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DIAGNOSING DUCTS
Finding the Energy Culprits

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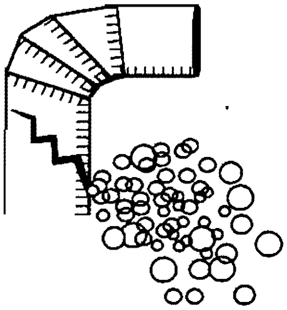


DIAGNOSING DUCTS

Finding the Energy Culprits

Leak Detectors: Experts Explain the Techniques

by John Proctor, Michael Blasnik, Bruce Davis, Tom Downey, Mark P. Modera, Gary Nelson, and John J. Tooley Jr.

This article is an effort to bring together the ideas of several innovators who have invented methods of diagnosing duct leakage. It focuses primarily on *production* technology—diagnostic tools that can be used in programs designed to seal tens to thousands of systems per year. Other, more time-consuming measurements exist for research purposes. These methods, along with other factors, are used to predict energy losses due to duct leakage.

Working on duct systems will often change the pressure distribution in a home, sometimes dramatically. These changes can effect combustion appliance drafting, radon migration, moisture, ventilation, and indoor air quality. The diagnostic tools we describe here should be used only by individuals who have a working knowledge of these safety issues and who take precautions to deal with them.

Each of the diagnostic methods can be viewed as a new tool for our toolbox. Some of the tools are for special cases, while others will become the tool we reach for most often. These diagnostic methods can be classified as quantitative or qualitative.

QUANTITATIVE MEASUREMENTS

Quantitative methods provide measurements of duct leakage in cubic feet per minute (cfm). They estimate neither the actual leakage from the ducts when the system is operating, nor the leakage across the leakage sites when all sites are at the same pressure. The purpose of a *production* quantitative measurement is to obtain quality work that will reliably impact energy use.

A good quantitative diagnostic tool has the following features:

- Repeatable results—so inspections will produce nearly identical readings.
- Accurate information—so technicians can immediately distinguish work resulting in high energy savings from work that has little or no effect.
- Quick—so technician time devoted to proper installation or repair of the distribution system is maximized.

With the wide variety of diagnostic tools available, investigators have noted substantial differences in the measured duct leakage between test methods. Variations between test methods are the result of differing pressures across the leakage sites (see Table 1) and different tests measuring different leakage locations (see Figure 1).

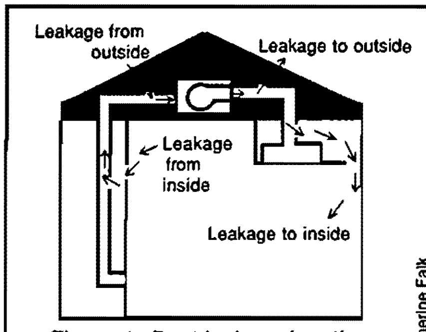


Figure 1. Duct leakage location categories.

A mainstay of diagnostic tools, the blower door can be used to pressurize and depressurize houses, thus allowing researchers to determine air flow and duct leakage.

Getting Started

The more closely the test conditions match the normal operating conditions of the ducts, the more accurate the test method. Ideally both flow and pressure should be duplicated in the test procedure.

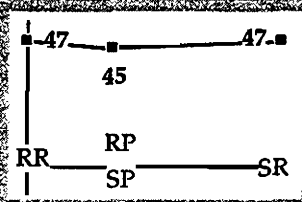
If duct leaks are evenly distributed throughout the system, the pressures in the system are distributed in a manner similar to Figure 2. Leakage location and location of the filter substantially influence the actual pressure distribution. The highest pressures occur at the supply and return plenums. The return system is under negative pressure while the supply system is positive. Reference pressure for the test must be specified as well.

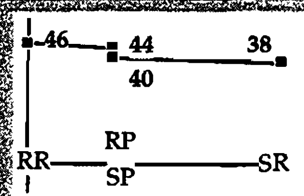
Since early testing was an expansion of blower door testing, the first test

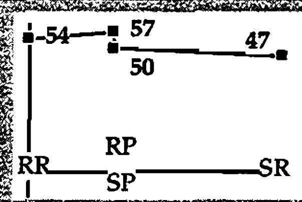
Table 1. Quantitative Duct Leakage Tests

TEST	Blower door subtraction	Flow Hood	Duct Blaster
EQUIPMENT	Blower door	Blower door and flow hood	Combined duct pressurization and flow device
ADVANTAGES	• Inexpensive—only one piece of equipment required • Good control over duct pressure • Measures only leakage to outside of envelope	• High certainty on flow rate • Measures only leakage to outside	• Inexpensive—only one piece of equipment required • Duct pressures well-controlled and pressure distribution closest to that in normal operating mode (except return is pressurized) • Measures low flows accurately • Measures total duct leakage • Can be used on houses before drywall is installed
COMMON DISADVANTAGE	Does not duplicate operating pressure distribution or flow (with the air handler fan on), resulting in under or over estimation of leakage at various points in the system		
DISADVANTAGES	• Low repeatability under windy conditions or on leaky homes • Inaccurate for low flows • Large piece of equipment • Cannot test ducts before dry-wall is installed • Overemphasizes leaks near the registers	• Less control over duct pressure • Requires two pieces of equipment • Cannot test ducts before dry-wall is installed • Overemphasizes leaks near return registers	• Requires a blower door to measure leakage to outside • Overemphasizes leaks near registers to a lesser degree than the other two tests

IDEALIZED TEST PRESSURE DISTRIBUTION







pressures were 50 pascals (Pa). There is now a trend toward more accurate pressure measurement (multiple duct locations with a digital manometer) and lower test pressures such as 25 Pa (or .1 in. of water column).

The actual measured operating pressures of the system (when the air handler fan is running) are helpful in interpreting the results of the quantitative duct leakage tests.

The three primary quantitative methods used to measure flow through leaks (at a test pressure) are: blower door subtraction, blower door and flow hood, and Duct Blaster (see Table 1). Other quantitative methods used primarily for research include: tracer gas, tracer temperature, and combined STEM/FAST testing. Tracer gas measures leakage and both tracer temperature and the STEM/FAST combination measure the energy effect of duct leakage and duct conduction.

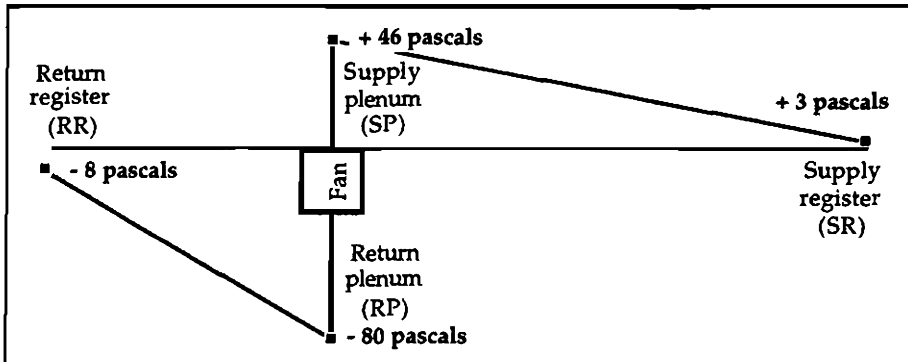


Figure 2. Idealized duct pressure distribution with fan on.

Blower Door Subtraction Method

The blower door subtraction method estimates flow through duct leaks to outside with the house at 50 Pa. (In all circumstances here, "outside" means outside the thermal envelope unless noted differently.) Either pressurization or depressurization tests are roughly equivalent (see "Two Favorite Test Methods, By the Book," p.32). These will both be referred to as "pressurization." This method uses two blower door flow readings to determine the amount of duct leakage. The house is pressurized with a blower door to obtain the *total* leakage

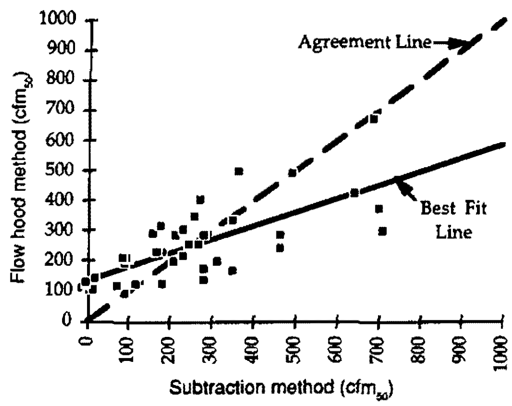


Figure 3. Subtraction method results versus flow hood results.

of the structure including the duct leaks. All duct openings are then covered and another blower door reading is taken to obtain just envelope leakage. Both tests are done with the house-to-outside pressure differential of 50 Pa. The total leakage of the second test is subtracted from the total leakage of the first test, yielding the duct system leakage.

Two significant errors are introduced using this method. First, the blower door is measuring relatively large flows (whole house leakage with and without ducts at 50 Pa). Small percentage errors in these readings become large percentage errors when applied to the duct leakage (typically 10%–20% of total house leakage). Second, the method assumes that all of the leakage from the ducts to the outside is eliminated when the registers are sealed. If there is any leakage at the registers, or any other leakage from the house to the duct system, this assumption is incorrect.

The first flaw is critical. An error of 5% in only one of the blower door readings (due to operator error or wind effects) becomes a 50% error in duct leakage for a system with 10% of the house leakage in the ducts. For example, if the initial test shows a leakage of 3,000 cfm_{50} (which is 150 cfm low), and the second test shows 2,700 cfm_{50} (with no error), the estimated duct leakage is 300 cfm. The true difference however, is 450 cfm (150% of the estimate).

The second flaw can be overcome. Using a method developed by Michael Blasnik, the error due to leakage from the house to the ducts can be estimated (more on this later).

Flow Hood Method

The flow hood method estimates flow through duct leaks to the outside. During the test, all registers except the largest, least restricted location are blocked. The house is pressurized (or depressurized) to 50 Pa relative to outside and the flow hood is used to measure the amount of air flowing through the open grille. Any flow through the flow hood into the grille must be duct leakage to the outside. One variation of this method is to bring the ducts near the return grille to 50 Pa relative to the outside.

A number of potential errors are introduced using the flow hood method. First, the pressures from one leakage site to another are more variable than with the subtraction method. Second, not all the leakage from the ducts flows through the flow hood. Some of the leakage to outside flows through gaps around the registers and other "communication" locations between duct and house. This effect is the same as noted in the subtraction method. However this problem is much smaller since the open grille provides a preferred (lower resistance) flow path. This will result in lower leakage measurements than actually occur during the test.

The flow hood directly measures the flow through the open grille during these tests, rather than inferring it from two larger measurements as in the subtraction method. Pressures applied to the duct system with this testing method are usually lower than those applied by using the blower door subtraction or the Duct Blaster methods. The flow hood method measures flow more accurately, but due to restrictions within the duct system and duct leakage, a higher uncertainty about pressures is introduced. Traveling from the open grille, pressure is lost as restrictions or duct leakage are encountered.

The ability of this method to estimate leakage flow at a uniform test pressure is largely determined by how well the average pressure across leaks is estimated. If based on a series of pressure measurements, such as at a number of blocked grilles as well as at the plenums, the accuracy will improve. Once a determination of the leakage and pressure is made, the leakage at any other pressure can be estimated (see "Estimation By Flow Exponent," p.30.)

The subtraction method and the flow hood method measure leakage at different pressures; therefore the results are not directly comparable. Figure 2 shows the relationship between the two tests when no corrections are made for leakage from the house to the ducts or for different pressures. The flow hood measurement measures higher leakage than the subtraction method on tight systems and lower leakage on loose systems. This data comes from tests conducted by Proctor Engineering Group on 42 houses.

$$\text{Flow hood } cfm_{50} = 134 + .45 \times \text{Subtraction } cfm_{50}$$

Duct Blaster Method

The Duct Blaster measures the flow through the ducts to leaks both inside and outside the house (total duct leakage). Measurements are taken with the Duct Blaster attached at the blower compartment of the air handler or attached to the return grille. During these tests all registers are covered and the Duct Blaster flow is adjusted to create a reference pressure (usually 25 Pa) in the supply plenum or the nearest connected supply grille.

Potential errors using this method are more limited than the other two methods. One source of error continues to be the variability of pressures across the leakage sites. Other errors are operator error, location of the reference pressure probe, and variations in the seals at the register.

Pressure variations increase due to a restriction such as a coil, blower, or small duct work. Pressure variations are also effected by large leakage sites. When the Duct Blaster is installed at the blower compartment, the pressure variations across the leakage sites are less than with the flow hood because of any restriction in the return system. The blower compartment door is preferred because it

Proctor Engineering Group

An air conditioning technician with the Auburn Heat Pump Project uses a flow hood, a diagnostic tool used to measure the amount of air flowing through the open grille of a duct system.

reduces the possibility of restrictions or leaks in the return system from influencing the leakage readings. As with the flow hood, a series of pressure measurements at different locations in the duct system reduce the effect of pressure variation errors.

Operator error can be reduced by using digital time averaged measurements (of five seconds or longer), proper training and quality assurance, as well as step by step procedures.

The Duct Blaster measures the total duct leakage (leakage to inside plus leakage to outside). In order to determine the leakage from the ducts to outside the house, a house pressurization test has to be performed. The most common method of measuring the leakage to outside known as "Blaster-blower door" is to first bring the house to a specified pressure with the blower door. Then, by adjusting Duct Blaster flow, the reference location in the ducts is brought to zero pressure differential with respect to the house. If the pressure in the ducts is uniform, all the flow through the Duct Blaster is leakage to outside. Another method known as the Blasnik method, can also be used.

In a small series of tests, the Blasnik method and the Blaster-blower door methods of estimating leakage to the outside gave similar results.

Table 2. Leakage Ratio Tests

TEST	Blasnik	"Half Nelson"
ESTIMATES	Ratio: Duct leakage area to house / Duct leakage area to outside	Ratio: Supply duct leakage area / Return duct leakage area
EQUIPMENT	Blower door and micromanometer	Micromanometer
ADVANTAGES	• Fast, once the registers are sealed and blower door installed • Can be used to convert total leakage to leakage to inside and leakage to outside	• Inexpensive—only one piece of equipment required • Fast, once the registers are sealed • Can be used to convert system leakage to supply and return leakages (which have differing energy effects)
COMMON DISADVANTAGE	• Based on assumption that flow exponent is .65 and duct test pressures are uniformly distributed	
DISADVANTAGES		• Should not be used on duct board systems since they are held together with tape and high pressures will damage them

Leakage Ratio Tests

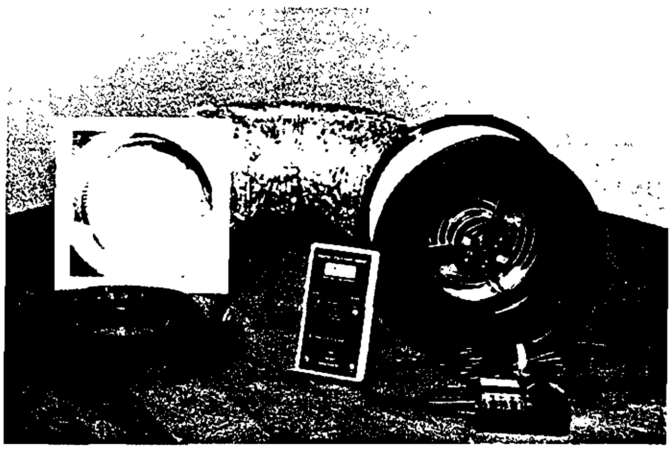
A leakage ratio test provides a technician with a rapid method of estimating what portions of the leakage can be assigned to different areas. This may sound simple, but it is quite complex. Between floors, for example, is not necessarily "inside" the actual building pressure envelope. When tested with a blower door, basements may be more inside or more outside the pressure envelope. The effect of duct leakage in these spaces is only now under investigation (see "The New Monster in the Basement" p.37 and "Stories from the Buffer Zone," p.40.)

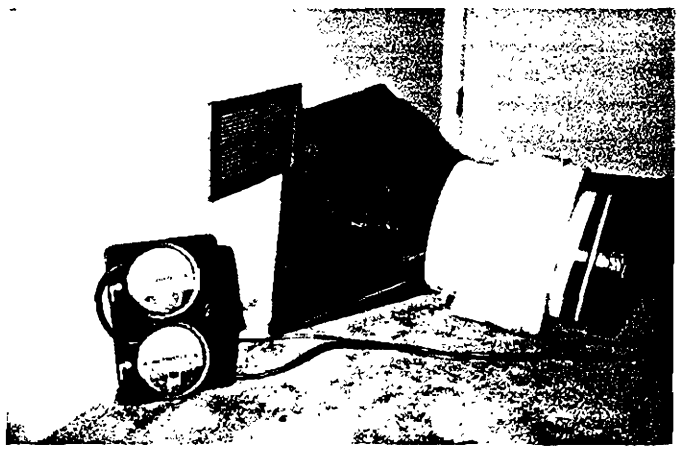
The features of a good leakage ratio tool are the same as a good quantitative tool and the tool should be faster than measuring both of the leakages that make up the ratio.

The two primary ratio test methods are the Blasnik and the "Half Nelson." The first quantifies the relationship between the leakage to inside the envelope and the leakage to outside the envelope. The second estimates the ratio of supply leakage areas to return leakage areas (see Table 2).

Blasnik Method: Inside-Outside Split

The Blasnik method is a valuable way of determining the proportion of duct leakage to outside versus inside. With the air handler fan off and with a blower door pressurizing the house to 50 Pa, two pressure readings are taken: pressure of the duct relative to the house ($P_{D\text{-}H}$) and pressure of the duct relative to outside ($P_{D\text{-}O}$). The ratio of the leakage between the duct and the house ($Q_{D\text{-}H}$) and the leakage between the duct and the outside ($Q_{D\text{-}O}$) when the duct is under pressure is computed (see "Estimation by Flow Exponent," p.30).

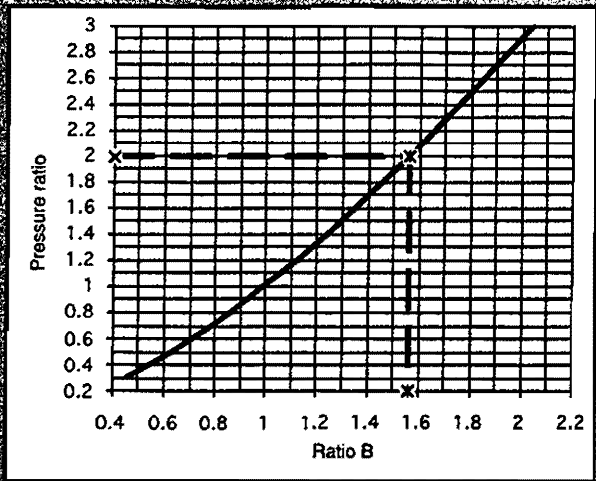

Energy Conservatory


Retrotec

The Duct Blaster by the Energy Conservatory, *left*, and this model from Retrotec, called the Omni-Flow, *right*, are two residential duct testers. While commercial units operating with higher pressures have been available for several years, the newer duct testers operate at lower pressures more appropriate for residential applications.

ESTIMATION BY FLOW EXPONENT

Many of the newer duct diagnostics are based on a basic flow equation that relates the static *pressure* across the leaks to the air flow through the leaks. The relationship involves the pressure raised to a power—*the flow exponent.* This is a visual method of using the basic flow equation.



Three calculations referred to in "Leak Detectors" can be accomplished with this graph:

- Correcting from one test pressure to another reference pressure.
- Blasnik method for estimation of inside-outside split.
- Half Nelson method for estimation of supply-return split.

This graph is based on a flow exponent of .65 which is currently being used for duct leaks. Limited data exists to justify this exponent. Modera calculated average supply and return leakage flow exponents of .64 to .80 from Robison flow hood data. Duct Blaster testing by Proctor Engineering yielded exponents from .48 to .64. Large correction factors should be avoided unless the true exponent is known.

Examples:

Pressure correction. Estimates the leakage (Q_r) at pressure (P_r) from the measured leakage (Q_t) and test pressure (P_t).

Suppose the duct leakage (Q_t) measured 200 cfm at a test pressure (P_t) of 12.5 Pa and we wish to estimate the leakage at a reference pressure (P_r) of 25 Pa.

- Pressure ratio = 25 Pa/12.5 Pa = 2
- Locate the pressure ratio (2) on the left axis of the graph and trace that value across the gridline to the curve.
- Follow the gridline down from the curve to the bottom axis (Ratio B). Ratio B = 1.56
- The duct leakage at 25 Pa would be 200 cfm × 1.56 = 312 cfm.

Inside-outside split. Estimates the ratio of the leakage between the duct and the house (Q_{D-H}) and the leakage between the duct and the outside (Q_{D-O}).

With the registers sealed and the house pressurized to 50 Pa, pressure of the duct relative to the house (P_{D-H}) was −16.7 Pa, the pressure of the duct relative to outside (P_{D-O}) was 33.3 Pa, and we wish to estimate the ratio of the leakage between the duct and the house (Q_{D-H}) and the leakage between the duct and the outside (Q_{D-O}).

- Pressure ratio = absolute value of 33.3/−16.7 = 2
- Locate the Pressure ratio (2) on the left axis of the graph and trace that value across the gridline to the curve.
- Follow the gridline down from the curve to the bottom axis (Ratio B). Ratio B = 1.56
- The duct leakage to inside is 1.56 times the leakage to outside.

Supply-return split. Estimates the ratio of the total supply leakage area (A_S) to the total return leakage area (A_R).

With the registers sealed and the air handler on, the supply (P_S) was 100 Pa, the return pressure (P_R) was −200 Pa, and we wish to estimate the ratio of the of the total supply leakage area (A_S) to the total return leakage area (A_R).

- Pressure ratio = Absolute value of −200Pa/100 Pa = 2.
- Locate the pressure ratio (2) on the left axis of the graph and trace that value across the gridline to the curve.
- Follow the gridline down from the curve to the bottom axis (Ratio B). Ratio B = 1.56.
- The supply leakage area is 1.56 times the return leakage area.

	Correcting from one test pressure to another reference pressure	Blasnik method for estimation of inside-outside split	"Half Nelson" method for estimation of supply/return Split
PRESSURE RATIO	P_R/P_t = Referencepressure / Test pressure	P_{D-O}/P_{D-H} = Duct-outside pressure / Duct-house pressure	P_R/P_S = Return pressure / Supply pressure
RATIO B	Q_r/Q_t = Reference flow / Test flow	Q_{D-H}/Q_{D-O} = Duct-house flow / Duct-outside flow	A_S/A_R = Supply leakage area / Return leak. area
RESULT	$Q_r = Q_t * B$		

This procedure is part of a method of estimating leakage flows without the use of a flow hood or Duct Blaster. The method adds a hole of known size to the duct system and by calculation estimates leakage.

Half Nelson—Supply-Return Split

Supply and return leaks have different impacts on energy use. The "Half Nelson" is a fast method which estimates the ratio between the total supply leakage area and the total return leakage area.

With all the registers sealed, the air handler is turned on and the pressures in the supply (P_S) and return (P_R) plenums are measured. The ratio of the total supply leakage area (A_S) to the total return leakage area (A_R) is estimated.

There are risks with this method. The test starves the blower motor for cooling air and should not be continued over a long period of time. It cannot be used immediately after repairs since the high pressures generated will "blow out" uncured mastic. In addition, John Tooley warns that these high pressures can damage duct board systems.

This procedure is part of a method of estimating leakage flows without the use of a flow hood, Duct Blaster, or blower door. The method (the "Full Nelson"), like the Blasnik method, adds a hole of known size to the duct system and calculates a leakage estimate.

Supply-return split can also be measured by conducting separate tests on both sections of the system with a blockage placed at the blower.

QUALITATIVE MEASUREMENTS

Qualitative measurements allow technicians to rapidly assess the areas of largest leakage and quickly check on progress of repairs. A good qualitative assessment tool

- Provides clear and unambiguous direction for the technician.
- Consumes as little time as possible to maximize technician time devoted to proper installation or repair of the distribution system.

The three primary qualitative methods are smoke stick, pressure pan, and register pressure (see Table 3.) Other qualitative methods include: tactile flow test, visual observation, and blocked return test.

Smoke Stick Method

Like the subtraction method, the smoke stick method is an extension of blower door technology. With the blower door pressurizing the house by 10–15 Pa, smoke released near a register will be more aggressively pulled into a register that has a major leak in that branch than a register that is distant from the larger leaks.

Pressure Pan

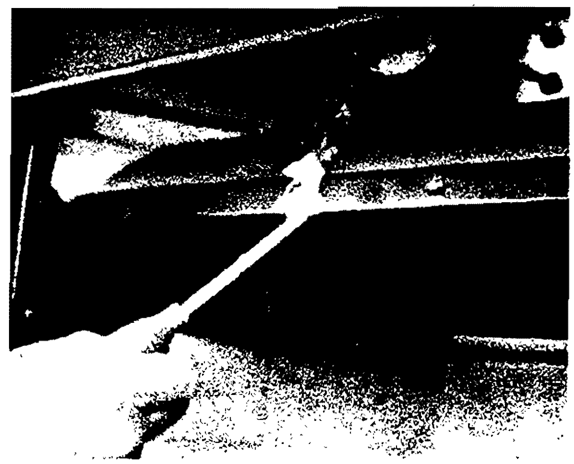
The pressure pan is a shallow pan (like a rectangular cake pan) that will cover and seal the supply or return register. The pan has a pressure tap that senses the pressure at the register when it is blocked off. Natural Florida Retrofit produces a combustion pressure pan and flow estimation device.

With the house pressurized to 50 Pa by the blower door, the technician records the pressure drop across the pressure pan when it blocks the register. If the pressure drop is less than half a pascal, any duct leaks are distant to that location. A larger pressure drop at one register (2–5 Pa) indicates that a large leakage site is near the location.

The pressure pan method is beneficial in prioritizing the attack on duct leakage sites, it can "see" leakage sites that are hidden in walls and under floors, and it provides a rapid check on progress (see "Pressure Pan Takes the Cake," *HE* Mar/Apr '92, p.17).

Blocked Register Pressure

The blocked register test is an extension of the pressure pan technique, usable while the registers are taped shut. With the ducts pressurized by the Duct Blaster, the pressure drop across each taped register is measured by inserting a small probe. The register with the *lowest* pressure drop is near a large leakage site. If a few registers show low pressures relative to the remaining ones, it is likely that a significant leak exists near the branch of ducts. This method is less descriptive than the pressure pan.



Where there's smoke, there's leakage. A smoke stick like this used in conjunction with a blower door is part of one qualitative duct leakage test.

Table 3. Qualitative Duct Leakage Tests

TEST	Smoke stick	Pressure pan	Blocked register pressure
EQUIPMENT	Smoke stick and blower door	Pressure pan and blower door	Duct Blaster
ADVANTAGES	• Fast once the blower door is set up	• Fast once the blower door is set up • Gives a numeric reading that relates to proximity and size of leak • Can be completed without sealing registers • Can be a quick stand in for measured air flow	• Fast once the Duct Blaster is set up and registers taped • Gives a numeric reading that relates to proximity and size of leak • Can be completed without removing tape from registers
DISADVANTAGES	• Requires more judgment (is more ambiguous) than the other two methods	• Once the registers are taped, it requires removing the tape	• Requires that the registers be taped • Less descriptive than the Pressure Pan

Duct Diagnostic Decisions

The duct technician's "tool box" should contain a wide variety of diagnostic procedures to be used as conditions dictate.

- Quantitative leakage measurement is best conducted with the Duct Blaster (and a blower door, if measurement of leakage to outside is required). We (with one exception) also consider the flow hood method useful.
- The ratio methods are helpful since they estimate the leakage to particular areas. To check the integrity of the duct system if a blower door is in place, the pressure pan method is suggested.
- We don't generally suggest the blower door subtraction method. It has the highest variability of the three quantitative methods described and provides weak feedback to the technicians sealing the duct system. The crew could be very successful at sealing the duct system, but would not see it indicated. ■

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