

## BLOWER DOORS

# Introduction to Blower Doors

by David Keefe

*Now a widely used diagnostic tool, blower doors have revolutionized the way most professionals approach retrofit work. This introduction explains how blower doors work, what can be gained from their use, and what a typical blower door test involves.*

Air flow through a building can have a powerful impact on comfort, expense, and air quality. Blower doors provide a way to quantify air flow and the resulting heat loss, along with a way to pinpoint specific leaks. Their use in retrofit work allows both instantaneous feedback and quantitative inspections. The benefits of their use have been understood and documented enough that most professionals now consider them essential for effective (and cost-effective) air sealing. New construction projects also make use of blower doors for quality control and retrofit contractors sometimes use them for customer education and sales.

Blower doors are highly useful and reliable diagnostic tools that are fairly simple to understand. Their use in retrofit work can greatly improve productivity, and their use is easily justified on a cost/benefit basis. A "blower door" consists of a powerful variable-speed fan, mounted in an adjustable panel that temporarily fits in a doorway, that is used to move air through the building in a controlled fashion. Pressure gauges connected to the fan measure the rate of airflow required to maintain the building at a certain pressure. This controlled airflow is used to find specific leaks.

Developed as a research instrument in the early 1970s, the blower door has evolved into a field tool. Blower doors are now more accurate, more portable, easier to use, and less expensive than in the past. My first blower door, purchased ten years ago, weighed about 200 pounds and required one-third the space of a full-sized van. It cost more than \$6,000 and needed 240 volt power. To unload,



Courtesy of Retrotec

This rigid-frame model from Retrotec is one of a variety of blower doors on the market today. Since its development in the early 1970s, the portability and accuracy of the blower door as a tool has grown, while its price has dropped.

set up, run a test, and return the unit to the truck took about one hour. Today's most popular blower door weighs about 50 pounds, carries easily in a small trunk, costs about one-quarter as much, and can be set up, used, and returned to the vehicle in about half the time.

### Pressure, Flow, and Holes

The increasing use of blower doors has led to a better understanding of airflow through buildings in general. Researchers and practitioners now have a better picture of air-related combustion safety and of airflow through ductwork. They have also developed advanced pressure diagnostic techniques. This basic concept is key to how blower doors work:

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The amount of air that flows through a hole(s) is dependent upon the characteristics of the hole(s) and the pressure driving the flow.

These three variables—hole, pressure, and flow—work together, so that a change in any one also changes at least one other. This behavior can be quantified and is fairly reliable. 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.
- 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, using that information to create a description of the group of holes which is involved.

### *"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 pressure), to estimate the airflow we might expect under normal conditions.

This step can be confusing, because we have moved from a direct measurement of the house's behavior under specified and controlled conditions to an estimate of how the house behaves "naturally." We lose some accuracy in the transition, largely because we can only estimate the natural pressures involved. 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.<sup>1</sup> It is important to keep in mind whether airflow descriptions are measurements of leakage under specified conditions, or estimates of airflow under normal conditions.

### *Accuracy*

How accurate are estimates of natural airflow? Given a large sample, the estimates usually show reasonable agreement with tracer gas measurements<sup>2</sup>, which directly measure natural air flow. However, in specific houses the actual airflow can vary quite widely. Actual air flow can sometimes be as little as one-half the estimate, or as much as twice the estimated amount. How accurate this makes the estimates depends upon a person's point of view.

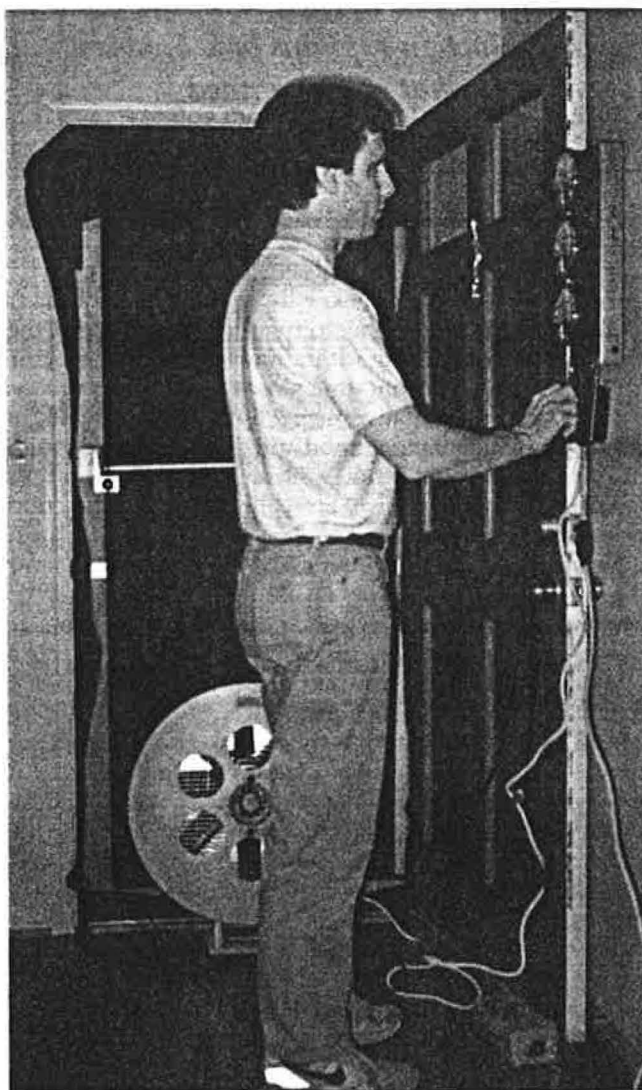
Although predictions of "natural" air flow, accurate within 5%–10% would be handy to have, no practical means exists to get them. For easily obtainable estimates for the decisions involved, blower doors are the easiest way to improve greatly on guesswork. (These comments on accuracy refer only to the estimates of "natural" infiltration. The actual measurements taken with a good blower door are, for all practical purposes, quite accurate.)

## Testing Procedures

The test is performed with doors and windows closed. Decisions often need to be made concerning doors to semi-conditioned spaces. The rule of thumb for basements and similar spaces is to include any area which is at least semi-heated (even if unintentionally, as in an unfinished basement with a furnace). Often, it makes sense to test both ways, which is easy and quick once the blower door is set up.

The test determines whether or not intentional openings like ventilation equipment are temporarily sealed. 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 remove any intentional openings from the measurement by sealing them up.

Since the test depressurizes the house, sucking air in through all the openings (including flues), it is important that all combustion devices be disabled during the test.



Each variety of blower door is slightly different. For instance this Infiltec model uses a fabric cover rather than a rigid frame to block off the doorway around the fan. It is important to "zero" the gauges according to manufacturer's directions before starting measurements.

Courtesy of Infiltec

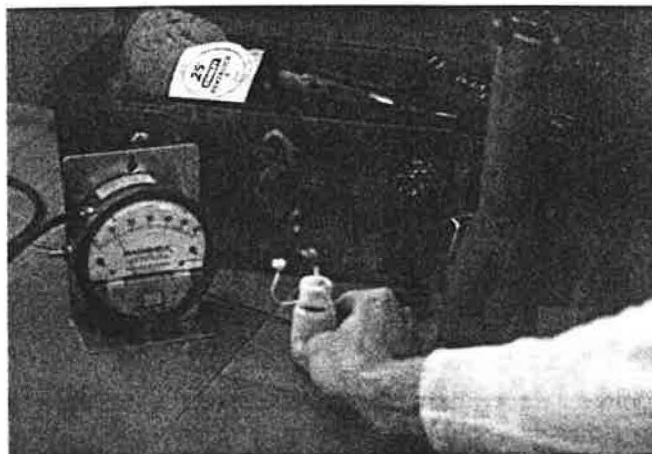
Heating systems and gas water heaters must be shut off. Pilot lights should be extinguished. All wood-burning appliances in the house need to be out, which requires prior notification for occupied houses during the heating season.

The physical form of the door is fairly straightforward. It varies with manufacturer, but usually consists of an expandable frame to fit the door opening, either a fabric cover or rigid panels to block off the doorway except for the fan, and pressure gauges to take the measurements. The gauges must be "zeroed" as part of the preparation; it is important to do this according to the manufacturer's directions.

Measurements are taken by increasing the speed of the fan until the pressure difference between the house and outside is at the desired level. Typically, testing is done between 10 and 60 Pascals (Pa). The airflow out of the house at that pressure is then recorded. For best accuracy, multiple readings are taken at different pressures, then averaged and adjusted for temperature<sup>3</sup> using a simple computer program. This approach results in detailed output using many different units of measure (see "Blower Door Terms," p.28). The pressures exerted on the house are quite small. About 60 Pa is the suction pressure required to lift a column of water up a soda straw only one-quarter of an inch.

Often, the detailed output is not required. Many situations do not require leakage ratios, correlation coefficients, or effective leakage area. We merely want to know how much a building leaks at a specified reference pressure. The industry standard has become 50 Pa. A single-point test consists of simply reaching 50 Pa and reading the flow. Single-point testing has gained wide use recently, especially with crews who do retrofit work. Once the door is set up, it takes only a few seconds to do a single-point test. This makes it easy for crews to measure the reduction from a given measure or group of measures.

With a decent blower door and a competent operator, the main determinant of test accuracy is wind. Since the test pressures the door exerts on the building are relatively



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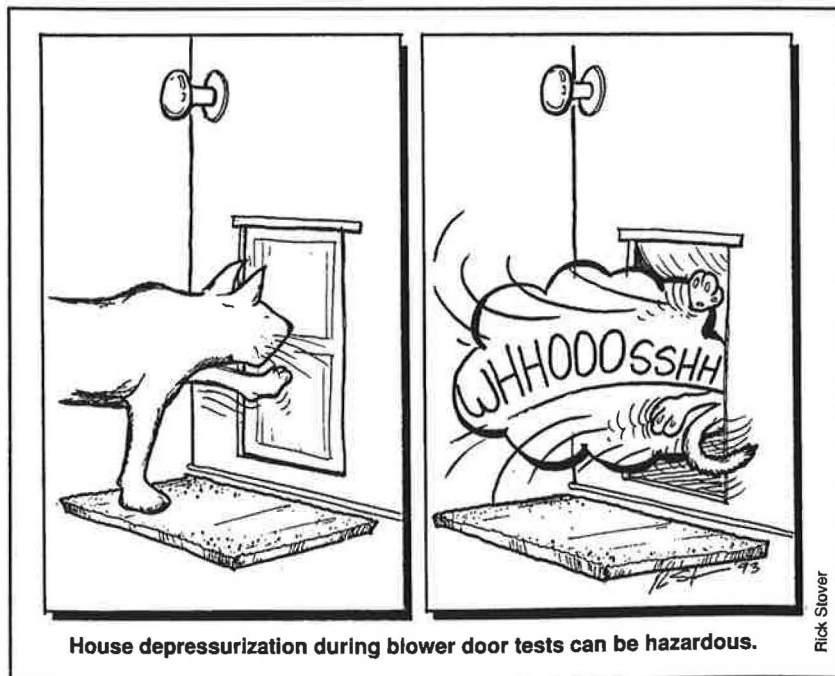
Chemical smoke can be used in conjunction with blower doors to visually illustrate the air paths of drafts and leaks. If weatherization crews leave the blower door running during their inspection of a house, they can check and seal individual locations, instead of sealing every spot that looks like a potential leak.

small, they can be affected by wind gusts. There are some tricks for increasing accuracy: multiple tubes can be run outdoors in order to sample the air pressure on different sides of the building, and wind-dampened ports for those tubes can be used. Both of these tend to moderate the effect of wind. Slightly higher pressures can also help, since lower pressures are more easily overpowered. These techniques enable most testing to proceed in all but the windiest weather. An experienced operator can tell whether or not reasonable measurements are possible by the behavior of the gauges, and the computer output includes a check on accuracy.

### Backdrafting

Any analysis of a house's air flow should include a check of all combustion equipment. Any device that uses indoor air for combustion must have an adequate air supply. In terms of safety, the greatest hazard—backdrafting—tends to be the result of excessive 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 an exhaust fan, range-top grill, 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 its flue system's draw (often only 3–5 Pa), the airflow in the flue will be reversed and flue gases will be dumped inside.

Although backdrafting tends to be more common in tight houses, it is also affected by the specific equipment involved, locations,



Rick Stover



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and compartmentalization created by interior doors. The procedure for checking the likelihood of backdrafting involves placing the house in a worst-case condition, turning on the air-moving equipment, and either measuring the resulting indoor-outdoor pressure or firing up the combustion device.<sup>4</sup>

### The Numbers

**B**lower door numbers can appear confusing at first. Not only are we measuring units we can't see, but we don't seem to be able to decide between metric and imperial units, and we have at least two CFMs and ACHs.

One fundamental distinction involves air flow—usually measured in cubic feet per minute (CFM)—as opposed to flow compared with volume—air changes per hour (ACH). Traditionally, the tightness or ventilation of a space has been expressed in air changes per hour. However, many professionals routinely use CFM as the primary unit of measure. Although both units clearly have their uses, CFM is more easily obtained, because it does not require calculations of volume. More importantly, it is a more direct expression of the main variable with which we are concerned. Although ACH includes an adjustment for the size of the building, that consideration may be less important than others and can be taken into account in other ways. If we are interested in estimating heating cost or sizing a heating system, we are concerned only with the flow itself, not the flow as it relates to volume.

If we are considering ventilation levels, we can more easily deal with CFM rather than ACH, and are probably more

concerned with absolute flow than the flow as compared to volume. If we are dealing with small, heavily occupied spaces (trailers, apartments) or large spaces with few occupants, ACH can be misleading. (ACH can sometimes 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.

CFM50, the cubic feet per minute with a 50 Pascal indoor-outdoor pressure difference, has become the main unit of measure for the description of airtightness. It is easily obtained with single-point tests; this pressure is low enough to be consistently reached and high enough to be resistant to the effects of wind.

### Blower Door-Guided Air Sealing

Blower doors are also useful for identifying specific leaks. Since the blower door provides control over the air flow in the building, we can force the leaks to become more apparent. By sucking air in through the leaks, we can feel them with the back of the hand. By forcing air out, chemical smoke can be used to point to air paths.

Leaks directly into the living space can be felt with the back of the hand from inside the house during depressurization (20–30 Pa is usually used, the higher pressure during warm weather and lower pressures in cold weather). Leaks from unconditioned spaces can also be checked from those spaces with a smoke bottle.<sup>5</sup> Occasionally, the flow is reversed to pressurize rather than depressurize 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 they are told that their main problem is not windows and doors, but plumbing penetrations and attic bypasses, they are often skeptical. But when customers feel the air pushing out from under the kitchen sink, they're

### Blower Door Terms

**Pascal. (Pa)** A metric unit of pressure. 50 Pascals is about one pound per square foot. 250 pascals is about one inch of water column.

**CFM.** Cubic feet per minute. A rate of air flow.

**Correlation Coefficient.** The extent to which the individual pressure and flow readings correspond to an average curve. A measure of the accuracy of the test—should be above .99.

**"C"** The flow rate, in CFM, with a 1 Pa pressure difference.

**"N."** The slope of the leakage curve. A rough indicator of the average size of the individual holes. The higher the number, the smaller the holes. Many houses tend to be between 0.6–0.7. Less than 0.6 indicates the existence of major large holes, above 0.7 smaller holes tend to dominate.

**ELA.** Effective leakage area. The area (in square inches) of a hole which, with a 4 Pa pressure difference, leaks the same amount as the house.

**EqLA.** Equivalent leakage area. The area (in square inches) of a hole which, with a 10 Pa pressure difference, leaks the same amount as the house.

**Leakage Ratio.** Leakage area as compared to surface area. It equals the EqLA in square inches divided by the surface area in 100's of square feet. A good unit for comparing the tightness of different building shells. Less than 3–4 indicates a very tight house, more than 10–12 a very leaky one.\* The

recently born "Minneapolis Leakage Ratio" compares CFM50 with above-grade surface area in square feet. A value greater than 1 indicates a likelihood of opportunities for cost-effective improvements.

**ACH.** Air changes per hour, a description of leakage as compared to volume. The number of times each hour an amount of air equal to the volume of the building leaks out. Used for both blower door measurements and estimates of normal flows.

**CFM50.** The flow, in cubic feet per minute, with a 50 Pa pressure difference. Tight houses tend to be less than 1,200 CFM50, 1,500–2,500 CFM50 indicates a moderately leaky home, over 3,000 is quite leaky.\*

**ACH50.** Air changes per hour at a 50 Pa pressure difference. Not to be confused with natural ACH. Houses with less than 5–6 ACH50 are quite tight and those over 20 are quite leaky.\* Can be misleading in very small or large houses.

**Natural Infiltration.** The average amount, in CFM or ACH, that a house leaks under "normal" conditions. Cannot be measured by blower doors, can only be roughly estimated. Not constant, varies widely over time.

**\$/100 CFM50.** An estimate of the heating cost (or the value of a reduction) of 100 CFM50. Depends upon climate, fuel cost, system efficiency, and payback assumptions. A very useful number for determining the cost-effectiveness of air sealing.

\* These descriptions of tightness are roughly appropriate for existing houses; new homes can and should be tighter.

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## Blower Door Testing Equipment and Basic Procedure

### Recommended Tools:

- Blower door with accessories
  - Extra tubing, wind dampers
  - Thermometers
  - Computer (best if portable, but can use desktop)
  - Small screwdriver for zeroing gauges
- Calculator, clipboard, and paperwork
- Duct tape, masking tape, scrap poly
- Stepladder, flashlight, measuring tape
- Smoke bottle
- Stand-alone Magnehelic gauge or digital manometer (optional)

### Procedure:

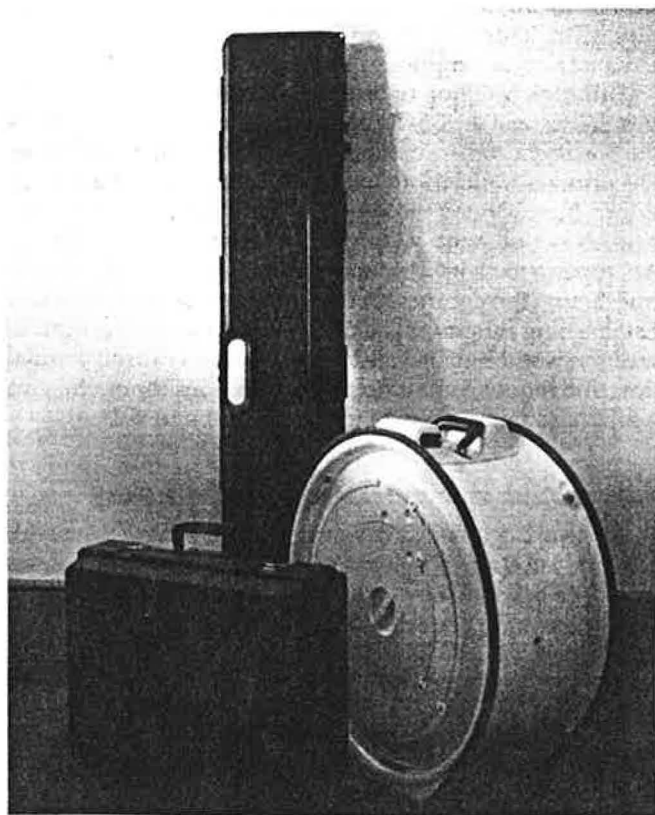
1. Measure building, calculate area and volume.  
Not needed for CFM, only for ACH and Leakage Ratio.
2. Measure temperature inside and out.
3. Shut off combustion appliances.  
Customers burning wood or coal need prior notification.  
Close fireplace damper, cover ashes if damper not tight.
4. Verify 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 semi-conditioned spaces.  
In general, include partially heated spaces.  
When in doubt, test both ways.
6. Set up blower door.  
Follow manufacturer's instructions.  
When possible, use doorway directly to outside.  
If not, make sure end of tubing is all the way outside.
7. Zero the gauges.  
Follow manufacturer's instructions.
8. Take measurements.  
Try for at least 5 readings at equal intervals from 10 to 60 Pa.  
If gauges move too much, use multiple outside ports, wind dampers.  
Correlation coefficient should be at least .98, preferably .99.  
Generate enough info (CFM50) on site to get idea of leakiness.
9. Look for leaks  
20-30 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 heated by a furnace, perform MAD-AIR tests (see "Air Handler Fan: A Driving Force for Air Infiltration," *HE* Nov/Dec '89, p.13).
12. Turn combustion appliances back on (check pilot lights).  
Remove temporary seals, if used.

convinced. 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.

To get a sense of where the major leaks are, depressurize the house, close interior doors most of the way (one at a time), and feel for air flow around the doors. If major leaks exist on the other side of the door, the airflow will be felt at the door. If little or no flow is felt, the area behind the door is reasonably tight. This method can reveal whether or not further investigation of an area is needed, without even entering the room.

Crews who do retrofit work can leave the door running for extended periods while they work, allowing instant diagnosis and feedback. No longer is it necessary to seal every hole that looks like it may leak. Instead, individual locations can be checked, sealed only if necessary, and re-checked to verify success (see "Blower Door Guidelines for Cost-Effective Air Sealing," *HE* Mar/Apr '90, p.34). This process is best conducted by the person doing the air-sealing, rather than as a separate step. 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 isn't) nor can they determine whether a leak found by an auditor has already been sealed by other work done in the building (and it often has).

Because crews measure results as they go along, it is possible to determine how much effect a particular measure



David Keele

Portability is another asset that weatherizers find in the blower door. This Minneapolis Blower Door packs away for easy storage and can easily be moved between jobs.

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has had, or how much reduction has been accomplished in a given period of time. This allows workers to improve productivity, by focusing on areas where good 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 working with diminishing returns. A common worry for those who consider using blower doors is that too much time will be spent sealing leaks which are not important. Usually, the opposite happens. Crews discover that some leaks they would have thought deserving of treatment are not, and they stop wasting time on them.

### *Building Tightness Guidelines?*

There is an increasing tendency for organizations involved with blower door seal-ups to establish program guidelines that specify a minimum leakiness. The objective is to prevent buildings from being made "too tight," and the approach usually involves stopping air sealing work when the leakiness of the building is such that the estimated average infiltration equals a recommended ventilation rate (see "Building Tightness Guidelines: When Is a House Too Tight?" *HE* Mar/Apr '93, p.18).

Proponents argue that building tightness guidelines are useful for weatherization crews who need specific guidelines to avoid overtightening houses. The guidelines are intended to provide 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.)

Although building tightness guidelines have their uses, they have some serious limitations. There is a strong potential for them to be misused. They are not appropriate as the primary indicator of indoor air quality or combustion safety. Blower door numbers indicate nothing about the sources of pollutants or the use of mechanical ventilation. Attempting to control indoor air quality by focusing on only one factor (the tightness of the building) is destined to fail. Establishing minimum leakiness standards on a program-wide basis without also addressing source control, ventilation, and indoor combustion is not a responsible or effective health and safety strategy. It's inefficient and risky.

### **Advanced Blower Door Techniques**

Measuring a building's overall leakage is very useful, but it doesn't tell the whole story. Using the same principle by which blower doors work, more sophisticated techniques have been developed to better understand how

a building's various areas and systems interrelate (see "In Search of the Missing Leak," *HE* Nov/Dec '92 p.27). Be forewarned that involvement with blower doors will likely generate a desire to use the hole-flow-pressure relationship in other ways.

Assuring that combustion products end up outside rather than inside a house is critical for health and safety reasons. Diagnosing ductwork problems involves the same principles (and much of the same equipment) as evaluating building shells. Radon mitigation is essentially the control of flows and pressures. New techniques to evaluate airflow through multiple barriers or between zones (pressure diagnostics) require knowledge of basic blower-door testing. Effective ventilation strategies are dependent upon holes and pressures, in addition to flows.

Originally developed as research tools, blower doors have proven their worth as practical, cost-effective assets for anyone working to improve the performance and safety of buildings. Their growing acceptance by weatherization agencies, consultants, and contractors has greatly aided in our collective understanding of the way in which air movement influences comfort, durability, affordability, health, and safety. ■

### **Notes**

1. Although natural infiltration has often been thought to be determined by wind and outside temperature, recent research has shown that the pressures exerted by fans and blowers can also greatly influence how much outside air flows through the building.
2. Tracer gas actually measures the airflow of buildings under normal conditions by introducing a known quantity of gas and timing how long it takes to "flush out." It is seldom used, except for research, because it is cumbersome, only gives results for the specific weather at the time, and does not reveal the locations of leaks.
3. As the temperature of air changes, so do its density and flow characteristics. In cold weather, the blower door is pushing out heated air that is less dense than the cold air being pulled in. Since we want to measure the air flowing through the holes rather than the air flowing through the blower door, a simple adjustment for temperature is made. Without this adjustment, houses tested in cold weather appear leakier than they really are (by about 1% for each 10 degree F difference in indoor and outdoor temperature).
4. Some blower door manufacturers provide information on backdraft testing. A leading guide is the "Combustion Venting Student Manual," available free from Canada Mortgage and Housing Corp, 682 Montreal Road, Ottawa, Ontario, Canada, K1A 0P7. Tel: (613) 748-2660. For more on backdrafting, see "Backdrafting Causes and Cures," *HE* May/June '91, p.30.)
5. Smoke bottles are small vials of a chemical (usually titanium tetrachloride) that emits a chemical smoke when exposed to atmospheric moisture. Better than a cigarette or incense, because the cool smoke doesn't tend to rise, they should be used with caution, as the fumes are quite nasty.

### **Blower Door Manufacturers**

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