HVAC Duct Air Leakage

Leakage is a function of the static pressure and the number and size of openings in the duct and is unaffected by airflow

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This article discusses the history of duct air leak testing and describes proper techniques and practical application when leak testing is performed in accordance with the Sheet Metal and Air Conditioning Contractors’ National Association (SMACNA) standards.

The “air tightness” of HVAC duct begins with the proper specification written by a design engineer. When proper methods of assembly and sealing are used, the total airflow should satisfy indoor air quality requirements. With the specification and well-trained contractors installing the ductwork, accessories and other components, the owner can be assured of a quality system meeting the specifications for occupant comfort and safety.

HISTORY


SMACNA research in 1972 showed that leakage was primarily a function of static pressure and the number and size of openings and not volume flow rate or velocity. This concept was included in subsequent SMACNA HVAC duct construction standards, High Pressure Duct Construction Standards 3rd Edition 1975,


It should be noted though that none of the SMACNA standards require duct air leakage testing by default. The designer is responsible to specify the amount of testing when the conditions justify the expense. Specifications must also specify the proper construction necessary for system performance. SMACNA encourages specifying seal class “A” which seal all joints, seams, and applicable penetrations.

RESEARCH

SMACNA and the American Iron and Steel Institute (AISI) performed a study called “Measurement and Analysis of Leakage Rate from Seams and Joints of Air Handling Systems”, 20 April 1972. Leakage rates were determined with and without airflow. With flow, velocities up to 2000 fpm were established. Static pressures up to 3 inches w.c. were tested. The leakage rates with and without airflow were virtually the same which essentially means that leakage was not a function of airflow or velocity.

It was thought that the leakage rate would follow a square root of static pressure equation as given by Equation 1 with N = 0.50. Leakage is a function of the static pressure and the number and size of openings in the duct. The number of openings were identified as seams and corners and were a function of the quality of the joint. However, the effective leakage area may be increased by the stress applied to the seams and joints as the static pressure is increased which causes the exponent in the equation representing the leakage to be greater than 0.50.

\[
Q = K P^N
\]

where:
- \( Q \) = leakage rate, cfm/ft²
- \( P \) = static pressure of the test duct, inches w.c.
- \( N \) = exponent
- \( K \) = constant based on the components being tested

SMACNA initiated a joint research project with the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc (ASHRAE) and the Thermal Insulation Manufacturers Association (TIMA) of which part of the objective and scope was to measure leakage of typical duct construction (ETL Report No. 459507. “Investigation of Duct Leakage”, 1985). The scope of tests included fibrous glass ducts, sealed and unsealed rectangular ducts round duct and flexible ducts fabricated to SMACNA standards.

Using Equation 1 as the basis, the research determined values for the exponent \( N \) were between 0.50 to 0.93. SMACNA determined, within acceptable tolerances, a duct surface area leakage factor identified by Equation 2, with an average exponent \( N \) of 0.65, and published the Equation in their 1985 HVAC Air Duct Leakage Test Manual. The equation for predicting and specifying the duct leakage under test conditions, became identifiable by Equation 2.
\[
F = C_L P^{0.65} \quad \text{Equation 2}
\]

where:
- \(F\) = leakage rate, cfm/100 ft\(^2\)
- \(P\) = static pressure of the test duct, inches w.c.
- \(N = 0.65\) for duct
- \(C_L\) = leakage class

**LEAKAGE CLASS**

Equation 2 correlates duct air leakage to duct surface area and static pressure. It does not account for the other system components such as fire dampers, VAV boxes, other dampers, control penetrations etc.

It has already been established that leakage is not a function of the amount of airflow, it is a function of the static pressure the duct will see and the number of openings (from the joints, seams and other penetrations.) So, a 10,000-cfm system would leak as much as a 100,000-cfm system operating at the same static pressure with the same number and size of the openings (seams, joints etc.).

For the same airflow and operating pressure, one would expect the leakage to double if the surface area doubled. For example, if we have a 10,000-cfm system, operating at 2 inches w.c., with 2000 ft\(^2\) of duct surface area, with a Leakage Class of 4, the expected leakage is 126 cfm. If nothing changes but the duct surface area becomes 4000 ft\(^2\), the expected leakage is about 252 cfm.

The leakage classification identifies a permissible leakage rate in cfm per 100 square feet. Solving for leakage class from Equation 2

\[
C_L = \frac{F}{P^{0.65}} \quad \text{Equation 3}
\]

Leakage class can be calculated using Equation 3 but needs to be specified if duct air leakage tests are required. Figure 5-1L from the 2012 SMACNA HVAC Air Duct Leakage Test Manual shows the allowable leakage as a function of Duct Leakage Classification and static pressure in the duct.
Why use a leakage class? It:
- Allows for consistent requirements for any part of the duct
- Adjusts for pressure
- Matches the research
- Matches what is in energy codes/standards

The leakage class was developed by testing ductwork and does not include other components therefore it would be incorrect to include those as part of a leakage test based solely on leakage class ratings for duct.

FIGURE 5-1L DUCT LEAKAGE CLASSIFICATION
OPERATING PRESSURE
There are a couple of other major points the designer must remember. The fan operating pressure is the static pressure at the fan outlet (or inlet for return or exhaust systems). It is highest in magnitude at the fan and decreases as air propagates through the system to the terminal device where it returns to the room static pressure (assumed to be 0.00-inch w.c.). So even though the test pressure may be the fan outlet (or inlet) static pressure, the only place the ductwork sees that pressure is at the fan and on a variable speed fan it would only see these conditions a few hours a year. Halfway through the system it may be half or less and on the low-pressure side of a VAV box, it may only be 0.10-inch w.c. or less.

To demonstrate how the potential for leakage in low pressure duct is small, let’s assume that low pressure rectangular ductwork downstream of a VAV box is not sealed, which corresponds to a leakage class of 48. The static pressure under operating conditions is expected to be 0.1 inches w.c. For a duct section consisting of 20 ft of 8” x 8” rectangular duct downstream of the box. The leakage would be:

\[
F = 48 \times (0.1)^{0.65} = 10.7 \text{ cfm/100 ft.}
\]
\[
\text{Surface area} = 20 \text{ ft} \times 2 \times (8/12 + 8/12) \text{ ft} = 53.3 \text{ ft}^2
\]
\[
\text{Leakage} = 10.7 \times 53.3/100 = 5.7 \text{ cfm}
\]

A very low amount, even though its unsealed.

Now if the low-pressure duct work has a leakage class of 4 for a Seal Class A, the leakage rate becomes:

\[
F = 4 \times (0.1)^{0.65} = 0.9 \text{ cfm}
\]
\[
\text{Leakage} = 0.9 \times 53.3/100 = 0.5 \text{ cfm}.
\]

If the low-pressure duct was sealed to a Seal Class A or even a B or a C Seal class, it would not be economical to expend the money to perform a leakage test on it. Unsealed duct would only leak 5 cfm, while sealed duct (even Seal Class C) would make the difference even more trivial. Table 5-1 from the SMACNA 2012 HVAC Leakage Test Manual shows the recommended Leakage Class.

<table>
<thead>
<tr>
<th>Duct Class</th>
<th>½ in., 1 in., 2 in. wg</th>
<th>3 in. wg</th>
<th>4 in., 6 in., 10 in. wg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal Class</td>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Sealing Applicable</td>
<td>Transverse Joints Only</td>
<td>Transverse Joints and Seams</td>
<td>Joints, Seams and all Applicable Wall Penetrations</td>
</tr>
<tr>
<td>Leakage Class</td>
<td>16</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Rectangular Metal</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Round Metal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5-1 Recommended Leakage Classes

For our example with a Seal Class of C for the low-pressure duct, the leakage would be about 2 cfm. Thus, it is not worth the cost of testing the low-pressure duct for leakage.

For the high-pressure ductwork, the designer must understand that an operating static pressure of 2 inches w.c. at the fan outlet, may only average 1-inch w.c. static pressure up to the terminal boxes. This means testing the entire system at 2 inches w.c. adds a factor of safety to the measured leakage. That is, at actual operating pressures in each section of duct, the leakage would be much less than the measured
values. That is also why testing low pressure ductwork, where the static pressure is well below 3 inches w.c. is seldom practical.

VAV systems operate at part load most of the time resulting in even lower static pressures. With the right design, static pressure setback, and economizers, today's ductwork designs may only be seeing 60% or less of the design static pressure for most of the year! Designers must account for the static pressure loss in a duct system and the actual operating conditions of a VAV system when evaluating the cost effectiveness of leakage testing.

Low leakage rates are just parts of the benefits of designing a high-performance air systems with low operating static pressures for VAV systems. These can be achieved with larger duct sizes that keep the system operating static pressures low at the fan outlet and in all duct sections.

BUILDING CODES
Most building codes and standards may require 25% of the duct surface area to be tested for or static pressures greater than 3 inches w.c. Documentation must be furnished by the designer demonstrating that representative sections total at least 25% of the duct area has been tested and that all tested sections comply with the requirements of this section. SMACNA encourages specifying $C_L = 4$ for all duct with a Seal Class A per the SMACNA 2005 HVAC Duct Construction Standards as sealing duct reduces leakage.

SUMMARY
Designers should consider whether the cost to perform leakage test is warranted remembering that, the actual static pressure the ductwork will see will likely be much less than the fan outlet static pressure and VAV systems may only be operating at 60% of capacity most of the year.

Airflow leakage is a function of the pressure in the duct system and the number and size of openings (seams, connections, penetration, etc.). It is logical to base leakage on pressure and the leakage class (see Equation 2) which accounts for surface area and better correlates the number and size of openings in the system.

Finally, a properly written leakage testing specification includes:

- The quantity (surface area) of duct to be tested
- The test parameters (test static pressure)
- The pass/fail criteria expressed as a leakage class not as a percent to design flow.

Proper specifications also avoid requiring work that conflicts with local codes and ordinances, manufacturer's instructions and products listing. HVAC systems are never perfectly leak free and that should never be part of a system specification for leakage.

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References


