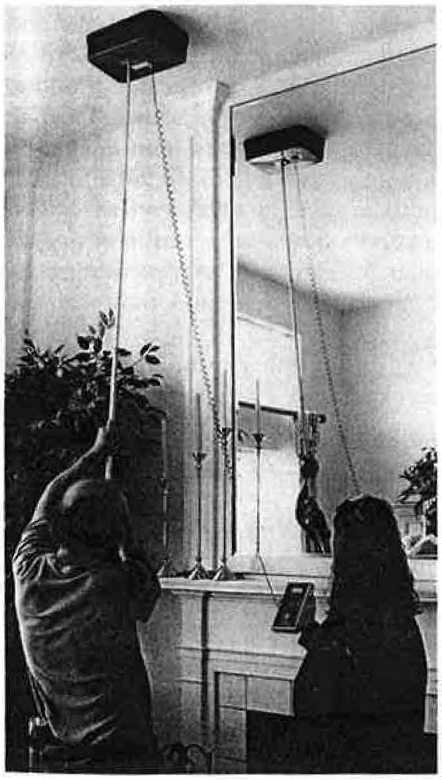
Pressure pans are often misused, and the information they provide can mislead the inexperienced. Bruce Manclark of Delta-T Incorporated (Eugene, Oregon) and Jeffrey Siegel, formerly of Ecotope Incorporated (Seattle, Washington), investigate how mistakes are made, and share their research into one strategy for more accurate pan readings.

Pressure Pans: New Uses and Old Fundamentals

by Jeffrey Siegel and Bruce Manclark



JOHN NAGIECKI

Duct leakage continues to be one of the biggest home performance problems, so duct sealing retrofits are in steady demand. Here at Ecotope and Delta-T, we've discovered a way for advanced duct sealers to speed up their diagnostics. At the same time, we have found that too many technicians are weak in the fundamentals of duct testing.

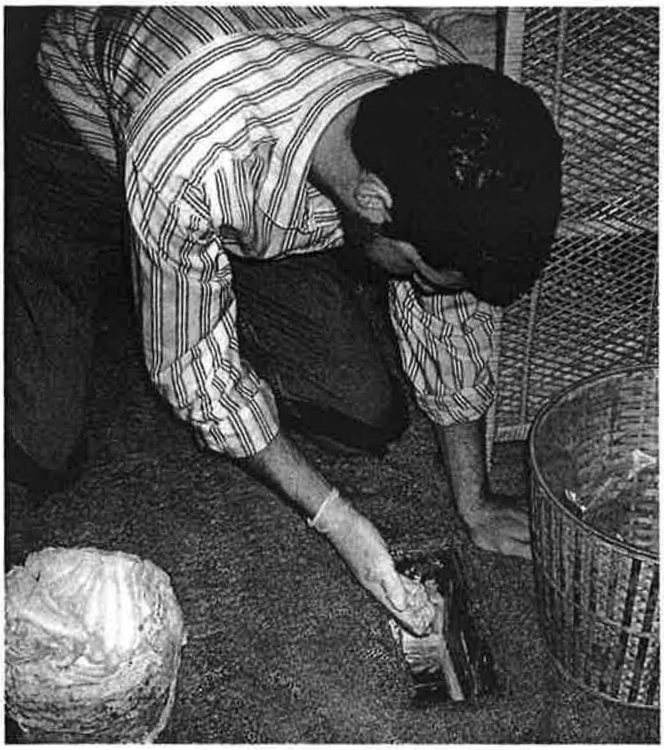
Contractors working on HVAC systems need to be able to measure duct system leakage. Before sealing, they need to determine whether the retrofit will be cost-effective. Getting correct information is the key to quality control; getting it quickly is the key to cost-effectiveness. Spend too much time, and the labor budget gets busted. Make the wrong decisions, and systems that need sealing don't get sealed, while other ducts get unnecessary work donc.

Retrofitters have many tools for measuring leakage. Two of the most common are pressure pans and duct pressurization devices. Duct pressurization devices like the Duct Blaster can give precise measurements of duct leakage. Pressure pans measure the ratio of leaks to the indoors versus leaks to the outdoors. Pressure pan readings are difficult to interpret, and the same number can reflect quite different leakage rates in different houses. Currently, duct leakage standards with numerical targets for duct tightness require duct pressurization testing.

Delta-T and Ecotope, funded by the Eugene Water and Electric Board and Puget Sound Energy, are developing a new way to use pressure pans, which may eventually speed up duct sealing (see "Not Your Daddy's Duct Sealing Method," p. 44). Based on retrofits in the Northwest, we have come up with an equation that uses pressure pan readings to provide estimates of duct leakage to the exterior. In certain cases, we have used quick pressure pan measurements to get data that are almost as reliable as the numbers from Duct Blasters. However, the equation still needs development. For now, what is most important is that technicians using pressure pans receive adequate training in duct diagnostics.

Conventional "Wisdom"

Because pressure pans are quicker to set up, retrofitters often try to use them instead of duct pressurization devices. This causes problems. Conventional wisdom suggests that a system with an average pressure pan reading of greater than 1 Pascal (Pa), or any individual register that has a reading of 2 Pa or greater, is leaky enough to require sealing. This rule may work well in some duct systems, but it can also lead to serious errors.



BRAD ANDREWS

Sam Karp of Delta-T seals a register boot after measuring initial leakage.

The potential for trouble was demonstrated in two houses sealed by a crew from Delta-T. In the first duct system, pressure pan readings were all 1 Pa or less. Based on the pressure pan test, this house seemed like a poor candidate for duct sealing. However, a duct pressurization test revealed that there were 375 cubic feet of leakage per minute to the outside with the ducts pressurized to 50 Pa (CFM_{50}), an amount that was unacceptably high to the sponsoring utility. This duct system was sealed. A second home's duct system had pressure pan readings that were all between 3 and 4 Pa. This seemed like an ideal candidate for duct sealing. However, a duct pressurization test revealed only 125 CFM_{50} of leakage to the outdoors, too low to justify a duct sealing retrofit. If the crew had based its decisions solely on pressure pan tests, they would have made the wrong decision at both of these houses.

Similarly, a crew in our area recently sealed the ducts in a house a utility (using pressure pans) had determined needed sealing. The crew's initial numbers were considerably lower than those reported by the utility. What had changed? Upon investigation, the crew found that the homeowner had replaced a very dirty furnace air filter the day before they arrived. The crew had also found and opened several dampers in the system. These are just a few examples of the factors that can affect pressure pan readings.

The duct pressurization test directly measures how much air leaks out of the system at a given pressure. This can be mathematically related to the equivalent leakage area in a system. The leakage area can be correlated with energy loss, giving the retrofitter useful information. The pressure pan test measures pressure in the duct, which is the result of interactions among leaks to the indoors, leaks to the outdoors, the physical details of those leaks, and the geometry of the duct system. For example, registers close to other registers will have low pressure pan readings, while dirty filters push all readings higher.

The Duct Pressurization Test

Duct pressurization tests are well documented; they have been used for several years to measure duct leakage to the outdoors. While there are several duct pressurization tests, this article uses the term to denote the test procedure described below. This test is also called an exterior duct leakage test, a blower door/duct tester test, a Duct Blaster test, or a leakage to exterior test.

First, all supply and return registers are sealed, usually with masking tape or garbage bags, and a blower door is installed. A duct tester, which is like a miniature blower door, is attached and sealed to the duct system, usually at the furnace cabinet. The air handler fan is off for the entire test. A Pitot tube or similar pressure tap measures the pressure of the duct system with respect to the house, and a tube is set up to measure outside pressure with respect to the ducts. The blower door pressurizes the house to about 50 Pa with respect to the outdoors. With the air handler off, the duct tester blows air into the duct system until there is no pressure difference between the house and the ducts. With no pressure difference between the house and the ducts, all air going through the duct tester is going to the outdoors through duct leaks. The duct tester shows how many CFM it is blowing to maintain a pressure difference of 50 Pa to the outdoors.

The test is often repeated with the house pressurized to about 25 Pa. The data from such a two-point duct pressurization test can be inserted into a formula to get a duct leakage curve. Such a curve allows the retrofitters to estimate leakage at actual operating pressures, which is more important than the leakage at 50 Pa. However, two-point tests can be time consuming, requiring an experienced crew to spend as much as two hours on testing, in addition to their sealing work.

The duct pressurization test results can be expressed in CFM_{50} or they can be mathematically manipulated to estimate leakage area. These numbers are directly comparable between different houses. A duct system that has a leakage rate of 300 CFM_{50} is leakier than a duct system that has a leakage rate of 200 CFM_{50}. Every contractor and utility duct sealing program has a different standard for determining what is an acceptable leakage rate and what requires duct sealing. For example, in the Pacific Northwest's smaller homes and manufactured homes, leakage of more than 250 CFM_{50} usually means that a duct retrofit is warranted.

Testing Techniques

Technicians in need of a faster estimate of duct leakage (or working to help pinpoint duct leakage) often conduct a pressure pan test (see "How to Pan for Pressure Gold"). The pressure pan test requires a blower door and a pressure pan, which is a modified cake pan with a gasket on the bottom and a pressure tap on top. A duct tester need not be installed, and the registers do not have to be sealed. The blower door is used to depressurize the house to -50 Pa with respect to outdoors. Alternatively, if the ducts are all in one space, the house can be depressurized to -50 Pa with respect to the space the ducts are in. Then the technician covers one register at a time with the pressure pan and records the pressure difference between the house and the ducts at each register, with the air handler off.

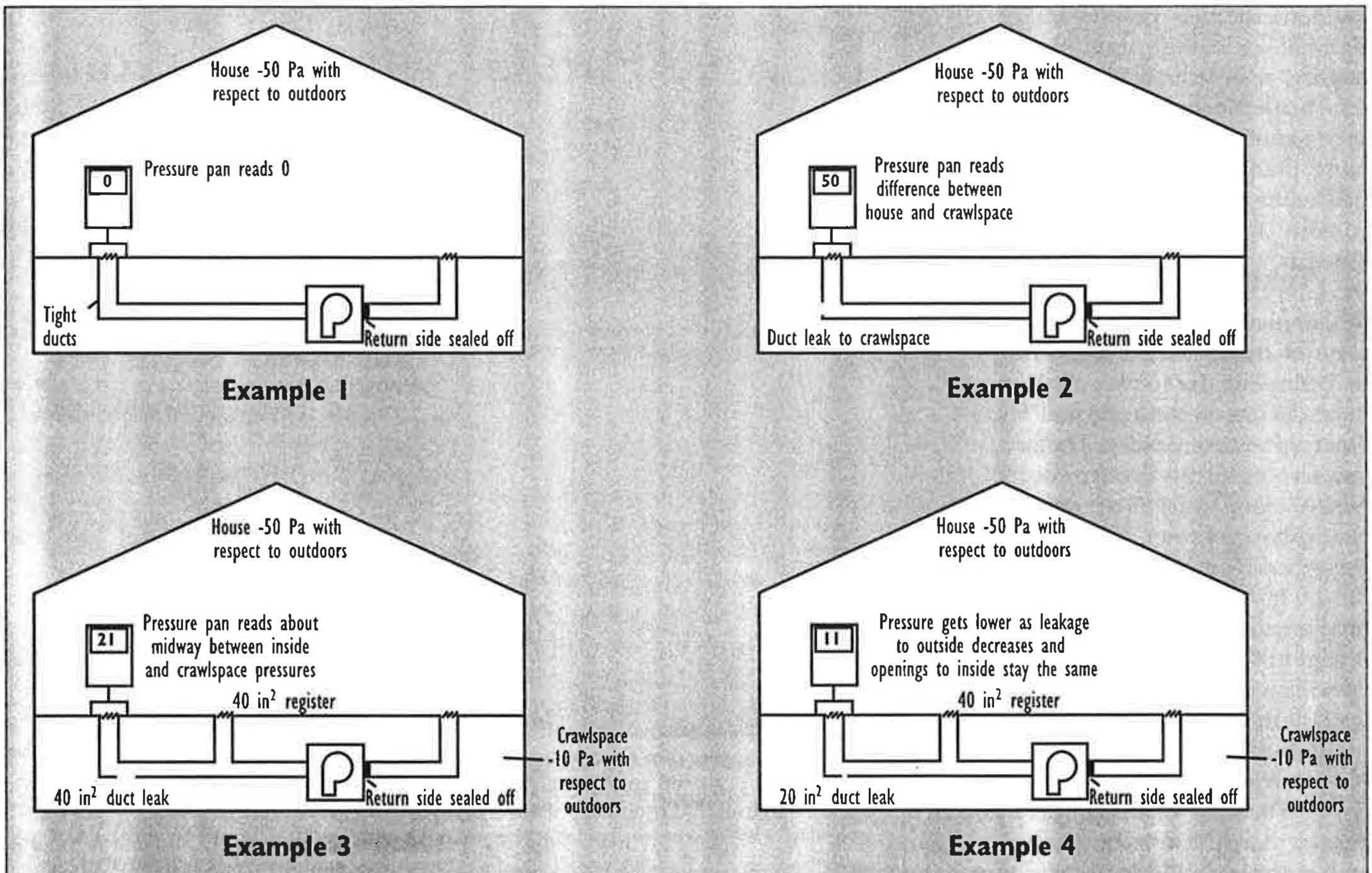
With the house depressurized to -50 Pa with respect to the outdoors, the duct system will have a pressure that ranges from 0 to 50 Pa with respect to the house. A duct system at 0 Pa is entirely within the pressure envelope of the house and has no leaks to the outdoors. A system approaching 50 Pa is essentially outside the pressure envelope, meaning that it has catastrophic leakage to the outdoors. Three sources of pressure can influence a pressure pan measurement.

- Pressure from outdoors. Air in any hole connecting the inside of a duct directly to the outdoors will have a driving force of 50 Pa.
- Intermediate zone pressure. Some areas, such as attics and crawlspaces, are not fully outdoors. These areas connect to the house through leaks, and to the outdoors through vents or unintentional leaks. The pressure difference between such zones and the house will be between 0 and 50 Pa, depending on the size of the leaks and vents. If the ducts leak to an intermediate zone, the zone's pres-

How to Pan for Pressure Gold

A pressure pan is a convenient way to seal a register and measure the resulting pressure between the duct system and the house. To use one, follow these steps.

- ❑ Make sure all interior doors are open and all exterior doors and windows are closed. If the blower door is not depressurizing some part of the house to -50 Pa, pressure pan readings will be wrong. The registers and grilles in zones not depressurized to -50 Pa will act like leaks to the outdoors.
- ❑ Remove all filters. A dirty filter can effectively block the supply side from the return side, causing higher pressure pan readings. If you only want to know the supply leakage, seal off the supply side from the return side with cardboard and tape at the air handler.
- ❑ Look out for dampers and other blockages. If there is a closed or nearly closed damper in a duct branch, it will isolate that supply line from the other registers, so the pressure pan reading at that register will be high (like the single register in Figure 1, Example 1).
- ❑ Make sure all the registers are wide open. If they are closed, their net free area will decrease. This causes outside leaks to have disproportionate effect, so the pressure pan readings will be higher than they should be.
- ❑ Set all air handlers to stay off throughout the test.
- ❑ Set up a blower door and depressurize the house to -50 Pa with respect to the outdoors.
- ❑ Measure the pressure to the zone containing the ductwork. For this example, call that zone the crawlspace. If there is no pressure difference between the crawlspace and the house, ducts in the crawlspace will effectively be leaking to the indoors. Thus all pressure pans will read zero, regardless of their leakiness. If the crawlspace is between indoor and outdoor pressure, there are two possible ways of using the pressure pan. One is to estimate what the pressure pan readings would be if the crawlspace were at 50 Pa with respect to the house. For example, if it is at 25 Pa with respect to the house, pressure pan readings should be doubled to show what the duct pressures would be if the crawlspace were outdoors. Alternatively, if the ducts are all in one cavity, you can actually depressurize the house to -50 Pa with respect to the space the ducts run through; this will make calculations easier.
- ❑ If a pressure pan is not available or doesn't fit on a register, you can measure the pressure at a register by sealing the register with tape and measuring the pressure difference across the tape with a Pitot tube.
- ❑ Toe kicks—registers underneath cabinets in kitchens and bathrooms—present a special problem. It is hard enough to fit a pressure pan against one of these long, awkwardly placed registers. And any pan number that you manage to get actually shows the pressure difference between the room and the space below the cabinet, not the duct. This pressure can vary radically depending on construction details. It is not clear what a technician can infer from toe kick pressure pan results. If possible, seal the duct off at the boot-to-duct connection with tape, foam, or a pillow, thereby removing that duct from the system. Put a pressure tap hose into the end of the duct and treat the resulting number like a pressure pan result.
- ❑ Most return grilles are larger than a pressure pan. To use the pressure pan, tape off part of the grille, leaving an untaped area small enough that the pan will cover it. This affects all the other pan readings, so do it before you begin testing. On a standard louvered return register, tape it all except a 10-inch x 5-inch opening to get a net free area equal to an average supply register. Other sizes will work, but this size may be easier for crews to work with, because they are used to it.
- ❑ If there are big gaps between the boot and the floor, this will affect the pressure pans. Tape over those gaps and use a pressure pan, or block the entire boot with tape or a pillow and measure pressure with a Pitot tube in the duct. If the gap is large, our crew typically seals it permanently and then retests that register.
- ❑ Do pre- and post retrofit duct tests under the same conditions. If the registers were in the boots for the preretrofit test and were not placed back in for the postretrofit test (to let wet sealing mastic dry, for example), the postretrofit test results would be artificially low—the lack of grills increases the register free area from 24 square inches to 40 square inches for typical floor registers. Similarly, if the air handler and/or the duct work is located in the garage, make sure any garage doors to the outdoors are in the same position for all tests.



In a perfect duct system with no leaks to the outdoors or to any intermediate zone, as in Example 1, a pressure pan over any register will read 0 Pa. The air pressure in the ducts is equal to that in the house. This pressure is not affected by the number of registers. Likewise, a simple duct system with only one register and a leak directly to the outdoors (as in Example 2) would have a pressure pan reading of 50 Pa. The only source of pressure is the outdoors. The register is not open to the indoors because it is sealed by the pressure pan during the test. Theoretically, whether the leak to the outside is 20 square inches or 0.01 square inches, the reading will still be 50 Pa—the ducts are outdoors. The pressure pan, as part of the boundary between outdoors and indoors, shows outdoor pressure with respect to the indoors.

Example 3 shows a slightly more complicated system with two registers. Each has an area of 40 square inches. The only other hole is a 40 square-inch hole to the outside. The pressure pan reading at each register is about 25 Pa, because the pressure pan is equally influenced by the pressure difference between the ducts and the outdoors (50 Pa) and the pressure difference between the house and the duct system (0 Pa). With the ratio of indoor to outdoor leakage at about one to one, the pressure pan reads midway between the indoor and outdoor pressures.

Moving toward increasingly complex—and realistic—duct systems, one finds a variety of holes to various zones at various pressures. The pressures are further complicated by fluid dynamics: pressures are influenced by the relative hole sizes between zones, the pressures in those zones, the physical location of the holes, the duct geometry, and the resulting air flow at the point in the duct system where the technician puts the pressure pan. These factors greatly complicate a mathematically rigorous physical interpretation of pressure pan results, particularly for anything other than a very simple and idealized house. The average house is decidedly neither simple nor idealized.

KATHERINEFALK

sure with respect to the indoors will give air in the duct some driving force.

- Pressure from indoors. Openings connecting the duct system to the indoors will lower pressure in the ducts. The registers are usually the biggest source of indoor pressure, and unintentional leaks also contribute.

A pressure pan reading is the ratio of effective leakage between the ducts and the indoors (including registers) to effective leakage between the ducts and outdoors. Holes to the indoors, such as registers, lower the numbers, while leaks to the outdoors raise the numbers. This is evident to any technician who has ever conducted a pressure pan test on two registers on opposing sides of the same wall. Because there is a very large leak to the indoors (the other register) very close to the register covered by the pressure pan, the pressure pan reading will be very low, regardless of the leakiness of the duct system.

In the Eugene houses where pressure pans gave the "wrong" result about the duct system tightness, the problem was that the ratios were thrown off by unusual situations. In the house with low pressure pan readings but high leakage, the problem was unusually high internal leakage. In the house with high readings but relatively little leakage, the problem was a single register that blew much of its air outdoors, causing the duct pressure to be excessively influenced by outside pressure.

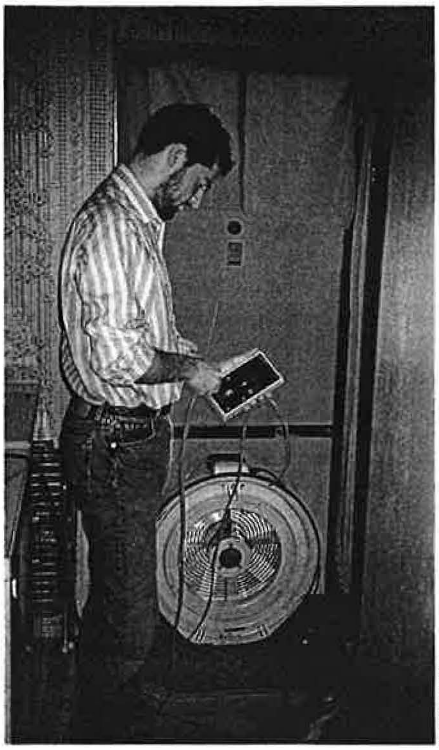
It takes about ten minutes to complete a pressure pan test in an average sized house, once the blower door is installed. This speed allows technicians to repeat the test several times during a retrofit to evaluate the effectiveness of a particular sealing action, such as sealing the leaks at register boots. Also, because using a pressure pan does not require sealing registers or opening and sealing the furnace cabinet, technicians do not have to worry about damaging wet duct seals in these locations.

Can a Pan Be Enough?

The disadvantage of the pressure pan test is that it is more art than science. As in the Eugene houses, pressure pan results are often hard to interpret—the physical significance of the readings is not always clear. It is even harder, if not impossible, to make meaningful comparisons between homes based on pressure pan results. The one exception is when homes have very similar duct geometry and installation, as is the case with manufactured homes or identical homes in a subdivision.

The best way to interpret pressure pan results correctly is to understand the physics behind the test. This, in turn, requires a firm grounding in the duct pressurization test.

Still, we have found that a technician with adequate background knowledge can get enough information from a properly executed and analyzed pressure pan test to make valid field decisions on certain homes. The standard pressure pan test assumes that the technician knows the pressure in the space where the ducts are located and duct leakage to the interior—numbers that normally come from doing a duct pressurization test. However, some populations of homes have consistent relationships among duct leakage to the exterior (or whatever space the ducts are in), duct leakage to the interior, and house leakage to the crawlspace. Experienced technicians can develop an intuitive sense of these relationships. Using a pressure pan test and plenty of experience with a given housing stock, some technicians can judge whether a house will be cost-effective to duct seal. We have developed a new mathematical technique so that experienced technicians can rely on something more than intuition.



BRAD ANDREWS

Sam Karp runs a blower door to depressurize a house in order to perform a pressure pan test.

If crews can make correct decisions using only pressure pans, they will save time and increase cost effectiveness. To see whether this is possible, we analyzed pressure pan data from 44 homes. The data showed trends relating pressure pan numbers, duct leakiness, and local construction styles. We analyzed these trends and developed the equation below, which helps relate pressure pan results to leakage. This formula allows similar homes to be compared on the basis of pressure pan tests.

The formula is intended to help a crew decide whether to seal ducts in a home. Once the work is underway, continued use of pressure pans and the formula may also help them decide whether they have sealed enough leaks to consider the retrofit finished.

The formula is an empirical curve fit, rather than a mathematically derived truth. It should be used with caution. It assumes that the duct technician can make an accurate assumption about unintentional leakage to the inside and it is intended to provide a general result rather than a precise value.

Typical 4-inch x 10-inch or 4-inch x 11-inch floor registers found in most Pacific Northwest homes have free areas (A_i) of 24.1 square inches. The free area for any register can be found in the manufacturer's register catalog. The formula is not particularly sensitive to the area value, so assuming a free area of 25 square inches per register usually works. While A_i is supposed to be the total interior leakage to the indoors, adding all registers together results in an overestimate, because one register is covered by the pressure pan. This overestimate is intended to account for some of the unintentional interior leakage that always seems to exist. If a crew has used Duct Blasters enough to have a good idea of the interior leakage in the housing stock they're working on, they can just add the area of this interior leakage to the sum of all of the register free areas. This will make the formula more accurate.

The most important part of the equation is the exponent, *b*. It summarizes the relationships among leakage to the indoors, house leakage, and leakage to the outdoors. Therefore, the exponent must be empirically derived for a given local housing stock. The exponent has the most influence on whether or not the equation works. In order to derive it, one needs duct pressurization test results (leakage to exterior in CFM_{50}) and the total pressure pan result for a sample of similar houses. Using algebra, the exponent is then determined for each house.

Pressure Pan Equation

$$Q_{50ext} = (A_i)^b \times \sqrt{\Sigma P_{ppan}}$$

Where:

Q_{50ext} = Duct leakage to the outdoors (CFM)

A_i = Total free area of all supply and return registers (square inches)

b = Empirically derived exponent

ΣP_{ppan} = Sum of pressure pan pressures (Pa)