The Current State of Duct Leakage Measurement:

Field Evaluation of Five Methods

A study of test methods for duct leakage revealed that there is room for improvement in this evolving field.

by Paul W. Francisco

An increasing number of codes and programs are requiring that air leakage from residential duct systems be measured in order to evaluate the efficiency of the distribution system. For example, proposed Standard 152P from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the Environmental Protection Agency (EPA) Energy Star program for existing duct systems both require that duct leakage be measured (see "Duct Leakage: How Much Is Too Much?" *HE* Jan/Feb '01, p. 10), and both specify methods for making this measurement. But how good are these methods, and how much of an impact does a bad estimate have on the actual figure of merit—the distribution efficiency?

In 1998, the Seattle, Washington–based HVAC consulting firm Ecotope, where I am a research scientist, undertook a project sponsored by ASHRAE and co-funded by the U.S. Department of Energy to evaluate Standard 152P in the field. This standard uses measurements for duct leakage, conduction loss, fan flow, and so forth and puts the results into a mathematical model to estimate the distribution efficiency. We investigated two questions: (1) how well can the inputs for the standard be measured, and (2) with fairly accurate inputs, do the equations in the standard provide a good estimate of the distribution efficiency?

The answer to the second question, at least for the houses that we tested, seemed to be that the equations do a fairly good job of predicting distribution efficiency if the inputs are fairly accurate. However, while many of the inputs could be measured reasonably well, measuring duct leakage was problematic.

Five Tests for Measuring Duct Leakage

We evaluated five different methods of measuring duct leakage. The first two were those that were incorporated into Standard 152P: the

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Duct Blaster test (referred to as the duct pressurization test in the standard), and the house pressure test. The other three that we evaluated were the supply-blocked house pressure test, which is a modification of the house pressure test; the hybrid test, which is a combination of the two tests in Standard 152P; and the nulling test, which we developed near the beginning of the project.

In order to assess the accuracy of the vari- ɔus methods, we needed to come up with an ndependent method of estimating the true duct leakage. For this best estimate, we decided to use a calibrated propeller flow 100d to measure the flow out of all of the supply registers, and then to subtract the total of those flows from the air handler flow. The ir handler flow was measured using a Duct Blaster as a surrogate return duct system, and adjusted with the air handler fan on to provide the same supply plenum pressure as would be provided with the air handler run- ing in its normal configuration. This flow 100d has proven to be quite accurate in pre- ious studies, and the method described for measuring air handler flow is the best method urrently available. Because the leakage of nterest is the leakage to outside only, we creened the houses for this study to have all f their ducts outside the conditioned space.

We tested ten one-story homes in the acific Northwest, including eight single- unily and two manufactured homes. We ested five of the homes with various modifi- ations made to the duct system—such as isconnecting certain ducts—in order to

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Left, two sections of duct have pulled apart, causing supply leakage at Site A02. Above, finger joints are pulling away from the return pan, resulting in return leakage at Site A05.

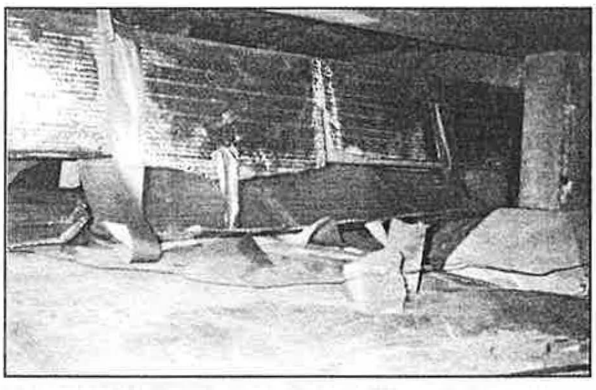
get more tests at a small number of houses. Altogether, we ran a total of 26 sets of tests. The three leakage test methods that were not in Standard 152P were performed in only about half the cases, due to time and practicality constraints.

The *Duct Blaster test* uses a calibrated fan at specific pressures on the supply and return ducts with all registers sealed. To test the supply and return separately, we placed an airtight barrier between the supply and return sides; the filter slot was frequently used as a location for this barrier. For tests of leakage to the outside, we operated a blower door to make the pressure difference between the house and the ducts 0, thus eliminating driving forces from the ducts to the house. To correct the leakage rate on the supply side to the leakage at operating conditions, a pressure pan is placed over each supply register with the air handler running. The average pressure is used in the power law leakage curve from the Duct Blaster test. The major drawbacks of this method are that the pressure you come up with may not be a good estimate of the actual pressure across the leaks and that it can be time-consuming.

The *house pressure test* uses the change in the pressure differential across the building envelope caused by turning on the air handler in conjunction with measured pressures in the ducts and a standard blower door test to get the unbalanced leakage. Then, by partially blocking the return grille, the envelope and duct pressures can be measured again to get a second point that allows separation of supply and return leakage. One drawback of this method is that it relies on a set of assumptions that are not always valid. For example, the method assumes a specific house leakage distribution (equal holes in the floor and ceiling, airtight walls), and it assumes that the result does not vary much even if duct pressure measurements are taken in widely different locations. This latter assumption is particularly problematic, because it can be difficult to verify the exact location of the pressure tap along the length of the return duct. A further drawback of this method is that it is sensitive to high wind speeds.

A *modified version of the house pressure test* was proposed in which the supply registers instead of the return grilles are partially blocked while measuring for separation of supply and return leakage. This was done in response to results showing frequent large errors in leakage when the house pressure test was done with the return grilles partially blocked.

The *hybrid test* uses the portion of the house pressure test that does not include blocking the grilles or registers to get unbalanced leakage and combines this with a Duct Blaster test on both the supply and return ducts to get supply and return leakage separately. For the Duct Blaster portion of the test, no barrier is placed between the supply and return sides. The duct pressure is measured by placing pressure hoses in both the supply and return ducts and joining them with a tee prior to measurement. This makes the duct pressure applied to all ducts the average of the supply and return pressures. The major drawbacks of this method are that the house pressure test component is still subject to the assumptions described above and that the



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It is common to find duct tape falling off ducts. In this case, the failed duct tape is allowing the insulation to hang below the plenum at Site A04. Duct tape failure also results in disconnected ducts, causing major leakage.

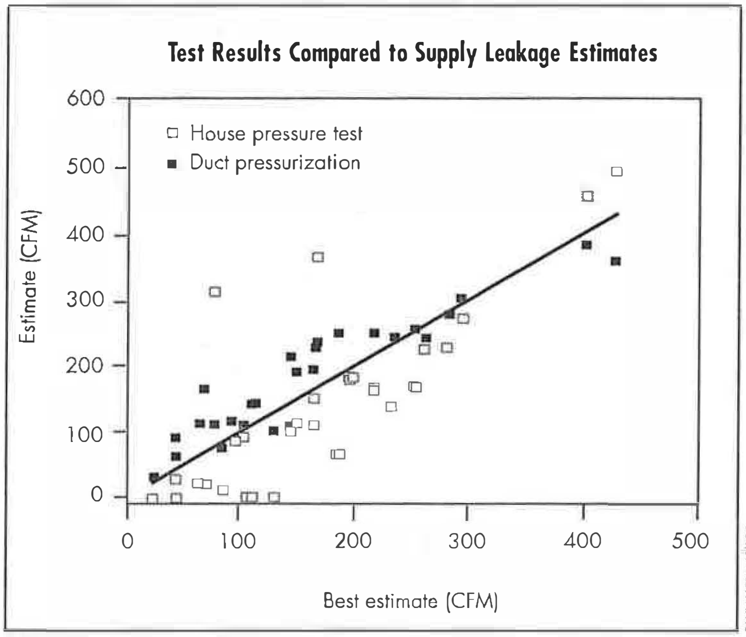


Figure 1. The test results showed that the house pressure test has more scatter and that the duct pressurization test is biased high, while the house pressure test is biased low.

supply and return sides of the ducts may not be pressurized equally during the fan pressurization test, even though a single, average pressure is applied to both sides.

The *nulling test* uses a Duct Blaster to null out the change in pressure across the envelope caused by running the air handler fan under normal operation. The envelope pressure is first measured with the air handler off. The air handler is then turned on, and the Duct Blaster is used to return the envelope to the original pressure. Since the cause of a change in pressure was the unbalanced leakage, the amount of air required to return the envelope to its original pressure is an estimate of the unbalanced leakage. This test gets repeated with a second Duct Blaster in place of the return ducts (as was done for getting the air handler flow) to get supply leakage. The unbalanced leakage and supply leakage are combined to get the return leakage. The major drawbacks of this method are that it is sensitive to wind and that it does not account for the effect of holes in the ducts on the envelope pressure when the air handler is not running.

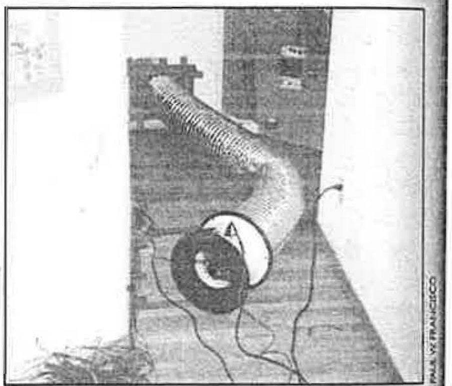
How the Five Tests Performed

From the leakage tests, we were able to draw important summary statistics on the five duct leakage tests considered in this study (see Table 1). Due to the difference in sample sizes for the various tests, straight means of the leakage results do not tell the whole story. In order to look at the tests on a more equal footing, we summarized the differences between the individual leakage test results and the best estimates.

The second section of Table 1 shows the average difference for each test method relative to the best estimate. Note that all methods except for the nulling test showed biased results. The two house pressure tests underestimated the leakage, while the Duct Blaster test and the hybrid test overestimated the leakage.

These biases do not capture the amount of scatter in the measurements. This is shown by the standard deviations. The Duct Blaster and nulling tests each have a standard deviation of about 40 CFM relative to the best estimate, which translates to about 20% of the average leakage estimate for each test. The other three methods each have about twice the standard deviation, and therefore more scatter, which represents about half of the average predictions for these tests.

We graphically compared the duct pressurization test and the return-blocked



A Duct Blaster is attached to a return grille for the return side duct pressurization test.

Table 1. Summary Statistics for Predictions of Supply Leakage from Various Test Methods

	Best Estimate	Duct Blaster	HPT, Return Blocked	HPT, Supply Blocked	Hybrid	Nulling
Number of cases	26	26	26	13	17	12
Mean leakage (CFM)	166	185	144	157	154	225
Leakage Difference from Best Estimate*						
Mean leakage (CFM)		19	−22	−30	36	0
Standard deviation (CFM)		36	84	79	76	44
Standard deviation (% of mean leakage)		19.4	58.1	50	49.1	19.6
Leak Fraction Difference from Best Estimate						
Mean leakage (%)		2.6	−2.1	−3.2	4.4	−0.4
Standard deviation (%)		4.8	11.4	10.8	9.2	5.2

*Leakage differences for the HPT, supply blocked, hybrid, and nulling tests are based only on those cases in which a given test was conducted.

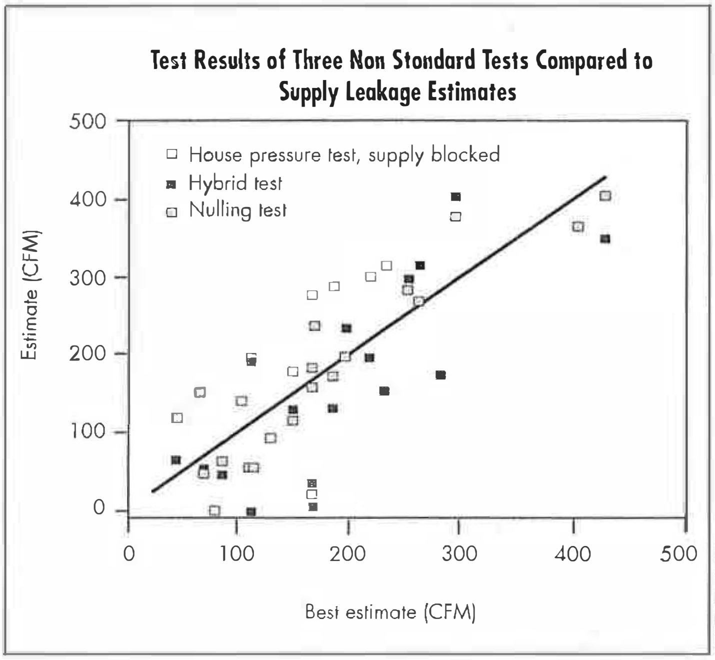


Figure 2. The test results for the nonstandard duct leakage test methods show that the nulling test promises to be a more accurate leak testing method.

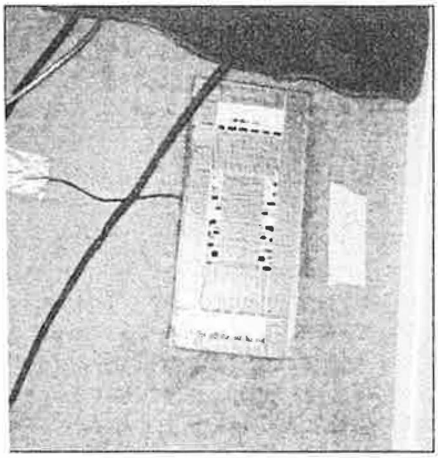
house pressure test with the best estimate (see Figure 1). These tests were done in all cases. Results show that the house pressure test has more scatter, and that the duct pressurization test is biased high while the house pressure test is biased low.

We also graphically compared the other proposed tests with the best estimate (see Figure 2). These tests were not done in all cases. Our results show that the supply-blocked house pressure test is biased high with quite a bit of scatter; the hybrid test also has a lot of scatter but tends to be biased low; and the nulling test has less scatter and no significant bias.

To predict the effect of duct leakage on energy loss, it is necessary to look at the ratio of the leakage to the air handler flow rate. For example, a 100 CFM supply duct leak to outside is more of a problem in an 800 CFM system than it is in a 1,200 CFM system. The final section of Table 1 shows these ratios. To a first approximation, the error in the ratio of supply leakage to air handler flow rate directly translates into an error of the same size in the duct efficiency.

On average, all of the methods are within 5% of the best-estimate ratio of duct leakage to air handler flow rate. However, the scatter (based on standard deviation) is quite large for the two house pressure tests and the hybrid test, at about 9%–11% of the air handler flow rate. This corresponds to about a 9%–11% error in duct efficiency and hence in the prediction of energy loss from the ducts. The Duct Blaster test and the nulling test both have a standard deviation of about 5% of the air handler flow.

These results do not tell the whole story for the house pressure test. At the time that we performed this project, the protocol was to measure the return duct pressure at the midpoint of the return duct. We investigated the sensitivity of the results to the actual location of this pressure measurement by also measuring pressures at the return grille and in the return plenum. When return leakage was large, the results were very sensitive to the location of the pressure measurement, and the midpoint usually produced the best results. Also, in one case the house pressure test predicted an increase in the supply leakage of about 300 CFM when we added a large hole in the return duct but did not touch the supply ducts. These results show that the house pressure test, which was already the least reliable of the test methods, can produce wildly varying predictions depending on the exact location of the pressure measurement, as well as on the characteristics of the leakage.



Partially-taped pieces of perforated metal were used for blocking supply registers for the supply-blocked house pressure test.

What We Learned

The findings of this project indicate that the measurement of duct leakage is still far from an exact science. The various methods for obtaining an estimate can produce results that differ from each other and from the actual leakage. Further, the level of discrepancy can have a large impact on the prediction of duct losses and will sometimes provide the wrong answer as to whether it is worth performing a leakage retrofit on the ducts. We found the Duct Blaster and nulling tests to be much more accurate, and therefore more likely to provide the right answer, than the other tests.

More research needs to be done to develop better duct leakage tests—tests that can be run in the field in a reasonable amount of time and that are widely applicable. The nulling test shows promise, especially since it is new and may still be capable of refinements. For the first set of houses tested, it was about as accurate as the Duct Blaster test with respect to scatter and it had no bias. However, the sample was small, and it would be premature to draw any final conclusions. We will be doing additional research on the nulling test, along with another test called the Delta-Q, in an upcoming research project sponsored by ASHRAE.

Paul W. Francisco has been a research scientist at Ecotope for seven years. He specializes in the modeling and field measurement of the efficiency and leakage of forced-air distribution systems.

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