Getting the Most From Your Duct Blaster

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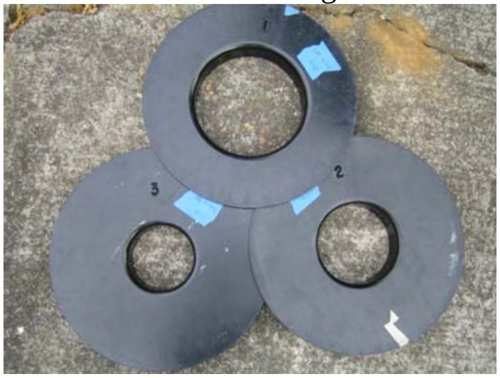
The Duct Blaster, made by the Energy Conservatory, or similar devices like it, is a durable, versatile calibrated fan/flexible duct assembly that accurately measures airflow over a range of about 30 to 1400 CFM. This means it can be very helpful in determining the performance of duct systems, supply and return registers, air handlers, and exhaust fans.

How Does it Work?

The fan assembly is an injection-molded, flaring 10" diameter smooth, round orifice with a known calibration that relates pressure drop across the orifice to a certain amount of air flowing through the orifice. The pressure tap found on the fan housing is attached to a metal flow sensor ring installed near the fan motor.

The amount of air going through the fan assembly is controlled by a rheostat operated by the tester. Depending on the amount of air that is being measured, a black plastic flow restriction ring may be needed. The flow restriction rings are also round, smooth orifices that increase the pressure drop across the entire fan assembly, thereby increasing the accuracy of he measurement. When the pressure drop across the fan assembly drops to below about 20 Pa, it is time to add a flow restriction ring.



Duct leakage tests typically involve pressurizing the duct system to a testing pressure of 25 or 50 Pa. If this pressure cannot be reached with a flow restriction ring installed, a less restrictive ring should be used.

If the fan is used in depressurization mode, it must include both the foam flow conditioner piece and a low flow ring to work properly. The depressurization mode is needed to measure supply register flows with a flow box and is preferred by some in making duct leakage measurements since it helps keep the temporary tape on the registers.

Flow equations can be found in the instruction manual that comes with the Duct Blaster. Also, some of the newer digital pressure gauges contain these flow equations and can display flows during testing.

Tests Described in These Handouts

Detailed instructions and data entry forms for 5 tests are attached. These tests are:

1) Duct pressurization test (to determine total and net duct leakage)
2) Duct depressurization test (to determine total and net duct leakage)
3) Air handler flow test (to determine whether the system is moving sufficient air to ensure capacity and efficiency upstream of the duct system; most manufacturers suggest around 400 CFM/ton of nominal air conditioner capacity or *approximately* 400 CFM/30,000 Btu/hr of gas furnace capacity)
4) Supply register flow tests (to determine how much air is actually being delivered to the conditioned space)
5) Garbage bag flow procedure (for figuring register flows)

Tools You Will Need

1) Duct Blaster or equivalent with tubing and low flow rings
2) Pressure gauge (digital preferred)
3) Static pressure tap
4) Device that can be used as a flow box (if measuring supply flows)
5) Cardboard scraps, cheaper duct tape, better masking tape
6) 33 or 55 gallon garbage bag and stopwatch

Duct Pressurization Tests (Total and Exterior Duct Leakage)

Set-up procedure for duct pressurization tests:

1. *Set blower door to pressurize house. May have to flip fan (from normal BD test position) if house leaky.*
2. *Set up for total test first; attach Duct Blaster to best point in system (typically at or near furnace).*
3. *If testing supply side, attach duct tester fan to furnace cabinet with cardboard and tape or directly to blower mount. (If you remove the blower, be careful with wires and record how to re-connect them.)*
4. *Tape all registers. Use appropriate tape (Long Mask) for friable surfaces.*
5. *Set up pressure tubes so that pressure gauge can read duct pressure WRT outside, duct tester fan pressure, and house pressure (for exterior duct leakage test).*
6. *Measure duct pressure in plenum or register. If you select a register, make sure it is not disconnected from the rest of the duct system. Specify on protocol sheet where duct pressure is measured. Use Pitot tube or static pressure tap for this measurement.*
7. *Make sure doors/access panels that go to buffer spaces such as the garage, attic, or are closed during the testing.*

Performing total duct pressurization test

1. *For "both sides" test, pressurize supply and return side to about 50 Pascals WRT outside with smallest flow ring possible. Fan pressure should be at least 20 Pa to ensure accuracy.*
2. *If split test (testing supply or return alone), once ducts are pressurized to near 50 Pa, check pressure in other side of system WRT outside. (Check return if testing supply; supply if testing return.) This pressure should be zero or close to zero. If not, check system split.*
3. *Measure the duct system pressure WRT outside. Record in table (next page).*
4. *Measure duct tester fan pressure. Look up flow in table, use gauge* (***make sure the pressure gauge you are using is paired with the right duct tester***) *or use flow equation.*
5. *Repeat steps 1-3 with ducts at about 25 Pa WRT outside.*
6. *Check flow exponent. (Formula on next page.) Repeat tests as needed.*
7. ***If you cannot reach 50 Pa or 25 Pa, test to the highest pressure you can reach and enter this in the 50 Pa column. Use a test pressure of half this pressure for the low pressure test.***
8. *Note any unusual testing conditions (wind, etc.):*

Total Duct Leakage Data (note duct pressure WRT outside does not have to be exactly 50 or 25 Pa)

	Both sides		Supply or Return (circle one)	
	50 Pa	25 Pa	50 Pa	25 Pa
Duct P	____	____	____	____
Ring	____	____	____	____
Fan P	____	____	____	____
Flow	____	____	____	____

Note position of pressure tap(s) in supply and return system:

To check each test, calculate flow exponent. The flow exponent, n, = $\ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. *If flow exponent not between 0.50 and 0.75, repeat test.*

Performing exterior duct leakage test:

1. *Exterior house doors and garage doors should be closed for exterior duct leakage test.*
2. *Pressurize the house to about 50 Pascals WRT outside.*
3. *Pressurize tested part of duct system to about 50 Pascals with smallest flow ring possible.*
4. *Measure pressure of ducts WRT house. Make sure blower door flow does not impinge on pressure tap measuring house pressure.*
5. *Adjust duct tester speed controller so that duct pressure WRT house is zero or very close.*
6. *Re-check pressure of ducts WRT outside.*
7. *Measure duct tester fan pressure. Look up flow in table, use gauge (**make sure gauge is paired with the right duct tester**) or use flow equation. Record duct pressure WRT out, DB fan pressure, DB fan ring.*
8. ***If you cannot reach 50 Pa or 25 Pa, test to the highest pressure you can reach and enter this in the 50 Pa column. Use a test pressure of half this pressure for the low pressure test.***
9. *Repeat steps 2-7 with house and ducts at about 25 Pa WRT outside.*
10. *Check flow exponent (as above).*
11. *Note any unusual testing conditions (wind, etc.):*

Duct Leakage to Outside Data (note duct pressure WRT outside may not be exactly 50 or 25 Pa)

	Both sides		Supply or Return (circle one)	
	50 Pa	25 Pa	50 Pa	25 Pa
Duct P	____	____	____	____
Ring	____	____	____	____
Fan P	____	____	____	____
Flow	____	____	____	____

Duct Depressurization Tests (Total and Exterior Duct Leakage)

Set-up procedure for duct depressurization tests:

1. *Set blower door to depressurize house. If you have just done a blower door test, you will not need to make any change.*
2. *Set up for total test first; attach Duct Blaster to best point in system.*
3. *For depressurization tests, you must install the foam flow conditioner ("honeycomb") into the round transition piece that attaches to the snorkel and you must also one of the low flow rings.*
4. *If testing supply side, attach duct tester fan to furnace cabinet with cardboard and tape or directly to blower mount. (If blower removed, be careful with wires and record how to re-connect them.)*
5. *Tape all registers. Use appropriate tape (Long Mask) for friable surfaces.*
6. *Set up pressure tubes so that pressure gauge can read duct pressure WRT outside and duct tester fan pressure WRT tap on snorkel transition piece **(important).***
7. *Measure duct pressure in plenum or register. If you select a register, make sure it is not disconnected from the rest of the duct system. Specify on protocol sheet where duct pressure is measured. Use Pitot tube or static pressure tap for this measurement.*
8. *Make sure doors/access panels that go to buffer spaces such as the garage, attic, or are closed during the testing.*

Performing total duct leakage test

9. *For "both sides" test, depressurize supply and return side to about -50 Pascals WRT outside with smallest flow ring possible. Absolute value of fan pressure should be at least 20 Pa to ensure accuracy. If it is not, install low flow ring with smaller opening.*
10. *If split test (testing supply or return alone), once ducts are depressurized to near -50 Pa, check pressure in other side of system WRT outside. (Check return if testing supply; supply if testing return.) This pressure should be zero or close to zero. If not, check system split.*
11. *Measure the duct system pressure WRT outside. Record in table (next page).*
12. *Measure duct tester fan pressure. Look up flow in table, use gauge **(make sure the pressure gauge you are using is paired with the right duct tester)** or use flow equation.*
13. *Repeat steps 1-3 with ducts at about 25 Pa WRT outside.*
14. *Check flow exponent. (Formula on next page.) Repeat tests as needed.*
15. ***If you cannot reach -50 Pa or -25 Pa, test to the highest pressure you can reach and enter this in the -50 Pa column. Use a test pressure of half this pressure for the low pressure test.***
16. *Note any unusual testing conditions (wind, etc.):*

Total Duct Leakage Data (note duct pressure WRT outside does not have to be exactly 50 or 25 Pa)

	Both sides		Supply or Return (circle one)	
	-50 Pa	-25 Pa	-50 Pa	-25 Pa
Duct P	____	____	____	____
Ring	____	____	____	____
Fan P	____	____	____	____
Flow	____	____	____	____

Note position of pressure tap(s) in supply and return system:

Calculate flow exponent. The flow exponent, n, = $\ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. If flow exponent not between 0.50 and 0.75, repeat test.

Performing exterior duct leakage test:

12. *Exterior house doors and garage doors should be closed for exterior duct leakage test.*
13. *Depressurize the house to about -50 Pascals WRT outside.*
14. *Pressurize tested part of duct system to about -50 Pascals with smallest flow ring possible.*
15. *Measure pressure of ducts WRT house. Make sure blower door flow does not impinge on pressure tap measuring house pressure.*
16. *Adjust duct tester speed controller so that duct pressure WRT house is zero or very close.*
17. *Re-check pressure of ducts WRT outside.*
18. *Measure duct tester fan pressure. Make sure Duct Blaster fan pressure is measured WRT tap on snorkel transition piece* ***(important).***
19. *Look up flow in table, use gauge (**make sure gauge is paired with the right duct tester)** or use flow equation. Record duct pressure WRT out, DB fan pressure, DB fan ring.*
20. ***If you cannot reach -50 Pa or -25 Pa, test to the highest pressure you can reach and enter this in the -50 Pa column. Use a test pressure of half this pressure for the low pressure test.***
21. *Repeat steps 2-7 with house and ducts at about 25 Pa WRT outside.*
22. *Check flow exponent (as above).*
23. *Note any unusual testing conditions (wind, etc.):*

Duct Leakage to Outside Data (note duct pressure WRT outside may not be exactly -50 or -25 Pa)

	Both sides		Supply or Return (circle one)	
	-50 Pa	-25 Pa	-50 Pa	-25 Pa
Duct P	____	____	____	____
Ring	____	____	____	____
Fan P	____	____	____	____
Flow	____	____	____	____

Calculate flow exponent. The flow exponent, n, = $\ln(Q_{50}/Q_{25})/\ln(P_{50}/P_{25})$. If flow exponent not between 0.50 and 0.75, repeat test.

Measuring System Airflow (TrueFlow or Duct Blaster)

Set-up: *Turn on air handler (by using fan-only switch or by turning on heat/AC). It is best to call for the flow that will be used during most of the year. Drill access hole as needed and point hooked end of static tap into airflow.* ***Do not drill into the duct at any point where you are concerned with hitting something.***

Measure pressure in supply plenum. Record pressure below as Normal System Operating Pressure (NSOP). Also measure pressure in return plenum and record:__________

Place appropriate plate and spacers into filter slot. Turn on air handler and record supply static pressure with TrueFlow in place (TFSOP) and pressure drop across plate.

Plate used (14 or 20) _______________

Normal System Operating Pressure (NSOP) _____Pa
True Flow System Operating Pressure (TFSOP) _____Pa
Correction Factor* √(NSOP/TFSOP) __________

Plate pressure drop ________Pa
Raw Flow (CFM)________
Corrected Flow ________CFM

*if using DG-700, unnecessary to record CF (but still a good idea)

Air Handler Flow Measurement Using Duct Blaster

Record normal system operating pressure (NSOP) as described in flow plate test. Install split between supply and return so that all air flowing through Duct Blaster will go into supply side. Install Duct Blaster on furnace (best without snorkel). ***Turn on air handler to get speed you are interested in.*** Turn Duct Blaster on and slowly increase flow until the supply plenum pressure is the same as NSOP. Check to make sure the pressure in the return system is 0 or very close to 0 (to confirm system split is good). Record Duct Blaster flow pressure, ring#, and CFM.

NSOP ______Pa   Ring # ______

Flow pressure ______Pa   Air Handler flow ______CFM*

Note: if NSOP cannot be reached, record highest pressure reached (HPR):______Pa

The Correction Factor table supplied with the TrueFlow can be used to correct the CFM* measured above to the flow at actual conditions. Substitute HPR for TFSOP in making the correction. Mathematically, the Correction Factor is ***square root***(NSOP/HPR)

Record the Correction Factor here______

Multiply Air Handler Flow recorded at HPR ______ by Correction Factor ______

to get Corrected Air Handler Flow______________

Supply Register Flow Measurements w/DB & Flowbox

1. *Registers should generally be numbered starting at the front door and proceeding clockwise. Or note location below next to number.*
2. *Construct a flow box that will be placed over registers; you may want to use weatherstripping to deal with irregular surfaces. Punch a small hole in the flow box so that you can measure the pressure inside the box with respect to the room.*
3. *Make sure to insert the honeycomb flow conditioner into the round transition piece and connect the flex duct and a low-flow ring (ring 3 recommended to start) to the inlet flange of the Duct Blaster. Connect the square transition piece of the Duct Blaster to the flow box.*
4. *The digital pressure gauge will be used both to measure the flow through the Duct Blaster and to determine when the flow out of the register has been neutralized by the depressurizing action of the Duct Blaster. When setting up to get Duct Blaster flow, make sure the Duct Blaster fan channel is referenced to the tap on the snorkel transition piece* ***(important).***
5. *Turn on the air handler to the speed desired.*
6. *Place the flow box on the register you are measuring and turn on the Duct Blaster until the pressure in the flow box is 0 WRT the room. At this point, record the DB fan pressure and convert to CFM. This is the flow out of the register.*

Register location	**Toe kick? Normally partially or fully closed? Other notes:**	**Flow (CFM)**	**Flow (CFM) method: ________**	**Flow (CFM) method: ________**
S1				
S2				
S3				
S4				
S5				
S6				
S7				
S8				
S9				
S10				
S11				
S12				
S13				
S14				
S15				
	Supply sum			

Notes:

Garbage Bag Flow for Measuring Register Flows

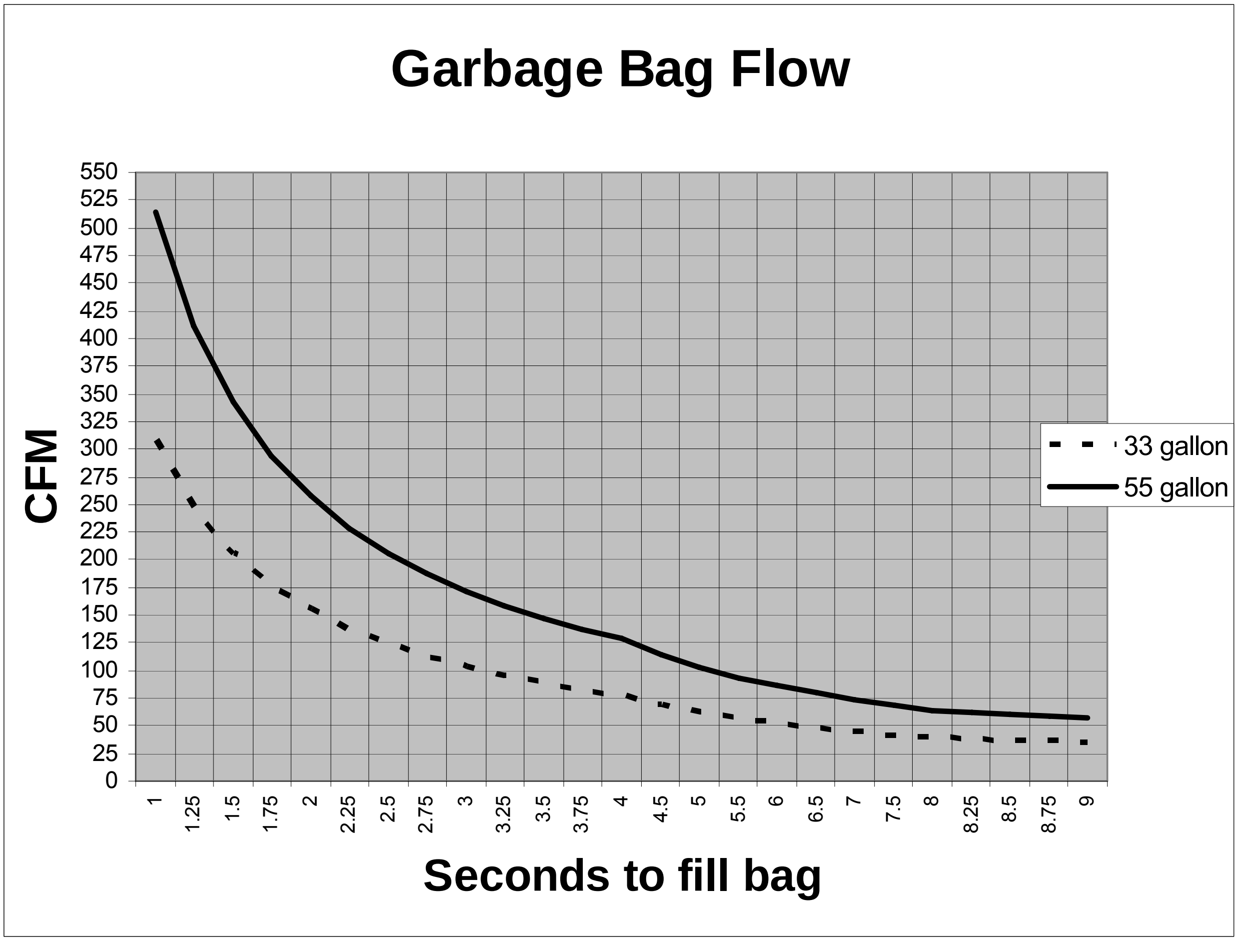
- Use familiar sizes (if 33/55 gallons can use graph on next page)
- An adapter (throat) from register to bag can help
- Start stop watch as soon as bag is on register; stop when bag is ***just*** full
- Take several readings and average them if needed
- Most accurate for air around 70° F (standard air is 68° F)

Garbage bag formula:

$$\frac{\underset{\text{(bag size in gallons)}}{\underline{\qquad\qquad}} \ \text{x } 0.156 \text{ ft3/gallon X } 60 \text{ sec/minute}}{\text{seconds to fill bag}} = \underline{\qquad}\ \text{CFM}$$

Example:

$$\frac{55 \text{ gallon x } 0.156 \text{ ft3/gallon x } 60 \text{ sec/minute}}{4 \text{ seconds to fill}} = 129 \text{ CFM}$$


Garbage Bag Flow
CFM
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
3.25
3.5
3.75
4
4.5
5
5.5
6
6.5
7
7.5
8
8.25
8.5
8.75
9
Seconds to fill bag
33 gallon
55 gallon

Procedure for Figuring the Leakage Fraction

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Just as we use ACH_{50} to compare the leakiness of different houses, we should use leakage fraction to compare the leakiness of different duct systems. Absolute duct leakage (in CFM) is important, but more important is how much air is leaking from the supply system or into the return as a fraction of the air that is being moved by the air handler. Leakage of 200 CFM in a system that moves 600 CFM is much more significant than leakage of 200 CFM in a system that moves 2000 CFM. Heat pump leakage counts more than the same leakage in other systems because (in heating) the air isn't terribly warm to begin with. Critical to being able to estimate your starting point and the savings potential is to estimate duct system static pressure at normal operating conditions; it is not enough to use duct leakage at 25 Pa or 50 Pa, since the leaks may be seeing very different pressures than 25 or 50 Pa. The procedure detailed below steps through the process of finding the leakage fraction. A spreadsheet version of this process (**now available as slffull.xls**) greatly simplifies matters.

1. Find air handler flow. Either use flow plate, temperature rise, Duct Blaster matching or measure register flows and combine with estimated duct leakage at normal operating conditions. See procedures in appendix. Use of the flowplate greatly simplifies matters, because only a few measurements are needed.

2. Determine the flow exponent (*n*) and coefficient (*C*) for total (to inside and outside) duct leakage. Refer back to the field data from the total duct leakage test. Use the power low equation ($Q = C\ \Delta P^n$) to do this, putting in measured values for Q and ΔP and solving first for the flow exponent and then for the coefficient. This is most easily done with slffull.xls, but the full process is shown here for explanation. For example, if the test pressures are exactly 50 and 25 Pa WRT out,

   $$Q_{50} = C(50^n) \text{ and } Q_{25} = C(25^n)$$

   (Note the testing pressure differentials may not be exactly 50 and 25 Pa; the exact testing pressures must be used.) Equating $Q_{50}/50^n$ and $Q_{25}/25^n$ (they both equal C) and then solving for *n*, we get

   $$n = \ln(Q_{50}/Q_{25})/\ln(50/25)$$

   Substitute in the values from the test to find *n*. Once *n* is determined, use it in the power law equation, along with known values for ΔP and Q, to find *C*. Write down the power law expression for total duct leakage with the *C* and *n* you have found.

3. Estimate system operating pressure (crucial). Measure static pressure at both the supply plenum and as many registers as possible. A long (12") Pitot tube is best. Insert tube into register boot and point the hook upstream. You may need to use a

5 or 10 second average because of fluctuation. If you get a negative reading, reposition the tube. Enter the values into the provided spreadsheet, or calculate a weighted average pressure of plenum and register pressures. We generally give the registers 75% of the weight and the plenum 25%. Example: if the average of the supply register statics is 5 Pa and the supply plenum static is 35 Pa, the weighted average system operating pressure is

$$0.75(5\text{ Pa}) + 0.25(35\text{ Pa}) = 12.5\text{ Pa}$$

In manufactured homes, you can simply average the values you find and use this in all cases where an average system pressure is needed.

4. Substitute the calculated system operating pressure into the flow equation from Step 2. This gives you the total duct leakage at operating pressure.

5. Add the value from step 4 to the sum of the register flows. You now have the air handler flow. (If using flow plate, Duct Blaster matching, or temperature rise method for determining AH flow, skip this step.)

6. Repeat Steps 3 and 4 for duct leakage to the outside. That is, determine the flow equation for exterior duct leakage, use the system operating pressure as the P in the power law equation, and calculate the duct leakage to outside at operating pressure.

7. Divide the result of Step 6 by the air handler flow (step 5). You now know the leakage fraction.

Here is an example of how this goes. **Note this is for the supply system only,** as that's where most of the savings will occur, unless you are in a heavy cooling climate. The same procedure can be used for the return side in these circumstances.

<u>Measurements </u>(this is a good example of what you would have from doing the field protocol):

Test	**Leakage @ test pressure WRT out**	**Leakage @ test pressure WRT out**
Supply leak total	625 CFM @ 52 Pa	410 CFM @ 27 Pa
Supply leak to out	300 CFM @ 50 Pa	190 CFM @ 25 Pa

Average of register static pressures: 6.5 Pa
Supply plenum static pressure: 32 Pa

Step 1: Find air handler flow by using flow plate or other method.
For this example, assume we use the flow plate and find a corrected (raw flow x correction factor) of 850 SCFM.

Step 2: Determine power law equation for total leakage and correct total leakage down to standard operating conditions:

General form of equation is $Q = C\,\Delta P^n$ -- we first solve for *n*, then solve for *C:*

$$n = \ln\left[Q_{\text{near }50}/Q_{\text{near }25}\right]/\ln\left[\Delta P_{\text{near }50}/\Delta P_{\text{near }25}\right] = \ln(625/410)/\ln(52/27) = 0.422/0.655 = 0.606$$

(Note "ln" is natural (base *e*) log. Also note this is also how we find the flow exponent for checking the validity of blower door or duct blaster tests.)

$$Q = C\,\Delta P^n \qquad \text{so } C = Q/\Delta P^n \quad \text{and in this case } C = 625/52^{.606} = 57.0$$

So the flow equation for total duct leakage in this house is $Q = 57\Delta P^{.61}$. Next we need to find the pressure to put into the equation; that is, what is pushing on those duct leaks?

Step 3: Determine average static pressure in supply system:

This requires some judgment. In site-built homes, a pretty good approximation of average system pressure is found by giving 75% of the weight to the registers and 25% weight to the supply plenum. In manufactured homes, an average of all registers statics is okay, since the system usually performs like a big extended plenum.

Here's an example of how to do the site-built case:

$$\text{Avg system static} = 0.75(6.5\text{ Pa}) + 0.25(32\text{ Pa}) = 12.9\text{ Pa}$$

Step 4*: Determine* total leakage at *average static pressure* ("operating conditions") *in supply system:*

$$Q_{total,\ oper.\ P} = 57(12.9)^{.61} = 268\text{ CFM.}$$

Step 5 **(only used if sum of register flows + Step 4 result are used to calculate air handler flow)**: Add supply leakage at operating conditions to sum of register flows (alternate method of completing Step 1) to get air handler flow (denominator of supply leakage fraction ratio):

268 CFM + 625 SCFM = 893 CFM

Step 6: Determine power law equation for exterior leakage and estimate leakage to outside at operating static:

This is the same thing we did in Step 2 but we use the results from the **duct leakage to outside** test to get *n* and *C* this time around.

$$n = \ln [Q_{near\ 50}/Q_{near\ 25}]/\ln [\Delta P_{near\ 50}/\Delta P_{near\ 25}] = \ln (300/190)/\ln(50/25) = 0.457/0.693 = 0.659$$

$$C = 300/50^{.659} = 22.78$$

$$Q_{to\ out,\ oper.\ P} = 22.78(12.9)^{.659} = 122.9\ CFM.$$

Note how our whopping 300 CFM to out at 50 Pa has diminished to only 123 CFM at normal operating conditions. This is very important to note, as it makes a big difference in the overall scheme of things. What looks to be big leakage at 50 Pa may not be so big if the pressure pushing on the leaks is closer to 10 Pa.

Step 7: Determine supply leakage fraction (SLF). This is the percentage of conditioned air which is not making it into the house through the expected duct pathways and is therefore causing energy waste:

SLF = leakage to out at operating pressure/air handler flow = 112.9 CFM/850 CFM = 14.4%

Discussion of Advisability to Perform a Retrofit (Mostly Site-Built Considerations)

The worked example came out with an SLF of about 15%. We generally consider a 15% SLF as a pretty good bet for a cost-effective retrofit, because there's room for improvement and we can expect to actually see something in the bills. But in order to go ahead we still have to consider a few things. (Note this list is not exhaustive, but it reflects what I usually consider in the majority of cases where a decision is being made whether to proceed):

- Do we think our crew can get rid of half the leakage? Can they get to the leaks in a reasonable time? They will need to get about half of the SLF to make a difference. Most crews should be able to do this, but someone needs to make sure the ducts are accessible and there are no other impossible conditions.

- Is there at least R-8 between the buffer space containing the ducts and the inside of the house? If not, quite a bit of the waste heat will be regained by the house. If the buffer space is uninsulated, we would like to see at least a 20% SLF to start. If we have perimeter insulation and uninsulated joist bays, regain is close to 100% so higher leakage is needed to justify the retrofit.

- Even if the crew may not be able to get half of the leakage, they can still do some homes with lower SLFs (say 10%) if the heating load of the house is sizable. For example, if we have a house with an estimated annual heating load of, say, 15000 kWh, and the crew gets half of a 10% SLF, or 5 points on the 1-100 efficiency scale, the relative savings (expected to be seen in the utility bill) are (0.95 – 0.90)/0.90 = 0.055 = 5.5%, and the annual dollar savings are estimated at (0.055 * 15000 kWh * $0.05/kWh) = $41. This means we have a payback on the work of about 10 years if the retrofit cost (no overhead) is $400. This is borderline but probably a go. Not every house has to provide a cost-effective retrofit to make the overall program economics favorable. Still, we should attempt to get cost-effective retrofits on a case-by-case basis.

- This is beyond the scope of this discussion, but duct insulation is also important. Even if the ducts aren't very leaky, if they are uninsulated or underinsulated (<R-4 installed value), adding insulation will make a big difference. The problem is finding someone to do the work.