# The Current (2021) ***State of the Art*** for Air Leakage in Ductwork

This is the 8th revision of a white paper that I originally authored over twelve (12) years ago under the title "*Duct Leakage White Paper.*" As the engineering manager for Linx Industries (a division of Ductmate Industries and formerly Lindab, USA) and an active member of ASHRAE Technical Committee 5.2 (Duct Design), I have a passion for the advancement of technical knowledge as it pertains to air leakage in ductwork.

This version is 8-pages long and 3,400 words in length; however, if you are a design professional responsible for designing HVAC air delivery systems, I trust you will find the words worth your time.

I would be remiss if I did not give credit to the following professionals whom I have had the privilege to learn from their work and research in the pursuit of more energy efficient air delivery systems:

1. Herman Behls, P.E., ASHRAE College of Fellows, author of the ASHRAE Duct Systems Design Guide and founding father of the ASHRAE Duct Fitting Database
2. Dr. Stephen Idem, Ph.D. – Professor, Department of Mechanical Engineering, Tennessee Tech University, contributing author of the ASHRAE Duct Design Guide and principal investigator for many ASHRAE research projects involving duct design
3. Dr. Mark Modera – Professor, University of California, Berkeley, ASHRAE member and author of many articles and research on air leakage in ductwork systems
4. Craig P. Wray, P.Eng. – ASHRAE member, formerly from Berkeley National Laboratory and author of many articles/research on air leakage in ductwork systems
5. Dr. Alexander Zhivov, PhD (US Army ERDC), ASHRAE member and author for the US Army Corp of Engineers IEA Deep Energy Retrofit Design Guide

**Background**

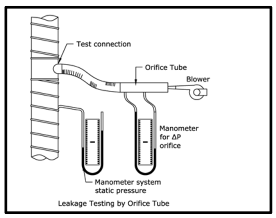
The ASHRAE Duct Design Committee (Technical Committee TC5.2) over fifteen (15) years ago made a major shift in the approach to air leakage in ductwork. This started after the 1999 and 2005 versions of the ASHRAE Handbooks[1,2] along with the current version of ASHRAE Standard 90.1[3].

It was reported by the TAB Journal, the magazine of the Associated Air Balance Council[4] in 2011 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% [of the design airflow]*." The article further states: "*SMACNA D.A.L.T. [Duct Air Leakage Test] Method being applied [leakage class versus % of design airflow]…benefits the mechanical contractor by allowing a higher rate of leakage on the ductwork he installs*." A comparison is also given that a 10% air leakage will increase the fan energy cost by 28% annually.

The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) states on page 2.6 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 24) have been providing self-sealing gaskets meeting Leakage Class 3 requirements for many years. ASHRAE states in their Handbook[2] (page 19.6, Table 5) 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) is isolated during the test.

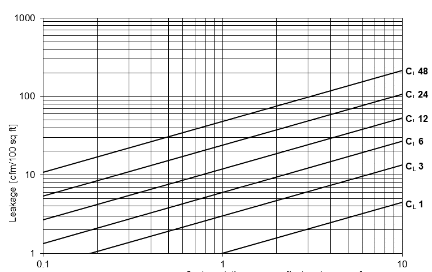



The Leakage Class ($C_L$) is determined using the following formula:

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

$C_L$ = 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.




**$C_L$ = Leakage Class**

ASHRAE Standard 90.1[3] (section 6.4.4.2.2) 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[3] for air leakage testing in systems designed to operate at 3-inch water gauge or less unless it is located outdoors. The required Leakage Class is stated as 4 for all ductwork. Earlier versions read similarly; however, they did not require testing the outside ductwork. In addition, all ductwork is required to meet seal class A (section 6.4.4.2.1).

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 certain Leakage Class under actual field conditions according to the following SMACNA tables:

**Table 1**

| 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[6]

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

**Table 2**

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

Source: SMACNA Technical Paper on Duct Leakage[6]

In addition, the SMACNA Technical Paper on Duct Leakage[6] states on page 3: "*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 changed by the more current SMACNA HVAC Air Leakage Test Manual[6] (Table 5-1) 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 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 the current version of Standard 90.1[3] 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 more than 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. Using a leakage Class criteria, the allowed air leakage is directly related to the exposed surface area of the duct!

In addition, due to ASHRAE Standard 90.1[3] limiting fan horsepower (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 energy code mandate to perform duct air leakage testing in the majority of ductwork systems.

In the 2005 and prior editions of the ASHRAE Handbook[1] Table 6, 7, 8A, and 8B are presented which is similar to the above SMACNA Tables as shown in SMACNA's Technical Paper on Duct Leakage[6]. The 2005 ASHRAE Handbook[1] references the leakage classes listed *".... are averages based on tests conducted by AISI/SMACNA (1972)[9], ASHRAE/SMACNA/TIMA (1985)[10], and Swim and Griggs (1995)[11].*" Two (2) of the three (3) references are ASHRAE research projects RP-308 (1985)[10] and RP-447 (1995)[11] respectively; the remaining was a AISI/SMACNA (1972)[9] report (AISI stands for the American Iron and Steel Institute).

By examining the research, it appears that simply specifying seal class A is insufficient to achieve leakage class ≤4; one needs to be more specific about the joint configuration, the sealant, and sealant application quality.

ASHRAE RP-447[11] states in the conclusions: ".... *leakage can be predicted, but the leakage rate will be strongly a function of the fit achieved for the sheet metal seams and joints. This fit will be controlled by both the shop fabrication of the sheet metal elements as well as the quality of the joint and seam makeup during erecting of the ductwork."*

Since the 1999 and 2005 versions of the ASHRAE Handbooks[1,2], the correlation between Seal Class to Leakage Class has been removed and an emphasis has been made from <u>predicting</u> ductwork air leakage to testing operating system air leakage.

The current ASHRAE Handbooks[1,2] contain an extensive commentary (dating back to the 2013 edition) 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 with the adverse economic impact of system air leakage on energy costs. The recommended maximum system air leakage percentages are found in the ASHRAE Handbook[2] with range between 1% and 5% of the total system design airflow at operating pressure.

The ASHRAE Handbooks[1,2]

1. Elaborate 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*."

2. Build on the previous work and expand 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 using ASHRAE Standard 215[12].
3. Include commentary to test at least 25% of all the ductwork during construction using a pressurization test. Final testing after construction at operating conditions is required to ensure that good workmanship was performed, and low air leakage components were used.
4. Include recommended specifications for low leakage duct mounted components and expands on the roles and responsibilities of the engineer, sheet metal contractor, and testing contractor.

**What is the economic impact of system air leakage?**
The ASHRAE Handbook[2] states: "*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)*." Each 100-shaft horsepower 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.[13], ranks air duct leakage as the #1 cause of energy inefficiencies in commercial building. Furthermore, Roth[13] 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 in 2005 dollars [$4 billion in 2021 dollars] per year in wasted energy.

**What is required by the code?**
SMACNA's Air Duct Leakage Test Manual[7] clearly states that "*specifications that read test per SMACNA or similar are invalid" and that "no leakage tests are required by the SMACNA HVAC Duct Construction Standards[14] or by this test manual.*"

ASHRAE's Handbooks[1,2] give clear and concise direction for the allowable air leakage for ductwork systems as a percentage of design system airflow, the required test pressure, and 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 the building owner significant monies on an annual basis.

Outside of any standards and/or regulatory requirements to properly seal and test ductwork systems for air leakage over the years, this writer has observed:
1. Increasing 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 design pressure class, and
3. Testing to include 10% of the ductwork downstream of the air terminal units.

**What has happened since the last revision of this white paper?**
ANSI/ASHRAE/IES Standard 215[12] was just reaffirmed in 2021. This Standard provides an important step forward in defining a practical field test for system air leakage at operating conditions. This will provide ASHRAE 90.1[3] and other energy codes with a test procedure that can be referenced or incorporated into the system air leakage concept.

Published in 2020 by the US Army Corp of Engineer[15], Annex H-6, authored by Dr. Alexander Zhivov, Herman Behls, P.E., Craig P. Wray, P.Eng., Larry A. Smith, P.E., and Lars-Ake Mattsson, several interesting points are discussed:

1. "*…HVAC system air leakage, which is ranked as the primary source of energy inefficiencies in commercial buildings, wasted an estimated $2.9 billion in 2005*."
2. A recommendation is made to obtain an equivalent of European air tightness Class C which equates to an ASHRAE air leakage class of 2.1 or a maximum air leakage of 4.5% of the design airflow.
3. It is recommended to use ANSI/ASHRAE/IES Standard 215 to test the installed duct work systems for compliance with the specified low air leakage requirements.

ANSI/SMACNA HVAC Air Duct Leakage Test Manual[7] 2nd edition has been published. Below is a brief summary of the writer's observations:

1. Table 2-1 contains duct sealing requirements to class A, B, and C depending on the pressure class. This conflicts with ASHRAE 90.1[3] and the ASHRAE Handbooks[1,2] calling for Class A regardless of the duct pressure class.
2. Section 2.5.1 states: "*The need to verify leakage control by field testing is not present when adequate methods of assembly and sealing are used.*" This conflicts with the leakage testing requirements of ASHRAE 90.1[3] and the ASHRAE Handbooks[1,2] for ductwork located outdoors and interior ductwork operating at a pressure greater than 3-iwg.
3. Section 2.5.1 makes a statement: "*The mere presence of sealant at a connection, however, is not an assurance of low [air] leakage.*" I may be accused of taking this statement out of context; however, I do agree!
4. Under section 3.1.d Designer's Responsibilities state: "*not to assign [air] leakage as a percent of [design] flow."* This conflicts with the current ASHRAE Handbooks[1,2].
5. Table 5-1 assigns applicable leakage classes ranging from 16 to 4 for rectangular duct depending on the pressure class and seal class. The corresponding round duct is listed at 50% of the rectangular value.
    a. No leakage class is assigned to flat oval. ASHRAE 90.1[3] recognizes a leakage class 4 regardless of the duct geometry; however, only applies for pressure class greater than 3 iwg.
    b. There is no known research that supports any correlation between seal class and leakage class as currently reflected in the ASHRAE Hanbooks[1,2].

SMACNA System Air Leakage Test Standard[16] has been published.

1. This Standard is not ANSI approved.
2. Section 1.9 misrepresents ASHRAE Standard 215 (not directly by name) as a valid method of test. Section 2.7 of the ASHRAE Standard 215[11] test states: "*This standard does not replace ductwork pressurization leakage testing*."
3. Section 1.10.1 misrepresents that the industry (I would have to assume that ASHRAE is a part of the industry) incorrectly recognizes duct leakage by using a percentage of measured leakage against the design airflow of a system. The simple fact is that the HVAC system energy consumption is directly impacted on system air leakage as a percentage of design airflow; refer to the full commentary in the ASHRAE Handbooks[1,2].

**What is next?**

Fifteen years ago, I was visiting our Linx sales representative in St. Louis and was told we just lost a large order to a competitor with our self-sealing ductwork. We visited the contractor, and before we sat down, the contractor told us he would never buy the competitors self-sealing gasket! It appears the engineer required ductwork air leakage testing and they had to seal all the round ductwork (purchased with a self-sealing gasket) and change their manufacturing process for the rectangular to comply with the specified air leakage limitation.

We left the contractor's office and visited the engineer of record. The engineer stated that he was aware that leaky air distribution systems would increase his customers' annual energy expense. He continued that construction job site issues would arise when ductwork air leakage testing was actually required! This requirement was only used for customers with which he had a good relationship.

You need to ask yourself:

1. Who cares about air leaks in ductwork?
2. Who is responsible to prevent air leaks in ductwork?
3. Who is paying the construction and commissioning cost?
4. Who is paying the monthly energy bill?
5. What role will you play as the engineer of record?
6. How will you validate you are getting what you want?

The ASHRAE Handbooks and Standards are the embodiment of the available technical expertise and considered the standard of care for a professional engineer. In my opinion, it is uncensored, unbiased, and based on the art and science of the HVAC industry.

<u>As a professional engineer, what is next, is up to you!</u>

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**About the author:**

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