The Current (2017) ***State of the Art*** for Air Leakage in Ductwork

Over the last ten years there has been a major shift in the way ASHRAE has approached air leakage in ductwork. This is reflected in the latest editions (as well has previous editions) of the ASHRAE Handbooks (2016, 2017)[1,2], along with ASHRAE Standard 90.1[3].

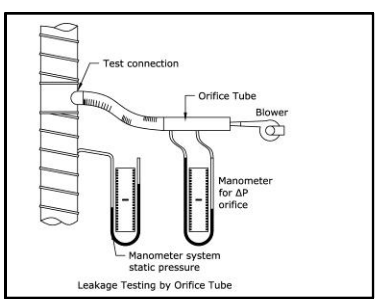
Background

It was reported by the Associated Air Balance Council (AABC)[4] that a major manufacturer of ductwork "maintains that a quality fabricated duct system, properly installed and sealed, can achieve [air] leakage rates as low as ½ of 1%."

The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) states in section 2.9 of their HVAC Systems Duct Design Manual[5] that "one percent air leakage rate for large HVAC duct systems is almost impossible to attain, and a large unsealed duct systems may develop [air] leakage well above 30% of the total system airflow."

Spiral duct manufacturers (at last count as many as 15) have been providing self-sealing gaskets meeting Leakage Class 3 requirements for many years. ASHRAE states in their Handbook (2016)[1] that Leakage Class 3 is equivalent to a range of 0.4% to 6.7% air leakage of system airflow at static pressures ranging from 0.5 to 10 inch water gauge; the range (0.4% – 6.7% air leakage) is dependent on the actual test pressure and fan cfm prorated per square feet of duct surface area.

The industry accepted method of air leakage testing is well documented by the SMACNA HVAC Air Duct Leakage Test Manual[6] and AABC's National Standards for Total System Balance[7]. The procedure is to partition off a section of ductwork, use a blower to pressurize the ductwork, and a calibrated orifice plate to measure the airflow (illustrated below) into the isolated ductwork and hence, the air leakage out of the sealed section of duct. Duct-mounted equipment (terminal units, access doors, coils, fire dampers) are isolated during the test.

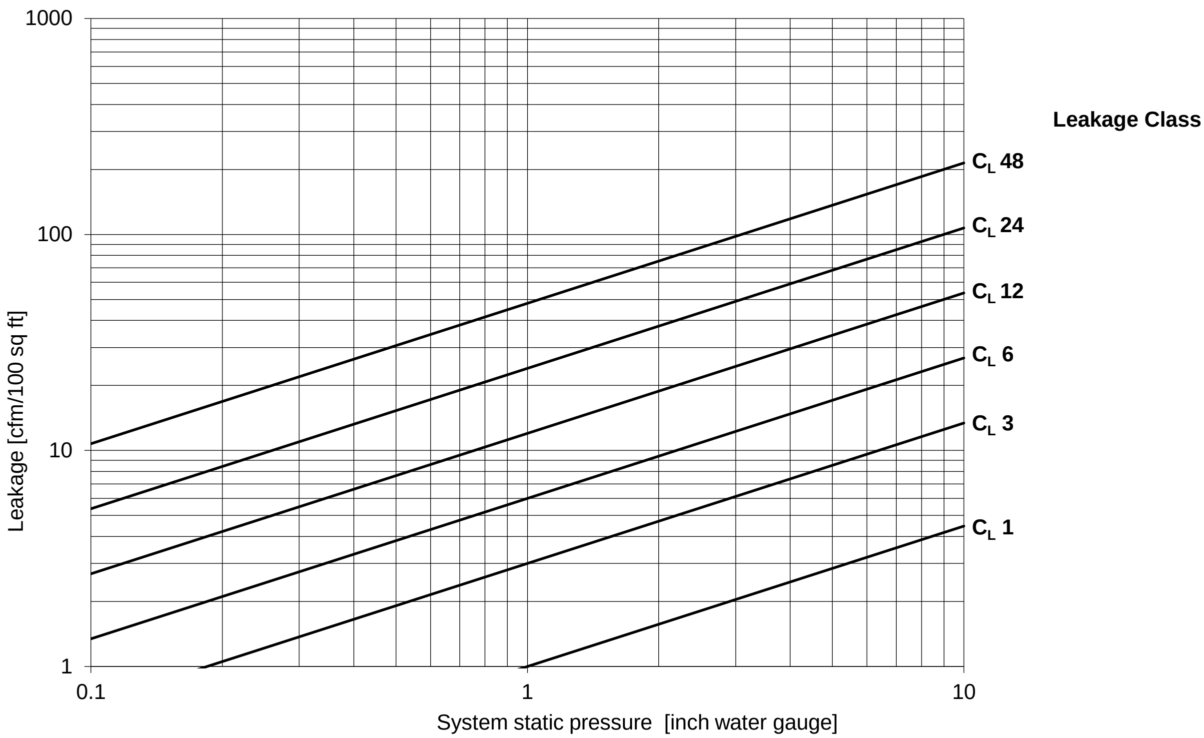


The Leakage Class (C_L) is determined using the following formula:

$$C_L = \frac{Q}{A\,p^{0.65}}$$

C_L = Leakage Class, cfm per (inch water gauge)$^{0.65}$ per 100 ft^2 of duct surface area
Q = air leakage, cfm
P = system static pressure, inch water gauge
A = 100 square feet of surface area of duct tested, 100 x ft^2

Leakage data can also be plotted on the following graph to determine leakage class or calculated directly from the above formula.



ASHRAE Standard 90.1 requires air leakage testing of 100% of all outside ductwork and 25% of representative sections of all other ductwork designed to operate at a static pressure in excess of 3 inch water gauge. There are no requirements in ASHRAE Standard 90.1 for air leakage testing in systems designed to operate at 3 inch water gauge and lower unless it is located outdoors. The required Leakage Class is stated as 6 for rectangular and 3 for round/flat oval ductwork. Earlier versions read basically the same, however, they did not require testing the outside ductwork.

It has become a generally accepted industry practice, as a pass/fail criteria, that ductwork sealed to a Seal Class A, B, or C is expected to achieve a Leakage Class under actual field conditions according to the following table:

Seal Class	Sealing Required	Static Pressure Construction Class
A	All transverse joints, longitudinal seams, and duct wall penetrations	4” w.g. and up
B	All transverse joints and longitudinal seams	3” w.g.
C	Transverse joints	2” w.g.

Source: SMACNA Technical Paper on Duct Leakage[8]

Where the applicable Leakage Class is cross-referenced as follows:

	Leakage Class		
Seal Class	**C**	**B**	**A**
Rectangular	24	12	6
Round & Flat Oval	12	6	3

Source: SMACNA Technical Paper on Duct Leakage

In addition, the SMACNA Technical Paper on Duct Leakage states “analysis of the available data allows for the estimation of a Leakage Class corresponding to a given Seal Class for both round and rectangular ductwork […] predictions are based on test research averages using SMACNA’s standards for construction and skilled, trained workers.”

The above tables have been modified (in the writers opinion arbitrarily as there is no research supporting the changes) by the more current SMACNA HVAC Air Leakage Test Manual[6] with the Seal Class for the corresponding Leakage Class A, B, and C changing from 24, 12, and 6 to 16, 8, and 4 respectively for rectangular and from 12, 6, and 3 to 8, 4, and 2 respectively for round/flat oval. SMACNA’s HVAC Air Duct Leakage Test Manual[6] commentary found in section 5.1 states, “Table 5-1 is the basis of evaluating duct conforming to the SMACNA duct construction standards unless a specifier gives other limits.”

A major shift

ASHRAE changed the Leakage Class in their Standard 90.1 from 6 and 3 for rectangular and round/flat oval respectively, to Leakage Class 4 for both rectangular and round/flat oval ductwork; all duct systems now have the same acceptance criteria. In addition, only Seal Class A is now recognized for all HVAC duct systems. Ductwork air leakage testing is required for no less than 25% of the installed ductwork surface area for all systems operating in excess of 3 inch water gauge and 100% of the ductwork located outdoors.

It is interesting to note that with all ductwork now having the same Leakage Class requirement it is permissible to have more air leakage from rectangular ductwork than round ductwork. For example, 24 inch diameter round duct has a surface area of 6.28 square feet per linear foot of duct and an equivalent size rectangular duct with an aspect ratio of 3:1 38% more surface area;

for a 2:1 aspect ratio 19% more. The allowed air leakage is directly related to the exposed surface area of the duct!

In addition, due to ASHRAE Standard 90.1 limiting fan horse power (Section 6.5.3.1), it is rare to encounter a system operating in excess of 3 inch water gauge; and therefore, there is no mandate to perform duct air leakage testing in the majority of ductwork systems.

Prior to the 2017 edition of the ASHRAE Handbook, a similar table as shown in SMACNA's Technical Paper on Duct Leakage[8], compares sealed ductwork to "Predicted Leakage Class". By footnote the predicted leakage classes assumes all transverse joints, seams, and opening in the duct wall are sealed (same as SMACNA Seal Class A) and "Leakage classes … are averages based on tests conducted by AISI/SMACNA[9], ASHRAE/SMACNA/TIMA[10], and Swim & Griggs[11]." The writer, after a careful review of the referenced documents, concluded that the referenced research does not try to, nor provides, any correlation between "Leakage Class" and "Seal Class". It is also interesting to note that "workmanship appears to be the only major factor in variation of leakage rates" is one of the conclusions of the AISI/SMACNA[9] report.

As there is no research to correlate "Seal Class" and "Leakage Class", it is obvious that conducting air leakage testing is required if the actual field installed Leakage Class of the ductwork needs to be determined.

The ASHRAE Handbook (2013, 2017) has removed the above referenced table relating Seal Class to Leakage Class and is also moving from *predicting* ductwork air leakage to *operating system air leakage.*

The ASHRAE Handbook (2016) contains an extensive commentary regarding a major shift in direction from leak testing ductwork to system air leakage testing. The ductwork system includes the air handler, ductwork, and all duct mounted components; not just the ductwork! In addition, testing would be required to meet a maximum system airflow percent leakage at operating pressure versus a Leakage Class which is independent of both flow and operating system pressure. This is supported by credible published research and the adverse economic impact of system air leakage on energy costs. The recommended maximum system air leakage percentages are found in the ASHRAE Handbook (2016) and range between 1% and 5% of the total system design airflow at operating pressure.

The ASHRAE Handbook (2016) elaborates on the responsibilities of the engineer, sheet metal contractor, and the testing contractor. Most importantly noted is that the engineer is responsible, in addition to other requirements, to "specify HVAC system components, duct mounted equipment, accessories, sealants, and sealing procedures that together will meet the system airtightness design objectives."

The ASHRAE Handbook (2017) builds on the previous work of the ASHRAE Handbook (2016) and expands the scope to include a recommendation to test 100% of supply air (both upstream and downstream of the VAV box primary inlet damper when used), return air, and exhaust air after construction at operating conditions. This is in addition to testing at least 25% of all the ductwork during construction. The final testing after construction at operating conditions is required to ensure that good workmanship was performed and low air leakage components were used.

The ASHRAE Handbook (2017) also includes recommended specifications for low leakage duct mounted components and expands on the roles and responsibilities of the engineer, sheet metal contractor, and testing contractor as previously mentioned in the ASHRAE Handbook (2016)[1].

What is the economic impact of system air leakage?

The ASHRAE Handbook (2016) states a "leaky VAV system (10% leakage upstream and 10% downstream of terminal box inlet dampers at operating conditions) uses 25-35% more fan energy than a tight system (2.5% upstream and 2.5% downstream at operating conditions)." For each 100 shaft horse power of fan energy running 24/7 equates to $22,840 wasted energy per year assuming energy cost is $0.10/kWh. Obviously this number is higher when the fan efficiency, fan belt drive efficiency, motor/VFD efficiency, and power factor are considered.

Duct air leakage, as reported by Roth et al[12] ranks air duct leakage as the #1 cause of energy inefficiencies in commercial building. Furthermore, Roth[12] reports that 30% of the estimate of 1.0 Quad of annual energy wasted in the United States is due to duct air leakage. This equates to approximately $2.9 billion per year in wasted energy.

What is required by the code?

SMACNA's Air Duct Leakage Test Manual[6] clearly states that "specifications that read test per SMACNA or similar are invalid" and that "no leakage tests are require by the SMACNA HVAC Duct Construction Standards or by this test manual."

ASHRAE's Handbooks (2016, 2017) give clear and concise direction for the allowable air leakage for ductwork systems (as a percentage of design system airflow), the required test pressure, how much and which systems to test. These requirements are neither mandatory nor required by any applicable codes. However, there is economic justification to substantiate testing. Testing ultimately verifies the quality control exercised by the installing contractor and saves energy.

Outside of any standards and/or regulatory requirements to properly seal and test ductwork systems for air leakage over the last several years, the writer has seen:

1. An increased frequency of specifications requiring 25% to 100% of the *ductwork systems* (including access doors, volume dampers, relief air doors, smoke dampers, fire dampers, fire smoke dampers, and end caps used to seal ducts) to be tested;
2. Specifying air leakage rates not to exceed 5% (sometimes as low as 2.5%) of system design air quantity with test pressures equal to duct pressure class; and
3. Testing to include 10% of the ductwork downstream of the air terminal units to be tested.

What is next?

The ASHRAE technical committee for duct design (TC 5.2) is working to put in place the research that will justify the economics of field testing along with new test procedures and methods for system air leakage testing on operating systems. The ultimate goal is to amend ASHRAE Standard 90.1 which will then be incorporated into the energy codes.

Currently under development (publication expected in 2018) is ASHRAE Standard Project Committee (SPC) 215P; a standard that will provide an important step forward in defining a practical field test for system air leakage at operating conditions. This will provide ASHRAE 90.1 (and other energy codes) with a test procedure that can be referenced or incorporated into the system air leakage concept.

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