

Chapter 1: Diagnosing and Sealing Air Leakage

1.1 Air Leakage Diagnostics Policy

Blower door testing is required on all buildings (except for mobile homes weatherized using the Mobile Home Measures List) before weatherization is started (“As-Is” test), and upon completion of all measures that effect building tightness (“Final” test). Conduct a pressurization test when indoor air quality hazards exist in the building. Follow the air-sealing protocol to complete air-sealing measures on the building. Always perform Zone Pressure Diagnostics Testing on buildings with an attached garage. Document the results of air-leakage diagnostic testing in the Diagnostic Workbook. Take corrective action when air-sealing activities have contributed to a safety hazard or an indoor air quality issue.

1.2 Diagnostic Overview

The testing described here will help to analyze the existing air barriers and decide whether and where air sealing is needed.

Air barrier materials in a building form the building’s **pressure boundary**, while insulation materials form the building’s **thermal boundary**. The location and condition of these barriers have a substantial effect on the insulation’s effectiveness. Optimal energy savings and minimal heat loss are achieved when the two systems are continuous and aligned in direct contact with each other, with the air barrier positioned between the conditioned space and the insulation materials.

1.2.1 Air Leakage Effects

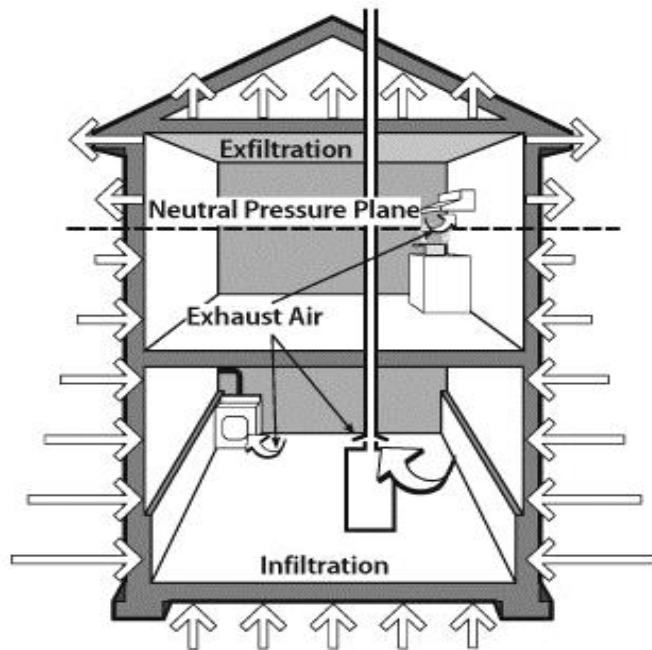
Controlling shell air leakage is a key to a successful weatherization job. Decisions made about sealing air leaks will affect a building throughout its lifetime. The following list highlights important ways air leakage effects buildings.

1. Air leakage can significantly change the net heat loss through a framing cavity.
2. Air leakage typically accounts for a significant percentage of a building’s heat loss.
3. Air leakage can carry moisture into and out of the house, affecting the relative humidity indoors, potentially creating mold and moisture problems.
4. The location and amount of air leakage can affect the draft on natural-draft combustion appliances or fireplaces.
5. Air leakage provides ventilation for exhausting pollutants and admitting fresh air. However, air leaks can bring pollutants into the home as easily as they can expel them.

Building height and location, weather, and mechanical equipment effect air leakage in buildings. Strong winds may create a positive pressure on one side of a building, and a

negative pressure on the opposite side. A forced air distribution system, a chimney, or an exhaust fan may create a negative pressure in the building.

Often air moves through a conditioned building as if the building is a chimney or smoke stack. Unconditioned air enters low in the building (infiltration) and conditioned air exits at the top of the building (exfiltration). This is called the **stack effect**. The area between the air coming in at the bottom (infiltration) and the air leaving the building at the top (exfiltration) is called the **neutral pressure plane**. Not much air leakage comes in or goes out at the neutral pressure plane. As the building is tightened at the bottom, the neutral pressure plane moves upward in the building. As the building is tightened at the top, the neutral pressure plane moves downward. For the best results, seal at both the top and bottom of the building.



Air leakage concepts: When performing air sealing, it helps to understand the effects of exhaust appliances, the stack effect, and wind effect.

Air sealing may affect the natural draft of combustion appliances that are connected to a non-positive venting system. After all weatherization measures are completed, worst-case draft testing must be done on all buildings that contain natural-draft combustion appliances or fireplaces. Exception to this is draft testing cannot be completed on wood heating systems or when the design of the appliance is not conducive to measure draft. See *Worst-Case Draft Protocol in Chapter 5 – Section 5.6*.

1.2.2 Goals of Air Leakage Testing

Air leakage tests are the tools used to determine the location and amount of air leakage through a building’s pressure boundary. Accurate tests allow fast, effective air sealing of the pressure boundary, while at the same time safeguarding indoor air quality.

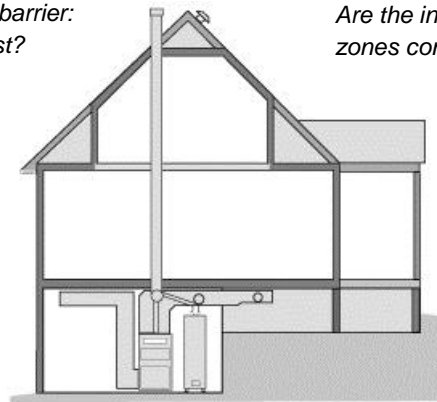
A secondary goal of air leakage testing is to decide where to locate the air barrier when an intermediate zone, like an attic or crawl space, provides a choice of air-barrier locations. The ceiling is usually the thermal boundary of a building, for example, rather than the roof. However, at the foundation, the air barrier may be located at the first floor deck or at the foundation wall. Air leakage testing helps establish the best, fastest, or least expensive place to locate a functioning air barrier. Whenever possible, locate the air barrier to include plumbing and the air distribution system inside the pressure boundary. In most buildings, the

Where is the primary air barrier:
at the rafter or ceiling joist?

Are the intermediate
zones connected?

Are the floor cavities
connected to outdoors?

Do ducts supply heated
air to the addition?



Is the half-basement inside or
outside the air barrier? Is it
heated?

Are the crawl space ducts
inside or outside the air
barrier?

Questions to ask and answer before air sealing: Your answers help determine the most efficient and cost-effective location for the air barrier.

air barrier can be located at the concrete/block foundation wall. In a building with a rubble foundation, the floor deck may be the best place to complete a functional air barrier, especially if limited (or no) air distribution or plumbing is in the area. If plumbing is isolated outside the thermal boundary, take precautions to prevent pipes from freezing.

Air-leakage testing is needed because there simply is no accurate prescriptive method for determining the severity and location of leaks. Varying levels of testing may need to be performed to assess shell leakage. A simple blower door test may be sufficient for a simple home. Work can be completed more efficiently in complex buildings when zone pressure tests and infrared diagnostic tests provide added information.

It is most efficient and cost-effective to seal the large air leaks first. Chasing small leaks consumes time, and is not usually cost-effective. Refer to the “Air-Sealing Protocol” worksheet in the Diagnostic Workbook for guidance about air-sealing protocol.

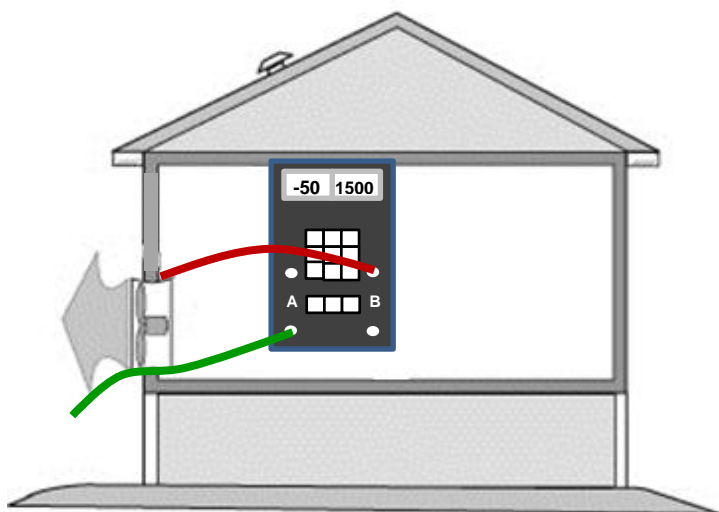
1.3 House Airtightness Testing

The blower door measures a home’s leakage rate at a standard pressure difference of 50 Pascals. This leakage measurement can be used to compare air-leakage rates before and after air sealing. The blower door also allows the technician to test parts of the home’s air barrier to locate air leaks. Sometimes air leaks are obvious. More often, the leaks are hidden, and the technician uses the blower door to obtain clues about their location.

This section outlines the basics of blower door air-leakage measurement along with some techniques for gathering clues about the location of air leaks.

1.3.1 Blower Door Testing

The blower door creates a 50 Pascal pressure difference across the building shell and measures airflow in cubic feet per minute at 50 Pascals. This provides an objective measure of the leakiness of a building. The blower door also creates pressure differences between rooms in the house and intermediate zones like attics, crawl spaces, and garages. Measuring these pressure differences can give clues about the location and size of a home's hidden air leaks.

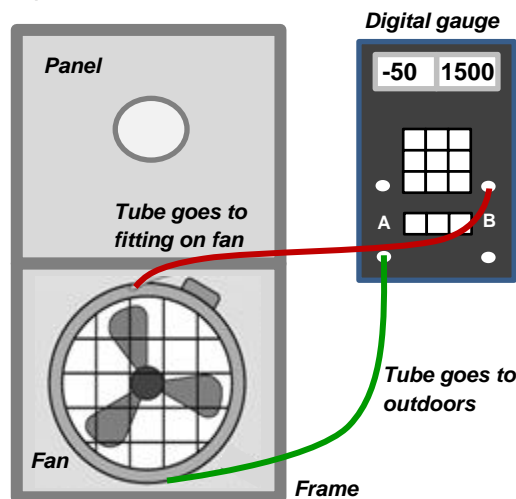


Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 Pascals negative with reference to outdoors. This house has 1,500 CFM₅₀ of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

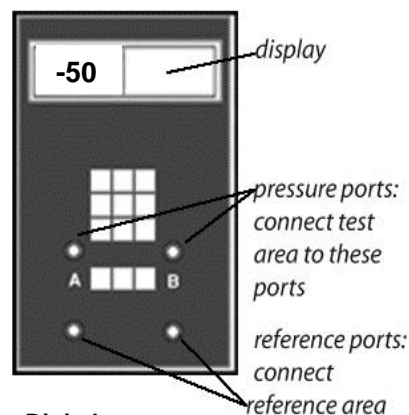
Blower Door Terminology

Connecting the digital gauge's hoses correctly is essential for accurate testing. There is an accepted method for communicating correct hose connections that helps avoid confusion.

This method uses the phrase "with reference to" (WRT) to distinguish between the input zone and reference zone for a particular pressure measurement. The outdoors is the most commonly used reference zone for blower door testing. The reference zone is considered the zero point on the pressure scale.



Blower door components: Include the frame, panel, fan and digital gauge.



Digital gauges: Used to diagnose house and duct pressures quickly and accurately.

For example, “*House WRT Outdoors = -50 Pascals*” means the house (Input) is 50 Pascals negative compared with the outdoors (Reference or zero-point). This pressure reading is called the house-to-outdoors pressure difference.

Flow Rings

During the blower door test, the digital gauge measures the airflow pressure through the fan and the size of the fan opening to calculate the air leakage of the building. For the digital gauge to calculate the building’s air leakage accurately, the air must be flowing at an adequate pressure through the fan. Tighter buildings may not have enough air leakage to create an adequate pressure for the airflow through an open fan. When the air pressure is too low through the fan, the digital gauge will indicate insufficient airflow by flashing “Lo”.

To increase fan pressure and airflow, use the flow rings commonly provided with the blower door, to reduce the fan’s opening and increase pressure of the airflow through the fan. After attaching the flow ring(s), follow the manufacturer’s instructions for selecting the proper setting on the digital gauge.

1.3.2 Preparing for a Blower Door Test

Preparing the house for a blower door test involves putting the house in “winter condition.” Interior doors should be open to **all** conditioned areas (e.g., conditioned knee-wall spaces, conditioned crawl spaces, etc.), while all exterior doors and windows, as well as accesses to unconditioned spaces, are closed. These conditions must be maintained for the duration of the test.

Try to anticipate problems the blower door test could cause. When a blower door test is being completed in depressurization mode, it can cause flame rollout and back drafting in combustion appliances, as well as debris being drawn out of fireplaces, opening unlatched attic access doors or ceiling tiles to be sucked down.

Follow these steps when preparing for a blower door test:

1. Identify the location of the pressure boundary.
2. Open interior doors to connect all conditioned areas of the house.
3. Close all exterior doors and windows including storms.
4. Survey outside air and intermediate zones for possible pollutants that may be drawn into the home during a blower door test. Test in pressurization mode if necessary.
5. Turn off combustion appliances connected to negative pressure venting systems—but do not forget to turn them back on after completing the test. **Tip:** Leaving vehicle keys next to or on an appliance that has been turned off, prevents departure without turning the appliance back on.

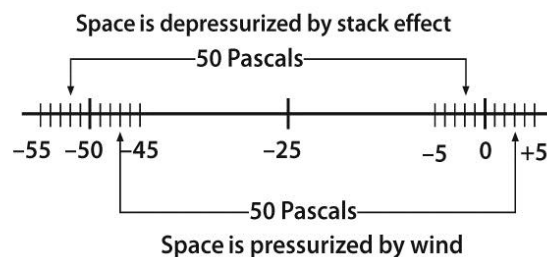
6. Close all fireplace and stove dampers. When the dwelling has an open-hearth fireplace, verify hot ashes/coins will not be blown out of the hearth, or complete test in pressurization mode. Proceed with caution when pressurizing to ensure that you do not stoke the fire in the fireplace with the added combustion air.

1.3.3 Blower Door Test Procedures

Follow this general procedure when performing a blower door test:

1. Install blower door frame, panel, and fan in an exterior doorway with a clear path to the outdoors and indoors. On windy days, try to place the fan parallel to the wind direction. FOR PRESSURIZATION TEST ONLY: Install the blower door fan with the inlet side facing outdoors (flow rings to the outside), so the fan is moving air from outdoors to indoors. Do not use the fan switch to reverse direction of air flow.
2. Place the digital gauge on the support bracket attached to the blower door frame or house door. Turn gauge on prior to placing any hoses on taps.
3. Connect a hose to the Reference tap of Channel A on the digital gauge. Run this hose outdoors, at least 5 feet to the side of the fan, and ensure the end of the hose is protected from the wind.
4. FOR PRESSURIZATION TEST ONLY: Connect an additional hose to the reference tap of Channel B. Run this hose outdoors with the end of the hose located next to the side of the fan.
5. Connect a hose to the Input tap of Channel B on the digital gauge. Connect the other end of this hose to the pressure tap on the blower door fan.
6. Set up the digital gauge to measure air flow at 50 Pascals (PR/FL@50). Select a flow ring setting to match blower door fan configuration.

7. To obtain accurate blower door measurements, readings must be adjusted for wind and stack effect. This adjustment is also referred to as “adjusting for the baseline.” Use the baseline feature of the digital gauge to adjust for the baseline. On windy days, allow the baseline function to record for at least 60 seconds.



8. Remove flow rings as needed. Confirm the digital gauge’s mode is still flow at 50 Pascals (PR/FL@50). Also, confirm the gauge’s flow ring setting matches the configuration of blower door fan.
9. Turn on the fan and increase its speed slowly until approximately 50 Pascals of pressure difference between indoors and outdoors is reached. If pressure across fan is too low, install one or more low-flow rings in order to display an accurate

measurement on the digital gauge. Adjust time average to 5 seconds after reaching 50 Pa pressure difference. Use up to 10 seconds or longer on windy days.

10. Document the CFM₅₀ from Channel B of the digital gauge in the Diagnostic Workbook. Also measure the inside and outside temperatures and record in the Diagnostic Workbook.

Blower Door Test Follow-up

1. Return the house to its original condition.
2. Inspect combustion appliance pilot lights to ensure blower door testing did not extinguish them.
3. Reset thermostats of heaters and water heaters that were turned down for testing.
4. Document any unusual conditions affecting the blower door test and location where the blower door was set up. Photo document the test if needed.

1.4 Air Sealing and Indoor Air Quality

Air sealing affects the home's indoor air quality by reducing the amount of natural ventilation. When natural ventilation is reduced below a certain level, mechanical exhaust ventilation is sometimes needed to ensure pollutants are exhausted to the outside and enough fresh air is brought into the building.

For instructions on how to calculate the whole-house ventilation requirement, refer to the "Instructions" page of the Diagnostic Workbook. Whenever feasible, install 100 percent of the required mechanical ventilation rate.

See *Mechanical Ventilation in Chapter 5 – Section 5.9* for more information about ventilation requirements.

1.4.1. Air Sealing

Complete air sealing work in a reasonable and cost-effective manner. The first blower door test (As-Is test) documents the overall leakiness of the building before weatherization work begins. It helps crews determine the potential for air sealing work to be completed. To identify what air sealing should be completed and where, use the blower door along with an infrared camera, smoke, or "feel" with your hands locates air leaks. Another tool to help guide air sealing is zone pressure diagnostics. See *Zone Pressure Diagnostics (ZPD) in Chapter 1 – Section 1.5* for instructions regarding the use of zone-pressure testing to guide air sealing.

Major air sealing is completed on the building along with or prior to installing any other shell measures. It includes installing window glass where missing, sealing gross holes in the building envelope, sealing construction key junctures, and sealing all major attic bypasses.

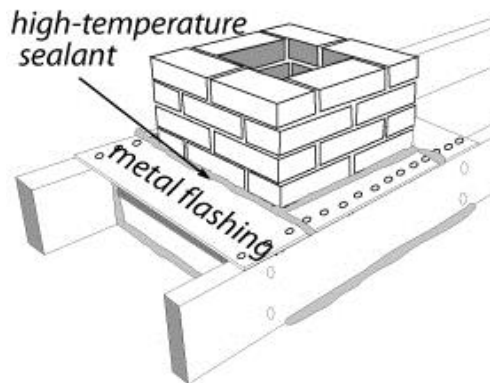
For gaps larger than ¼", use caulking, steel wool, or other pest-proof material to fill the penetration before sealing. If a span is greater than 24 inches, install support spans that are rated to span such distance under the existing (if not insulating) or prescribed load (if adding insulation). Penetrations shall be sealed with a durable material with a minimum expected service life of 10 years.

Minor air sealing is air-sealing that occurs after the completion of major air sealing and all shell measures and is limited to 1 labor hour. The decision to complete minor air sealing shall be determined by the crew leader. Often, minor air sealing has a minimal impact on energy savings, but can improve occupant comfort. Minor air sealing may include window and door weather-stripping, door sweeps, window air-sealing, and caulking around trim.

Common air barrier flaws requiring air sealing include, but are not limited to:

Attics and Other Concealed Spaces

- 1. Interior dropped soffits:** Cap the soffit with rigid material, and air-seal around the perimeter of the cap. If the soffit is located in a hard-to-access area, or along an exterior wall, consider dense-packing the soffit. When the soffit contains a non-IC-rated light fixture, ensure any insulation will be kept at least 3 inches away from the top and sides of the fixture or obtain the homeowner's approval to replace with an IC-rated or flush-mounted fixture. ZPD sometimes reveals these areas do not leak. Consider testing prior to air sealing, and document based upon the test results the decision to seal or not seal.
- 2. Around masonry chimneys:** Use 26-gauge or heavier metal and appropriate temperature rated sealant to seal within 2 inches of the chimney.
- 3. Balloon framing/open partition walls:** Cap the stud openings with rigid material and air-seal around the perimeter of the cap. Stuff the cavity with batts so the infill backing will not bend, sag, or move once installed. Seal with foam or dense-pack with insulation.
- 4. Recessed lights:** For IC rated fixtures, seal the fixture. Use sealant or mastic to prepare for insulation. For non-IC rated fixtures, build a cover using non-combustible materials that do not allow for rapid heat transfer. Drywall may be used only if a three-inch clearance is maintained. Sheet metal is not an allowable material.



Sealing around chimneys: Only non-combustible materials, like metal, may be used for sealing around chimneys.

5. **Wall top-plates identified as leaking (exterior and interior walls):** Look for dirty insulation above top plates — this indicates air leakage. Pressurizing the home with the blower door will magnify smaller, hard-to-locate leaks. Use foam or caulk to seal leaky top plates. On multifamily homes this can also include between party walls.
6. **Electrical and other penetrations through wall top-plates:** Use one-part-foam or caulk.
7. **Ceiling penetrations:** These can include electrical fixtures, exhaust fans, soil stacks, dryer-exhaust pipes, and HVAC ductwork, etc. Seal with foam or caulk, as appropriate. Seal from the interior when possible, rather than from the attic.
8. **Key junctures:** Key junctures are framing voids and shared spaces where two or more building assemblies converge. Use foam or caulk to seal key junctures, another option is to utilize the bag method with cellulose. *See Installing Attic Insulation in 1½ Story Homes in Chapter 2 – Section 2.2.7* for information on the bag method.
9. **Whole-house fan:** If the fan is operational, box around it and install a removable and airtight cover. The occupant should be able to remove the cover easily for future use.

Basement

1. **Rim Joist:** Seal leaks between sill plate and foundation either from the interior or exterior depending on accessibility. Look for dirty sill-box insulation as evidence of air leakage. Using the blower door can magnify smaller leaks. Seal leaks with foam or caulk. If leaks are inaccessible from the interior, seal outside where the sill plate meets the foundation behind the siding.
2. **Foundation and Sillbox penetrations:** Use foam or caulk to seal large penetrations identified in the foundation. If the foam will be exposed to sunlight, take precautions to protect the foam from deterioration.
3. **Inactive chimneys and clean-outs:** Air-seal to prevent leakage and reduce convective looping. Clearly label the chimney to state it is no longer suitable for use.
4. **Bathtubs on exterior walls:** Install dense-packed insulation in the open space between the bathtub and the exterior wall, if feasible.

Windows

1. **Missing window glass:** Install new window glass, or otherwise seal the opening, following lead- and asbestos-safe work practices. *See Window Repair and Replacement in Chapter 6 – Section 6.1.1* for information on window repairs and replacements. *Note: Air sealing of cracked window glass is considered Minor Air Sealing.*

Doors

1. **Door repair:** Seal gaps between the stop and jamb with caulk. Note: Sealing gaps between the door stop or jam falls under *Minor Air Sealing*.
2. **Garage doors:** Weather-strip all doors connecting conditioned areas to an attached garage.

1.5 Zone Pressure Diagnostics

ZPD tests help to quantify the air leakage from the house to intermediate “zones.” By using ZPD tests, workers can prioritize air-sealing to areas of the pressure boundary where it will be most effective. ZPD tests may allow workers to save time working in zones whose air bypasses are insufficient to warrant extensive air sealing. Some common intermediate zones are attics, garages, and crawl spaces.

ZPD tests calculate a **total path** of CFM₅₀ leakage from the outside through the zone into the conditioned space. For example, a good goal for “all major attic bypasses” is the total path through all attics into the conditioned space should equal no more than 10 percent of the home’s total air leakage. For example, a home with a final blower door test of 2200 CFM₅₀ should have a total path through all intermediate attic zones of no more than 220 CFM₅₀.

When performing ZPD tests, use the auditor’s estimated final blower door test, not the in-progress blower door test, to calculate a zone’s leakiness. Document any unusual circumstances in the Comments section of the Blower Door Data worksheet within the Diagnostic Workbook.

Always perform ZPD testing when weatherizing a building with an attached garage. Record the results of the test on the Garage ZPD worksheet within the Diagnostic Workbook.

Use ZPD to guide decisions about where to direct air-sealing efforts. ZPD can allow workers to:

1. Evaluate the air tightness of specific sections of a building’s pressure boundary — especially floors and ceilings.
2. Decide which of two possible air barriers to air seal — for example, sealing at the first floor deck versus at the foundation walls. Please see table 1-2 in section 1.5.3
3. Estimate the air leakage in CFM through a particular air barrier.
4. Determine whether areas like floor cavities, porch roofs, and overhangs are conduits for air leakage.
5. Determine whether building cavities, intermediate zones, and ducts are connected by air leaks.

ZPD testing should be used whenever appropriate. Typically, that is when the dwelling has one or more of the following conditions:

1. Structural moisture problems related to moist air escaping into unheated zones.
2. Multiple zones where determining linkage between zones or setting air-sealing priorities is necessary.
3. Unusually high blower door result with no indication as to where the infiltration originates.
4. Results of completed ZPD should be documented on the required Zone Pressure Diagnostics Form within the Diagnostic Workbook.

Table 1-1: Air Performance of Building Components

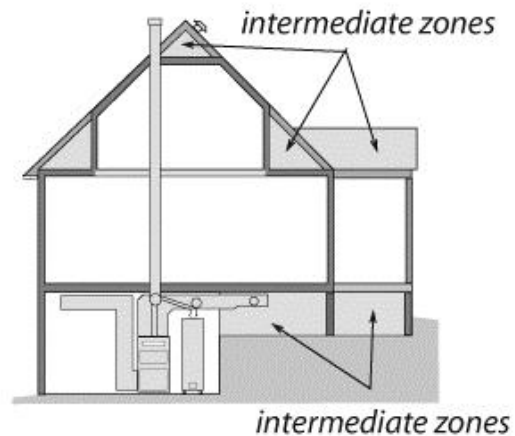
Good Air Barriers (<2 CFM₅₀ per 100 ft.²)	Fair Air Barriers (2-10 CFM₅₀ per 100 ft.²)	Poor Air Barriers (10-1000 CFM₅₀ per 100 ft.²)
$\frac{5}{8}$ " oriented strand board	15# perforated felt	$\frac{5}{8}$ " tongue-and-groove wood sheathing
$\frac{1}{2}$ " drywall	concrete block	6" fiberglass batt
4-mil air barrier paper	rubble masonry	1 $\frac{1}{2}$ " wet-spray cellulose
asphalt shingles and perforated felt over $\frac{1}{2}$ " plywood	$\frac{7}{16}$ " asphalt-coated fiberboard	wood siding over plank sheathing
$\frac{1}{8}$ " tempered hard-board	1" expanded polystyrene	wood shingles over plank sheathing
painted un-cracked lath and plaster	brick veneer	blown fibrous insulation
Measurements taken at 50 Pascal pressure. Based on information from: "Air Permeance of Building Materials" by Canada Mortgage Housing Corporation, June 1988, and estimates of comparable assemblies by the author. Although cellulose reduces air leakage when blown into walls, it is not considered an air-barrier material.		

Primary vs. Secondary Pressure Boundary

The **primary pressure boundary**, or air barrier, comprises those building-shell surfaces which contain the dwelling's conditioned air and which prevent air leakage. Ideally, the primary pressure boundary will be as continuous as possible, and it will be aligned with the building's thermal boundary.

The **secondary pressure boundary** comprises building surfaces that are outside the thermal boundary and which combine with the primary pressure boundaries to form intermediate zones.

Intermediate zones are spaces that are isolated outside of the home's thermal boundary, but which are sheltered within the home's exterior shell. Intermediate zones may include such unconditioned areas as basements, crawl spaces, attics, enclosed porches, and attached garages. Pre-weatherization, intermediate zones may be included either inside the home's primary pressure boundary or outside it. One goal of weatherization is improve the pressure boundary so these unconditioned zones are isolated outside the home's primary pressure boundary.



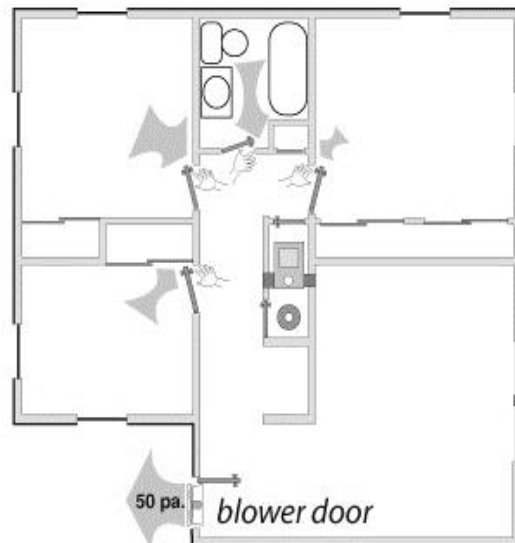
Intermediate zones have two potential pressure boundaries: one between the zone and house and one between the zone and outdoors. For example, an attic has two pressure boundaries: the ceiling and the roof deck. It is essential to determine which of the two serves as the primary pressure boundary.

After weatherization is complete, the most airtight boundary should be the primary pressure boundary and the least airtight should be the secondary pressure boundary. The primary pressure boundary should be adjacent to the insulation to ensure the insulation's effectiveness. The air barrier should be composed of materials that are continuous, sealed at seams, and relatively impermeable to airflow.

1.5.1 Simple Air-Leakage Tests

During a blower door test, valuable information about the relative leakiness of rooms or sections of the home can be identified. Following are five simple methods for locating air leakage.

1. **Feeling air leakage:** From inside the building along the primary pressure boundary, air movement will be felt during a depressurization test. From inside an intermediate zone along the primary pressure boundary, air movement will be felt during a pressurization test. Air leakage from a room can be felt by closing an interior door. A smaller gap between the door and doorjamb causes the airflow to speed up. Feel the airflow along the



Interior door test: Feeling airflow with your hand at the crack of an interior door gives a rough indication of the air leakage coming from the outdoors through that room.

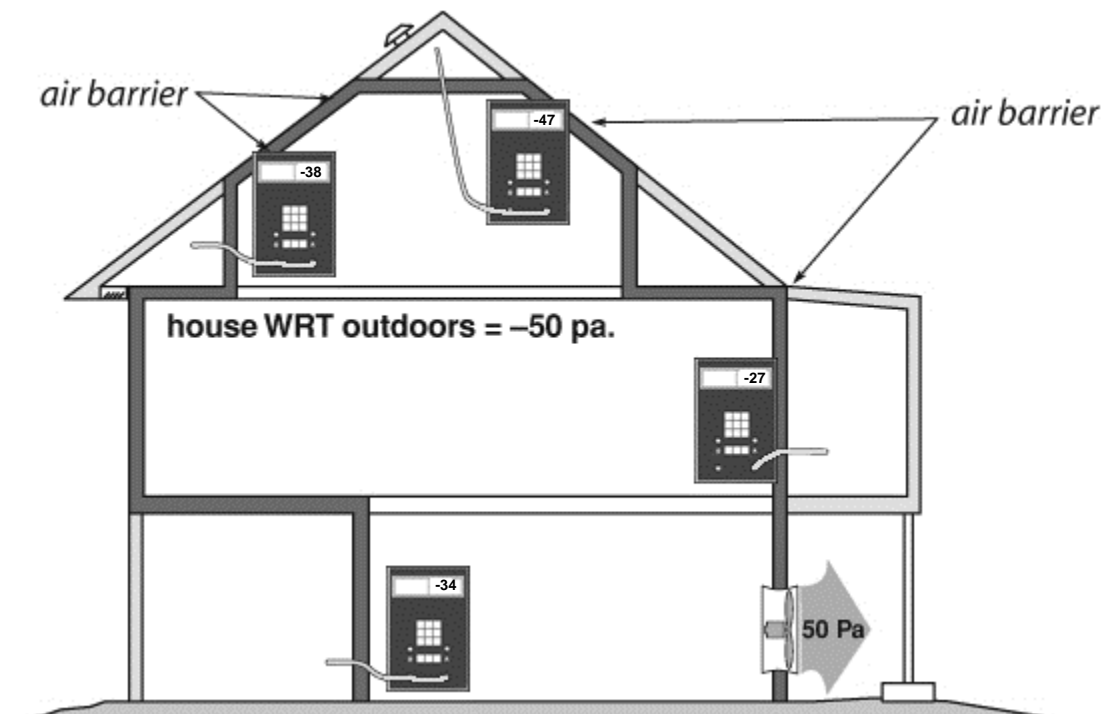
- length of that crack, and compare that airflow intensity with airflow from other rooms, using the same technique.
2. **Observing movement caused by air leakage:** To locate air leaks from the interior, depressurize the home and look for moving cobwebs, moving curtains, and blowing dust. To locate air leaks from intermediate zones, pressurize the home, and look for movement of loose-fill insulation, blowing dust, or moving cobwebs.
 3. **Observing smoke movement:** Using a smoke generator to detect areas of air leakage is the best method to diagnose primary pressure boundary air leakage during a **pressurization** test.
 4. **Thermal Imaging:** Observe surfaces with an infrared camera. Areas of high contrast or flaring along building trim can indicate the presence of air leakage. Observing surface before and then after running blower door can indicate change in temperature of surface by air leakage.
 5. **Room-airflow difference:** Measure the house CFM₅₀ with all interior doors open. Close the door to a single room or the basement and note the difference in the CFM₅₀ reading. The difference is the approximate leakage through that room or the basement.

Tests 1- 3 can be completed by the occupant as part of customer education. Feeling for airflow or observing smoke are simple observations and can identify many air leaks or reveal that windows and doors have minimal air leakage. Tests 4-5 require experience to interpret observations. High contrast surfaces may be lack of insulation or air leakage when using an infrared camera. When airflow within the home is restricted by closing a door, as in test 5, it may take alternative indoor paths that reduce the accuracy of the test. Only good sense and experience can guide decisions about the applicability and usefulness of these simple tests.

1.5.2 Using a Digital Gauge to Test Pressure Boundaries

A digital gauge, used for blower door testing, also can measure pressures between the house and its intermediate zones during blower door tests. The blower door, when used to create a house-to-outdoors pressure difference of 50 Pascals, also creates house-to-zone pressures that can range from 0 to 50 Pascals in the building's intermediate zones. The amount of pressure differential depends on the relative leakiness of the zone's two pressure boundaries.

For example, in an attic with small holes in the ceiling and a well-ventilated roof, the house-to-zone pressure may be 45 to 50 Pascals. This attic is described as being “mostly outside” the house pressure boundary. The larger the holes in the ceiling with smaller holes in the roof, the smaller the house-to-zone pressure differential will be, and the more the attic could be described as “being inside.” This principle holds true for other intermediate zones like crawl spaces, attached garages, and unheated basements.



Pressure-testing building zones: Measuring the pressure difference across the assumed thermal boundary tells you whether the air barrier and insulation are aligned. If the digital gauge reads close to -50 Pascals, they are aligned, assuming the tested intermediate zones are well-connected to outdoors.

Pressure-Only Zone Pressure Diagnostics

1. Find existing holes between the conditioned space and the intermediate zone. Or, with the customer's permission, drill a hole through the floor, wall, or ceiling into the zone.
2. Run a hose into the zone, and connect the hose to the Channel B Reference tap of the digital gauge.
3. Leave the Input tap of the digital gauge open to the indoors.
4. Turn the blower door on and create a 50-Pascal pressure difference between the House with reference to Outdoors (HwrtO).
5. Read the pressure differential. This is the House with reference to Zone (HwrtZ) pressure differential. As a rule, readings close to 50 Pascals indicate the zone is less connected to the house compared to the connection to outdoors. Test readings much lower than 50 Pascals generally indicate the presence of air leaks along the primary pressure boundary. The lower the house to zone pressure, the greater the size of holes from the house to the zone if the size of holes from the zone to outside are larger.

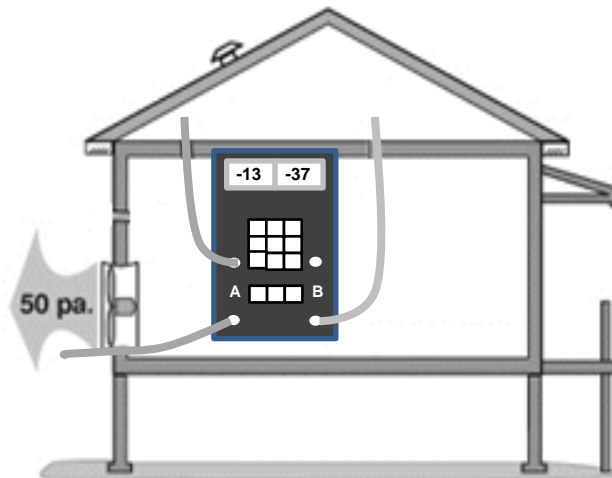
The main principle of series air leakage is a direct relationship between the measured pressure differentials and the ratio of the size of holes in the primary and secondary pressure boundaries.

This method allows the user to calculate the air-leakage surface area through one of the boundaries, if the air-leakage surface area through the other boundary is known or presumed.

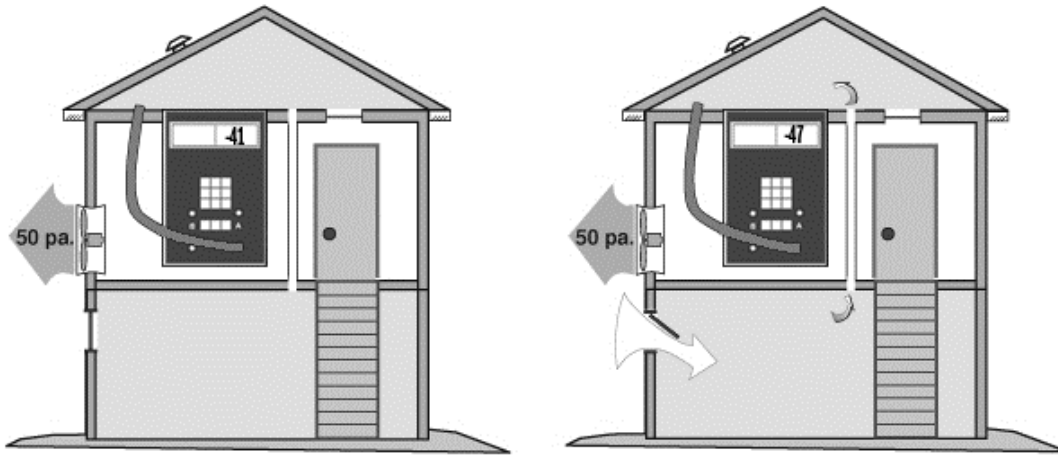
For example, testing may indicate a HwrtZ pressure differential of 41 Pascals and a ZwrtO differential of 9 Pa, when the HwrtO pressure difference is 50 Pascals. Per Attic Bypass Relationships chart, if the secondary pressure boundary (roof) contained 300 square inches of ventilation, then this would indicate the presence of roughly 100 square inches of bypasses located in the primary pressure boundary (ceiling).

Attic Bypass Relationships		
Zone Pressures		Relative Size of Bypass Holes Compared to Roof Holes (e.g., ventilation)
ZwrtO	HwrtZ	HwrtZ
1	49	1/13
2	48	1/8
5	45	1/4
9	41	1/3
13	37	1/2
25	25	1
38	12	2

6. If testing indicates the presence of substantial air leaks, find and seal the air barrier's leaks.

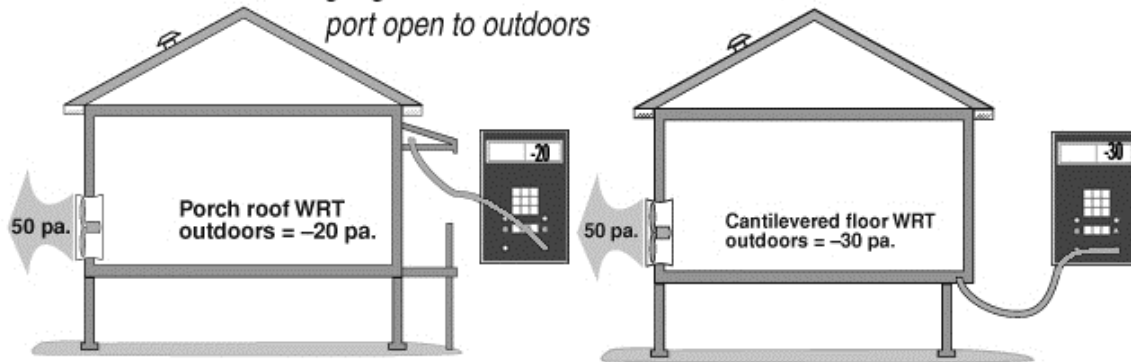


Attic-to-outdoors pressure: The left side of the gauge shows an Attic WRT outside pressure of -13 Pascals and the right side of the gauge shows a House WRT Attic pressure of -37 Pascals. The two readings add up to -50 Pascals to confirm House WRT Outside of 50 Pascals.



Zone connectedness: The attic measures closer to outdoors after the basement window is opened, indicating that the attic and basement are connected by a large bypass.

These examples assume that the digital gauge is outdoors with the reference port open to outdoors



Porch roof test: If the porch roof were outdoors, the digital gauge would read near 0 Pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find; however, it is partially connected to indoors, indicating it may contain significant air leaks through the thermal boundary.

Cantilevered floor test: We hope to find the cantilevered floor to be indoors. A reading of -50 Pascals would indicate that it is completely indoors. A reading less negative than -50 Pascals is measured here, indicating that the floor cavity is partially connected to outdoors.

Leak-Testing Building Cavities

Building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms can also be pressure-tested with a digital gauge to determine their connection to the outdoors.

Testing Zone Connectedness

Sometimes it is useful to determine whether two intermediate zones are connected by an air passage like a large bypass. Determining whether two zones are connected can be completed by measuring the house-to-zone pressure during a blower door test and then later after opening the other zone to the outdoors. Opening an interior door leading into one of the zones and check for pressure changes in the other zone can also help determine connections.

1. Turn on the blower door and establish a house-to-outside pressure differential of 50 Pascals.
2. Test and record the house-to-zone pressure differential of one of the zones.
3. Open a door, or create some other pathway, into the other zone.
4. Re-establish a house-to-outside pressure differential of 50 Pascals, as opening the pathway will change the overall house pressure.
5. Re-test the house-to-zone pressure differential in the first zone. If opening the pathway has caused the test result to change, then this is evidence of a connection between the two zones.

1.5.3 Locating the Pressure/Thermal Boundary

Where to air-seal and insulate are important retrofit decisions. Zone pressures are one of several factors used to determine where the thermal boundary should be located. When there are two choices of where to insulate and air-seal, zone pressures along with other considerations help decide where to locate the pressure and thermal boundaries.

For zone-leak-testing, the house-to-zone pressure is often used to determine which of the two pressure boundaries is tighter (has smaller sized holes).

For example, a house-to-zone pressure differential of 26 to 50 Pascals means the primary pressure boundary is likely tighter than the secondary boundary. If the secondary boundary is quite airtight, achieving a 50-Pascal house-to-zone pressure differential is difficult. However, if the roof is well ventilated, creating a nearly 50-Pascal differential is possible. If the roof is over-ventilated, creating a nearly 50-Pascal differential is easy.

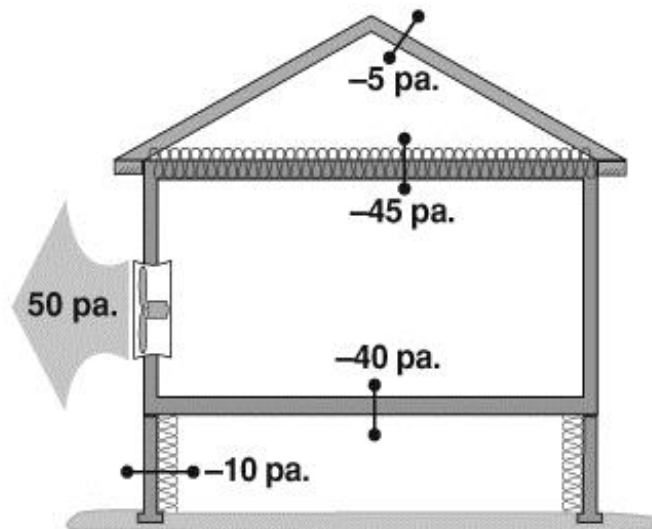
By contrast, a house-to-zone pressure differential of zero to 25 Pascals means the secondary pressure boundary is tighter than the primary boundary. If the roof is well ventilated, then these readings indicate the ceiling has even more leakage surface area than the roof.

Floor vs. Crawl Space

The floor shown here is tighter than the crawl-space foundation walls. If the crawl-space foundation walls are insulated, holes and vents in the foundation wall should be sealed until the pressure difference between the crawl space and outside is as close to 50 Pascals as possible—ideally more than 48 Pascals. A leaky foundation wall renders its insulation ineffective.

It might be more effective to weatherize the floor above the crawl space. If the floor is insulated instead of the foundation walls, completely air sealed, then the pressure and the thermal boundary would be in alignment at the floor. When the crawl space is adjacent to a basement and the thermal boundary is to be moved to the floor, remember the thermal boundary now includes the wall separating the basement from the crawl space. Insulate and air-seal this wall appropriately.

However, it will usually make more sense to locate the thermal boundary at the crawl-space foundation walls, rather than at the floor. Locating the thermal boundary at the foundation walls eliminates the concern about frozen pipes in the crawl space. In addition, treating the foundation walls usually requires less work and material than treating the floor.



Pressure measurements and air-barrier location:
The air barrier and insulation are aligned at the ceiling as they should be. The crawl space pressure measurements show that the floor is the air barrier and the insulation is misaligned—installed at the foundation wall. We could decide to close the crawl space vents and air-seal the crawl space. Then the insulation would be aligned with the air barrier.

Table 1-2: Crawl Space: Where Should the Air Barrier Be?

Factors Favoring Foundation Wall	Factors Favoring Floor
Ground moisture barrier and good perimeter drainage present or planned	Damp crawl space with little or no improvement offered by weatherization
Foundation walls test tighter than floor	Floor tests tighter than foundation walls
Furnace, ducts, and plumbing located in crawl space	No plumbing or heating located in crawl space
Foundation wall is insulated	Floor is insulated

Table 1-3: Unoccupied Basement: Where Should the Air Barrier Be?

Favors Foundation Wall	Favors Floor
Ground drainage and no existing moisture problems	Damp basement with no solution during weatherization
Interior stairway between house and basement	Floor air sealing and insulation is a reasonable option, considering access and obstacles
Ducts and furnace in basement	No furnace or ducts present
Foundation walls test tighter than the floor	Floor tests tighter than foundation walls
Basement may be occupied some day	Exterior entrance and stairway only
Laundry in basement	Rubble masonry foundation walls
Floor air sealing and insulation would be very difficult	Dirt floor or deteriorating concrete floor
Concrete floor	Badly cracked foundation walls

Garage Boundary

For a tuck-under or attached garage, locate the thermal and pressure boundaries at the floor and walls that separate the garage from the living spaces. Ensure plumbing pipes in these floor and wall cavities are located on the interior (warm) side of the thermal and pressure boundaries to prevent frozen pipes.

For tuck-under garages, make sure to air-seal the floor-joint key juncture above the wall that separates the garage from the home. Use the Bag Method if necessary. See *Installing Attic Insulation in 1½ Story Homes (Finished Attics)* in Chapter 2 - Section 2.2.7 on for more information about the Bag Method.

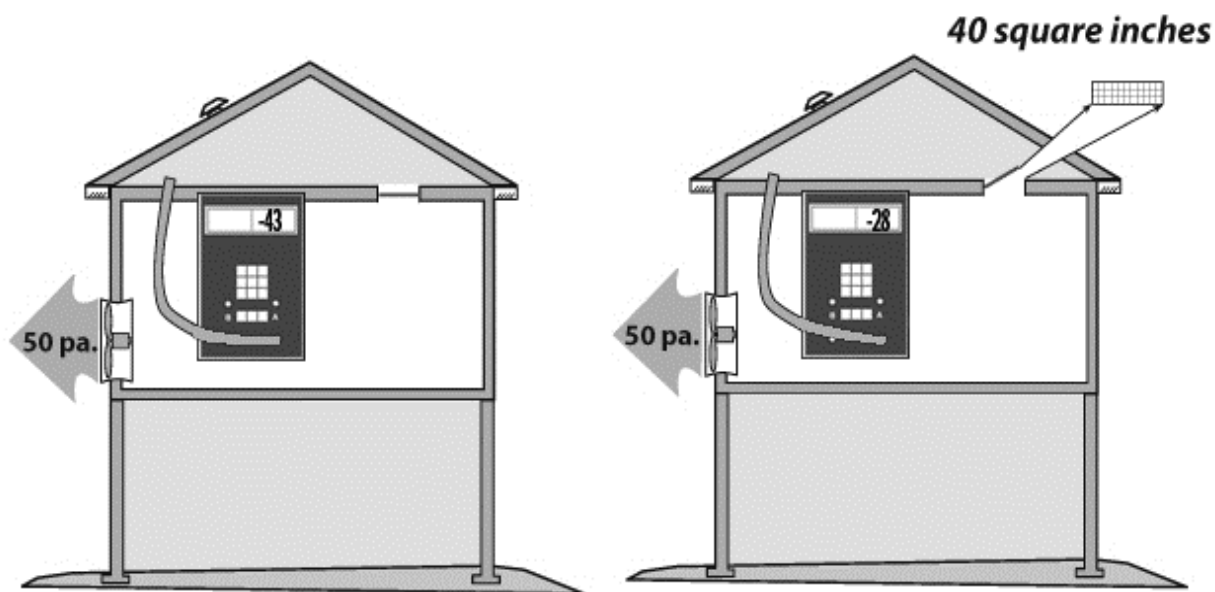
Duct Location

Whenever feasible, locate the thermal and pressure boundaries to include ductwork. This is a better option than isolating the ducts outside the thermal boundary, because it reduces energy waste from duct leakage.

1.5.4 Add-a-Hole Zone-Leakage Measurement

The Add-a-Hole procedure estimates the actual airflow between the house and zone. Use the Add-a-Hole worksheet within the Diagnostic Workbook to perform the calculations described here. This procedure works for most intermediate zones that have an opening or access to the indoors.

The Add-a-Hole worksheet calculates Leakage Results based on user data inputs. The three Leakage Results calculations are:



Add-a-hole test: The first house-to-attic pressure is -43 Pascals. This test works equally well with crawl spaces and attached garages.

Add-a-hole test 2: Opening a hole of approximately 40 square inches drops the second house-to-zone pressure by 15 Pascals.

Total path: This number represents the amount of leakage (inCFM₅₀) passing through both pressure boundaries.

House with reference to zone: This number represents the amount of leakage between the house and zone.

Zone with reference to outside: This number represents the amount of leakage between the zone and outside.

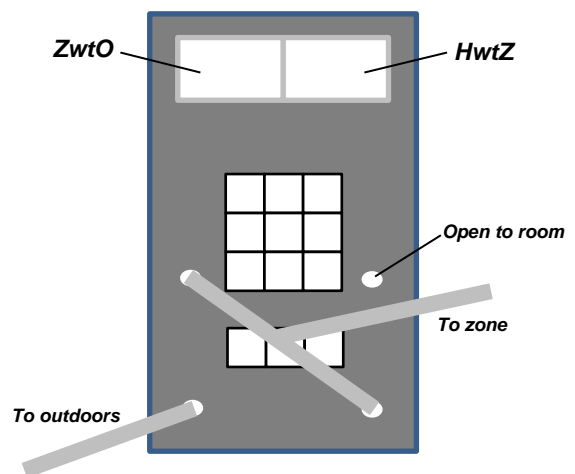
Ideally, total path leakage percentage through attics is 10 percent or less of the total blower door value. This number is calculated using the following equation:

$$\text{Percentage} = \text{Total Path} \div \text{Whole-House CFM}_{50}$$

Before starting an Add-a-Hole Zone-Leakage Test, confirm a “hole” can be opened between the house and the zone and/or between the zone and the outside. The hole might be an attic hatch, a door to the zone, or some other opening.

Follow these steps to complete the Add-a-Hole ZPD test:

1. Set up for a standard blower door test. Put the home in winter condition, turn off all combustion appliances, and keep interior doors open and stationary during testing.
2. Run a reference pressure hose to a location outdoors unaffected by the wind. Run a second pressure hose into the zone, keeping the hose end away from air currents that could be caused by roof vents and large bypasses. Both hoses will be connected to the digital pressure gauge later during the test. Ensure both hoses are long enough to reach the gauge at the same time.
3. Turn on the pressure gauge and leave in PR/PR mode for all testing. *Do not use the Adjusted Baseline feature of the digital gauge when completing zone-pressure diagnostics.*
4. Connect a jumper tee to the Channel A Input tap and the Channel B Reference tap. Leave the jumper tap open to the indoors for the time being, with no hose connected. Connect the outdoor pressure hose to the Channel A Reference tap of the digital pressure gauge.
5. Open the Add-a-Hole worksheet in the Diagnostic Workbook. Select the Type of Test — depressurization or pressurization — to be conducted.
6. Connect the zone pressure hose to the jumper tee. Record the baseline pressures, the Zone with reference to Outside (ZwrtO) baseline from Channel A, and the House with reference to Zone (HwrtZ) baseline from Channel B.
7. Remove the zone pressure hose. Measure the House with reference to Outdoors (HwrtO) baseline pressure differential. Enter the result in the Diagnostic Workbook, as a positive or a negative number. The Workbook will then calculate the Adjusted Pressure — which becomes the target building pressure for the blower door test.
8. Start the bower door fan to create an HwrtO pressure difference and adjust the fan speed to within 1 Pascal of the target building pressure.
9. Without changing the fan speed, reconnect the zone pressure hose to the jumper tee. Record the ZwrtO reading from Channel A, in the Pressure with House at 50 Pascals line



of the Add-a-Hole worksheet. Record the HwrtZ reading from Channel B, in the same line of the worksheet.

10. Turn off the blower door fan. Create a hole by opening the access between the zone and the house. The size of the hole created should be sufficient to change the measured HwrtZ Pressure with house at 50 Pascals by 6 to 20 Pascals. A hole that is too large or too small may lead to incorrect results.
11. Repeat Steps 6-9. If the HwrtZ reading is more than 20 Pascals different, reduce the size of the hole. If the HwrtZ reading is fewer than 6 Pascals different, increase the size of the hole. *If the size of the hole is changed, the baseline pressures will change, and should be re-measured (Go back to Step 6).*
12. Determine the surface area of the final hole, in square inches. Be sure to account for the triangular spaces created on either side of the access hatch, if the hatch was tilted open. Enter the dimensions of the opening so the Add-a-Hole worksheet calculates an Opening Size to match the hole's measured surface area.
13. When the HwrtZ reading from Channel B falls within the range of 6 to 20 Pascals difference, record it in the Pressure With House at 50 Pascals line of the Add-a-Hole worksheet, in the "Pressure Readings After Adding a Hole" section. Record the ZwrtO reading from Channel A, in the same line of the worksheet.
14. The worksheet will calculate leakage rates and total path leakage. Return the home to the pre-test conditions — and remember to turn combustion appliances back on.

Follow the warning indicators in the Add-a-Hole worksheet, if they appear.

1.5.5 Open-a-Door Zone-Leakage Measurement

The Open-a-Door method is another way of determining how much leakage in CFM₅₀ travels through an intermediate zone like a walk-up attic, unoccupied basement, or attached garage. This method is used when a door exists between the house and zone or between the zone and outdoors. Use the Open-a-Door or garage ZPD worksheet within the Diagnostic Workbook to perform the calculations.

The Open-a-Door worksheet calculates Leakage Results based on user data inputs. The three Leakage Results calculations are:

Total path: This number represents the amount of CFM₅₀ passing through both pressure boundaries.

House with reference to zone: This number represents the amount of leakage between the house and zone.

Zone with reference to outside: This number represents the amount of leakage between the zone and outside. If the attic is the zone, this is attic ventilation.

The target air leakage between a house and an attached garage is 50 CFM. Ideally the goal should be to have no leakage between a house and garage.

Follow these steps to complete the Open-a-Door test:

1. Set up for a standard blower door test. Put the home in winter condition, turn off all combustion appliances, and keep interior doors open and stationary during testing.
2. Run a pressure hose to the outdoors to a location unaffected by wind. Run a second pressure hose into the zone, keeping the hose end away from roof vents and large bypasses that may create air currents. Both hoses will be connected to the digital pressure gauge later during the test. Ensure both hoses are long enough to reach the gauge at the same time.
3. Turn on the pressure gauge and leave in PR/PR mode for pressure testing. *Do not use the Adjusted Baseline feature of the digital gauge when completing zone-pressure diagnostics.*
4. Connect a jumper tee to the Channel A Input tap and the Channel B Reference tap. Leave the jumper tap open to the indoors for the time being, with no hose connected to the third leg of the tee. Connect the outdoor pressure hose to the Channel A Reference tap of the digital pressure gauge.
5. Start the Open-a-Door or Garage ZPD worksheet in the Diagnostic Workbook. Select the Type of Test — depressurization or pressurization — to be conducted.
6. Connect the zone pressure hose to the jumper tee. Record the baseline pressures, the Zone with reference to Outside (ZwrtO) baseline from Channel A, and the House with reference to Zone (HwrtZ) baseline from Channel B.
7. Remove the zone pressure hose. Measure the House with reference to Outdoors (HwrtO) baseline pressure. Enter the result in the Diagnostic Workbook, as a positive or a negative number. The Workbook will then calculate the Adjusted Pressure — which is the target building pressure reading for the blower door test.
8. Start the bower door fan to create an HwrtO pressure difference and adjust to within 1 Pascal of the targeted pressure reading.
9. Without changing the fan speed, reconnect the zone pressure hose to the jumper tee. Record the ZwrtO reading from Channel A, in the Pressure with House at 50 Pascals line of the Open-a-Door or Garage ZPD worksheet. Record the HwrtZ reading from Channel B, in the same line of the worksheet.
10. Complete the blower door test with the door to the zone closed and record the reading on the worksheet.
11. Open the door between the house and the zone. The door to be opened will be between the basement and the outside when determining leakage to the basement from outside.

12. Complete a blower door test with the door wide open and record on the Open-a-Door or Garage ZPD worksheet.
13. The worksheet will calculate leakage rates and total path leakage. Return the building to the pre-test conditions — and remember to turn combustion appliances back on.
14. Follow the warning indicators in the Open-a-Door or Garage ZPD worksheet, if they appear.

The sum of the HwrtZ and ZwrtO pressures should be approximately equal to the actual HwrtO pressure. For example, if the HwrtZ pressure is -45 Pascals and the ZwrtO pressure is -6 Pa, then the indirect HwrtO pressure will calculate out to -51 Pascals ($-45 + -6 = -51$). The greater the difference between the HwrtO and the sum of the HwrtZ + ZwrtO pressures, the less accurate the test will be. If the sum difference is greater than 2 Pascals, the Open-a-Door worksheet will instruct workers to consider re-testing.

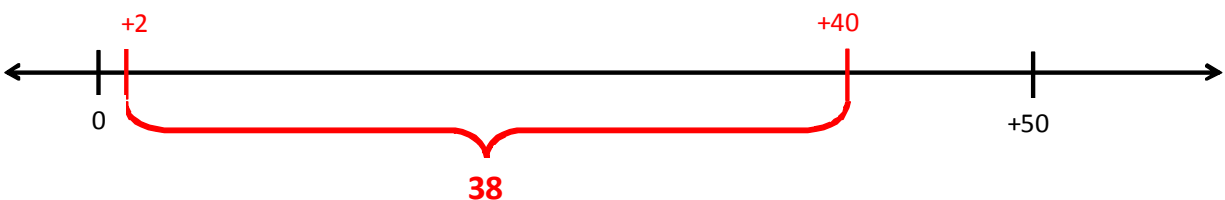
1.5.6 Adjusting Zone Pressure Measurements for Baseline

The Diagnostic Workbook automatically adjusts test results to measured baseline pressures. However, it is important to understand how baseline pressures (caused by stack effect, wind, or air handlers and fans) affect zone pressure measurements. The measured zone pressure baseline readings are subtracted from the measure zone pressure readings taken with the house at a 50 Pascal pressure difference. This can be confusing when subtracting a negative number from a negative reading (depressurization) or a positive reading (pressurization). The number lines below are examples on how to adjust for baseline for both pressurization and depressurization testing methods.

Pressurization

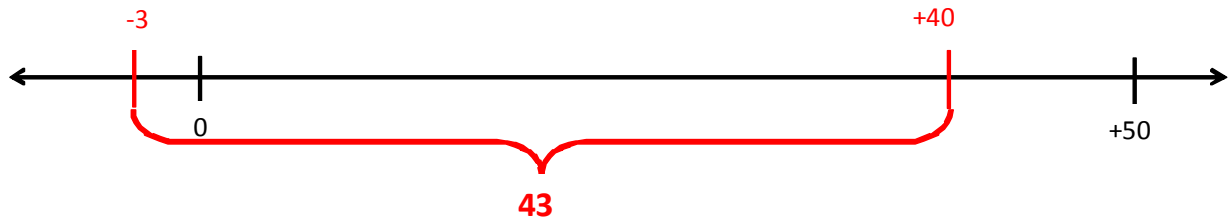
Positive baseline of +2, zone reading of 40 with house at 50.

Adjusted zone pressure reading is 38 ($40 - (+2) = 38$).



Negative baseline of -3, zone reading of 40 with house at 50.

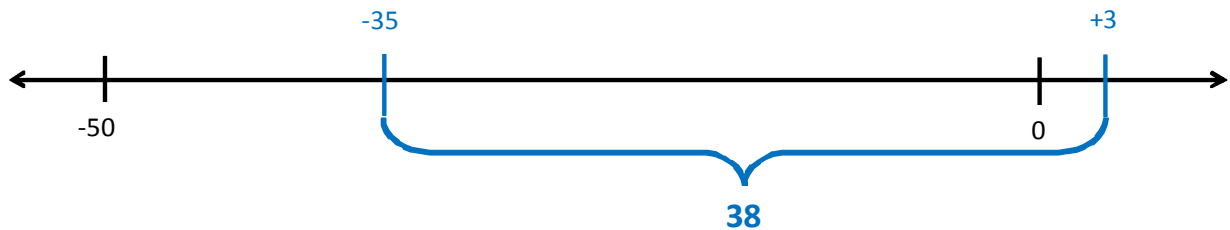
Adjusted zone pressure reading is 43 ($40 - (-3) = 43$).



Depressurization

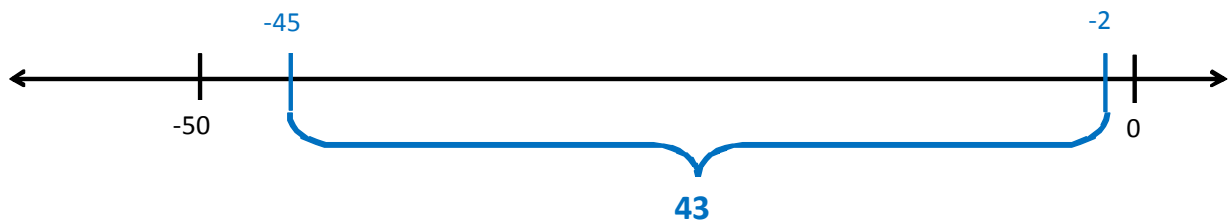
Positive baseline of +3, zone reading of -35 with house at -50.

Adjusted zone pressure reading is 38 ($-35 - (+3) = -38$).



Negative baseline of -2, zone reading of -45 with house at -50.

Adjusted zone pressure reading is 43 ($-45 - (-2) = -43$).



Final Inspection and Quality Assurance Standards

Acceptable installations shall meet the following standards.

Air Sealing and Building Diagnostics

General

1. The customer file contains documentation of all diagnostic, air-sealing, and combustion-safety testing that was performed at the building.
2. Diagnostic tests were appropriate for the building's configuration.
3. Program guidelines were followed in reducing air leakage (e.g., major and minor air sealing and ZPD testing).

Air Sealing

1. All major attic bypasses and building key junctures are sealed.
2. All major bypasses and gross holes in the box-sill are air sealed.
3. Broken or missing windows or window panes have been patched, repaired, or replaced.
4. The air sealing hours and testing are documented in the Diagnostic Workbook.
5. Air sealing materials perform the intended function.
6. Paintable caulk was used where the occupant or owner is likely to paint the completed work.
7. If used, foam sealant was applied effectively and without waste. Overspray was cleaned up.
8. Weather-stripping is installed only on exterior doors, not on interior doors.

Blower Door Test

1. The equipment was calibrated per manufacturer instruction.
2. The final blower door value can be replicated to +/- 20%. (Final Inspection, QA Inspection).
3. The Diagnostic Workbook is complete.

Zone Pressure Diagnostics

1. Where required, ZPD testing was performed and is properly documented in Diagnostic Workbook.
2. The appropriate method was used when ZPD testing was completed (e.g., open-a-door, add-a-hole).