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BLOWER DOORS

In Search of the Missing Leak

by Michael Blasnik and Jim Fitzgerald

Two weatherization mavericks took an idea and the versatile blower door into the field and returned with three new methods to find and measure house envelope air leakage across building boundaries.

With the use of blower doors, weatherization programs have improved cost-effectiveness by prioritizing air sealing work, developing effective inspection procedures for determining if work was done properly, and assessing the impact of air sealing on indoor air quality and moisture problems. Yet possibilities still abound for increasing the sophistication of these programs through even newer blower door techniques. Using a new diagnostic approach and three related test procedures, we have found ways to make both qualitative and quantitative insights into the location and interconnections of building shell air leakage. Adding these procedures to the diagnostic "toolbox" will help improve the work of weatherization practitioners.

The tests are all relatively quick and easy to do (5–10 minutes each) and involve taking just a couple of measurements using a standard blower door and its gauges. Users shouldn't become discouraged if these tests seem too complicated from reading this article, which is intended to introduce the weatherization community to these new tools. Field training and experience will provide the fullest understanding. Be forewarned also that the numerical test results can be very inaccurate if measurements aren't made carefully and results interpreted cautiously.

Of Air Sealing and Series Leakage

Using current approaches, experienced blower door practitioners often find themselves unable to answer difficult questions about building air leakage. For example,

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Michael Blasnik demonstrates one of three methods for pressure diagnostic measurement. Most useful for attics, kneewalls and smaller cavities, this method is distinguished by the addition of a hole to an inside surface.

how can one tell where to start air sealing in complicated houses with two attics, kneewalls, a basement, and a garage? Is it worth cutting an access hatch into an inaccessible attic? Will it be easier to seal the perimeter or the ceiling of the basement? Why do blower door readings sometimes fail to show much air flow reduction even though large leaks were sealed? How can we tell if we sealed all of the major bypasses? Is it worth the time to move all the stuff stored in a kneewall to look for leaks? Are the two kneewalls connected? Why do some houses seem to get leakier after the attic is insulated and vented? How can we tell if we successfully sealed the garage from the house?

All of these questions can be related to the central diagnostic problem of measuring or understanding "series" leakage paths. A "series" leakage path can be defined as a leak which passes through at least two boundaries between the inside of a house and the outside, usually with a "buffer" zone in between. These buffer zones can include attics, basements, garages, kneewall areas, or even individual rooms.

Experienced blower door practitioners recognize that most leaks in houses are not "direct" leaks to the outside like window and door leakage, but instead follow more complicated paths through two or more surfaces between the inside and outside. For example, attic bypasses often involve long paths through building cavities before they enter the attic and then connect to the outside through the roof vents. Other leakage paths may go through basements or garages before connecting to the outside.

BLOWER DOORS

Basic Principles of Series Leakage Paths

Series leakage paths have certain properties which allow blower door users to gain considerable understanding about where to locate the major leaks in a house, how they are connected, and whether they have been sealed effectively. But because these properties are not obvious, they have not been used until recently.

When depressurizing a house by 50 Pascals (Pa) with a blower door we should find about a 50 Pa pressure difference anywhere we stick a tube outside (if it isn't very windy). We should also find no pressure difference between any two zones inside the house. What does it mean if we measure the pressure difference between the house and the attic and find that it reads 40 Pa? If there are any connections between the house and a zone, then depressurizing the house by 50 Pa will lead to some depressurization of the zone relative to the outside and therefore less than a 50 Pa difference between the house and the zone. Measuring house-to-zone and zone-to-exterior pressure differences indicates how tight house and zone are relative to each other. These zone pressure difference measurements are fundamental for understanding series leakage paths. The measurements begin to have some meaning if we recognize a basic principle of series leakage paths:

> *The ratio of the pressure differences across the interior and exterior surfaces of the zone in a series leak is related to the ratio of their leakage rates.*

For example, if the ceiling (in other words, attic bypasses) and roof are equally leaky, then the pressure difference across the ceiling will be midway between the inside and outside pressures: 25 Pa if the house is depressurized by 50 Pa. If the ceiling is completely airtight, then the pressure

Three Pressure Diagnostic Tests

Method 1: Adding A Hole

Common Uses:

Attics, kneewalls, smaller cavities (bays, floor systems)

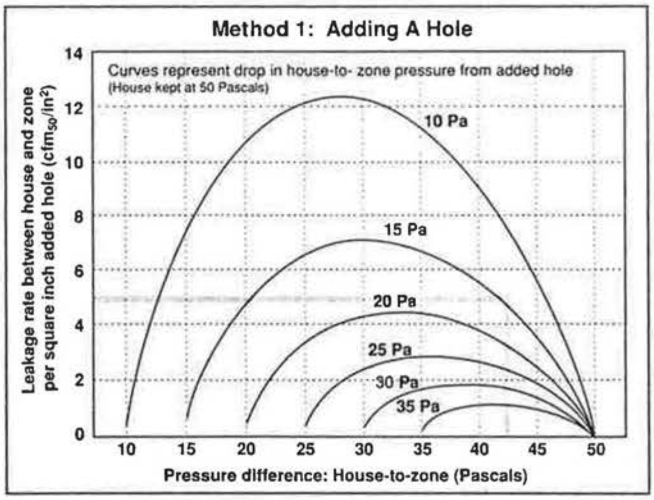
Measurements:

1) With house at 50 Pa, measure zone pressure differences—house-to-zone, zone-to-exterior, and house-to-exterior—checking that the first two add up to the third.
2) Add a hole to inside surface, for example open the attic or kneewall access fully or partly.
3) Remeasure pressures—making sure house is depressurized 50 Pa, adjusting fan as needed.
   - If pressures change little (less than 10 Pa), make the hole larger.
   - If house-to-zone pressure difference is near zero, make hole smaller.
4) Pressure drop (Step 3) = decrease in house-to-zone pressure from added hole.
5) Measure size of hole in square inches.

Calculations

6) In the Method 1 graph, find initial house-to-zone pressure difference on horizontal axis.
7) Find where this value intersects the "Pressure drop" curve corresponding to the value in Step 4.
8) On left axis, find the "Leakage rate between house and zone per square inch added hole (cfm_{50}/in^2)."
9) The house-to-zone leakage rate = value in Step 8 × the area of hole.
10) Calculate zone-to-exterior and total path leakages by looking up multipliers from Table 1. (Look in the column labeled with the initial house-to-zone pressure difference.) Then multiply each value by house-to-zone leakage rate (Step 9).

Method 1 works best when the initial pressures are not near 0 Pa or 50 Pa and the pressure drop is substantial (for example, 15–25 Pa).



Method 2: Opening A Door

Common Uses:

Basements, garages, attics with doors or pull-down stairs

Measurements:

1) With house depressurized to 50 Pa, measure whole house leakage rate and zone pressure differences.
2) Open door between inside and zone.

Table 1. Method 1 Multipliers

Initial pressure difference, house-to-zone (Pascals)	10	15	20	25	30	35	40	45	48	49
Multipier to obtain zone-to-exterior leakage rates[1]	0.4	0.6	0.8	1.0	1.3	1.7	2.5	4.2	7.9	12.6
Multiplier to obtain total flow path leakage rates[2]	.35	.46	.55	.64	.72	.79	.87	.93	.97	.99

1. Ratio of zone-to-exterior leakage rate to house-to-zone leakage rate. 2. Ratio of total flow path leakage rate to house-to-zone leakage rate.

difference across it will be 50 Pa, and the pressure difference across the roof will be 0 Pa, indicating that the attic is really "outside." If the roof is airtight, then the pressure difference across it will be 50 Pa and the pressure difference across the ceiling will be 0 Pa, indicating that attic is really "inside." If the roof is leakier than the ceiling, then the pressure difference between the house and attic (the tighter side) will be greater than 25 Pa and the pressure difference between the attic and outside (the leakier side) will be less than 25 Pa. The tighter one side is relative to the other, the greater is the pressure difference across that side.

If we make certain assumptions about the nature of the leaks (in particular, about their flow exponents), these measurements can be used to quantify the ratio of the interior side leakage rate to the exterior side leakage rate. For example, assuming typical building leakage (flow exponent=0.65), then if the pressure difference between the house and attic is about 45 Pa (when the house is depressurized by 50 Pa), then the roof is about four times leakier than the ceiling. (For the technically precise reader, the sensor is the reciprocal of the ratio of the pressures raised to the 0.65 power.)

Quantifying Zone Leakage

While measuring the pressure differences across the interior and exterior surfaces of the zone can provide useful information about the leakage path (for example, the ceiling is leakier than the roof or the basement is leakier to the inside than to the outside), it doesn't tell anything about *how much* leakage there is. The leakage rate can be quantified if one more piece of information is known about the flow path. For example, if we measure 25 Pa across the ceiling and we also know that the roof is leaky (because it is vented), then the ceiling must be leaky, too. We have developed three test methods which quantify the leakage rates using different approaches for getting this other piece of information about the flow path:

3) Remeasure whole house leakage rate, making sure house is still at 50 Pa.
   - Check house-to-zone pressure difference, making sure it's very close to or at zero.
4) The house leakage rate increase = leakage rate with the zone door open (Step 3) minus initial house leakage rate (Step 1).

Calculations:

5) In the Method 2 graph, find initial house-to-zone pressure difference on horizontal axis.
6) Find where this value intersects the "House-to-zone" curve.
7) On the left axis, find the "Ratio of zone leakage rate to the house leakage rate increase (cfm_{50}/cfm_{50})."
8) House-to-zone leakage rate = value in Step 7 × the house leakage rate increase (Step 4).
9) Use same method (Steps 5–8) to calculate leakage rate of zone-to-exterior and total flow path, finding "Zone to exterior" and "Total path" curves and reading new values from vertical axis.

Method 2 works best when the air leakage rate increase can be measured well (at least 200 cfm_{50}), and when the initial pressure difference is not near 0 Pa or 50 Pa.

Method 3: Single Point Attic Test For Roof Venting

Common Uses:

Vented Attics

Measurements:

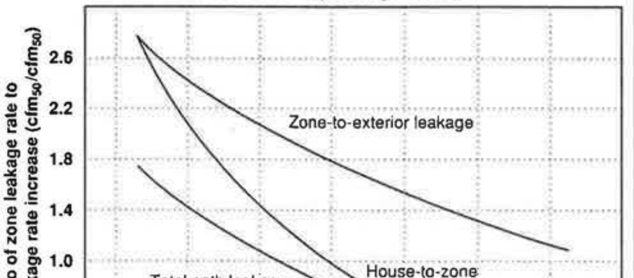
1) With house at 50 Pa, measure zone pressure differences.
2) Estimate net vent area of roof in square inches (based on visual inspection and accounting for screening, louvers, and other features).

Calculations

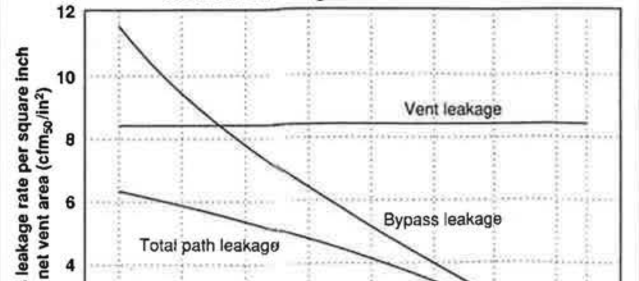
3) In the Method 3 graph, find inital house-to-attic pressure difference on horizontal axis.
4) Find where this value intersects with "Bypass leakage" curve.
5) On the left axis, find the "Bypass leakage rate per square inch of net vent area (cfm_{50}/in^2)."
6) Bypass (house-to-attic) leakage rate = value from Step 5 × vent area (Step 2).
7) Use same method (Steps 3–6) to calculate leakage rate of entire flow path, finding "Total path leakage" curve and reading new value from vertical axis.

Method 3 is quick and easy—but crude because of the difficulty in accurately estimating net vent area and fixed assumptions about the leakage rate per square inch of vent area (which actually varies depending on the type of vent). Like the other methods, it performs poorly when either pressure is close to 0 Pa or 50 Pa.

Method 2: Opening A Door



Method 3: Single Point Attic Test



Method 1 requires adding a hole of known size to one side of the flow path and measuring how the pressure differences change.

Method 2 requires opening a door between the house and zone and measuring the change in whole house leakage.

Method 3 requires estimating the amount of roof venting for attics.

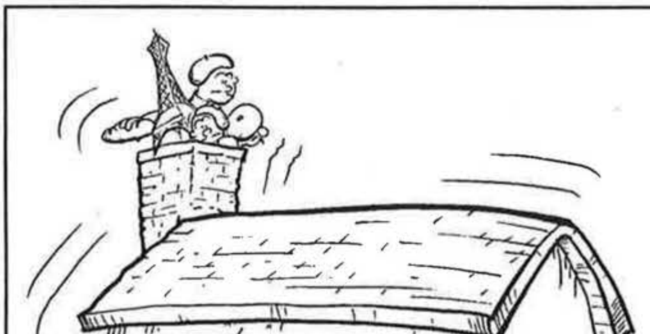
These tests all provide estimates of the effective leakage rates of the interior and exterior surfaces of the leakage path, and of the total leakage rate attributable to the series flow.[1] (See box "Three Pressure Diagnostic Tests.") All of these methods use the common leakage rate "cfm_{50}" which is the leakage rate of the building in cubic feet per minute when the pressure difference is 50 Pa. (For background on this measurement, see *HE* July/Aug '86, p. 16.)

While they haven't been validated against the more established but difficult and time-consuming zone leakage tests which require two or more blower doors, these tests (particularly Methods 1 and 2) have provided surprisingly accurate predictions of blower door-measured leakage reductions from air sealing in the few limited cases where such comparisons have been made by the authors. They have also repeatedly proven their value in the field, predicting where major problems would be found.[2]

In addition to measuring the leakage rates of the zones, pressure measurements can be used to find connections between different zones. For example, when measuring the pressure difference between the house and kneewall on one side of the house, and then opening an access into the opposite kneewall, a near total loss of pressure would indicate that the two kneewalls are well connected through the floor system or top attic. Connections are also frequently found between the attic and the garage or basement. These interconnections can be tricky, leading to errors when combining zone leakage rates because of measuring some leakage paths twice. (For example, leakage paths usually go from the attic down into the basement and back up into the house.) In this situation, one can seal the more important zone first (the attic in this case) and then get more realistic estimates for the other connected zones.

Jim Fitzgerald

"Opening a door" to air leakage measurements, this method of testing is simple. Visible here are the gauges measuring pressure across an open attic door.



Rick Stover

A House Pressurized with 50 Pascals.

Common Measurements and Problems

All three methods start by using the blower door to depressurize the house by 50 Pa and then taking three initial pressure difference measurements: house-to-zone, zone-to-exterior, and house-to-exterior. (The 50 Pa requirement is merely a convenience which simplifies the usage of the accompanying graphs.) One may need to drill a hole in a closet ceiling to push a tube into the attic if it can't just slide around the hatch or door. The measurements can be made with a standard blower door pressure gauge although a digital manometer makes measurements faster and more accurate. Regardless of the device, measurements must be made very carefully:

- Use the same device for each measurement.
- Check the zero, or initial, natural pressure difference without the blower door running.
- See that measurements add up right—the house-to-zone and zone-to-exterior pressure differences should add up to 50 Pa, which should be equal to the house-to-exterior pressure difference.

Accuracy in measurement is most important when either pressure difference is less than 5 Pa. It is the ratio of the pressures that enters the calculations—a ratio of 48:2 is very different from a ratio of 49:1, but a ratio of 30:20 is quite close to a ratio of 31:19. The results can be particularly misleading at the extreme pressure ratios common with well vented attics. When it doesn't require much effort, some practitioners have temporarily sealed off some of the roof venting to get more reliable estimates of bypass leakage in these circumstances.

Because of the greater uncertainty when one side is much leakier than the other, the methods generally work better at finding a problem rather than proving that there isn't one. Wind can create very large errors necessitating extra care on windy days, particularly in finding a good reference for the exterior pressure. (Four tube pressure-averaging devices may help.) Never trust the test results blindly; judgement and experience will help decide if the results are plausible.

Using Results Wisely

Just because it's possible to measure air leakage rates between the house and the attic, garage, or basement doesn't necessarily mean that one should always make these measurements or believe them. These tests should only be used to reveal something worthwhile or help a weatherization crew work more effectively. The tests can be particularly helpful for prioritizing work in complicated houses with many places to look for leaks (like houses with two attics, kneewalls, a garage, or a basement). In simpler houses the tests may be most useful for checking whether the crew missed something important.

In houses in which it proves difficult to reduce leakage, the tests may help explain why. Tests may also help indicate where the real leakage is. Some weatherization programs use the tests primarily as an inspection procedure to determine, for instance, if the contractor really did seal the bypasses as claimed.

Understanding *when* to use the tests and how to interpret the results is as important as knowing *how* to use them. Be aware of the large uncertainties in the results, particularly on windy days or when trying to measure small pressure differences. Diagnostic tests are meant to supplement, not replace, primary diagnostic tools—one's head, eyes, and hands. If the results seem unbelievable, they probably aren't accurate.

Indoor Radon Group, LBL

The use of blowers doors to guide air sealing work has enabled program managers to get intimately involved in the process.

One Attic's Bypass Leakage

A retrofitter would like to determine the extent of bypass leakage in an attic as part of an inspection or prioritizing work. Because there is an attic access in a closet ceiling, she finds that Method 1 would work best.

She depressurizes the house by 50 Pascals (Pa) and sets up the pressure gauge in the room with the closet, and then runs a tube into the attic and a tube out a nearby window. Pressure gauges indicate 42 Pa between the house and the attic, 7 Pa between the attic and outside, and 51 Pa between the house and outside. The numbers are close to adding up ($42+7 \approx 50$ and $51 \approx 50$).

The retrofitter removes the attic access cover, leaving an opening 15 in. × 12 in. (180 in.^{2}). She adjusts the blower door to maintain 50 Pa house pressure. Now the gauges measure 27 Pa between the house and attic, and 25 Pa between the attic and outside. (The house-to-exterior measurements read 50 Pa.) The house-to-attic pressure dropped by 15 Pa ($42 - 27 = 15$). The numbers are close to adding up correctly.

She finds 42 Pa on the Method 1 graph's horizonal axis, and then finds the "15 Pa Pressure Drop" curve. On the vertical axis—"Leakage area between house and zone per square inch of added hole (cfm_{50}/in^2)"—she finds about 5 cfm_{50}/in^2. The leakage rate of attic bypasses is calculated as 5 cfm_{50}/in^2 (from the graph) × 180 in^2 (the size of the hole) = 900 cfm_{50}.

Anyone using this method can get a rough estimate of uncertainty by assuming the first measurement was either a couple of Pascals too high or low. Using the graph, someone might estimate that the bypass leakage is 500–1,200 cfm_{50}, and since 100 cfm_{50} is probably too much anyway, one shouldn't be worried about the exact number now.

The retrofitter can estimate how leaky the roof is by looking at the table for Method 1 (see Table 1) and looking for a column labeled 42 Pa. However, because there are only columns for 40 Pa and 45 Pa, she averages, from "Multiplier to obtain zone-to-exterior leakage rates," 2.5 Pa and 4.2 Pa to find a factor of 3.3 for attic-to-exterior leakage. Attic-to-exterior leakage is then estimated as 3.3 x 900 cfm_{50} (leakage rate of 900 cfm_{50} between the house and zone) ≈ 3000 cfm_{50}. The total flow path is estimated similarly—0.9 (the "Multiplier for total flow path pressure difference") × 900 cfm_{50} ≈ 800 cfm_{50}.

There are plenty of leaks, so get to work!

Future Directions

With experience, practitioners and researchers may find their own uses for these tests or variations on them. For example, the methods can be "reversed"—the hole or door is opened on the outside and certain adjustments are made in using the graphs. The methods can be integrated into a blower door field computer program, eliminating the need for graphs and the 50 Pa test requirement. The computer can do all the calculating. Some researchers have started applying Methods 1 and 2 to duct leakage measurements, treating the ductwork as a zone. In particular, Method 2 can improve the standard "blower door subtraction method" for measuring duct leakage. When this proves unworkable, Method 1 can be used. Others are wondering whether favorable tests results could qualify as "credit" for unintentional roof ventilation, limiting the need for added venting when insulating.

These procedures are still evolving, and while they have been published only for the first time here, the authors have written a short guide used to supplement field training sessions throughout the country. A paper on the theoretic underpinnings of these techniques has been accepted for an upcoming American Society for Testing and Materials conference in October 1993. ■

Endnotes

1. The total air series leakage rate is always smaller than the leakage rate of either side because the interior and exterior sides both contribute to reducing the leakage rate. For example, the house-to-zone leakage rate represents the leakage rate value one would get by testing *just that surface by itself*, without the exterior surface slowing down the air flow. Therefore, leakage through the total flow path—as measured by a blower door—will always be less than the leakage through the tighter of the two surfaces. The multipliers in Table 1 take this into account.
2. For a discussion of more established zone leakage measurements, see Modera, M.P. and M.K. Herlin, "Investigation of a Fan-Pressurization Technique for Measuring Interzonal Air Leakage, " *Air Change Rate and Airtightness in Buildings*, ASTM STP 1067, M.H. Sherman, Ed., American Society for Testing and Materials, Philadelphia, 1990, pp. 183–193.