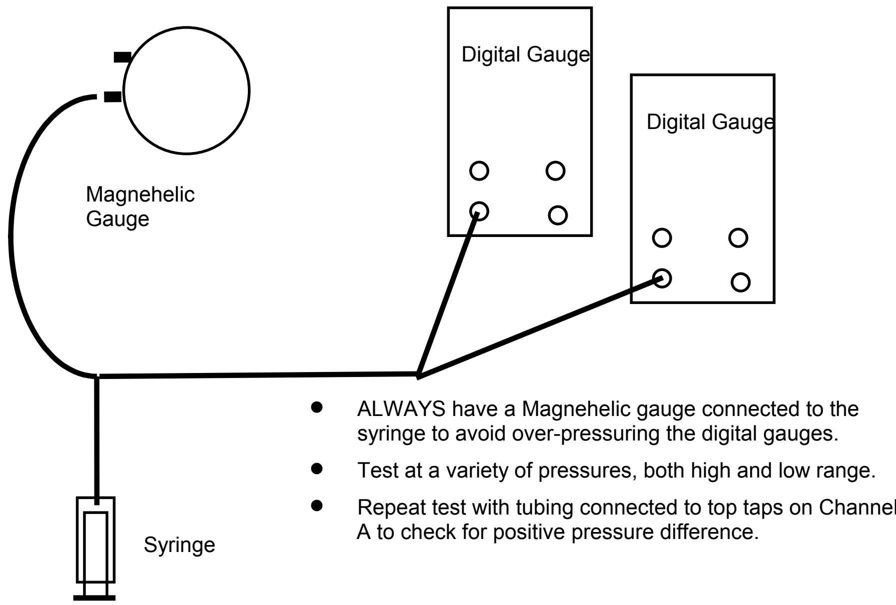
Parts Needed for Comparison

- 2 digital gauges
- one Magnehelic gauge
- 2 “T” fittings
- one syringe
- five 1 foot sections of tubing

Comparison Procedure

Using the two T fittings and short sections of hose, hook up the gauges and syringe as shown in Figure 12 below. Turn on the digital gauges, (if DG-3’s, set on High Range). They should both be reading 0 Pa. Pull out on the syringe slowly until the desired test pressure on the digital gauges is achieved. Record your results and compare with the specifications above.

Figure 12: Digital Gauge Comparison Setup



A.4.b Digital Gauge Maintenance:

- Operating temperature range: 32 ^{o}F to 120 ^{o}F.
- Storage temperatures 5 ^{o}F to 160 ^{o}F (best to keep it warm during cold weather).
- Avoid conditions where condensation could occur, for example taking a gauge from a cool environment into a hot humid environment.
- Do not store gauge in the same container as chemical smoke. The smoke can and does cause corrosion.
- Do not ignore low battery indicator (readings can start being in error almost immediately).
- Avoid exposing the gauge to excessive pressures, such as caused by hoses slammed in a door.

A.5 Checking for Leaky Tubing

It does not happen very often, but leaky tubing can seriously degrade the accuracy of Blower Door airtightness tests. These leaks can be small enough to go undetected for years but large enough to affect fan calibration.

- Before starting, inspect both ends of the tubing to make sure they are not stretched out to the point where they will not make a good seal when attached to a gauge.
- Seal off one end of the tubing by doubling it over on itself near the end.
- Create a vacuum in the tubing by sucking on the open end (make sure the hose is clean first!). Let the end of the tubing stick to your tongue due to the vacuum.
- The tubing should stick to your tongue indefinitely if there are no leaks. Waiting for 5 seconds or so is a good enough test.
- If the tubing has a leak, it should be replaced immediately.
- The ends of the tubing will sometimes get stretched out or torn after many uses. Periodically trim 1/4" off the ends of the tubing to remove the damaged end.

Appendix B Flow Conversion Tables

<u>Model 3 (110V)</u>

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
20	2156	796	261	101
22	2260	834	274	106
24	2360	871	286	111
26	2455	906	298	116
28	2547	940	309	120
30	2635	972	320	124
32	2721	1004	331	128
34	2803	1035	341	132
36	2884	1064	351	136
38	2962	1093	361	140
40	3038	1121	371	144
42	3112	1149	380	147
44	3185	1175	389	151
46	3255	1201	398	154
48	3325	1227	406	158
50	3392	1252	415	161
52	3459	1277	423	164
54	3524	1301	431	167
56	3588	1324	439	170
58	3651	1347	447	173
60	3713	1370	455	176
62	3773	1393	463	179
64	3833	1415	470	182
66	3892	1436	478	185
68	3950	1458	485	188
70	4007	1479	492	191
72	4063	1500	499	193
74	4118	1520	506	196
76	4173	1540	513	199
78	4227	1560	520	201
80	4280	1580	526	204
82	4333	1599	533	207
84	4385	1618	540	209
86	4436	1637	546	212
88	4487	1656	552	214
90	4537	1675	559	217
92	4586	1693	565	219
94	4635	1711	571	221
96	4684	1729	577	224
98	4732	1747	583	226
100	4779	1764	589	228
102	4826	1782	595	231
104	4873	1799	601	233
106	4919	1816	607	235
108	4965	1833	613	237
110	5010	1849	619	240
112	5055	1866	624	242
114	5099	1882	630	244
116	5143	1899	635	246
118	5187	1915	641	248
120	5230	1931	646	250

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
122	5273	1947	652	253
124	5316	1962	657	255
126	5358	1978	663	257
128	5400	1993	668	259
130	5441	2009	673	261
132	5483	2024	678	263
134	5524	2039	684	265
136	5564	2054	689	267
138	5605	2069	694	269
140	5645	2084	699	271
142	5684	2099	704	273
144	5724	2113	709	275
146	5763	2128	714	276
148	5802	2142	719	278
150	5841	2156	724	280
152	5879	2170	729	282
154	5917	2184	733	284
156	5955	2198	738	286
158	5993	2212	743	288
160	6030	2226	748	290
162	6067	2240	753	291
164	6104	2254	757	293
166	6141	2267	762	295
168	6177	2281	767	297
170	6213	2294	771	299
172	6249	2307	776	300
174	6285	2321	780	302
176	6321	2334	785	304
178	6356	2347	789	306
180	6392	2360	794	307
182	6427	2373	798	309
184	6461	2386	803	311
186	6496	2398	807	312
188	6530	2411	811	314
190	6565	2424	816	316
192	6599	2436	820	317
194	6633	2449	824	319
196	6666	2461	829	321
198	6700	2474	833	322
200	6733	2486	837	324
202	6767	2498	842	326
204	6800	2511	846	327
206	6833	2523	850	329
208	6865	2535	854	331
210	6898	2547	858	332
212	6930	2559	862	334
214	6962	2571	866	335
216	6995	2583	871	337
218		2594	875	338
220		2606	879	340
222		2618	883	342
224		2629	887	343
226		2641	891	345
228		2653	895	346
230		2664	899	348
232		2675	903	349
234		2687	907	351
236		2698	910	352
238		2709	914	354
240		2721	918	355

Model 3 (110V) Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
242		2732	922	357
244		2743	926	358
246		2754	930	360
248		2765	934	361
250		2776	937	363
252		2787	941	364
254		2798	945	366
256		2809	949	367
258		2820	953	369
260		2831	956	370
262		2841	960	371
264		2852	964	373
266		2863	967	374
268		2873	971	376
270		2884	975	377
272		2895	978	378
274		2905	982	380
276		2916	986	381
278		2926	989	383
280		2936	993	384
282		2947	996	385
284		2957	1000	387
286		2967	1004	388
288		2978	1007	390
290		2988	1011	391
292		2998	1014	392
294		3008	1018	394
296		3018	1021	395
298		3028	1025	396
300		3038	1028	398
302		3048	1032	399
304		3058	1035	400
306		3068	1039	402
308		3078	1042	403
310		3088	1045	404
312		3098	1049	406
314		3108	1052	407
316		3117	1056	408
318		3127	1059	410
320		3137	1062	411
322		3147	1066	412
324		3156	1069	413
326		3166	1072	415
328		3176	1076	416
330		3185	1079	417
332		3195	1082	419
334		3204	1086	420
336		3214	1089	421
338		3223	1092	422
340		3232	1095	424
342		3242	1099	425
344		3251	1102	426
346		3261	1105	427
348		3270	1108	429
350		3279	1112	430
352		3288	1115	431
354		3298	1118	432
356		3307	1121	434
358		3316	1124	435
360		3325	1128	436
362		3334	1131	437
364		3343	1134	438
366		3352	1137	440
368		3362	1140	441
370		3371	1143	442

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
372		3380	1147	443
374		3389	1150	444
376		3398	1153	446
378		3406	1156	447
380		3415	1159	448
382		3424	1162	449
384		3433	1165	450
386		3442	1168	452
388		3451	1171	453
390		3460	1174	454
392		3468	1177	455
394		3477	1180	456
396		3486	1183	458
398		3494	1186	459
400		3503	1189	460
402		3512	1192	461
404		3520	1195	462
406		3529	1198	463
408		3538	1201	464
410		3546	1204	466
412		3555	1207	467
414		3563	1210	468
416		3572	1213	469
418		3580	1216	470
420		3589	1219	471
422		3597	1222	472
424		3606	1225	474
426		3614	1228	475
428		3622	1231	476
430		3631	1234	477
432		3639	1237	478
434		3647	1240	479
436		3656	1242	480
438		3664	1245	481
440		3672	1248	483
442		3681	1251	484
444		3689	1254	485
446		3697	1257	486
448		3705	1260	487
450		3713	1263	488
452		3722	1265	489
454		3730	1268	490
456		3738	1271	491
458		3746	1274	492
460		3754	1277	493
462		3762	1279	495
464		3770	1282	496
466		3778	1285	497
468		3786	1288	498
470		3794	1291	499
472		3802	1293	500
474		3810	1296	501
476		3818	1299	502
478		3826	1302	503
480		3834	1305	504
482		3842	1307	505
484		3850	1310	506
486		3857	1313	507
488		3865	1315	508
490		3873	1318	509
492		3881	1321	510
494		3889	1324	512
496		3897	1326	513
498		3904	1329	514
500		3912	1332	515

Model 3 (230V)

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
20	2120	811	267	98
22	2222	851	280	103
24	2320	888	292	108
26	2414	924	304	112
28	2504	959	316	117
30	2591	992	327	121
32	2675	1024	338	125
34	2756	1056	348	129
36	2835	1086	358	133
38	2912	1115	368	137
40	2987	1144	378	141
42	3060	1172	387	144
44	3131	1200	396	148
46	3201	1226	405	151
48	3269	1252	414	155
50	3336	1278	423	158
52	3401	1303	431	161
54	3465	1328	439	164
56	3528	1352	447	167
58	3590	1376	455	171
60	3650	1399	463	174
62	3710	1422	471	177
64	3769	1445	478	180
66	3827	1467	486	182
68	3884	1489	493	185
70	3940	1510	500	188
72	3995	1532	507	191
74	4049	1553	514	194
76	4103	1573	521	196
78	4156	1594	528	199
80	4209	1614	535	202
82	4260	1634	542	204
84	4311	1653	548	207
86	4362	1673	555	210
88	4412	1692	561	212
90	4461	1711	568	215
92	4510	1730	574	217
94	4558	1748	580	219
96	4606	1766	586	222
98	4653	1785	592	224
100	4700	1803	599	227
102	4746	1820	604	229
104	4792	1838	610	231
106	4837	1856	616	234
108	4882	1873	622	236
110	4927	1890	628	238
112	4971	1907	634	240
114	5015	1924	639	243
116	5058	1940	645	245
118	5101	1957	650	247
120	5143	1973	656	249

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
122	5186	1990	661	251
124	5228	2006	667	254
126	5269	2022	672	256
128	5310	2037	678	258
130	5351	2053	683	260
132	5392	2069	688	262
134	5432	2084	693	264
136	5472	2100	698	266
138	5512	2115	704	268
140	5551	2130	709	270
142	5590	2145	714	272
144	5629	2160	719	274
146	5668	2175	724	276
148	5706	2190	729	278
150	5744	2204	734	280
152	5782	2219	739	282
154	5819	2233	743	284
156	5856	2248	748	286
158	5893	2262	753	288
160	5930	2276	758	290
162	5967	2290	763	292
164	6003	2304	767	293
166	6039	2318	772	295
168	6075	2332	777	297
170	6111	2345	781	299
172	6146	2359	786	301
174	6181	2373	790	303
176	6216	2386	795	304
178	6251	2400	800	306
180	6286	2413	804	308
182	6320	2426	809	310
184	6355	2439	813	312
186	6389	2453	817	313
188	6423	2466	822	315
190	6456	2479	826	317
192	6490	2491	831	319
194	6523	2504	835	320
196	6556	2517	839	322
198	6589	2530	843	324
200	6622	2542	848	325
202	6655	2555	852	327
204	6687	2568	856	329
206	6720	2580	860	330
208	6752	2592	865	332
210	6784	2605	869	334
212	6816	2617	873	335
214	6848	2629	877	337
216	6879	2641	881	339
218		2653	885	340
220		2666	889	342
222		2678	893	344
224		2689	897	345
226		2701	901	347
228		2713	905	348
230		2725	909	350
232		2737	913	352
234		2748	917	353
236		2760	921	355
238		2772	925	356
240		2783	929	358

Model 3 (230V) Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
242		2795	933	359
244		2806	937	361
246		2817	941	363
248		2829	944	364
250		2840	948	366
252		2851	952	367
254		2862	956	369
256		2874	960	370
258		2885	963	372
260		2896	967	373
262		2907	971	375
264		2918	975	376
266		2929	978	378
268		2940	982	379
270		2951	986	381
272		2961	989	382
274		2972	993	383
276		2983	997	385
278		2994	1000	386
280		3004	1004	388
282		3015	1007	389
284		3026	1011	391
286		3036	1015	392
288		3047	1018	394
290		3057	1022	395
292		3067	1025	396
294		3078	1029	398
296		3088	1032	399
298		3099	1036	401
300		3109	1039	402
302		3119	1043	403
304		3129	1046	405
306		3140	1050	406
308		3150	1053	408
310		3160	1057	409
312		3170	1060	410
314		3180	1063	412
316		3190	1067	413
318		3200	1070	414
320		3210	1074	416
322		3220	1077	417
324		3230	1080	419
326		3240	1084	420
328		3250	1087	421
330		3259	1090	423
332		3269	1094	424
334		3279	1097	425
336		3289	1100	427
338		3298	1103	428
340		3308	1107	429
342		3318	1110	430
344		3327	1113	432
346		3337	1116	433
348		3346	1120	434
350		3356	1123	436
352		3365	1126	437
354		3375	1129	438
356		3384	1133	440
358		3394	1136	441
360		3403	1139	442
362		3413	1142	443
364		3422	1145	445
366		3431	1148	446
368		3441	1152	447
370		3450	1155	449

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
372		3459	1158	450
374		3468	1161	451
376		3477	1164	452
378		3487	1167	454
380		3496	1170	455
382		3505	1173	456
384		3514	1176	457
386		3523	1180	459
388		3532	1183	460
390		3541	1186	461
392		3550	1189	462
394		3559	1192	463
396		3568	1195	465
398		3577	1198	466
400		3586	1201	467
402		3595	1204	468
404		3604	1207	470
406		3612	1210	471
408		3621	1213	472
410		3630	1216	473
412		3639	1219	474
414		3648	1222	476
416		3656	1225	477
418		3665	1228	478
420		3674	1231	479
422		3682	1234	480
424		3691	1237	482
426		3700	1239	483
428		3708	1242	484
430		3717	1245	485
432		3725	1248	486
434		3734	1251	487
436		3742	1254	489
438		3751	1257	490
440		3759	1260	491
442		3768	1263	492
444		3776	1265	493
446		3785	1268	494
448		3793	1271	496
450		3802	1274	497
452		3810	1277	498
454		3818	1280	499
456		3827	1283	500
458		3835	1285	501
460		3843	1288	502
462		3852	1291	504
464		3860	1294	505
466		3868	1297	506
468		3876	1299	507
470		3884	1302	508
472		3893	1305	509
474		3901	1308	510
476		3909	1310	512
478		3917	1313	513
480		3925	1316	514
482		3933	1319	515
484		3941	1321	516
486		3950	1324	517
488		3958	1327	518
490		3966	1330	519
492		3974	1332	520
494		3982	1335	522
496		3990	1338	523
498		3998	1341	524
500		4006	1343	525

Model 4 (230V)

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
20	1793	708	214	55
22	1881	743	225	57
24	1964	775	235	60
26	2044	807	244	62
28	2121	837	253	65
30	2196	866	262	67
32	2268	894	271	69
34	2337	922	279	71
36	2405	948	287	74
38	2471	974	295	76
40	2535	999	303	78
42	2597	1023	310	80
44	2658	1047	317	81
46	2718	1071	324	83
48	2776	1093	331	85
50	2834	1116	338	87
52	2890	1138	345	89
54	2945	1159	351	90
56	2999	1180	358	92
58	3052	1201	364	94
60	3104	1221	370	95
62	3155	1241	376	97
64	3205	1261	382	99
66	3255	1281	388	100
68	3304	1300	394	102
70	3352	1318	400	103
72	3400	1337	405	105
74	3446	1355	411	106
76	3493	1373	416	107
78	3538	1391	422	109
80	3583	1409	427	110
82	3628	1426	432	112
84	3672	1443	437	113
86	3715	1460	443	114
88	3758	1477	448	116
90	3800	1493	453	117
92	3842	1510	458	118
94	3884	1526	463	120
96	3925	1542	467	121
98	3965	1558	472	122
100	4005	1574	477	124
102	4045	1589	482	125
104	4085	1604	486	126
106	4124	1620	491	127
108	4162	1635	496	129
110	4201	1650	500	130
112	4239	1664	505	131
114	4276	1679	509	132
116	4314	1694	513	133
118	4351	1708	518	134
120	4387	1722	522	136

Flow (cfm)

Fan Pressure (Pa)	Open Fan	Ring A	Ring B	Ring C
122	4424	1737	527	137
124	4460	1751	531	138
126	4495	1765	535	139
128	4531	1778	539	140
130	4566	1792	543	141
132	4601	1806	548	142
134	4636	1819	552	143
136	4670	1833	556	145
138	4704	1846	560	146
140	4738	1859	564	147
142	4772	1872	568	148
144	4805	1885	572	149
146	4839	1898	576	150
148	4872	1911	580	151
150	4904	1924	583	152
152	4937	1937	587	153
154	4969	1949	591	154
156	5001	1962	595	155
158	5033	1974	599	156
160	5065	1987	602	157
162	5096	1999	606	158
164	5128	2011	610	159
166	5159	2023	614	160
168	5190	2035	617	161
170	5221	2047	621	162
172	5251	2059	624	163
174	5282	2071	628	164
176	5312	2083	632	165
178	5342	2094	635	166
180	5372	2106	639	167
182	5401	2118	642	168
184	5431	2129	646	169
186	5460	2141	649	169
188	5490	2152	653	170
190	5519	2163	656	171
192	5548	2174	660	172
194	5576	2186	663	173
196	5605	2197	666	174
198	5633	2208	670	175
200	5662	2219	673	176
202	5690	2230	676	177
204	5718	2241	680	178
206	5746	2252	683	178
208	5774	2263	686	179
210	5801	2273	690	180
212	5829	2284	693	181
214	5856	2295	696	182
216	5884	2305	699	183
218		2316	702	184
220		2326	706	185
222		2337	709	185
224		2347	712	186
226		2358	715	187
228		2368	718	188
230		2378	721	189
232		2388	725	190
234		2399	728	190
236		2409	731	191
238		2419	734	192
240		2429	737	193

Model 4 (230V) Flow (cfm)

Fan Pressure	Open Fan	Ring A	Ring B	Ring C
242		2439	740	194
244		2449	743	195
246		2459	746	195
248		2469	749	196
250		2479	752	197
252		2488	755	198
254		2498	758	199
256		2508	761	199
258		2518	764	200
260		2527	767	201
262		2537	770	202
264		2546	773	202
266		2556	775	203
268		2566	778	204
270		2575	781	205
272		2584	784	206
274		2594	787	206
276		2603	790	207
278		2613	793	208
280		2622	795	209
282		2631	798	209
284		2640	801	210
286		2650	804	211
288		2659	807	212
290		2668	809	212
292		2677	812	213
294		2686	815	214
296		2695	818	215
298		2704	820	215
300		2713	823	216
302		2722	826	217
304		2731	829	218
306		2740	831	218
308		2749	834	219
310		2758	837	220
312		2766	839	220
314		2775	842	221
316		2784	845	222
318		2793	847	223
320		2801	850	223
322		2810	853	224
324		2819	855	225
326		2827	858	225
328		2836	860	226
330		2844	863	227
332		2853	866	227
334		2862	868	228
336		2870	871	229
338		2878	873	230
340		2887	876	230
342		2895	879	231
344		2904	881	232
346		2912	884	232
348		2920	886	233
350		2929	889	234
352		2937	891	234
354		2945	894	235
356		2953	896	236
358		2962	899	236
360		2970	901	237
362		2978	904	238
364		2986	906	238
366		2994	909	239
368		3002	911	240
370		3011	914	240

Flow (cfm)

Fan Pressure	Open Fan	Ring A	Ring B	Ring C
372		3019	916	241
374		3027	918	242
376		3035	921	242
378		3043	923	243
380		3051	926	244
382		3059	928	244
384		3066	931	245
386		3074	933	246
388		3082	935	246
390		3090	938	247
392		3098	940	248
394		3106	943	248
396		3114	945	249
398		3121	947	249
400		3129	950	250
402		3137	952	251
404		3145	954	251
406		3152	957	252
408		3160	959	253
410		3168	961	253
412		3175	964	254
414		3183	966	254
416		3191	968	255
418		3198	971	256
420		3206	973	256
422		3213	975	257
424		3221	978	258
426		3228	980	258
428		3236	982	259
430		3243	984	259
432		3251	987	260
434		3258	989	261
436		3266	991	261
438		3273	993	262
440		3281	996	262
442		3288	998	263
444		3295	1000	264
446		3303	1002	264
448		3310	1005	265
450		3317	1007	266
452		3325	1009	266
454		3332	1011	267
456		3339	1013	267
458		3347	1016	268
460		3354	1018	268
462		3361	1020	269
464		3368	1022	270
466		3375	1024	270
468		3383	1027	271
470		3390	1029	271
472		3397	1031	272
474		3404	1033	273
476		3411	1035	273
478		3418	1037	274
480		3425	1040	274
482		3432	1042	275
484		3439	1044	276
486		3446	1046	276
488		3453	1048	277
490		3460	1050	277
492		3467	1052	278
494		3474	1055	278
496		3481	1057	279
498		3488	1059	280
500		3495	1061	280

Appendix C Using Flow Rings C, D and E

C.1 Using Ring C

Ring C is used with the Model 3 and 4 Minneapolis Blower Door to measure fan flows between 100 and 300 cfm. Flows in this range are typically only measured in very tightly constructed new houses.

C.1.a Installation:

To install Ring C, nest it in the center of Ring B so that the 3 notches on the outside of Ring C line up with the 3 fastening washers on Ring B. Be sure the finger hole on Ring C is located on the top of the ring (12 o'clock) before attaching it to Ring B. While gently pushing Ring C against Ring B, turn Ring C clockwise until it is securely fastened in place.

Note: For maximum accuracy when using Ring C, temporarily tape the following locations to prevent leakage between the Rings. Taping is not necessary when using Rings A and B.

- the outer edge between Ring A and the fan housing.
- the edge (joint) between Ring B and Ring A.
- the edge (joint) between Ring C and Ring B.

C.1.b Calibration Formulas for Ring C:

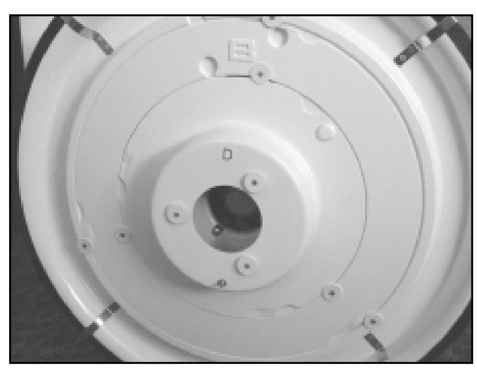
Model 3 (110V):	Flow (cfm) = 22.34 x (Fan Pressure in Pa)$^{.5048}$
Model 3 (230V):	Flow (cfm) = 20.51 x (Fan Pressure in Pa)$^{.5217}$
Model 4 (230V):	Flow (cfm) = 11.89 x (Fan Pressure in Pa)$^{.5084}$

A flow conversion table for Ring C can be found in Appendix B.

C.2 Using Rings D and E

Rings D and E have been designed to measure very low air flows with Model 3 and 4 Minneapolis Blower Door systems. Ring D will accurately measure flows between 125 and 40 cfm. Ring E will accurately measure flows between 40 and 15 cfm.

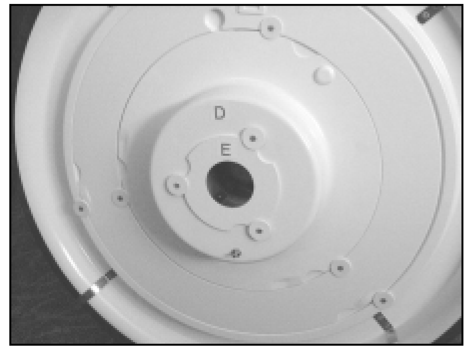
C.2.a Installation:



Ring D

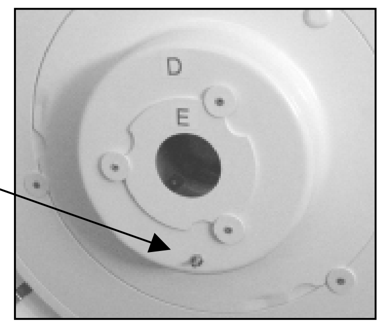
Ring D is fabricated from a modified flow Ring C. Ring D attaches directly to Ring B and is secured by the 3 fastening washers found on Ring B. To install Ring D, first orient the Ring so that the letter "D" is facing towards you and is located at approximately the "11 o'clock" position. In this position, the 3 notches on Ring D should line up with the 3 fastening washers on Ring B. While gently pushing Ring D against Ring B, turn Ring D clockwise so that the edges of Ring D slide underneath the fastening washers. Continue to turn Ring D clockwise until the letter "D" is in the "12 o'clock" position. Once installed correctly, the pressure tap located on Ring D should be located on the bottom of the Ring (or at the "6 o'clock" position).

Ring E



Ring E attaches directly to Ring D and is secured by the 3 fastening washers located on Ring D. To install Ring E, first orient the Ring so that the letter "E" is facing towards you and is located at approximately the "11 o'clock" position. In this position, the three notches on Ring E should line up with the 3 fastening washers on Ring D. Nest Ring E against Ring D, and while gently pushing the Rings together, turn Ring E clockwise so that the edges of Ring E slide underneath the fastening washers. Continue to turn Ring E until the letter "E" is in the "12 o'clock" position.

C.2.b Measuring Fan Pressure:



When using Rings D and E, it is necessary to measure fan pressure by using the pressure tap mounted directly on Ring D, rather than the pressure tap located on the top of the fan.

In addition, for maximum accuracy when using Rings D and E, tape the following locations to prevent leakage between Rings:

- the outer edge between Ring A and the fan housing.
- the edge (joint) between Ring B and Ring A.
- the edge (joint) between Ring D and Ring B.

C.2.c Calibration Formulas (for both Model 3 and Model 4 fans):

Ring D: Flow (CFM) = $7.596 \times (\text{Fan Pressure in Pa})^{.4927}$

Ring E: Flow (CFM) = $3.041\ (\text{Fan Pressure in Pa})^{.5016}$

A flow conversion table for Rings D and E is presented below:

Flow Conversion Table for Rings D and E

Fan Pressure (Pa)	Low-Flow Ring D Flow (cfm)	Low-Flow Ring E Flow (cfm)	
20	33	14	
25	37	15	
30	41	17	
35	44	18	
40	47	19	
45	50	21	
50	52	22	
55	55	23	
60	57	24	
65	59	25	
70	62	26	
75	64	27	
80	66	27	
85	68	28	
90	70	29	
95	72	30	
100	73	31	

Fan Pressure (Pa)	Low-Flow Ring D Flow (cfm)	Low-Flow Ring E Flow (cfm)	
105	75	31	
110	77	32	
115	79	33	
120	80	34	
125	82	34	
130	84	35	
135	85	36	
140	87	36	
145	88	37	
150	90	38	
155	91	38	
160	93	39	
165	94	39	
170	95	40	
175	97	41	
180	98	41	
185	99	42	

Fan Pressure (Pa)	Low-Flow Ring D Flow (cfm)	Low-Flow Ring E Flow (cfm)	
190	101	42	
195	102	43	
200	103	43	
205	105	44	
210	106	44	
215	107	45	
220	108	45	
225	110	46	
230	111	47	
235	112	47	
240	113	48	
245	114	48	
250	115	49	
255	116	49	
260	118	49	
265	119	50	
270	120	50	
275	121	51	
280	122	51	

Fan Pressure (Pa)	Low-Flow Ring D Flow (cfm)	Low-Flow Ring E Flow (cfm)	
285	123		
290	124		
295	125		
300	126		
305	127		
310	128		
315	129		
320	130		
325	131		
330			
335			
340			
345			
350			
355			
360			
365			
365			
370			

Appendix D Sample Test Forms

Example Completed Form

Building Airtightness Test Form

Customer Information:

Name: Tom Jones
Address: 2345 First ave.
City: Minneapolis
State/Zip: MN, 55444
Phone: 612-566-6000
Email: tjones@wildworld.com

Building Address: (if different from above)

Street: ______
City/State: ______

Building and Test Conditions:

Date: Jan 1, 2000
Time: 1:00 PM
Indoor Temperature (F): 70
Outdoor Temperature (F): 20
Volume (ft^3): 22000
Floor Area (ft^2): 2800
Surface Area (ft^2): 3000
Bedrooms: 4
Occupants: 4
Wind Shielding: Moderate

Comments:

Owner complains of condensation on windows.
Crawlspace is wet.
2 smokers in the house.
Downspouts dump directly at the base of the house.

Test #1

Depress __x__ Press ______

Pre-test Baseline Pressure: 0 (Pa) Mag Gauges

Bdlg Press. (Pa)	Flow Ring Installed	Fan Press (Pa)	Flow (cfm)
-55	Open	73	4091
-50	Open	65	3862
-44	Open	56	3588
-38	Open	45	3220
-30	Open	33	2762
-26	Open	26	2455
-15	Ring A	100	1764

Post-test Baseline Pressure: N/A (Pa)
Fan Model/SN: Model3 S/N 8331

Results: (from TECTITE Program)

CFM50: 3674
ACH50: 10.0
CFM50/ft^2: 1.3
Mpls Leakage Ratio: 1.2

Test #2

Depress ______ Press ______

Pre-test Baseline Pressure: ______ (Pa)

Bdlg Press. (Pa)	Flow Ring Installed	Fan Press (Pa)	Flow (cfm)

Post-test Baseline Pressure: ______ (Pa)
Fan Model/SN: ______

Results:

CFM50: ______
ACH50: ______
CFM50/ft^2: ______
Mpls Leakage Ratio: ______

Example Blank Form

Building Airtightness Test Form

Customer Information:

Name: ____________________

Address: ____________________

City: ____________________

State/Zip: ____________________

Phone: ____________________

Email: ____________________

Building and Test Conditions:

Date: ____________

Time: ____________

Indoor Temperature (F): ____________

Outdoor Temperature (F): ____________

Volume (ft^3): ____________

Floor Area (ft^2): ____________

Surface Area (ft^2): ____________

Bedrooms: ____________

Occupants: ____________

Wind Shielding: ____________

Building Address: (if different from above)

Street: ____________________

City/State: ____________________

Comments:

____

____

____

____

Test #1

Depress ______ Press ______

Pre-test Baseline Pressure: ______ (Pa)

Bdlg Press. (Pa)	Flow Ring Installed	Fan Press (Pa)	Flow (cfm)

Post-test Baseline Pressure: ______ (Pa)

Fan Model/SN: ____________________

Results:

CFM50: ____________

ACH50: ____________

CFM50/ft^2: ____________

Mpls Leakage Ratio: ____________

Test #2

Depress ______ Press ______

Pre-test Baseline Pressure: ______ (Pa)

Bdlg Press. (Pa)	Flow Ring Installed	Fan Press (Pa)	Flow (cfm)

Post-test Baseline Pressure: ______ (Pa)

Fan Model/SN: ____________________

Results:

CFM50: ____________

ACH50: ____________

CFM50/ft^2: ____________

Mpls Leakage Ratio: ____________

Appendix E Home Energy Article *

Infiltration: Just ACH50 Divided by 20?

by Alan Meier
*Alan Meier is executive editor of **Home Energy Magazine**.*

This** **Home Energy** **classic, originally printed in 1986, explains a simple way to take one air infiltration measurement and determine a home's average air infiltration rate.

Many researchers have sought to develop a correlation between a one-time pressurization test and an annual infiltration rate. Translating blower door measurements into an average infiltration rate has bedeviled the retrofitter and researcher alike. The rate of air infiltration constantly varies, yet the pressurization test is typically a single measurement. Nevertheless, many researchers have sought to develop a correlation between a one-time pressurization test and an annual infiltration rate.

ACH Divided by 20

In the late 1970s, a simple relation between a one-time pressurization test and an average infiltration rate grew out of experimentation at Princeton University. For a few years, the correlation remained "Princeton folklore" because no real research supported the relationship. In 1982, J. Kronvall and Andrew Persily compared pressurization tests to infiltration rates measured with tracer-gas for groups of houses in New Jersey and Sweden. They focused on pressurization tests at 50 Pascals because this pressure was already used by the Swedes and Canadians in their building standards. (This measurement is typically called "ACH50.") Other countries and groups within the United States have also adopted ACH as a measure of house tightness. Persily (now at the National Institute of Science and Technology) obtained a reasonably good estimate of average infiltration rates by dividing the air change rates at 50 Pascals by 20, that is:

$$\text{average infiltration rate (ACH)} = \frac{\text{ACH50}}{20} \quad (1)$$

In this formula, ACH50 denotes the hourly air change rate at a pressure difference of 50 Pascals between inside and outside. Thus, for a house with 15 ACH at 50 Pascals (ACH50 = 15), one would predict an average air change rate of (15/20 =) 0.75 ACH.

This simple formula yields surprisingly reasonable average infiltration estimates, even though it ignores many details of the infiltration process. These "details" are described below:

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- ***Stack effect.*** Rising warm air induces a pressure difference, or "stack effect," that causes exfiltration through the ceiling and infiltration at (or below) ground level. The stack effect depends on both the outside temperature and the height of the building. A colder outside temperature will cause a stronger stack effect. Thus, given two identically tall buildings, the one located in a cold climate will have more stack-induced infiltration. A taller building will also have a larger stack effect. Even though outside temperature and building height affect average infiltration rates, neither is measured by the pressure test. During the summer, stack effects disappear because the inside air is usually cooler (especially when the air conditioner is operating). Wind-induced pressure therefore becomes the dominant infiltration path.

- ***Windiness and wind shielding.*** Wind is usually the major driving force in infiltration, so it is only reasonable to expect higher infiltration rates in windy areas. Thus, given two identical buildings, the one located in a windy location will have more wind-induced infiltration. Nevertheless, a correlation such as ACH50/20 does not include any adjustment for windiness at the house's location. Trees, shrubs, neighboring houses, and other materials also shield a house from the wind's full force. Since a brisk wind can easily develop 10 Pascals on a windward wall, the extent of shielding can significantly influence total infiltration. A pressurization test does not directly measure the extent of shielding (although a house with good shielding may yield more accurate measurements since it is less affected by wind).

- ***Type of leaks.*** The leakage behavior of a hole in the building envelope varies with the shape of the hole. A long thin crack, for example, responds less to variations in air pressure than a round hole does. The pressure/air change curve (determined with a calibrated blower door) often gives clues to the types of leaks in a house.

A person conducting pressurization tests on a particular house can collect considerable information about these details. For example, it is easy to measure a house's height and estimate the wind exposure. The kinds of cracks can often be judged through careful inspection of the building construction. Climate data, including windiness and temperature, can be obtained from local weather stations. Ideally, this additional information should be applied to the formula in order to get a correlation factor more accurate for that house. Unfortunately, the formula was developed from data in just a few houses in New Jersey and Sweden, and it cannot be easily adjusted to other locations and circumstances. Should a retrofitter in Texas also use ACH50/20, or is dividing by 15 more appropriate for the Texas climate and house construction types?

The LBL Infiltration Model

Researchers at Lawrence Berkeley Laboratory developed a model to convert a series of fan pressurization measurements into an "equivalent leakage area." (See HE, "Blower Doors: Infiltration Is Where the Action Is," Mar/Apr. '86, p.6. and the ASHRAE Book of Fundamentals chapter on ventilation and infiltration.) The equivalent leakage area roughly corresponds to the combined area of all the house's leaks.

A second formula converts the equivalent leakage area into an average infiltration rate in air changes per hour. This formula combines the physical principles causing infiltration with a few subjective estimates of building characteristics, to create relatively robust estimates of infiltration. ASHRAE has approved the technique and describes the formulae in ASHRAE Fundamentals. The LBL infiltration model is now the most commonly accepted procedure for estimating infiltration rates.

Max Sherman at LBL used this model to derive the theoretical correlation between pressure tests at 50 Pascals and annual average infiltration rates.[1] His major contribution was to create a climate factor to reflect the influence of outside temperature (which determines the stack effect) and windiness. Sherman estimated the climate factor using climate data for North America and plotted it (see Figure 1). Since the factor reflects both temperature and seasonal windiness, a cold, calm location could have the same climate factor as a warm, windy location. The map also reflects summer infiltration characteristics. Note how Texas and Vermont have the same climate factors.

Sherman found that the correlation factor in the revised formula could be expressed as the product of several factors:

$$\text{correlation factor, } N = C * H * S * L \quad (2)$$

where:

C = climate factor, a function of annual temperatures and wind (see Figure 1)

H = height correction factor (see Table 1)

S = wind shielding correction factor (see Table 2)

L = leakiness correction factor (see Table 3)

Values for each of the factors can be selected by consulting Figure 1 and Tables 1-3. An estimate of the average annual infiltration rate is thus given by

$$\text{average air changes per hour} = \frac{ACH50}{N} \quad (3)$$

This formula provides a more customized "rule-of-thumb" than the original ACH50/20 , when additional information about the house is available.

An Example

The application of the climate correction is best shown in an example. Suppose you are pressure testing a new, low-energy house in Rapid City, South Dakota. It is a two-story house, on an exposed site, with no surrounding vegetation or nearby houses to protect it from the wind.

1. At 50 Pascals, you determine that the ACH50 is 14.
2. You consult Figure 1, and determine that the house has a climate factor, "C," of 14-17. Since Rapid City is near a higher contour line, select 17.
3. The house is two stories tall, so the appropriate height correction factor, "H" (from Table 1), is 0.8.
4. The house is very exposed to wind, and there are no neighboring houses or nearby trees and shrubs. The appropriate wind shielding correction factor, "S" (from Table 2), is 0.9.
5. The house is new, and presumably well-built. The appropriate leakiness factor, "L" (from Table 3), is 1.4.

6. Calculate N:

$$N = 17 * 0.8 * 0.9 * 1.4$$

$$= 17$$

Calculate the average annual infiltration rate:

$$ACH = \frac{ACH50}{17}$$

$$= \frac{14}{17}$$

$$= 0.82$$

The difference in this case (between dividing by 20 and 17) is not great--only 17%--but it demonstrates how the building conditions and location can affect the interpretation of pressurization tests.

Sherman compared his results to those reported by Persily. Sherman noted that he obtained a correlation factor (N) of about 20 for a typical house in the New Jersey area. Thus, Sherman's theoretically derived correlation factor yields results similar to Persily's empirically derived correlation factor.

The range of adjustment can be quite large. In extreme cases, the correlation factor, N, can be as small as 6, and as large as 40. In other words, the ACH50/20 rule of thumb could overestimate infiltration by a factor of two, or underestimate it by a factor of about three.
This formula is still only a theory; it has not been validated with field measurements. Moreover, there is considerable controversy regarding the physical interpretation of the climate factor. For example, the formula yields a year-round average infiltration rate, rather than just for the heating season. Such a result is useful for houses with both space heating and cooling, but it may be misleading for some areas.

Recommendations

There is no simple way to accurately convert a single pressure-test of a building to an average infiltration rate, because many building and climate-dependent factors affect true infiltration. Long-term tracer gas measurements are the only reliable way to obtain average infiltration rates. However, tracer gas measurements are impractical for retrofitters, and even most conservation researchers. A simplified rule of thumb to let the retrofitter quickly translate a pressure-test to an infiltration rate is clearly attractive.

Persily and Kronvall developed a crude conversion technique, ACH50/20, that provides reasonable results. On the other hand, it was impossible to customize the relationship of ACH50/20 to local conditions. What are the components of the magic number, 20?

Now Sherman has created a similar conversion factor that can be modified to reflect local building and climate conditions. This correlation factor accounts for windiness, climate, stack effect, and construction quality. Some judgement is needed to select the appropriate correction factors, but the blower-door user can now understand the quantitative impact of local conditions on infiltration. For example, a three-story house will have significantly more infiltration than a ranch house--even though the pressure tests are identical--due to a greater stack effect. (Clearly an infiltration standard should take these factors into account.)

Of course, Sherman's correlation factor still cannot account for occupant behavior or perversities in the building's construction. Nor is it a substitute for tracer-gas measurements. Field measurements must also be conducted to validate the formula. Still, it puts a scientific foundation behind what was previously an empirically derived relationship. It is a modest step forward in the efficient and accurate use of the blower door.

Table 1. Height Correction Factor

Select the most appropriate value and insert in Equation 2.

Number of stories	1	1.5	2	3
Correction factor "H"	1.0	0.9	0.8	0.7

Table 2. Wind Shielding Correction Factor

Select the most appropriate value and insert in Equation 2.

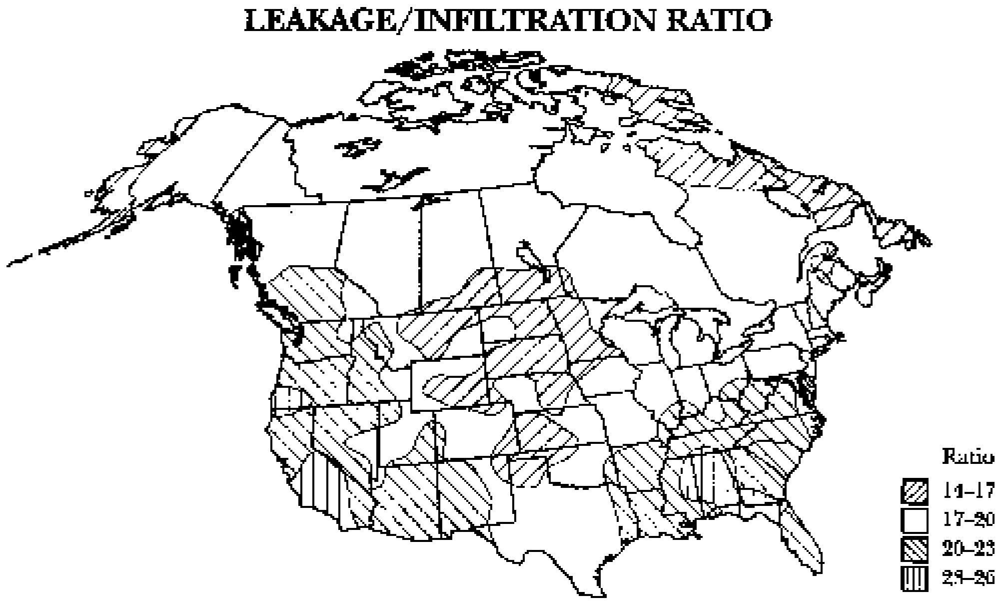
Extent of shielding	well-shielded	normal	exposed
Correction factor "S"	1.2	1.0	0.9

Table 3. Leakiness Correction Factor

Select the most appropriate value and insert in Equation 2.

Type of holes	small cracks (tight)	normal	large holes (loose)
Correction factor "L"	1.4	1.0	0.7

Figure 1: LEAKAGE/INFILTRATION RATIO



Climate correction factor, "C," for calculating average infiltration rates in North America. Note that the climate correction factor depends on both average temperatures and windiness. It also includes possible air infiltration during the cooling season. For these reasons, locations in greatly dissimilar climates, such as Texas and Vermont, can have equal factors. Select the value nearest to the house's location and insert it in Equation 2. This map is based on data from 250 weather stations.

Appendix F Calculating a Design Air Infiltration Rate

The following procedure can be used to calculate a design air infiltration rate for a house from a single or multi-point blower door airtightness test. Calculated design air infiltration rates can be used in ACCA Manual J load calculations in lieu of the estimation procedures listed in Manual J. The calculation procedure presented below is based on the Lawrence Berkeley Laboratory (LBL) infiltration model. More information on this procedure can be found in the 1997 ASHRAE Fundamentals Handbook, Section 25.34.

Note: This calculation procedure is contained in the TECTITE test analysis software.

- Determine the 4 Pascal Effective Leakage Area (ELA) of the house in square inches from the Blower Door test data. This can be done in 2 ways:

  1. Perform a multi-point Blower Door test of the house and determine the ELA using the TECTITE software, or

  2. Perform a single-point 50 Pa Blower Door test to determine house CFM50. Multiply CFM50 by 0.055 to estimate the ELA of the house in square inches. This procedure assumes the "House Leakage Curve" has a slope (or "N" value) of 0.65. Research has shown that N = 0.65 is a reasonable assumption for a large sample of houses.

- Determine the ***Stack Coefficient (A)*** and the ***Wind Coefficient (B)*** for the house from the Tables below:

Stack Coefficient (A)

House Height (Stories)		
One	Two	Three
0.0156	0.0313	0.0471

Wind Coefficient (B)

Shielding Class	House Height (Stories)		
	One	Two	Three
1	0.0119	0.0157	0.0184
2	0.0092	0.0121	0.0143
3	0.0065	0.0086	0.0101
4	0.0039	0.0051	0.0060
5	0.0012	0.0016	0.0018

Shielding Class Description

1. No obstructions or local shielding.
2. Light local shielding, few obstructions, a few trees or small shed.
3. Moderate local shielding; some obstructions within two house heights, thick hedge, solid fence or one neighboring house.
4. Heavy shielding; obstructions around most of perimeter, building or trees within 30 feet in most directions; typical suburban shielding.
5. Very heavy shielding; large obstructions surrounding perimeter within two house heights; typical downtown shielding.

- Determine the air flow rate due to infiltration from the following equation:

$$Q = L \times ((A \times T) + (B \times V^2))^{1/2}$$

where:

Q = airflow rate in cubic feet per minute (CFM).
L = Effective Leakage Area (ELA) in square inches.
A = Stack Coefficient.
T = Design indoor-outdoor temperature difference (F).
B = Wind Coefficient.
V = Design wind speed (MPH - measured at a local weather station).

Frequency data for mean hourly wind speeds within the United States can be found in a summarized printed pamphlet from the National Climatic Center in Asheville, North Carolina, and from the Atmospheric Environment Service in Downsview, Ontario for Canadian sites.

- Convert airflow rate in CFM to Air Changes per Hour (ACH).

$$ACH = (Q \times 60) / \text{Volume of House in Cubic Feet}$$

Example Calculation

Estimate the winter-time design infiltration rate for a 2 story, 30,000 cubic foot house in Minneapolis with suburban wind shielding. Use a design wind speed of 20 MPH and a design temperature difference of 82 degrees F. A single-point Blower Door test of the house measured an airtightness rate of 2,350 CFM50.

Estimated ELA in square inches = 2,350 x 0.055 = 129.25

$$Q = 129.25 \times ((0.0313 \times 82) + (0.0051 \times 20^2))^{1/2}$$

$$= 277.4 \text{ CFM}$$

ACH = (277.4 x 60) / 30,000 = 0.55 ACH

Appendix G References

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Appendix H Air Density Correction Factors

H.1 Air Density Correction Factors for Depressurization Testing

		INSIDE TEMPERATURE (F)								
		50	55	60	65	70	75	80	85	90
	-20	0.929	0.924	0.920	0.915	0.911	0.907	0.903	0.898	0.894
	-15	0.934	0.930	0.925	0.921	0.916	0.912	0.908	0.904	0.899
	-10	0.939	0.935	0.930	0.926	0.921	0.917	0.913	0.909	0.904
	-5	0.945	0.940	0.935	0.931	0.927	0.922	0.918	0.914	0.909
	0	0.950	0.945	0.941	0.936	0.932	0.927	0.923	0.919	0.914
	5	0.955	0.950	0.946	0.941	0.937	0.932	0.928	0.924	0.919
	10	0.960	0.955	0.951	0.946	0.942	0.937	0.933	0.929	0.924
	15	0.965	0.960	0.956	0.951	0.947	0.942	0.938	0.934	0.929
	20	0.970	0.965	0.961	0.956	0.952	0.947	0.943	0.938	0.934
	25	0.975	0.970	0.966	0.961	0.957	0.952	0.948	0.943	0.939
	30	0.980	0.975	0.971	0.966	0.962	0.957	0.953	0.948	0.944
	35	0.985	0.980	0.976	0.971	0.966	0.962	0.957	0.953	0.949
OUTSIDE	40	0.990	0.985	0.981	0.976	0.971	0.967	0.962	0.958	0.953
TEMPERATURE	45	0.995	0.990	0.985	0.981	0.976	0.972	0.967	0.963	0.958
(F)	50	1.000	0.995	0.990	0.986	0.981	0.976	0.972	0.967	0.963
	55	1.005	1.000	0.995	0.990	0.986	0.981	0.977	0.972	0.968
	60	1.010	1.005	1.000	0.995	0.991	0.986	0.981	0.977	0.972
	65	1.015	1.010	1.005	1.000	0.995	0.991	0.986	0.981	0.977
	70	1.019	1.014	1.010	1.005	1.000	0.995	0.991	0.986	0.982
	75	1.024	1.019	1.014	1.009	1.005	1.000	0.995	0.991	0.986
	80	1.029	1.024	1.019	1.014	1.009	1.005	1.000	0.995	0.991
	85	1.034	1.029	1.024	1.019	1.014	1.009	1.005	1.000	0.995
	90	1.038	1.033	1.028	1.024	1.019	1.014	1.009	1.005	1.000
	95	1.043	1.038	1.033	1.028	1.023	1.019	1.014	1.009	1.005
	100	1.048	1.043	1.038	1.033	1.028	1.023	1.018	1.014	1.009
	105	1.053	1.047	1.042	1.037	1.033	1.028	1.023	1.018	1.014
	110	1.057	1.052	1.047	1.042	1.037	1.032	1.027	1.023	1.018

To use the air density correction factor, multiply the measured fan flow by the appropriate correction factor from the Table above. For example, if the measured fan flow was 3,200 cfm, and during the test the inside temperature was 70 F and the outside temperature was 40 F, the appropriate correction factor would be 0.971. The density corrected fan flow is 3,200 x 0.971 = 3,107 cfm

H.2 Air Density Correction Factors for Pressurization Testing

OUTSIDE TEMPERATURE (F)	INSIDE TEMPERATURE (F)								
	50	55	60	65	70	75	80	85	90
-20	1.077	1.082	1.087	1.092	1.098	1.103	1.108	1.113	1.118
-15	1.071	1.076	1.081	1.086	1.091	1.097	1.102	1.107	1.112
-10	1.065	1.070	1.075	1.080	1.085	1.090	1.096	1.101	1.106
-5	1.059	1.064	1.069	1.074	1.079	1.084	1.089	1.095	1.100
0	1.053	1.058	1.063	1.068	1.073	1.078	1.084	1.089	1.094
5	1.047	1.052	1.058	1.063	1.068	1.073	1.078	1.083	1.088
10	1.042	1.047	1.052	1.057	1.062	1.067	1.072	1.077	1.082
15	1.036	1.041	1.046	1.051	1.056	1.061	1.066	1.071	1.076
20	1.031	1.036	1.041	1.046	1.051	1.056	1.061	1.066	1.070
25	1.025	1.030	1.035	1.040	1.045	1.050	1.055	1.060	1.065
30	1.020	1.025	1.030	1.035	1.040	1.045	1.050	1.055	1.059
35	1.015	1.020	1.025	1.030	1.035	1.040	1.044	1.049	1.054
40	1.010	1.015	1.020	1.025	1.030	1.034	1.039	1.044	1.049
45	1.005	1.010	1.015	1.020	1.024	1.029	1.034	1.039	1.044
50	1.000	1.005	1.010	1.015	1.019	1.024	1.029	1.034	1.038
55	0.995	1.000	1.005	1.010	1.014	1.019	1.024	1.029	1.033
60	0.990	0.995	1.000	1.005	1.010	1.014	1.019	1.024	1.028
65	0.986	0.990	0.995	1.000	1.005	1.009	1.014	1.019	1.024
70	0.981	0.986	0.991	0.995	1.000	1.005	1.009	1.014	1.019
75	0.976	0.981	0.986	0.991	0.995	1.000	1.005	1.009	1.014
80	0.972	0.977	0.981	0.986	0.991	0.995	1.000	1.005	1.009
85	0.967	0.972	0.977	0.981	0.986	0.991	0.995	1.000	1.005
90	0.963	0.968	0.972	0.977	0.982	0.986	0.991	0.995	1.000
95	0.959	0.963	0.968	0.973	0.977	0.982	0.986	0.991	0.995
100	0.954	0.959	0.964	0.968	0.973	0.977	0.982	0.987	0.991
105	0.950	0.955	0.959	0.964	0.969	0.973	0.978	0.982	0.987
110	0.946	0.951	0.955	0.960	0.964	0.969	0.973	0.978	0.982

To use the air density correction factor, multiply the measured fan flow by the appropriate correction factor from the Table above. For example, if the measured fan flow was 3,200 cfm, and during the test the inside temperature was 70 F and the outside temperature was 40 F, the appropriate correction factor would be 1.030. The density corrected fan flow is 3,200 x 1.030 = 3,296 cfm