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.

Measurements (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:*

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

(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):*

$$268\ \text{CFM} + 625\ \text{SCFM} = 893\ \text{CFM}$$

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.

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

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

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

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.

Air Handler Flow Measurement Using TrueFlow™ Plate

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 (probably heating) so that the leakage fraction will be applied to the predominant use. Also, measure static pressure with long Pitot tube (extended so that hooked end extends into trunk and points into flow) in at least 4 registers (on each side of the home is best) and record:

Reg. loc or #	**Static P (Pa)**

Leave long Pitot tube in place in register near furnace. Tape probe in place to make sure it doesn't move. Record pressure below as Normal System Operating Pressure (NSOP).

Place appropriate plate and spacers into filter slot. Turn on air handler and record register static with TrueFlow in place (TFSOP) and pressure drop across plate. Convert to raw flow with provided tables or read directly from pressure gauge if possible.

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 pressure gauge, unnecessary to record CF (done automatically during test)

Air Handler Flow Measurement Using Duct Blaster™

Record normal system operating pressure (NSOP) as described in flow plate test. Install Duct Blaster on furnace. Turn on air handler. Turn Duct Blaster on and slowly increase flow until the supply plenum pressure is the same as NSOP*. Record Duct Blaster flow pressure, ring#, and CFM.

NSOP ______Pa

Highest pressure reached* _______Pa

DB Ring # ______

Flow pressure ______Pa

Air Handler flow ______CFM

*if cannot reach NSOP, record highest pressure reached and use the correction factor of √(NSOP/highest pressure reached) x DB flow to get corrected flow

Supply Register Pressures and Flows **(you need reliable flowhood and thermometer for this test)**

Set up: Open all registers. Look for toekicks. If it is helpful to make sure you haven't forgotten a register, name registers as you go or number starting at the front door and going clockwise.

Pressures: Measure pressure in register boot with the air handler running, using a long Pitot tube pointed into the flow.

Flows: Measure supply flows and temperatures with the air handler running. It is necessary to measure temperatures because air temperature affects the volumetric flow reading. Use a good thermometer and fast-acting thermocouple. The Fast-1 flowhood temperature is generally unreliable. Make sure flowhood has known calibration. A spreadsheet is also available that makes corrections for temperature, flowhood calibration, and site altitude.

The flow hood should be centered on the register wherever possible and it should be noted where centering is not possible. Use plastic bags or cardboard boxes if necessary.

Flow hood used: _______________ Temperature Measurement Device: _____________
Flow hood calibration equation:_________________
Site altitude (feet above sea level):_____________________

Reg. loc or #	Static P (Pa)	Temp (°F)	Raw flow	Corrected Flow

Measuring Air Handler Flow With the Temperature Rise Method (Electric Heat)

1. Turn up the thermostat and let equipment run for at least 5 minutes on resistance heat only. Measure supply plenum static pressure ________Pa
2. Record return plenum temp ______ (specify °F or °C)
3. Record supply temp in nearest register ==> _______________ (specify °F or °C)
4. Remeasure return plenum temp _______ (°F or °C) avg return T_______
   delta T ___________
5. Record element amps and volts to get input Watts

Element	amps	volts	watts
1			
2			
3			
4			
		total	

6. Alternately, use utility meter to get input Watts. You must turn off all appliances but furnace for this test, or make sure you can accurately determine the baseload during the test.

$$W = (3600 \times k_h \times revs)/t$$

Where: k_h = meter constant on face of meter in watt-hrs per revolution (often 7.2)
revs = number of revolutions of meter wheel counted
t = time required for the revolutions you count

7. Record baseload (as needed) = (3.6 x ___ x ___)/ _____ = _______ W
8. Record total watts = (3.6 x ____x _____)/_____ = _______ W
9. Subtract baseload from total to get furnace Watts in: _______ W
10. For heat pumps: turn on heat in normal heating mode (not emergency heat) and remeasure supply plenum static pressure__________
11. If result from step 10 is more than 3 Pa different from result in Step 1, calculate correction factor of √(step 10 static/step 1 static)_____________
12. raw SCFM = (Watts in · **constant)**/(delta T)

Where the **constant** is either 3.16 (if using °F) or 1.75 (if using °C)

Show work:

If applicable, multiply raw result ______ by correction factor (step 1):_______= ________

Measuring Air Handler Flow With Temperature Rise Method on Gas Furnace (ºF)

1. Select position(s) to measure supply temperature. Measure in main trunk near plenum.
2. Turn off all gas appliances but furnace. Note or draw water heater temperature setting:
3. Turn up thermostat and let furnace run at least 5 minutes.
4. Record combustion efficiency for each port in natural draft equipment or use single reading for induced draft equipment:_____/_____/_____/_____/_____

   Average efficiency: ________%

   *Note: if not measuring this directly, record assumed efficiency from dataplate*____________

5. Measure return temperature _________
6. Measure supply temperature(s):

Record average:__________________

7. Remeasure return temperature:___________
8. Subtract average of Steps 5_______ & 7 __________:_____________

   from average of Step 6____________

   temperature rise __________

9. **Clock the meter** by timing several revolutions of the ½ CCF dial (assume 1040 BTU/CCF if not otherwise known. Use table on next page to speed up process if desired):

   CCFs:_________ BTU/CCF:________ Time:_________ seconds
   Total input consumption = (CCF * BTU/CCF) /(seconds for revs) * 3600 sec/h
   =____________BTUh at meter (or use table)

10. Multiply result from Step 9 by the combustion efficiency (Step 4):
    ______Btu/hr at meter * _____avg effic = _______ Btu/hr into supply airstream

11. Find system airflow in standard CFM (SCFM):
    (Step 10 result_______* 1.08)/temp rise (Step 8 result) = ____________SCFM

12. Turn on any gas appliances turned off earlier; set to as-found levels.

Notes:

- Should also record CO readings on separate form and give to homeowner. Note any problems with furnace (deteriorated or incorrect venting, cycling on high limit, electrical wiring problems, etc.)
- Must derate for altitude if house at over 2000 ft. Consult Sun Power procedure for this correction.

Gas Input to Burner in Cubic Feet per Hour								
Seconds for 1 revolution	**One-half Cu Ft dial**	**One Cu Ft dial**	**Seconds for 1 revolution**	**One-half Cu Ft dial**	**One Cu Ft dial**	**Seconds for 1 revolution**	**One-half Cu Ft dial**	**One Cu Ft dial**
10	180	360	32	56	113	54	33	67
11	164	327	33	55	109	55	33	65
12	150	300	34	53	106	56	32	64
13	138	277	35	51	103	57	32	63
14	129	257	36	50	100	58	31	62
15	120	240	37	49	97	59	30	61
16	112	225	38	47	95	60	30	60
17	106	212	39	46	92	62	29	58
18	100	200	40	45	90	64	29	56
19	95	189	41	44	88	66	29	54
20	90	180	42	43	86	68	28	53
21	86	171	43	42	84	70	26	51
22	82	164	44	41	82	72	25	50
23	78	157	45	40	80	74	24	48
24	75	150	46	39	78	76	24	47
25	72	144	47	38	77	78	23	46
26	69	138	48	37	75	80	22	45
27	67	133	49	37	73	82	22	44
28	64	129	50	36	72	84	21	43
29	62	124	51	35	71	86	21	42
30	60	120	52	35	69	88	20	41
31	58	116	53	34	68	90	20	40