Measuring Duct Leakage with a Blower Door: Field Results

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ABSTRACT

Duct leakage is recognized as a major source of energy losses in residential buildings, and one of the most important parameters for estimating duct efficiency. One useful diagnostic in the field is the measured duct leakage to outside at a fixed pressure difference. The most commonly used method for this measurement requires simultaneous use of both a blower door and a duct pressurization fan. As part of a larger study (Francisco and Palmiter 2002) funded by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) and the United States Department of Energy, we evaluated two methods of measuring duct leakage using only a blower door. One of the methods was a modified blower door subtraction technique; the other was a modified version of the add-a-hole method, which consists of a blower door test with all registers sealed and another with known holes added between the house and the ducts. The second method allows separate but simultaneous measurement of the leakage on the supply side and on the return side. Field tests were conducted on seven homes with a total of 20 different duct configurations (approximately balanced supply and return leakage, supply dominated leakage, and return dominated leakage). This paper presents a derivation of the equations for the two methods, and summarizes the results of the field tests. The two methods are compared with the standard technique using both a blower door and duct pressurization fan. The two new methods gave results that were in fair agreement with the standard method, and they also required less time and effort in the field.

Introduction

The two leakage test methods discussed in this paper are the add-a-hole test and the modified blower door subtraction test. Both of these methods require only the use of a blower door. The leakage that they measure is not at operating conditions, but is rather at a fixed pressure. Both of these are modifications of methods proposed by Michael Blasnik (Blasnik 1989). However, the actual details of the tests we performed differ sufficiently from those proposed by Blasnik that a new derivation is required.

Descriptions and Derivations

First we present a common nomenclature for the two test methods.

Nomenclature

Q_f flow through house pressurization fan
Q_h flow through house envelope not including ducts
Q_i flow through internal leakage from house to ducts
Q_d flow through duct leaks to outside

Q_{hole}	measured flow through added hole
Q_{reg}	flow through open registers
P_h	pressure difference: house to outside
P_i	pressure difference: house to duct
P_d	pressure difference: duct to outside
C_d	flow coefficient: duct to outside
C_h	flow coefficient: house to outside
C_i	flow coefficient: house to duct, excluding registers and grilles
nd	assumed flow exponent: duct to outside = 0.6
nh	measured flow exponent: house to outside
ni	assumed flow exponent: house to duct = *nh*
s, u	indicate whether hole/registers sealed or unsealed

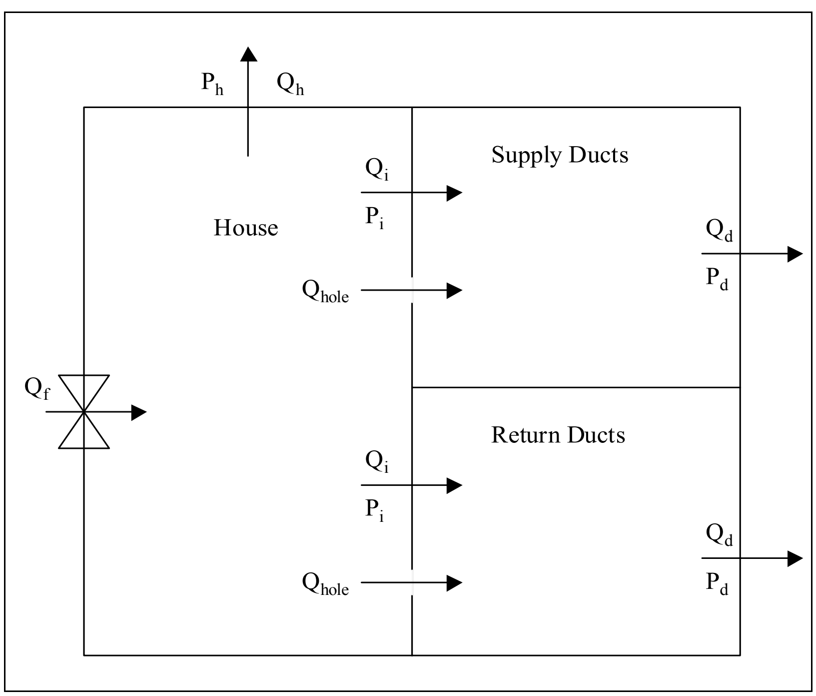
For all tests we have the following identity

$$P_h = P_i + P_d \tag{1}$$

Add-a-Hole Method

Description. The test setup for the add-a-hole method is shown schematically in Fig. 1.

Figure 1. Schematic of the Add-a-Hole Test Setup



As indicated in Fig 1, this method allows the simultaneous measurement of leakage on the supply and return sides of the duct system. Pressures are measured from the house to outside and from the house to the duct system (all results presented here used the supply plenum and return plenums for the house-to-duct pressures. The supply and return ducts are separated by an airtight seal at the location of the filter slot in the return box. We use the same nomenclature for the supply side and the return side because they are calculated separately, one at a time.

For the first step in this method, the registers are all sealed. The blower door is run to pressurize the house to a target pressure of 50 Pa and also 25 Pa. We used this test get the value of *nh*. The pressure differences P_h and P_i were measured.

In the second step, two calibrated holes are added, one for the supply ducts and one for the return ducts. In our case, we used two unpowered calibrated fans attached to either side of the air handler, resulting in measured flows, but in general a box with a hole of known area would work just as well. The blower door is again used to pressurize the house to target pressures of 50 and 25 Pa, and the house-to-outside and house-to-duct pressures are measured. In addition, the fan pressures of the two duct blasters are recorded so the flow through the holes can be calculated.

Derivation. With this information we can calculate the duct leakage to outside and to inside. The equations are the same for the supply side and the return side, so only one set is provided. The flow through the hole and the pressure from house to ducts are the only quantities that differ for the return and supply calculations. Notice that the flows through the blower door are not used in estimating the leakage, only the flows through the added holes. The flow exponent for internal leakage *ni* was assumed to be the same as that for the house.

A flow balance with the hole sealed results in

$$Q_{i,s} = Q_{d,s} \tag{2}$$

so that

$$C_i P_{i,s}^{ni} = C_d P_{d,s}^{nd} \tag{3}$$

$$C_i = C_d \frac{P_{d,s}^{nd}}{P_{i,s}^{ni}} \tag{4}$$

A flow balance with the hole unsealed results in

$$Q_{hole} = Q_{d,u} - Q_{i,u} \tag{5}$$

so that

$$Q_{hole} = C_d P_{d,u}^{nd} - C_i P_{i,u}^{ni} \tag{6}$$

Combining eqs. **(5)** and **(6)** we can solve for C_d

$$C_d = \frac{Q_{hole}}{P_{d,u}^{nd} - P_{d,s}^{nd}\left(\frac{P_{i,u}^{ni}}{P_{i,s}^{ni}}\right)} \quad \textbf{(7)}$$

from which we can calculate the duct leakage to outside as

$$Q_{d,25} = C_d 25^{nd} \quad \textbf{(8)}$$

and the duct leakage to inside as

$$Q_{i,25} = C_i 25^{ni} \quad \textbf{(9)}$$

Modified Blower Door Subtraction Method

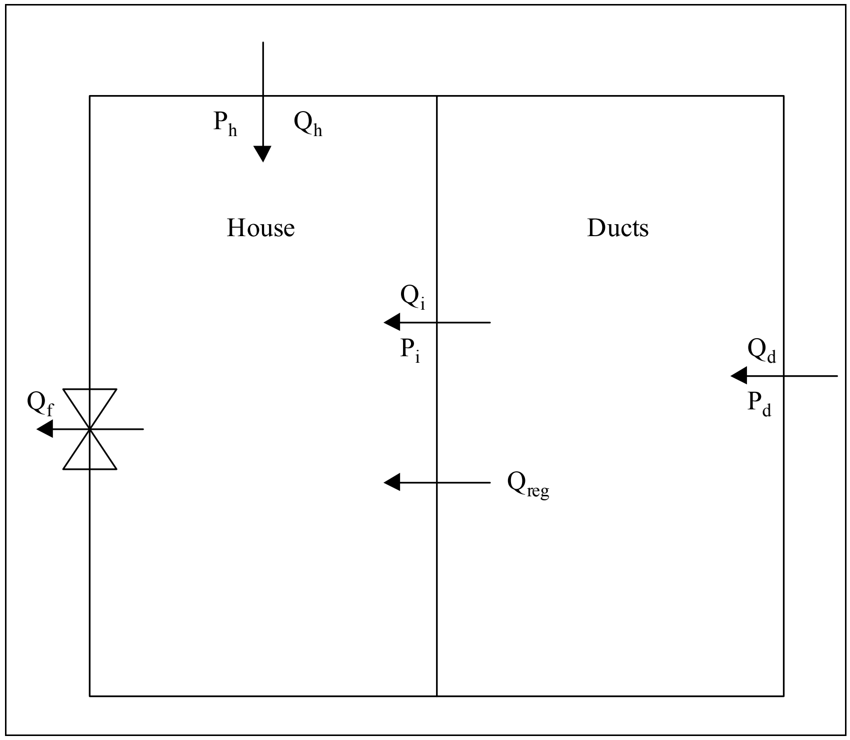
Description. Unmodified blower door subtraction was one of the first residential duct leakage tests invented. This test involves performing a blower door test twice, one with all the registers and grilles sealed and one with all of them open. Tests are usually done in depressurization mode at either one or two pressure differences between the house and outside: one or both of -25 Pa and –50 Pa. The difference in flow through the blower door between the two tests was supposed to be an estimate of duct leakage at that pressure.

The main problem with the unmodified blower door subtraction method is that it does not properly account for internal leakage between the ducts and the house. The unsealed test gives correct results, but the sealed test does not because there is still flow through the internal leakage to the ducts and then to outside. As a result, the flow measured when the registers are sealed is biased high, and when we subtract it from the unsealed result to get the duct leakage, the value will be biased low, and the greater the internal leakage, the greater the bias. The modified subtraction method is a procedure for using an additional measured pressure to correct the bias.

The development of software to automate the blower door testing process in conjunction with a pressure datalogger that allows the recording of pressures between the ducts and the house and between the duct zones and the house warrant a rethinking of the utility of the blower door subtraction idea. The automation reduces the uncertainties of the test results. The test is referred to as the “modified” blower door subtraction test because of the use of the interzonal pressures to make adjustments for communication between the home and the duct zone. This test can also be done using a sufficiently precise hand-held manometer, especially if long-term averaging is used.

The test set-up for this method is shown in Fig. 2. In the first step, all registers are sealed and measurements are made exactly as for the previous method, except that the blower door is set to depressurize the house and the flow through the blower door will be used in the calculation. In step two, the blower door is run again but with the registers unsealed, and the blower door flow and pressures to ducts and outside are recorded.

Figure 2. Schematic of the Modified Blower Door Subtraction Test Setup



Derivation. The duct leakage to inside and outside can then be calculated as follows.

A flow balance for the sealed test results in

$$Q_{f,s} = Q_{h,s} + Q_{d,s} \quad \textbf{(10)}$$

$$Q_{f,s} = C_h P_{h,s}^{nh} + C_d P_{d,s}^{nd} \quad \textbf{(11)}$$

$$C_h = \frac{Q_{f,s} - C_d P_{d,s}^{nd}}{P_{h,s}^{nh}} \quad \textbf{(12)}$$

and for the duct leakage to inside we have

$$Q_{i,s} = Q_{d,s} \quad \textbf{(13)}$$

$$C_i P_{i,s}^{ni} = C_d P_{d,s}^{nd} \quad \textbf{(14)}$$

so that

$$C_i = C_d \frac{P_{d,s}^{nd}}{P_{i,s}^{ni}} \quad \textbf{(15)}$$

A flow balance for the unsealed test results in

$$Q_{f,u} = Q_{h,u} + Q_{d,u} \tag{16}$$

$$Q_{f,u} = C_h P_{h,u}^{nh} + C_d P_{d,u}^{nd} \tag{17}$$

$$C_h = \frac{Q_{f,u} - C_d P_{d,u}^{nd}}{P_{h,u}^{nh}} \tag{18}$$

Equating the two expressions for C_h in eqs. **(12)** and **(18)**, we can solve for C_d in terms of the other quantities:

$$C_d = \frac{P_{h,s}^{nh} Q_{f,u} - P_{h,u}^{nh} Q_{f,s}}{P_{h,s}^{nh} P_{d,u}^{nd} - P_{h,u}^{nh} P_{d,s}^{nd}} \tag{19}$$

Notice that if the sealed and unsealed house-to-outside pressures are exactly the same, the equation simplifies to

$$C_d = \frac{Q_{f,u} - Q_{f,s}}{P_{d,u}^{nd} - P_{d,s}^{nd}} \tag{20}$$

where the numerator is just the blower door subtraction result and the denominator is the correction factor.

Now, we can calculate the leakage from ducts to outside at 25 Pa as

$$Q_{d,25} = C_d 25^{nd} \tag{21}$$

and the leakage from the ducts to inside at 25 Pa as

$$Q_{i,25} = C_i 25^{ni} \tag{22}$$

Field Test Results

The field tests were performed on nine homes, with each home having three configurations: supply-dominated leakage, nearly balanced leakage, and return-dominated leakage. We did not perform the modified blower door subtraction and add-a-hole tests on all site/configuration possibilities. There were a total of about twenty different site/configurations for these tests. For various reasons some tests were not completed for some of the site/configurations.

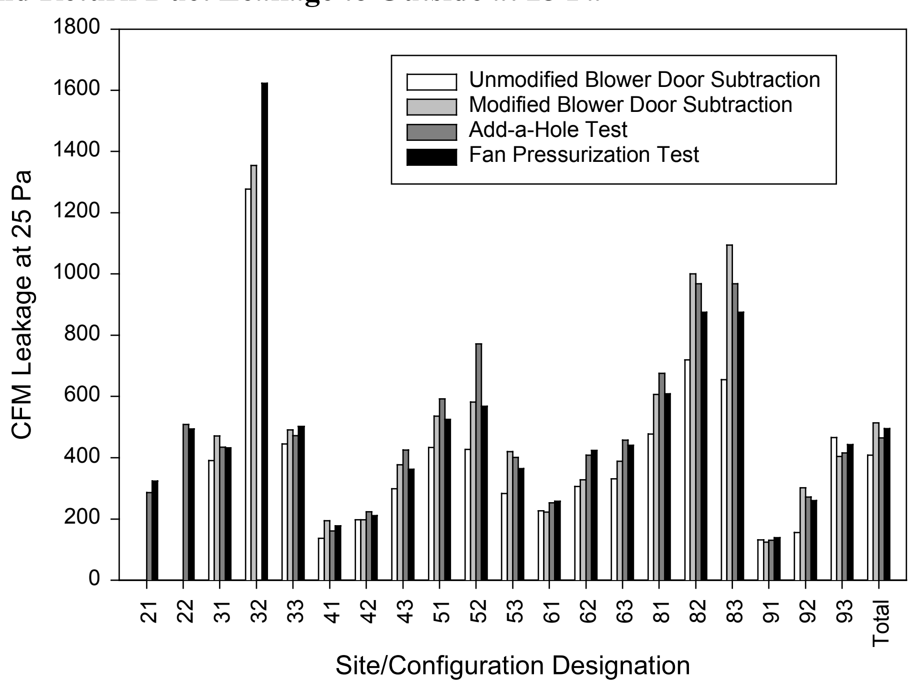
The combined supply and return duct leakage to outside at 25 Pa was calculated for the add-a-hole, unmodified blower door subtraction and modified blower door subtraction methods. Table 1 summarizes these results for the 17 cases in which all of the tests were performed. It also shows the bias and the root-mean-square deviation (RMS) for each of the blower door based methods when compared with the fan pressurization method. The unmodified blower door subtraction method shows a large negative bias of about 20% of the leakage. The modified blower door and add-a-hole methods show a smaller positive bias of about 5% of the leakage. The RMS error of the modified blower door test is noticeably more than that of the add-a-hole method despite the smaller bias of the former. This is partially due to the fact that two large numbers are being subtracted for the modified blower door test.

The test results are shown graphically in Fig. 3. The designation numbers refer to the site and configuration numbers for each test. As can be seen from the graph, the add-a-hole and modified subtraction methods both produce results fairly close to those from the fan pressurization tests. The unmodified blower door subtraction method underpredicts as expected.

Table 1. Comparison of Combined Supply and Return Duct Leakage to Outside at 25 Pa for Three Methods (CFM)

Test Method (n=17)	Mean	RMS from Fan Pressurization	Bias from Fan Pressurization
Fan Pressurization	439.2	--	--
Unmodified Blower Door Subtraction	357.4	101.3	-81.7
Modified Blower Door Subtraction	463.9	81.6	24.8
Add-a-Hole	472.1	66.7	33.0

Figure 3. Comparison of Unmodified Blower Door Subtraction, Modified Blower Door Subtraction, Add-a-Hole Test, and Fan Pressurization Test Predictions of Combined Supply and Return Duct Leakage to Outside at 25 Pa



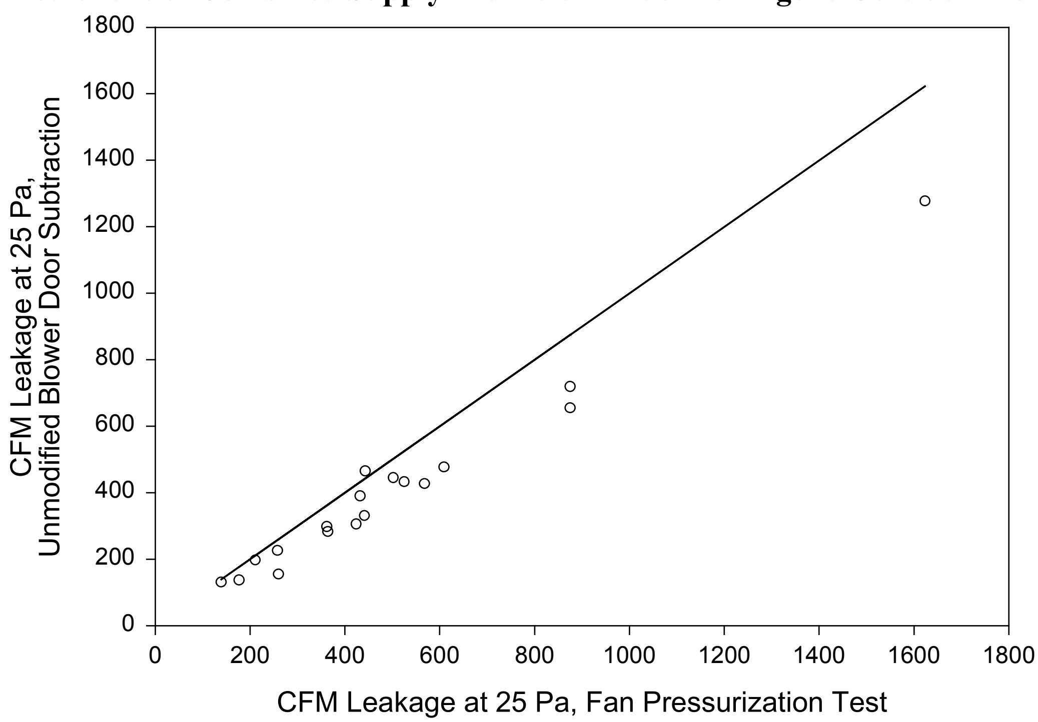
It is also useful to express the results in terms of percentage error relative to the fan pressurization tests. The median percentage error for the unmodified blower door subtraction method was -17.8%, for the modified blower door subtraction method it was 2.5% and for the add-a-hole method it was 5.2%. This shows that, on a percentage basis, both the modified subtraction and the add-a-hole method provide a significant improvement over the unmodified blower door subtraction method. As mentioned earlier, one of the criteria for selecting these test homes was low internal leakage (e.g., we excluded two-story homes which tend to have large portions of the duct system in the joist space separating the floors). As a result one would expect that the benefit of correcting the bias due to subtraction would be even greater in the general case than for the homes tested in this project.

Figure 4 is a scatter plot with a one-one line that plots the unmodified blower door subtraction method results versus the fan pressurization results. There is a fairly consistent percentage bias apparent.

Figure 5 shows a scatter plot of the add-a-hole test results for total leakage versus the fan pressurization results. The agreement is fairly good over the whole range of data.

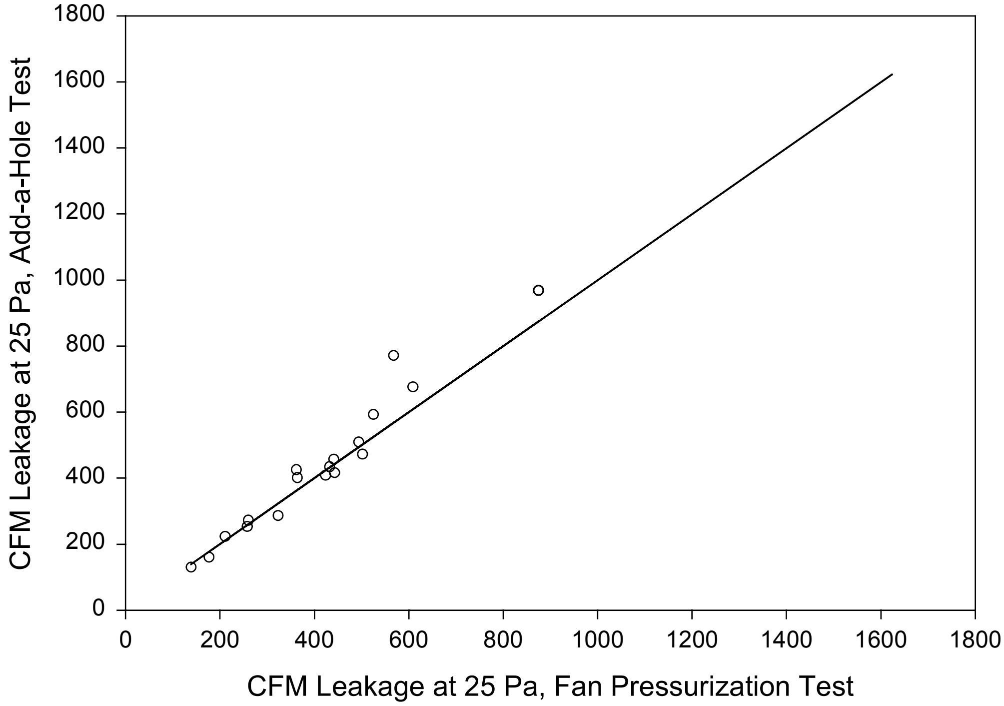
Figure 6 shows a scatter plot of the modified blower door subtraction method versus the fan pressurization results. Again there is fairly good agreement.

Figure 4. Comparison of Unmodified Blower Door Subtraction and Fan Pressurization Test Predictions of Combined Supply and Return Duct Leakage to Outside at 25 Pa



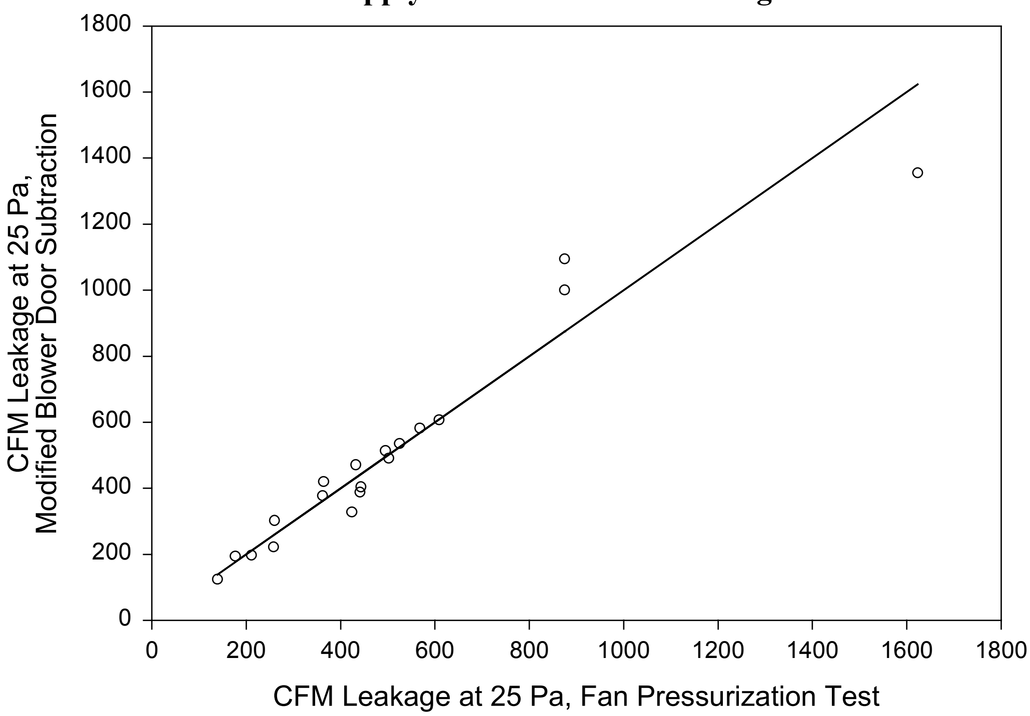
Note: the line indicates perfect agreement.

Figure 5. Comparison of Add-a-Hole Test and Fan Pressurization Test Predictions of Combined Supply and Return Duct Leakage to Outside at 25 Pa



Note: the line indicates perfect agreement.

Figure 6. Comparison of Modified Blower Door Subtraction and Fan Pressurization Test Predictions of Combined Supply and Return Duct Leakage to Outside at 25 Pa



Note: the line indicates perfect agreement.

The add-a-hole method produces separate values for the return and supply ducts, so it is of interest to compare those separately with the results from the duct blaster tests. Table 2 shows the numeric comparison of the add-a-hole method and the fan pressurization method for the separate supply and return leakage to outside at 25 Pa. There is a positive bias of about 15 cubic feet per minute (CFM) on both the supply and return sides. Both the bias and the RMS error are somewhat larger on the return side than on the supply side.

Figure 7 shows a bar chart of the add-a-hole duct leakage to outside for the supply ducts only with the fan pressurization results for comparison. There is fairly good agreement with the exception of configurations 81-83 (which were all at the same house), where the add-a-hole method is noticeably high. This one site contributes significantly to the small bias exhibited by the averages shown at the far right.

Table 2. Comparison of Add-a-Hole Method with Fan Pressurization for Separate Supply and Return Leakage to Outside at 25 Pa (CFM)

Test Method (n=19)	Mean	RMS from Fan Pressurization	Bias from Fan Pressurization
Fan Pressurization			
Supply	255.5	--	--
Return	179.4	--	--
Add-a-Hole			
Supply	268.6	35.8	13.1
Return	195.7	48.9	16.3

Figure 7. Comparison of Add-a-Hole Test and Fan Pressurization Test Predictions of Supply Duct Leakage to Outside at 25 Pa

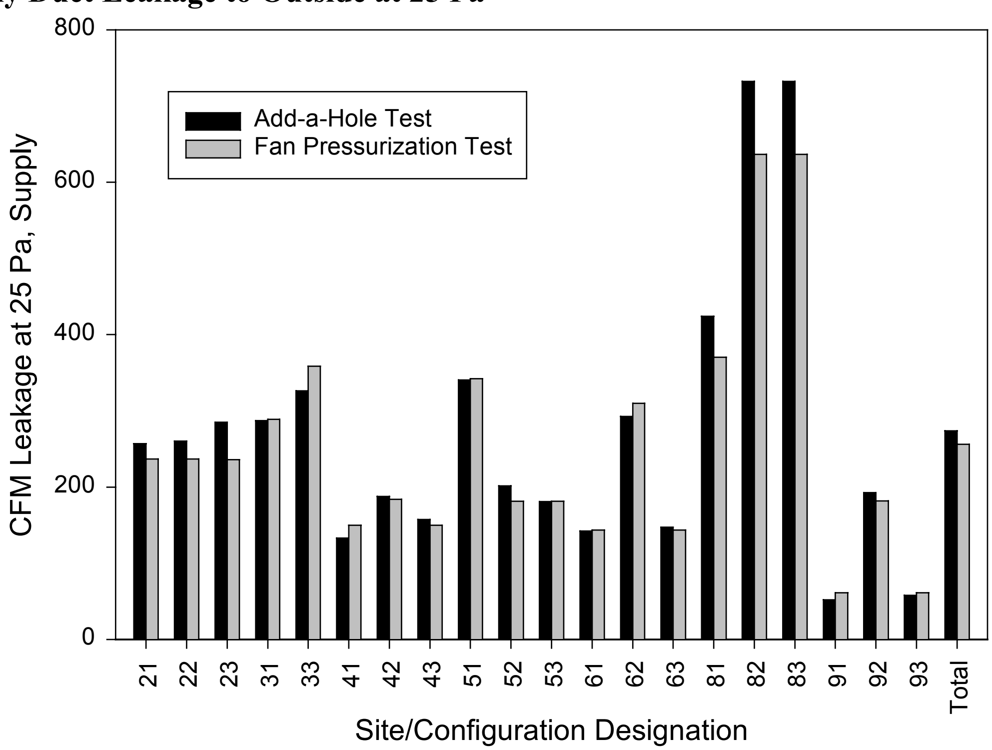
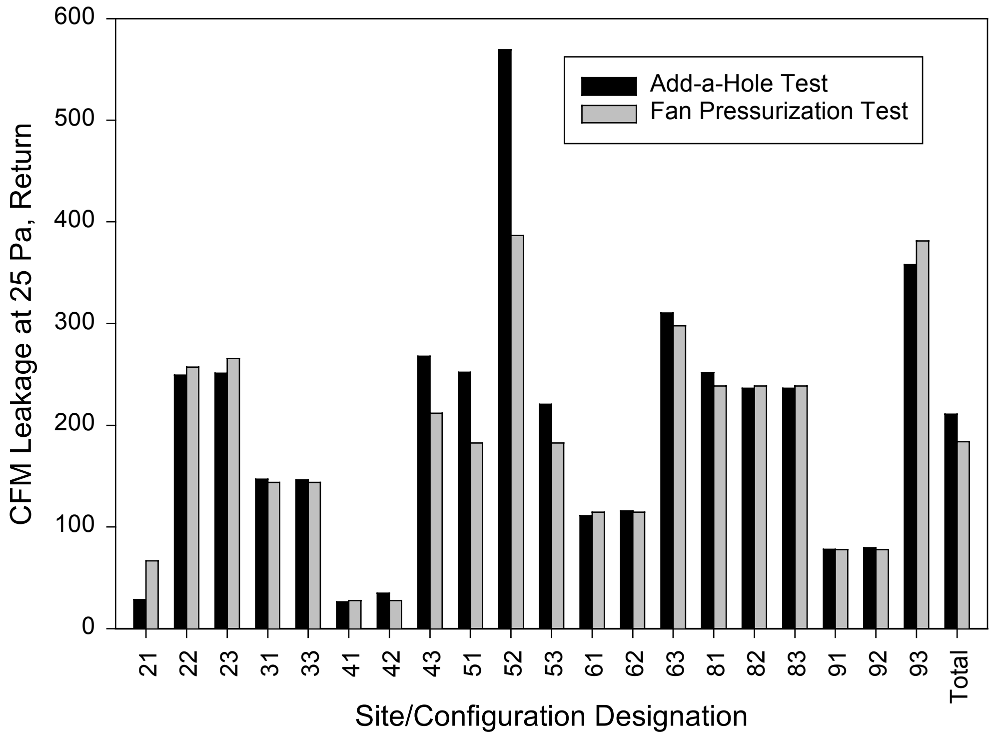


Figure 8 shows a bar chart of the add-a-hole method and the fan pressurization method for the return ducts only. There is a large discrepancy for configuration 52. The cause of this is not known.

Although not illustrated here, both tests also gave fairly good agreement with the fan pressurization tests for the internal duct leakage (leakage between the ducts and the house).

Figure 8. Comparison of Add-a-Hole Test and Fan Pressurization Test Predictions of Return Duct Leakage to Outside at 25 Pa



Summary and Conclusions

Both the add-hole and modified subtraction methods show promise where the goal is to measure duct leakage to outside at a given reference pressure. They share the drawback of the fan pressurization method in requiring an estimate of an appropriate "effective" duct-to-outside pressure difference if the goal is to estimate leakage at operating conditions. The add-a-hole method as performed here produces values separately for the return and supply ducts. This is important because, in most conditions, the thermal losses associated with supply leaks are significantly larger than those associated with return leaks of the same size.

References

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