# Blower Door Testing

by David Keefe

## Diagnose problems in the building envelope with this simple, reliable tool

Air flowing in and out of a building can cause lots of problems; in fact, air leakage can account for 30 percent to 50 percent of the heat loss in some homes. But air flowing through a building can help solve lots of problems too — as long as it's the result of a blower-door test. With a blower door, builders can quantify airflow and the resulting heat (or cooling) loss, pinpoint specific leaks, and determine when a home needs additional mechanical ventilation.

First developed in the 1970s as a research tool, a typical blower door consists of a powerful variable-speed fan mounted in an adjustable panel temporarily set up in a doorway (**see Figure 1, next page**). The fan moves air through the building in a controlled fashion, while a pressure gauge — connected to the fan and to the outdoors by small-diameter pressure tubes — measures the rate of airflow required to maintain the building at a certain pressure. The blower creates exaggerated air leaks, which can then be found with the help of tools like smoke puffers or infrared cameras, or even just by feeling with the face or the back of the hand.

Blower doors for residential work now weigh less than 50 pounds and can be easily carried in a small trunk. A basic kit costs between $2,500 and $3,500 and can be set up, used, and repacked in a half-hour. (For more information on blower-door kits, see “Blower-Door Manufacturers” on page 7.)

## Pressure, Airflow, and Holes

The amount of air that flows through a hole depends on the characteristics of the hole and the pressure driving the flow. Since the three variables — hole, pressure, and flow — interact, a change in any one also changes at least one other. This behavior can be measured fairly reliably, so given any two of these variables, we can calculate the third.

- If we know the size and shape of a hole and the force pushing the air, we can figure out how much air must be going through.
- If we measure the amount of air going through a known hole, we can calculate what pressure must exist in order to push that much air.
- If we know nothing about the hole, but can measure the pressure and the flow, we can figure out what the hole must be like.

That’s what a blower door does: It generates and measures airflow and pressure. We then use that information to describe the size and shape of the hole.

***About natural infiltration.*** Once we have used flow and pressure to determine what the leaks are like, we can use that hole description, along with weather and site data (the test pressure), to estimate the airflow that can be expected under normal conditions. But estimates of “natural airflow” are inherently inaccurate, because it’s difficult to know how the wind blows on a particular site, or what the occupant behavior is like, or how the mechanical equipment interacts with the building. So it’s important to know whether airflow descriptions are measurements of leakage under specified conditions or estimates of airflow under normal conditions.

To measure airflow, a closed-up house is depressurized with the blower-door fan to a constant pressure differential as compared with outside conditions, typically 50 pascals (Pa). A pressure gauge attached to the blower-door assembly measures the rate of airflow required to maintain that pressure differential in cfm (cubic feet per minute).

Sometimes several readings are taken at different pressures, then averaged and adjusted for temperature using a simple computer program. This provides the most accurate picture of airflow, including leakage ratios, correlation coefficients, and effective leakage area (**Figure 2, next page**).

Most of the time, though, this detailed output isn’t needed, and all we want to know is how much the building leaks at the specified reference pressure of 50 Pa. So-called single-point testing is popular with crews who do retrofit work, because

Figure 1. Equipment needed for comprehensive blower-door testing can be packed into a few easily-transported cases (above). The blower door consists of an adjustable aluminum frame and a nylon panel (right), fitted with a powerful variable-speed fan (far right).

BDWin 2.04 Blower Door Measurements File: Demo E3-DM4 blower door.ibd

File Print Units Help

Input Data

Pre-test Static Pressure= .1 Pa Negative Avg= -.3 Pa Positive Avg= .4 Pa

| | Pres Gauge (Pa) | Flow Gauge (m3/h) | Low Flow Plate Correction | Fan Flow (m3/h) | Curve Fit (m3/h) | Fit Error (%) |
|---|---|---|---|---|---|---|
| #1 | 62.3 | 7543.6 | DM4:Plate Off | 7281.7 | 7263.2 | .254 |
| #2 | 56 | 7050.8 | DM4:Plate Off | 6806 | 6791.1 | .219 |
| #3 | 49.8 | 6490.2 | DM4:Plate Off | 6264.9 | 6306.7 | -.668 |
| #4 | 43.6 | 5980.5 | DM4:Plate Off | 5772.9 | 5799.3 | -.458 |
| #5 | 37.4 | 5487.8 | DM4:Plate Off | 5297.3 | 5264.2 | .625 |
| #6 | 31.1 | 4842.2 | DM4:Plate Off | 4674.1 | 4685.2 | -.238 |
| #7 | 24.9 | 4230.5 | DM4:Plate Off | 4083.6 | 4070.8 | .314 |
| #8 | ? | 0 | DM4:Plate Off | 0 | 0 | 0 |
| #9 | ? | 0 | DM4:Plate Off | 0 | 0 | 0 |

Post-test Static Pressure= .2 Pa Negative Avg= -.2 Pa Positive Avg= .3 Pa

Curve Fit: Correlation= .99969 Pressure Exponent= .6288 Flow Coefficient= 541.196 m3/h @ 1 Pa

Leakage Area: ELA-CGSB@10Pa= 2568. cm2 ELA-LBL@4Pa= 1392. cm2 LR@10Pa= 18.43 cm2/m2

50 Pa Leakage: ACH50= 18.642 Flow50= 6334.6 m3/h Perm Index 15.931 m3/h/m2

Avg Annual Infiltration: Inf.ACH= .9321 Flow= 316.73 m3/h 79.183 m3/h/person, 79.183 m3/h/bedroom

Back Inf.DEAP Index= .7965 m3/h/m Graph

**Figure 2.** Blower-door testing can generate a detailed summary of a building's airflow characteristics. Leakage can be expressed either as an equivalent hole size — called effective leakage area, or ELA — or as a ratio of leakage to shell area, or leakage ratio (LR), a useful unit for comparing the tightness of different building shells.

once the door is set up, it takes only about a minute to measure the effectiveness of their air-sealing strategies (**Figure 3**).

The pressures exerted on a building are quite small (50 Pa is the suction pressure required to lift a column of water up a soda straw less than a quarter inch), so test results can be affected by wind gusts. There are some tricks for moderating wind effects and increasing accuracy: For example, multiple tubes protected with wind dampers can be run outdoors to sample air pressure on different sides of the building, and several measurements can be taken and averaged. Using these techniques, blower-door testing can be done in all but the windiest weather. An experienced operator can tell whether or not reasonable measurements are possible by the behavior of the gauges. Computer analysis of the data — if it's done — also includes a check for accuracy.

***Cfm and ACH.*** While airflow can be measured in cfm, it can also be expressed as airflow compared with volume, or air changes per hour (ACH). ACH50 indicates air changes per hour at a 50 Pa pressure difference (not to be confused with natural ACH). Generally speaking, houses with less than 5 to 6 ACH50 are considered tight, and those over 20 are quite leaky, though these numbers can be misleading without considering other variables such as climate, house size, and old vs. new construction.

While the airtightness and ventilation requirements of a space have traditionally been expressed in ACH, many blower-door professionals routinely use cfm as their primary unit of measure. Cfm is easier to obtain, because it doesn't require calculations of volume. More important, it's a more direct expression of the main variable with which we are concerned — namely, air leakage.

If we're considering ventilation levels, we can more easily deal with cfm than ACH, and are probably more concerned with absolute flow than the flow as compared with volume. If we're dealing with large spaces with few occupants — or small, heavily occupied spaces like trailers and apartments — ACH can be misleading because it can make a large space look tighter and a small space look leakier. For these and other reasons, cfm is being used more often and ACH less. Because cfm50 (the cubic-feet-per-minute airflow with a 50 Pascal indoor-outdoor pressure difference) is easily obtained with single-point tests — and is low enough to be consistently reached yet high enough to

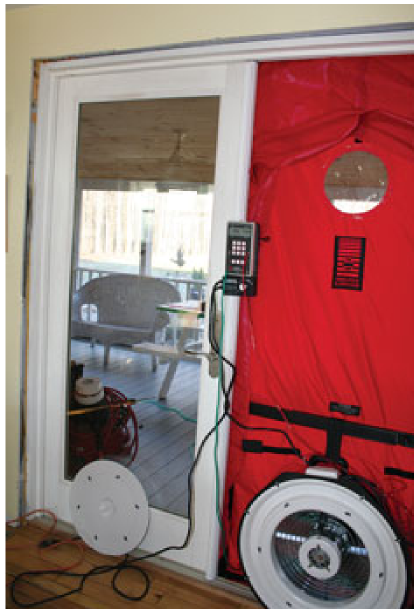

**Figure 3.** Heated air is less dense than cold air, so houses tested in cold weather appear leakier than they really are (by about 1 percent for each 10°F difference between indoor and outdoor temperature) unless an adjustment for temperature has been made. Otherwise, testing will indicate the amount of less dense air flowing through the blower door, and not the amount of colder, denser air flowing through the holes.

Figure 4. In a depressurized house, air will rush in through any available opening, so combustion appliances need to be shut down during a blower-door test to prevent backdrafting. Here, a smoke puffer indicates that the chimney flue is leaky even with its damper fully closed.

Figure 5. A digital manometer is used to measure the oil-fired furnace's draft, or ability to vent combustion gases.

be resistant to the effects of wind — it has become the main unit of measure for the description of airtightness. Tight houses tend to measure less than 1,200 cfm50, and moderately leaky homes measure between 1,500 and 2,500 cfm50. Homes that measure over 3,000 cfm50 are considered leaky.

## Testing a Home

Blower-door tests are performed with doors and windows closed, and often decisions have to be made concerning doors to semiconditioned spaces. The rule of thumb for basements and similar spaces is to include any area that is at least semiheated (even if unintentionally, as in an unfinished basement with a furnace). Often, it makes sense to test both ways, which is simple once the blower door is set up.

Whether or not intentional openings like ventilation ports are temporarily sealed depends on the test being performed. For a description of how an existing house normally behaves, such openings are usually left uncovered. On the other hand, if a new house is being tested for sufficiently tight construction, it may make sense to seal intentional openings, removing them from the measurement.

Since the test depressurizes the house, sucking air in through all the openings (including flues), combustion devices must be disabled. Heating systems and gas water heaters must be shut off. All wood-burning appliances in the house need to be out, which requires prior notification for occupied houses during the heating season (**Figure 4**).

***Checking for backdrafting.*** An analysis of a house's airflow should include a check of all combustion equipment. Any device that uses indoor air for combustion must have an adequate air supply. The greatest occupant safety hazard — backdrafting — tends to be the result of excessive

## Blower-Door Testing Equipment and Basic Procedure

### Recommended Tools

Blower door with accessories
Extra tubing, wind dampers
Thermometers
Computer (best if portable)
Calculator, clipboard, and paperwork
Duct tape, masking tape, scrap poly
Stepladder, flashlight, measuring tape
Smoke bottle

### Procedure

1. Measure building, calculate area and volume (not needed for cfm, only for ACH and leakage ratio).
2. Measure temperature inside and out.
3. Shut off combustion appliances.
   - Customers burning wood or coal need prior notification.
   - Close fireplace damper, cover ashes if damper not tight.
4. Verify condition of intentional openings.
   - Doors and windows closed, interior doors open.
   - Seal mechanical ventilation, clothes dryer if desired.
   - Fill plumbing traps if house not occupied.
5. Decide on configuration of doors to semiconditioned spaces.
   - In general, include partially heated spaces.
   - When in doubt, test both ways.
6. Set up blower door, following manufacturer's instructions.
   - When possible, use doorway directly to outside. If not, make sure end of tubing is all the way outside.
7. Record the baseline pressure between the house and outside, following the manufacturer's instructions.
8. Take measurements.
   - Turn the fan up enough to change the house pressure by 50 Pa and record the flow.
   - For multipoint tests, take several readings at pressures between 10 and 60 Pa, instead of just one at 50 Pa.
   - If gauges move too much, use multiple outside ports, wind dampers, or time averaging.
9. Look for leaks.
   - 20 to 30 Pa depressurization, depending upon temperature outside.
   - Focus on:
     - Areas that experience higher pressures (top and bottom).
     - Areas where moisture escapes (upper stories, humid rooms).
     - Areas where pipes freeze.
     - Areas with specific comfort problems (cold drafts).
     - Problems that are cheap (quick) to fix.
     - Rough holes, often not accessible from living space.
   - Compartmentalize: Check individual rooms by cracking open door.
10. If heated by combustion equipment, perform combustion safety tests.
11. If the house has a forced-air system, perform a room-to-room pressure test to evaluate whether interior door closing affects the distribution of conditioned air.
12. Turn combustion appliances back on (check pilot lights).
    - Remove temporary seals, if used.

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negative pressure caused by air-moving appliances. This works the same way as the blower door: A fan moves air out of a space, which produces a pressure difference relative to the outside. This fan can be one that is intended to remove air from the building — like a bathroom exhaust fan, range hood, clothes dryer, or central vacuum system — or it can be a fan that moves air within the building, such as a furnace fan. It can also be a combination of several fans or an exhaust force other than a fan, such as the heat-driven force of a chimney. If the negative pressure in a combustion appliance's space is greater than the chimney draft (often only 3 to 5 Pa), the airflow in the flue will be reversed and flue gases will be dumped inside (**Figure 5, previous page**).

Although backdrafting tends to be more common in tight houses, it is also affected by the specific appliances involved and where they are located. Compartmentalization created by interior doors can contribute to the problem as well.

To check for the likelihood of backdrafting, I place the house in a worst-case condition, turn on the air-moving equipment, and either measure the resulting

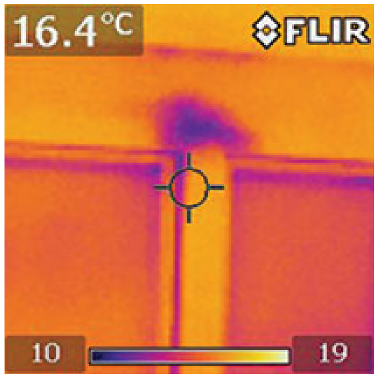


Figure 6. An infrared camera can be a handy tool during a blower-door test. Air leaks around windows and doors typically appear as blue "fingers" on the IR screen, while blue patches (above) indicate conductive losses from problems like thermal bridging, insulation voids, and moisture damage.

Figure 7. Duct system leakage can be estimated using the "blower-door subtraction method," but a Duct Blaster test is more accurate. After the supply and return registers are sealed with tape, airflow is directed into the supply plenum, measured at a reference pressure of 25 Pa, and compared with accepted leakage rates.

indoor-outdoor pressure or fire up the combustion device. Many testing protocols (such as the Building Performance Institute's) specify a maximum allowed depressurization. If this maximum is exceeded, or if the appliance does not establish draft under the worst-case condition, some action must be taken to either improve the draft or reduce the depressurization so that flue gases are reliably exhausted outside.

## Air-Sealing

In addition to measuring total airflow, a blower-door test is useful for identifying specific leaks, since it can force the leaks to become more apparent. Larger leaks directly into the living space can be felt with the back of the hand from inside the house when the house is depressurized, typically to between 20 and 30 Pa. A smoke bottle or pencil is handy for finding smaller leaks and leaks from unconditioned spaces. Sometimes it's more effective to reverse the airflow and pressurize the house. In general, airflow toward a person can be felt; airflow away is more easily found with smoke.

This demonstration can have a powerful impact on customers. When told that their main problem is not windows and doors but plumbing penetrations and attic bypasses, customers are often skeptical, but they become convinced when they actually feel the air pushing out from under their kitchen sink. Even people who understand almost nothing about their home's thermal performance can easily tell the difference between small and large leaks when they feel them with their own hands or see them with their own eyes (**Figure 6**).

To get a sense of where the major leaks are, I depressurize the house with the blower door. I close the interior doors most of the way (one at a time) and feel for airflow around the doors. If major leaks exist on the other side of the door, I can feel the airflow at the door. If little or no flow is felt, the area behind the door is reasonably tight. This way, I can tell whether further investigation of an area is needed without even entering the room.

Crews who do retrofit work often leave the blower running for extended periods while they work, allowing instant diagnosis and feedback. Instead of sealing every hole that looks like it may leak, specific locations can be checked, sealed only if necessary, and rechecked to verify success.

It's always more efficient to air-seal while the blower door is running than to conduct a blower-door test and then come back later. Attempting to itemize leaks in advance wastes time, since each leak has to be described on paper, understood by the crew, and found a second time. Many leaks take less time to seal than they require for access. In addition, crews without blower doors have no way to verify that their first attempt at sealing a given area has been successful (often it hasn't been), nor can they determine whether a leak found by an auditor has already been sealed by other work done in the building (often it has).

Because crews measure results as they go along, blower-door–directed air-sealing makes it possible to determine how much effect a particular measure has had, or how much reduction has been accomplished in a given period of time. Workers become more productive because they can focus on areas where the best results are likely to be obtained. By establishing simple rules of thumb for cost-effectiveness, crews can determine when to stop retrofit work and move on to the next building, rather than continuing work with diminishing returns. In fact, a common worry for those who consider using blower doors is that too much time will be spent sealing leaks that are not important. But usually the opposite happens: Crews discover that some leaks they would have thought deserving of treatment are not, and they don't waste time on them.

## Building Tightness Guidelines

Many organizations involved with blower-door air-sealing have established program guidelines that specify a minimum leakiness and advise stopping air-sealing work when the building's estimated average infiltration equals a recommended ventilation rate. Building-tightness guidelines are thought to be helpful for weatherization crews who need to be concerned about providing adequate fresh air for occupants in situations where there is little or no mechanical ventilation (the issues of combustion safety and makeup air for exhaust fans are supposed to be dealt with separately).

But I agree with the many experts who think this approach is fundamentally flawed and that buildings should be sealed as tightly as economically sensible. Tightness guidelines have serious limitations, because blower-door numbers indicate nothing about the sources of pollutants or the use of mechanical ventilation, and estimates of natural infiltration (which determine the building tightness limit) can easily be off by 50 percent or more.

Indoor air quality is affected by many factors, not just the tightness of the building. Establishing minimum leakiness standards on a programwide basis without also addressing source control, ventilation, and indoor combustion is an ineffective and risky health and safety strategy.

## Advanced Blower-Door Techniques

Once you start using a blower door for basic diagnostics, you'll likely start discovering other ways to use the hole/flow/pressure relationship. For example, diagnosing ductwork problems involves the same principles and much of the same equipment as evaluating building shells (**Figure 7, previous page**). Ensuring that combustion products end up outside rather than inside a house comes with understanding and controlling airflows and pressures. So does radon mitigation. Advanced pressure diagnostics — like evaluating airflow through multiple barriers or between zones — requires knowledge of blower-door testing. Effective ventilation strategies are dependent upon holes and pressures, in addition to flows.

The blower door has greatly increased our collective understanding of the ways in which air movement in buildings influences comfort, durability, health, and safety. It's a practical, cost-effective tool for anyone working to improve home performance and safety.

*Former contractor **David Keefe** is manager of training services for the Vermont Energy Investment Corp.* *This article is adapted with permission from* Home Energy *magazine. Thanks to Ted Lylis for his assistance with photos.*

## Blower-Door Manufacturers

**The Energy Conservatory**
612/827-1117
energyconservatory.com

**Minneapolis Blower Door Model 3** system includes DG-700 digital micro-manometer and calibrated 300- to 6,300-cfm fan. Price includes tubes, door case, and padded accessory case. Fan weighs 33 pounds. $2,625.

**Infiltec**
540/943-2776
www.infiltec.com

**Model E3-A-DM4-110** system includes DM4 digital micro-manometer and calibrated 42- to 5,450-cfm fan. Price includes tubes, door case, and padded accessory case. Fan weighs 36 pounds. $2495.

**Retrotec**
604/732-0142
retrotec.com

**Model Q46** system includes DM-2A digital micro-manometer and calibrated 38- to 6,300-cfm fan. Price includes case for gauge and hard cases for fan and for frame and cloth. Fan weighs 34 pounds. $3,150.