HVAC AIR DUCT LEAKAGE TEST MANUAL

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Inch-Pound Version

SHEET METAL AND AIR CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC.
www.smacna.org

HVAC AIR DUCT
LEAKAGE TEST MANUAL

SECOND EDITION – 2012

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FOREWORD

SMACNA first published a procedure for leakage testing of so-called medium and high pressure ductwork since January 1965. It appeared in Chapter 10 of the high velocity (later high pressure) construction standards and in Chapter 8 of the "*Balancing and Adjustment of Air Distribution Systems Manual*" of 1967 vintage. In the 1970's energy conservation measures led to a decline in the use of truly high pressure commercial HVAC systems. Now, greater concern with the amount of leakage in systems of less pressure has evolved from the efforts of reducing carbon via energy saving strategies.

New research in the leakage rates of sealed and unsealed ductwork has disclosed a need for a better method of evaluating duct leakage. European countries introduced an evaluation approach using the surface area of the duct and the pressure in the duct as the basic parameters. SMACNA concluded that this approach is far superior to the arbitrary assignment of a percentage of fan flow rate as a leakage criteria. The surface area basis highlights the effect of system size and is now one of the primary factors of SMACNA duct leakage classifications.

Leakage testing on job sites disrupts productivity and is costly. Only recently has industry begun to recognize the extent of leakage of any in-line equipment. Designers must account for equipment leakage separately from duct leakage allowances as they evaluate system leakage. SMACNA encourages designers to specify equipment leakage control and to rely on prescriptive sealing of ductwork as measures that will normally lead to effective control of leakage without the need for extensive leakage testing. Non-Ducted Under Floor Air Distribution (UFAD) systems present a unique set of circumstances that make leakage testing a very time consuming process not fully covered in this standard. Further information on this topic can be found in the commentary of this manual.

Application of the information and guidance herein should facilitate design, improve system performance and reduce the difficulty of testing and balancing newly installed systems. SMACNA expresses appreciation to all of those whose knowledge and effort led to the introduction of this new publication.

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CHAPTER 1

FOR THE DESIGN PROFESSIONAL

1.1 INTRODUCTION

It is imperative that HVAC system design and specifying engineers have a thorough knowledge of duct air leakage, equipment air leakage, accessory air leakage, and how they combine to create *HVAC Air Distribution System Air Leakage*.

Air duct leakage is the leakage of air from the air distribution system ductwork. The leakage can occur at joints, seams, and penetrations. Research shows that air duct leakage can be represented as a function of duct surface area, leakage class, and static pressure. Leakage class is determined by the construction methods employed in duct fabrication in accordance with the ANSI/SMACNA *HVAC Duct Construction Standards*.

Equipment and accessory air leakage is the air leakage associated with HVAC equipment and all other inline accessories such as VAV boxes, fire dampers, control/volume dampers, access doors, etc..

ASHRAE Standard 193 provides standardized methods to test for equipment leakage, and ASHRAE Standard 130 provides leakage tests for VAV boxes. In most cases it is not practical to seal these components "air tight" since they must be accessible for service and field adjustments.

Sealing fire dampers beyond the manufacturer's installation instructions can render the damper useless, void the listing, and create liability risks for the author of the specification.

Volume dampers, access doors, and other accessories require moving parts to function properly. The design of these types of devices shall be specified so that the desired leakage is achieved by permanent gaskets, seals or other methods such that attempts at after-installation sealing do not prevent these items from working as designed. When performing duct air leakage tests the leakage for these items needs to be accounted for separately and, where practical, shall not be tested with the ductwork. Designers must consider the leakage rates for these accessories and provide allowances when they are included in a duct air leakage test. (Refer to Appendix D for sample specifications)

Because system air leakage is the combination of duct, equipment, and accessory air leakage it is usually impractical or impossible to test the entire system as a whole. Where testing is desired or economically justified, the duct must be tested by logical subsystems. For example, with VAV systems it is often impractical to test the low pressure side of that sub-system. The workable approach would be to test the high pressure side but do not include any VAV boxes in the test. It is not correct to test the "high" pressure side and the "low" pressure side simultaneously. The duct on either side of a VAV box is constructed differently based on the design pressure class and shall be tested at different pressures, their operating pressures as listed by the HVAC system designer.

Leakage requirements shall not be an arbitrary value and shall be assigned on the basis of:

- Static Pressure
- Construction
- Type of duct
- Research and experience

1.2 SEAL CLASS REQUIREMENTS AND PREDICTED AIR LEAKAGE RATES

If a system is constructed to 2 in. wg per ANSI/SMACNA *HVAC Duct Construction Standards* the ductwork must be sealed to seal class C unless specified otherwise. For rectangular duct the leakage class determined through testing is 16, and for round the leakage class is 8. If a seal class of A or B is specified it is reasonable to expect less leakage but predicting the exact relative result is difficult. Other factors affect the performance of the duct work. The types of joints and seams used and fabrication must also be considered. In keeping with SMACNA's policy on sustainability, contractors are encouraged to use products with the least environmental impact for the intended application and jobsite conditions.

Seal class specifies where sealant is applied. Seal class does not denote a leakage class or leakage rate.

Other considerations must also be made when writing specifications for duct sealing. Requiring the sole use of water based sealants is not always practical. It is impossible to properly apply a water based sealant when outside temperatures are below 40°F (5°C) and the building has not been enclosed and heated.

1.3 INFORMATION ON SPECIFICATIONS

Specifications that read "test per SMACNA" or similar are invalid. A properly written leakage testing specification contains the following:

- Which portions or systems require testing. (All is not usually practical option unless cost is not a concern)

- Test static pressure of the system (not to exceed the construction static pressure class of the ductwork)

- The leakage class must be specified, arbitrary values must be avoided. Use values that coincide with the type, construction, and operating pressure of the ductwork.

No leakage tests are required by the SMACNA *HVAC Duct Construction Standards*, 3rd ed., 2005 or by this leakage test manual. When the designer has only required leakage tests to be conducted in accordance with the SMACNA *HVAC Duct Leakage Test Manual* for verification that the leakage classifications in Table 5-1 have been met (and has given no other criteria and scope), the designer is deemed to have not fulfilled the responsibilities outlined in Section 3.1 for providing a clear scope of work. When duct construction pressure classes are not identified in the contract drawings and the amount of leakage testing is not set forth in the contract documents, any implied obligation of the installer to fulfill the responsibilities under Section 3.2 in regard to leakage are deemed to be waived by defective specification.

When deciding which portions of the system to test the designer should consider the potential gains. Testing does not reduce duct air leakage.

Lower pressure ductwork, particularly ductwork located downstream of VAV boxes does not provide the same potential gain as ductwork located upstream of a VAV box. Although the downstream ductwork is often constructed to 1 or 2 in. w.g. the reality is that these portions of the system rarely exceed 0.25 in. w.g. of static pressure under operating conditions and are often operating near 0.1 in. w.g.. These low pressures greatly reduce the potential for air leakage. There also tends to be less ductwork (by surface area) downstream of VAV boxes. Since these smaller sections still require the same set-up and procedure as larger sections the potential gains relative to the effort required are much smaller than other portions of the duct system.

When testing negative pressure systems (returns, exhaust) it is not necessary to perform the duct air leakage tests under negative pressure. Research indicates that the results for positive pressure tests are within the margin of error for negative pressure tests. Requiring negative pressure ducts to be tested under negative pressure can increase costs without an improvement in the test results. For this reason, positive pressure testing is permitted for all HVAC ductwork.

Please refer to Appendix D for a sample specification.

CHAPTER 2

OVERVIEW

2.1 GENERAL APPLICATION

This document identifies certain leakage limits for ducts and outlines procedures for testing ducts for conformity with air leakage limits that are set forth in a designer's project specification. This document is not an endorsement of the routine use of testing. When proper methods of assembly and sealing are used leakage testing can be a major redundant expense that is unnecessary. Visual inspection for application of such proper methods will ordinarily suffice for verification of reasonably tight construction. Under any circumstances reasonable allowances for leakage must be adopted because no duct is absolutely airtight.

2.2 SEALING PROVISIONS

The sealing provisions contained in the SMACNA *HVAC Duct Construction Standards Metal and Flexible*, 2005 3rd edition, are reproduced here for convenient understanding of use of prescriptive measures. Consult the SMACNA *Fibrous Glass Duct Construction Standards*, 7th ed., 2003 for fibrous glass duct assembly. Closures of joints and seams in fibrous glass ducts rely on taped adhesive systems to make connections. Metal ducts typically use mechanical fasteners for connection and use sealants for supplemental leakage control.

2.3 LEAKAGE FACTORS

Duct leakage reduces the air quantities at terminal points unless the total air quantity is adjusted to compensate. Leakage should be considered a transmission loss in duct systems. The farther air is conveyed the greater the air leakage. Key variables that affect the amount of leakage are:

- Static pressure, not velocity pressure. (The higher the static pressure the more leakage will occur.)
- The amount of duct (the greater the surface area of duct the more opportunity for leakage there will be).
- The openings in the duct surface (the major contributors are joints, seams, access doors, and rod penetrations).
- Workmanship (poor workmanship undermines the best construction standards).

It is practical to relate leakage to duct surface area. Although rates of loss per foot of seam, per diameter of hole or per dimension of crack can be evaluated, duct surface area is the most reliable parameter by which to accurately evaluate duct air leakage. Furthermore, research (in Europe and independently in the United States) has led to the conclusion that within acceptable tolerances, a duct surface leakage factor can be identified by the following relationship.

$$F = C_L P^N$$

Where:

F is a leak rate per unit of duct surface area (typically cfm/100 s.f.)

C_L is the leakage class and is a constant

P is static pressure (typically in inches water gage)

N is an exponent (most typically it is 0.65 but in some cases it is 0.5 to 0.9)

The SMACNA Leakage Classifications are based on this leakage factor relationship. Whether the designer uses the rates identified or prefers other constants, it is practical to evaluate leakage by this method.

2.4 DUCT CONSTRUCTION AND INSTALLATION STANDARDS

1. General Requirements
2. The construction and installation specifications and illustrations herein include:
   a. Single-prescription-method requirements,
   b. Optional alternatives, and
   c. Performance requirements for specific items that are different in detail from the generalized illustrations.
3. This standard is not meant to exclude any products or methods that can be demonstrated to be equivalent in performance for the application. Substitutions based on sponsor demonstrated adequacies and approval of the regulating authority are required.
4. These requirements presume that the designers have prepared contract drawings showing the size and location of ductwork including permissible fitting configurations. Where area change, direction change, divided flow or united flow fittings other than those illustrated here are shown on the contract drawings, are not of proprietary manufacture and are defined with total pressure loss coefficients in either the SMACNA *HVAC Systems Duct Design, 4th ed., 2006* manual or the ASHRAE

Duct Fitting Database, such fittings shall be fabricated with materials, assembly techniques and sealing provisions given here.

5. EACH DUCT SYSTEM SHALL BE CONSTRUCTED FOR THE SPECIFIC DUCT PRESSURE CLASSIFICATIONS SHOWN ON THE CONTRACT DRAWINGS FOR THE PROJECT. WHERE NO SPECIFIC DUCT PRESSURE CLASS DESIGNATIONS ARE PROVIDED BY THE DESIGNER THE 1 IN. WATER GAGE PRESSURE CLASS IS THE BASIS OF COMPLIANCE WITH THESE STANDARDS, REGARDLESS OF VELOCITY IN THE DUCT, EXCEPT WHEN THE DUCT IS VARIABLE AIR VOLUME: ALL VARIABLE AIR VOLUME DUCT UPSTREAM OF VAV BOXES HAS A 2 IN. WG BASIS OF COMPLIANCE WHEN THE DESIGNER DOES NOT SPECIFY A PRESSURE CLASS.

6. No specification or illustration herein shall, by virtue of adoption of these standards, be an obligation to supply volume control dampers, fire dampers, smoke dampers, or fittings that are not shown on contract drawings.

7. Where dimensions, sizes and arrangements of elements of duct assembly and support systems are not provided herein the contractor shall select such to be suitable for the service.

8. The contractor shall follow the application recommendations of the manufacturer of all hardware and accessory items and make selections of such consistent with the duct classification and services.

9. Ducts shall be sealed in accordance with Table 2-1.

10. Where sealing is required in Table 2-1 or in other tables or illustrations in this manual. It means the following:

    a. The use of adhesives, gaskets, tape systems or combinations thereof to close openings in the surface of the ductwork and field-erected plenums and casings through which air leakage would occur; or the use of continuous welds.

    b. The prudent selection and application of sealing methods by fabricators and installers, giving due consideration to the designated pressure class, pressure mode (positive or negative), chemical compatibility of the closure system, potential movement of mating parts, workmanship, amount and type of handling; cleanliness of surfaces, product shelf life, curing time and manufacturer-identified exposure limitations.

    c. That these provisions are applicable to duct connections to equipment and to apparatus but are not for equipment and apparatus.

    d. That where distinctions between seams and joints are made herein, a seam is defined as joining of two longitudinally (in the direction of airflow) oriented edges of duct surface material occurring between two joints. Helical (spiral) lock seams are exempt from sealant requirements. All other duct surface connections made on the perimeter are deemed to be joints. Joints are inclusive of but not limited to girth joints; branch and sub-branch intersections; so-called duct collar tap-ins; fitting subsections; louver and air terminal connections to ducts; access door and access panel frames and jambs; duct, plenum and casing abutments to building structures.

    e. Penetrations are defined as pipe, tubing, rods, and wire. Screws and other fasteners are not considered to be ductwork penetrations when referring to seal class A. Rods that penetrate the duct wall that must be allowed to move in order to function properly (control rod for volume damper) should not be sealed in a fashion that prevents them from working properly.

Seal Class	Sealing Required	Static Pressure Construction Class
A	All transverse joints longitudinal seams and applicable duct wall penetrations	4 in. wg and up
B	All transverse joints and longitudinal seams	3 in. wg
C	Transverse joints	2 in. wg
In addition to the above any variable air volume system duct of 1 in. and ½ in. wg construction class that is upstream of the VAV boxes shall also meet Seal Class C.		

Table 2–1 DUCT SEALING REQUIREMENTS

f. Unless otherwise specified by the designer, sealing requirements do not contain provisions to:

   i. Resist chemical attack.

   ii. Be dielectrically isolated.

   iii. Be waterproof, weatherproof or ultraviolet ray resistant.

   iv. Withstand temperatures higher than 120°F or lower than 40°F.

   v. Contain atomic radiation or serve in other safety-related construction.

   vi. Be electrically grounded.

   vii. Maintain leakage integrity at pressures in excess of the duct classification.

   viii. Be underground below the water table.

   ix. Be submerged in liquid.

   x. Withstand continuous vibration visible to the naked eye.

   xi. Be totally leak-free within an encapsulating vapor barrier; and

   xii. Create closure in portions of the building structure used as ducts, *e.g.*, ceiling plenums, shafts, pressurized compartments.

g. The requirements to seal apply to both positive pressure and negative pressure modes of operation.

h. Externally insulated ducts located outside of buildings shall be sealed prior to being insulated as though they were inside. If air leak sites in ducts located on the exterior of buildings are exposed to weather, they shall receive exterior duct sealant. An exterior duct sealant is defined as a sealant that is marketed specifically as forming a positive air and water tight seal, bonding well to the metal involved, remaining flexible with metal movement and having a service temperature range of –30°F to 175°F. If exposed to direct sunlight it shall also be ultraviolet ray and ozone resistant or shall, after curing, be painted with a compatible coating that provides such resistance. The term sealant herein is not limited to materials of adhesive or mastic nature but is inclusive of tapes and combinations of open weave fabric strips and mastics.

2.5 DUCT SEALING COMMENTARY

Ducts must be sufficiently airtight to insure economical and quiet performance of the system. It must be recognized that air tightness in ducts as a practical matter should not and need not, be absolute (as it must be in a water piping system). Codes normally require that ducts be reasonably airtight. Concerns for energy conservation, humidity control, space temperature control, room air movement, ventilation and maintenance, etc., necessitate regulating leakage by prescriptive measures in construction standards. Leakage is largely a function of static pressure and the amount of leakage in a system is significantly related to system size. Adequate air tightness can normally be assured by a) selecting a static pressure construction class suitable for the actual operating condition, b) using duct construction methods as detailed in SMACNA's Duct Construction Standards sealing the ductwork properly.

The designer is responsible for carefully determining the pressure class or classes required for duct construction and for evaluating the amount of sealing necessary to achieve system performance objectives. It is recommended that all duct constructed for 1 and ½ in wg pressure class meet Seal Class C. However, in consideration of those occasions in which designers deem leakage in unsealed ducts not to have adverse effects, sealing of all ducts at 1 and ½ in wg pressure class is not required by this manual. Small systems, residential occupancies, location of ducts directly in the zones they serve, short runs of ducts from volume control boxes to diffusers, certain return air ceiling plenum applications, etc., have at times been exempted by designers from sealing requirements. When Seal Class C is to apply to all 1 and ½ in wg pressure class duct the designer must require this in the project specification. The designer should assume that unsealed rectangular ducts will have a leakage class of 48.

Seven pressure classes exist for HVAC Duct, each can be positive or negative (½, 1, 2, 3, 4, 6 and 10 in. wg). The designer is also reminded that if a pressure class is not designated for duct construction on the contract drawings the basis of compliance with the SMACNA *HVAC Duct Construction Standards*, 3rd ed., 2005 is as follows: 2 in. wg for all duct between the supply fan and variable volume control boxes; 1 in. wg for all other duct of any application.

2.5.1 Leakage Tests

The need to verify leakage control by field testing is not present when adequate methods of assembly and sealing are used. Leakage tests are an added expense in system installation. Costs include the time and materials to prepare and test the section of duct, coordinating the testing with other trades and potential delays to the overall construction schedule. It is not required that duct systems constructed to 3 in. wg class or lower be tested. For duct systems constructed to 4 in. wg class and higher, the designer must determine if any justification for testing exists. If it does, the designer must clearly designate in the contract documents the portions of the system(s) to be tested and must also specify appropriate test methods.

Apparent differences of the order of ten percent between fan delivery and sum of airflow measurements at terminals do not necessarily mean poor sealing and excess leakage. The accuracy of flow measurements and the devices and methods used to take those measurements should be evaluated.

Otherwise, open access doors, unmade connections, missing end caps or other oversights contribute to such discrepancies. When air terminals are at great distances from fans (for example, 500 to 1000 ft) more effective sealing is probably required to avoid adverse influence on system performance.

Schools, shopping centers, airports and other buildings may use exposed ductwork. Selection of sealing systems for such ducts may involve more attention to the final appearance of the duct system than in concealed spaces.

Long standing industry acceptance of so called low pressure duct systems without the addition of sealants may have left some contractors (and designers) with little or no previous experience with sealing. The contractor should carefully select construction detail consistent with sealing obligations, the direction of the air pressure and the sealing methods familiar to the employees responsible for sealing ductwork. Costs related to restoration of systems not receiving the required sealing or of those haphazardly sealed can greatly exceed the cost of a proper initial application. Contractors must control connector length and notch depth on rectangular duct ends to facilitate sealing. Failure to do so will compromise seal effectiveness. Round duct joints are normally easier to seal than other types. However, with proper attention to joint selection, workmanship, and sealant application, almost any joint can achieve low leakage. The mere presence of sealant at a connection, however, is not an assurance of low leakage. Applying sealant in a spiral lock seam can result in poor seam closure and less satisfactory control. There is no single sealant which will be the best for all applications. The selection of the most appropriate sealant will depend primarily on the basic joint design and also on application conditions such as joint position, clearances, direction of air pressure in service, air temperature etc.

Conditions of listing of certain duct products by recognized test laboratories may dictate use of a particular joint sealing product. Such a component listing reflects performance only under the scope of the laboratory test and it will not necessarily mean that the closure method can routinely be successful for the contractor or that it will withstand in service operation of the system on a long term basis.

2.5.2 Liquids

Many manufacturers market liquid sealants specifically for ducts. They have the consistency of heavy syrup and can be applied either by brush with a cartridge gun, lay spray equipment, or powered pump. Liquid sealants normally contain 30 to 60 percent volatile solvents by weight therefore, they shrink considerably when drying. They are recommended for slip-type joints where the sealant fills a small space between the overlapping pieces of metal. Where metal clearances exceed $\frac{1}{16}$ inch, several applications may be necessary to fill the voids caused by shrinkage or runout of the sealant.

2.5.3 Mastics

Heavy mastic type sealants are more suitable for application as a fillet, in grooves or between flanges. Mastics must have excellent adhesion and elasticity. Oil base caulking and glazing compounds should not be used.

2.5.4 Gaskets

Durable materials such as soft elastomer butyl or extruded forms of sealants should be used in flanged joints. For ease of application, gaskets should have adhesive backing or otherwise be tacky enough to adhere to the metal while assembling the joint. The choice of open cell or closed cell rubber gaskets depends on the amount and frequency of compression and the elastic memory.

2.5.5 Tapes

Nothing herein is intended to unconditionally prohibit the use of pressure sensitive tapes. Several such closures are listed as components of systems complying with U.L. Standard 181 tests. At this time there are no industry recognized performance standards that set forth peel adhesion, shear adhesion, tensile strength, temperature limits, accelerated aging, etc., quality control characteristics that are specifically correlated with metal duct construction service. However, the SMACNA *Fibrous Glass Duct Construction Standards*, 7th ed., 2003 illustrate the closure of a fibrous duct to metal duct with a tape system. The variety of products advertised in industry is very broad. Some test results for tapes are published in the product directories of the Pressure Sensitive Tape Council located in Glenview, IL.

Shelf life of tapes may be difficult to identify. It may be only six months or one year. Although initial adhesion may appear satisfactory, the aging characteristics of these tapes in service is questionable. Tendencies to lose adhesion progressively at edges or from exposures to air pressure, flexure, the drying effects at the holes or cracks being sealed, etc., have been reported. The specific adhesive may be chemically incompatible with the substrate as is apparently the case with certain non-metal flexible ducts. Application over uncured sealant may have failures related to release of volatile solvents. Coastal atmospheres may have different effects on rubber, acrylic, silicone, (or other) based adhesives.

2.5.6 Heat Applied Materials

Hot melt sealants and those of a thermally activated nature are less widely known but are used for ductwork. The hot melt type is normally a shop application. Thermally activated types use heat to either shrink fit closures or to expand compounds within joint systems.

2.5.7 Mastic and Embedded Fabric

There are several combinations of woven fabrics (fibrous glass mesh, gauze, canvas, etc.) and sealing compounds (including lagging adhesive) that appear better suited for creating and maintaining effective seals than the application of sealant (*e.g.*, before and after assembly of connections) alone.

2.5.8 Surface Preparation

Surfaces to receive sealant should be adequately clean (free from oil, dust, dirt, rust, moisture, ice crystals and other substances that inhibit or prevent bonding). Solvent cleaning is an additional expense. Surface primers are now available but the additional cost of application may not result in measurable long term benefits.

2.5.9 Sealant Strength

At this time no sealant system is recognized as a substitute for mechanical fasteners.

2.5.10 Shelf Life

Shelf life of all sealant products may be one year or less; often it is only six months. The installer is cautioned to verify that shelf life has not been exceeded.

2.5.11 Safety Considerations

Sealant systems may be flammable in the wet, partially cured, or cured state.

USE LIQUIDS AND MASTICS IN WELL VENTILATED AREAS AND OBSERVE PRINTED PRECAUTIONS OF MANUFACTURERS

The contractor should carefully consider the effects of loss of seal and fire potential when welding on or close to sealed connections.

2.5.12 Building Certification Processes

The industry offers a wide variety of building certifications such as LEED® and Energy Star. These certifications apply another set of requirements to the project and may have a direct impact on the materials used by contractors. The use of particular duct sealants may not comply with these additional requirements, most notably the VOC content. Contractors need to be aware if any of the requirements for certification limit the choice of duct sealants. Designers and certification specialists need to understand the impact of limiting the contractor's choice of products. For instance, limiting the contractor to water-based sealants may not be practical if construction occurs when conditions are regularly below 40°F.

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CHAPTER 3

RESPONSIBILITIES

3.1 DESIGNER'S RESPONSIBILITIES

1. The duct system designer shall:

   a. Match the fan to the system pressure losses.

   b. Designate the pressure class or classes for construction of each duct system, as appropriate and cost effective, and clearly identify these in the contract document.

   c. Evaluate the leakage potential for ducts conforming to SMACNA or other standards and supplement the requirements therein with deletions and additions as may be prudent and economical, giving due attention to the location of the ducts, the type of service, the equipment, dampers and accessories in the system, the tolerances on air balance and the performance objectives. They must account for leakage in equipment such as fans, coils, volume regulating boxes, etc., independently of duct leakage.

   d. Prudently specify the amount and manner of leakage testing (if testing is deemed justified) and clearly indicate the acceptance criteria by assigning a leakage class (do not assign leakage as a percent of flow) See Appendix B.

   e. Reconcile all significant inconsistencies between the performance specifications and the prescription specifications before releasing contract documents for construction.

   f. Avoid ambiguity created by references to non-specific editions of SMACNA or other specified documents.

   g. Have contract documents reflect a clear scope of work known to conform to applicable codes and regulations, including those addressing energy conservation.

   h. Require adequate submittals and recordkeeping to insure that work in progress conforms to the contract documents in a timely manner.

3.2 CONTRACTOR'S RESPONSIBILITIES

1. The ductwork installer shall:

   a. Comply with the contract documents.

   b. Provide all required preconstruction and after-installation submittals.

   c. Report discovery of conflicts and ambiguities, etc., in a timely manner.

   d. Schedule any required leakage tests in a timely manner, with appropriate notice to authorities.

   e. Seal duct as specified. Class A, B or C.

   f. Examine the leakage criteria, the specified duct construction classes, and the testing and balancing specifications for consistency.

   g. Select duct construction options and sealing methods that are appropriate and compatible, giving due consideration to the size of the system.

   h. Control workmanship.

   i. Acquire increased understanding of the nature and amount of leakage and of the methods and costs of sealing and leak testing, especially the amount of preparation time inherent in demonstrating a successful test.

   j. Demonstrate that following prescriptive measures for construction precludes the need for leak testing.

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CHAPTER 4

GENERAL PROCEDURES

4.1 AIR DUCT LEAKAGE TESTING

1. Conventional leak testing is based on positive pressure mode analysis. It involves inserting temporary plugs (plates, sheets, balloons, bags, etc.) in openings in a section of duct and connecting a blower and a flowmeter to the specimen in such a manner that pressurizing the specimen will cause all air escaping from the specimen to pass through the flowmeter.

2. Select a test pressure not in excess of the pressure class rating of the duct.

3. Calculate the allowable or allocated leakage using leakage factors related to the duct surface area. Refer to Appendix G

4. Select a limited section of duct for which the estimated leakage will not exceed the capacity of the test apparatus at the test pressure determined in step 2.

5. Connect the blower and flowmeter to the duct section and provide temporary seals at all open ends of the ductwork.

6. To prevent over pressurizing of the ducts, start the blower with the variable inlet damper closed. Controlling pressure carefully, pressurize the duct section to the required level.

7. Read the flowmeter and compare the leakage in cfm per square foot with the allowable rate determined in step 3. If it meets the allowable rate proceed to step 8. If it does not meet the allowable rate follow steps 7a. through 7c.

   a. Inspect the pressurized duct (and all connections between the flowmeter and the duct) for all sensible leaks. A smoke bomb test may be used to identify actual leak sources. If necessary apply a soap solution to locate small leaks.

   b. Depressurize; repair all audible and other significant leaks. If the first pressurization failed to develop the required test pressure level and significant leak sites were not discovered, consider the following alternatives: divide the specimen being tested into smaller segments or use larger test apparatus. (refer to Appendix G)

   c. Allow repaired seals to cure and retest until the leakage rate is acceptable.

8. Complete test reports and, if required, obtain witness' signature.

9. Remove temporary plugs, blanks and seals.

10. Precautions:

    a. Verify that an adequate and matched electric power source is available for the test apparatus.

    b. Determine that the capacity of the test apparatus is suitable for the amount of duct to be tested.

    c. Acquire experience with leakage rates in the type of construction used before formally conducting field tests. This is especially important if the contractor has little experience with testing, is attempting to meet allowable rates much lower than normal, is including equipment in the test, or is dealing with unfamiliar duct construction.

    d. Isolate equipment (fans, in-line flanged coils, volume regulating boxes, etc.) from tested ductwork. The system designer shall have independently accounted for leakage in equipment.

    e. Anticipate difficulty with any test of ductwork that has no prescription for sealing yet is required to meet an allowable leakage level.

    f. Do not over pressurize ducts. Provide pressure control or pressure relief; *e.g.*, start test apparatus with flow restricted and gradually build up pressure.

    g. Do not test uncured seals.

    h. Prepare carefully when testing in cold weather. Low temperature influences the effectiveness of sealants and gaskets.

    i. Instruct installers to use special care when assembling ducts that will be relatively inaccessible for repair.

    j. Conduct required tests before external insulation is applied and before ducts are concealed by building enclosures.

    k. Do not overlook leakage potential at access doors.

l. Do not leave test apparatus unattended.

m. Avoid confusion by informing occupants and bystanders when you will conduct smoke tests. IEQ specifications may have requirements associated with smoke testing.

n. Avoid excessive blanking, consistent with industry practice, by testing prior to installation of collars for room air terminals.

o. Take testing seriously; work sequence, work duration and costs can be significantly affected.

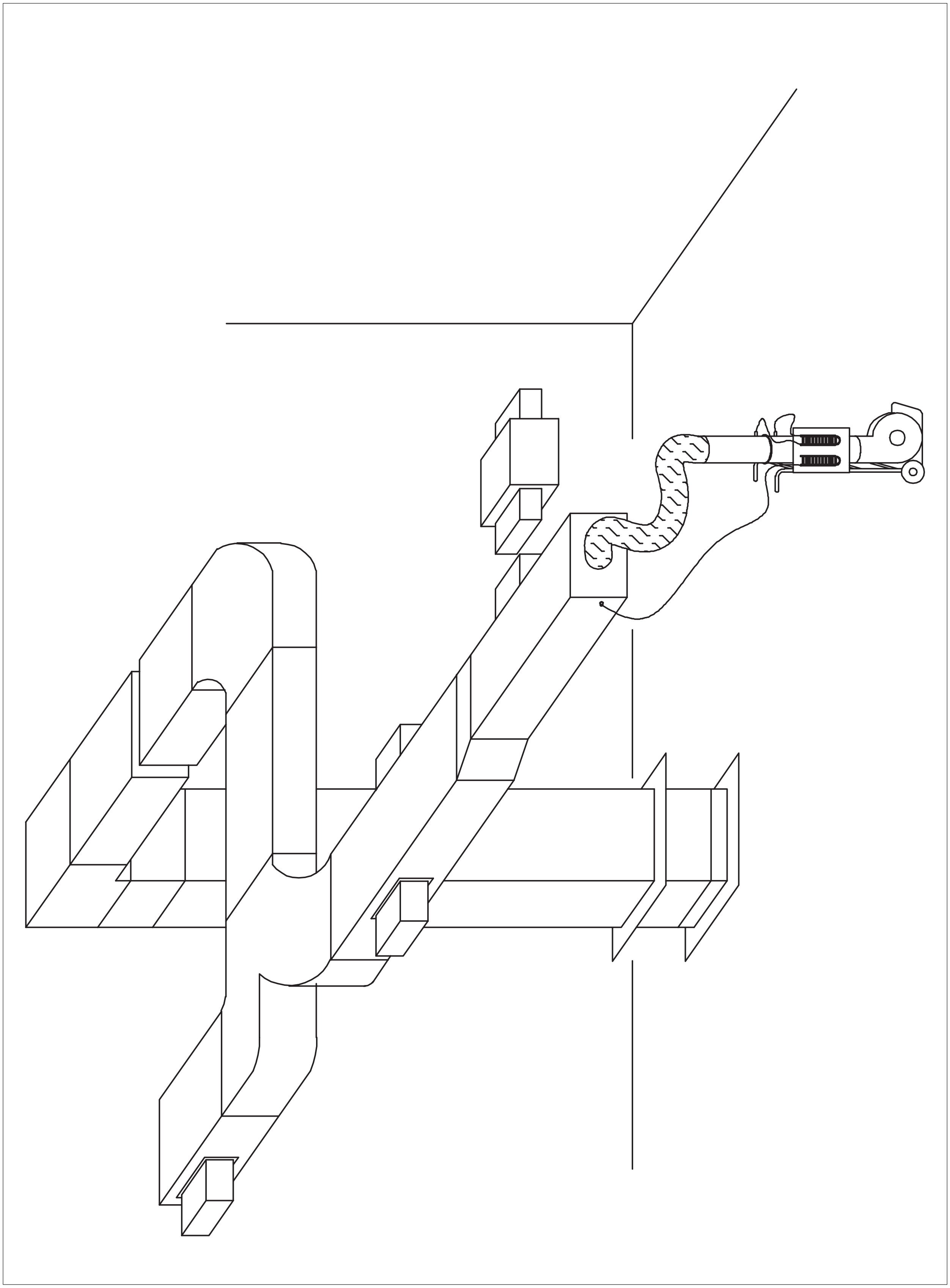

FIGURE 4–1 ILLUSTRATION OF TESTING

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CHAPTER 5

LEAKAGE CLASSIFICATION

5.1 DUCT LEAKAGE CLASSIFICATIONS

Leakage classification identifies a permissible leakage rate in cfm per 100 square feet of duct surface according to the relationship $C_L = \frac{F}{P^{0.65}}$ as defined in Section 2.3.

F is the leakage rate in cfm/100 ft^2 of duct surface (It varies with static pressure).

P is the static pressure. Values for $P^{0.65}$ are given in Appendix E. Note that when $P = 1$, $C_L = F$.

C_L is the leakage class and is a constant.

Leakage classifications 2, 4, 8, and 16 are shown in Figure 5-1 for pressures up to 10 in. wg. They are associated with duct type, seal classes, and construction pressure classes in Table 5-1. Table 5-1 is the basis of evaluating duct conforming to the SMACNA duct construction standards unless a specifier gives other limits.

If, at the specified test pressure, the leakage factor (F), by test, is lower than or equal to that associated with the specified leakage class, the duct is in compliance. Alternatively, if the leakage constant (C_L) determined from tests is lower than or equal to the specified leakage class, the duct is in compliance.

Assignment of leakage classes involves careful consideration of system size, duct location, sealing, and construction class. Arbitrary assignment of an allowable percentage of leakage with disregard to these factors can indicate unobtainable results. A ½% allowance, for example, on a 3900 cfm system with 1300 sf of duct or on a 39,000 cfm system with 13,000 sf of duct would mean an unrealistic leakage factor of 1.5 cfm/100 sf in each case. Similarly, arbitrary assignment of 10 in. wg class construction for a system operating at 1 in. wg in order to get leak class 4 rectangular duct would not be cost effective. Assigning a leakage class 4 to a 1 in. wg rectangular duct system may address an achievable result but the associated difficulty and costs will be excessive. Table 5-1 represents the leakage expected using Seal Classes A, B, and C as indicated on duct construction of the types typically selected for each pressure class. Conceivably Seal Class B or A could be applied at construction pressure classes lower than indicated in Table 5-1. However, unless joint type, seam type, duct wall thickness, and specific sealing method were already collectively prequalified by tests (or by an acceptable experience record at a higher pressure) leakage rate is less predictable. The benefits of setting allowable leakage rates lower than shown in Table 5-1 should be carefully weighed against the costs of achieving them.

A sample leakage classification analysis is given in Appendix B.

No leakage tests are required by the SMACNA duct construction standards or by this leakage test manual. When the designer has only required leakage tests to be conducted in accordance with the SMACNA *HVAC Air Duct Leakage Test Manual* for verification that the leakage classifications in Table 5-1 have been met (and has given no other criteria and scope), the designer is deemed to have not fulfilled the responsibilities outlined in Section 3.1 for providing a clear scope of work. When duct construction pressure classes are not identified in the contract drawings and the amount of leakage testing is not set forth in the contract documents, any implied obligation of the installer to fulfill the responsibilities under Section 3.2 in regard to leakage are deemed to be waived by defective specification.

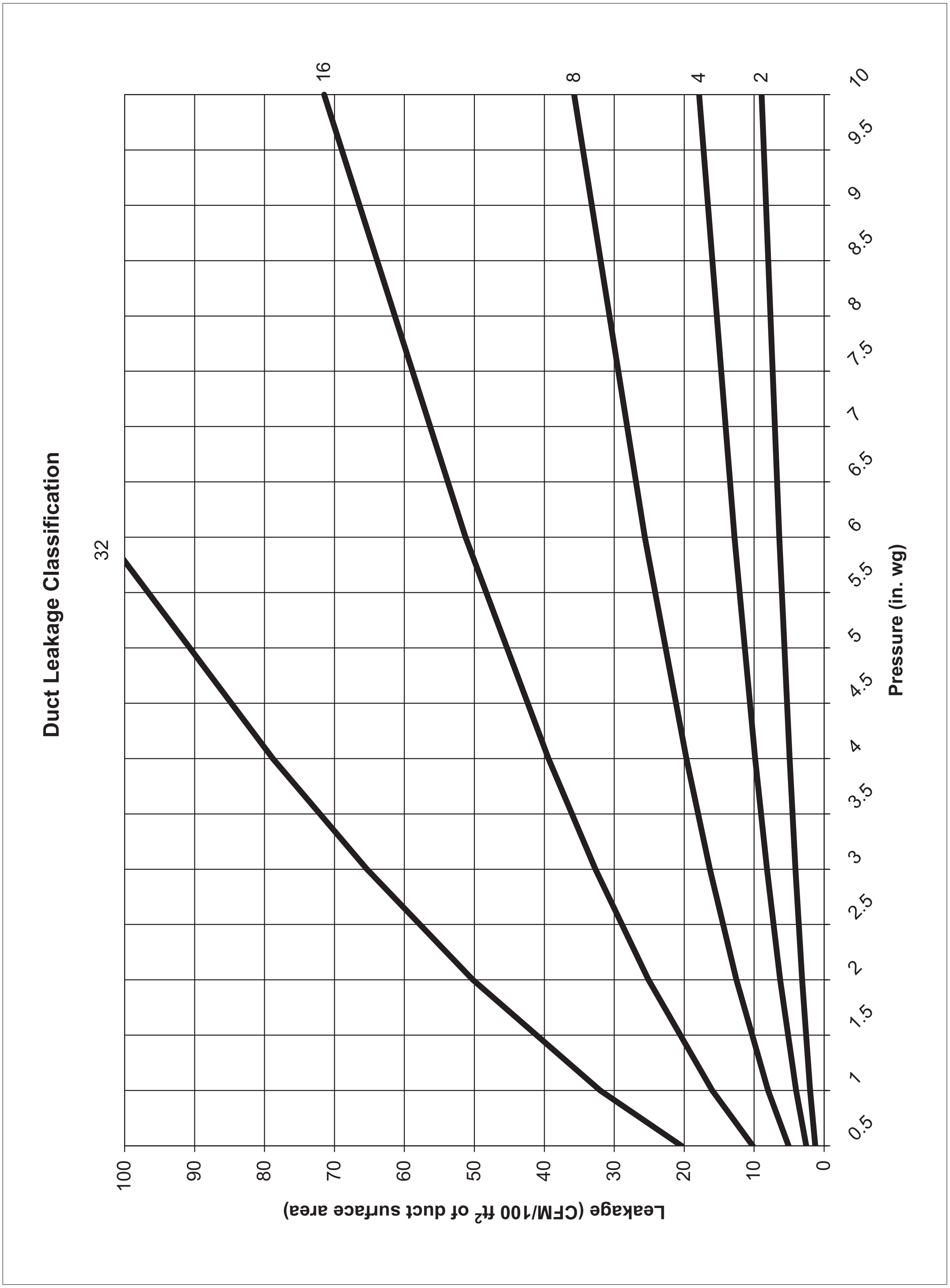


FIGURE 5–1 DUCT LEAKAGE CLASSIFICATION

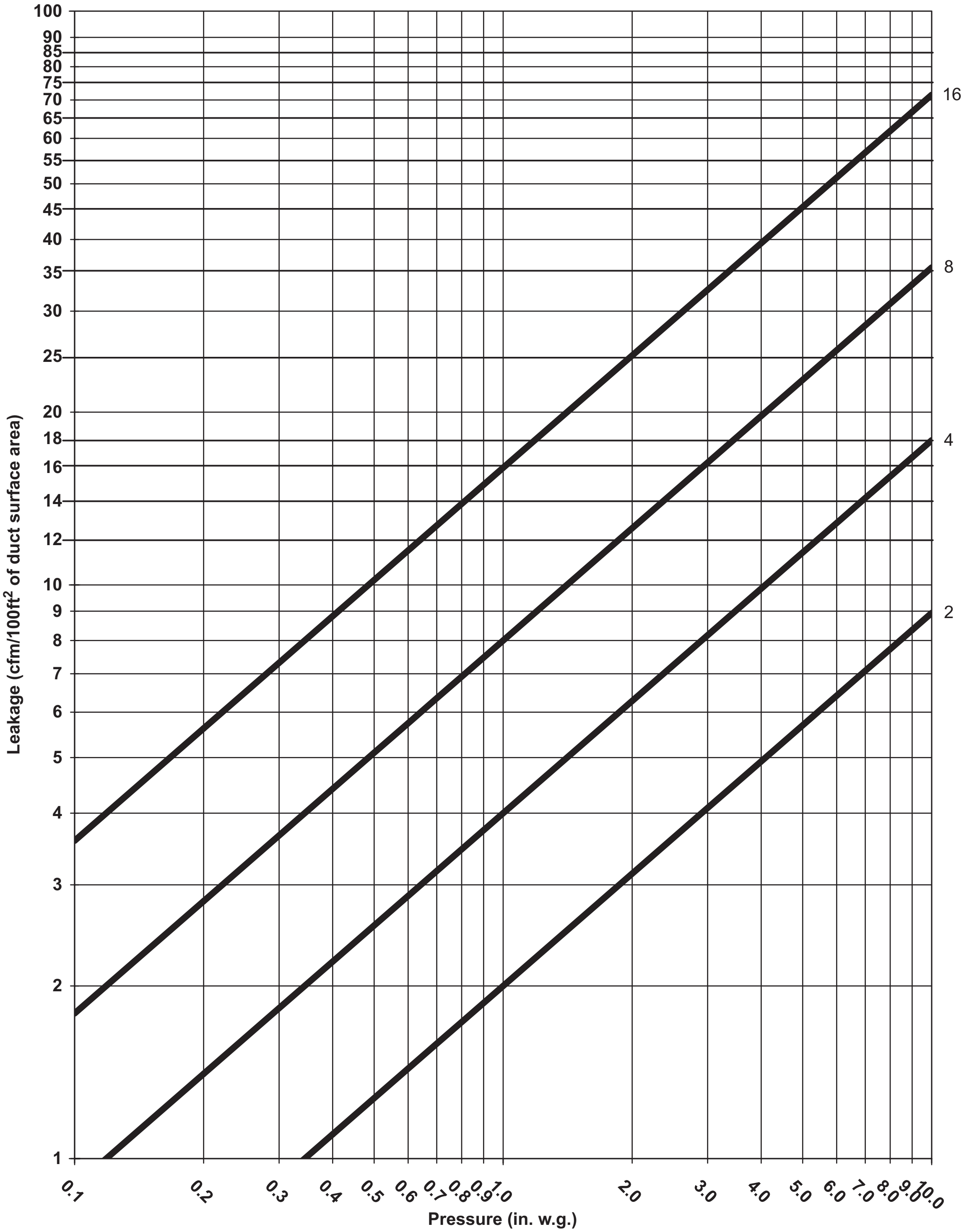


FIGURE 5–1L DUCT LEAKAGE CLASSIFICATION

Duct Class	½ in., 1 in., 2 in. wg	3 in. wg	4 in., 6 in., 10 in. wg
Seal Class	C	B	A
Sealing Applicable	Transverse Joints Only	Transverse Joints and Seams	Joints, Seams and all Applicable Wall Penetrations
Leakage Class			
Rectangular Metal	16	8	4
Round Metal	8	4	2

Table 5–1 Recommended Leakage Classes

NOTES:

a. Leakage classes in Table 5-1 apply when the designer does not designate other limits and has specified Seal Class C for ½ and 1 in. wg. *See* text on sealing in the *HVAC Duct Construction Standards*, 3rd., 2005 manual.

b. Unsealed rectangular metal duct may follow Leakage Class 48.

c. Fibrous glass duct may follow Leakage Class 6 (at 2 in. wg or less).

d. Unsealed flexible duct leakage average is estimated to be Class 30. Sealed nonmetal flexible duct is an average of Class 12.

e. *See* SMACNA *HVAC Systems Duct Design*, 4th ed., 2006 manual Table 5-1 for estimates of longitudinal seam leakage rates.

f. Although Seal Class A or B might be assigned for lower pressures, the leakage class may not conform to those associated with the higher pressure. Other construction details influence results.

g. Leakage Class (C_L) is defined as being the leakage rate (cfm/100 sf) divided by $P^{0.65}$ where P is the static pressure (in wg). When P is numerically equal to 1 the leakage rate is C_L. *See* Figure 5-1.

h. The duct pressure classification is not the fan static pressure nor the external static pressure (on an HVAC unit) unless the system designer has made such an assignment in the contract documents. Unless construction class is otherwise specified it means a static pressure classification in the SMACNA *HVAC Duct Construction Standards*, 3rd., 2005. Those classifications pertain to maximum operating pressure in the duct as follows:

0.5 in. wg maximum

0.6 to 1 in. wg maximum

1.1 to 2 in. wg maximum

2.1 to 3 in. wg maximum

3.1 to 4 in. wg maximum

4.1 to 6 in. wg maximum

6.1 to 10 in. wg maximum

CHAPTER 6

TEST APPARATUS

6.1 DUCT LEAKAGE TESTING APPARATUS

Test apparatus shall consist of an airflow measuring device, flow producing unit, pressure indicating devices, and accessories necessary to connect the metering system to the test specimen.

The contractor conducting tests shall arrange for or provide all temporary services, all test apparatus, all temporary seals and all qualified personnel necessary to conduct the specified testing.

Test apparatus shall be accurate within plus or minus 7.5% at the indicated flow rate and test pressure and shall have calibration data or a certificate signifying manufacture of the meter in conformance with the ASME Requirements for Fluid Meters. ASME qualified orifice meters do not require calibration.

Unless otherwise specified, test apparatus shall be used as outlined in this section, as described in Chapter 4 and as recommended for good practice.

Typical construction and use of orifice meters is indicated in Figures 6-1 and 6-2. Typical orifice selections are shown in Figure 6-3.

The use of flow nozzles, venturi meters, laminar flow meters, rotameters, Pitot tube meters or other meters having equivalent accuracy and suitability is not prohibited by the references herein to orifice meters.

The minimum thicknesses for orifice plates in tubes of various diameters are 1⁄16" upto 6" diameter, 3⁄32" upto 12" diameter and 1⁄8" for larger diameters. Steel or stainless steel plate material is recommended. Plates shall be flat and have holes with square edges (90°) that are free of burrs. Orifice openings shall be centered in the meter tube. Plates shall be perpendicular to the flow path and shall be free of leaks at points of attachment.

Taps for static pressure indication across orifices shall be made with 1⁄16" to 1⁄8" diameter holes drilled neatly in the meter tube wall. The interior of the tube shall be smooth and free of projections at the drilled holes.

Pressure differential sensing instruments shall be readable to 0.05" scale division for pressure differentials at or below 0.5 in. wg. For higher pressure differentials divisions of 0.1 in, are permissible.

Liquid for manometers shall have a specific gravity of 1 (as water) unless the scale is calibrated to read in inches of water contingent on use of a liquid of another specific gravity, in which case the associated gage fluid must be used.

The duct test pressure shall be sensed only from an opening in the duct.

The orifice tube may be used on either the inlet or outlet side of the fan.

Instruments must be adjusted to zero reading before pressure is applied.

Airflow across a sharp edge orifice with standard air density of .075 lb/ft^3 is calculated from

Equation 6-1

$$Q = 21.8K(D_2)^2\sqrt{\Delta P}$$

Where:

Q = air volume, cfm

K = coefficient of airflow from Table 6-1 or Appendix K

D_2 = orifice diameter, inches

ΔP = Pressure drop across orifice, inches wg.

The ratio of orifice diameter D_2 to meter tube interior diameter D_1 is known as the Beta (β), or diameter ratio. It is normally selected in the range of 0.7 to 0.3. The orifice-to-tube area ratio (A_2/A_1) is an indication of the contraction of flow. Kp in Table 6-1 is the overall pressure loss that occurs from contracting and expanding the flow. Thus, the orifice causes a Kp × P loss that affects blower capacity.

D_2/D_1	.70	.60	.50	.40	.30
A_2/A_1	.490	.36	.250	.160	.090
K	.699	.650	.623	.608	.600
Kp	.52	.63	.73	.82	.88

Table 6–1 ORIFICE COEFFICIENTS

Select a flowmeter suitable for the leakage in the duct to be tested:

- Using the target leakage rate (cfm/100 sf) for the desired amount of tested duct find the cfm required. At this cfm the blower will have to produce a pressure approximately equal to the sum of the duct test pressure and the orifice differential pressure. Add 0.5 in. wg if

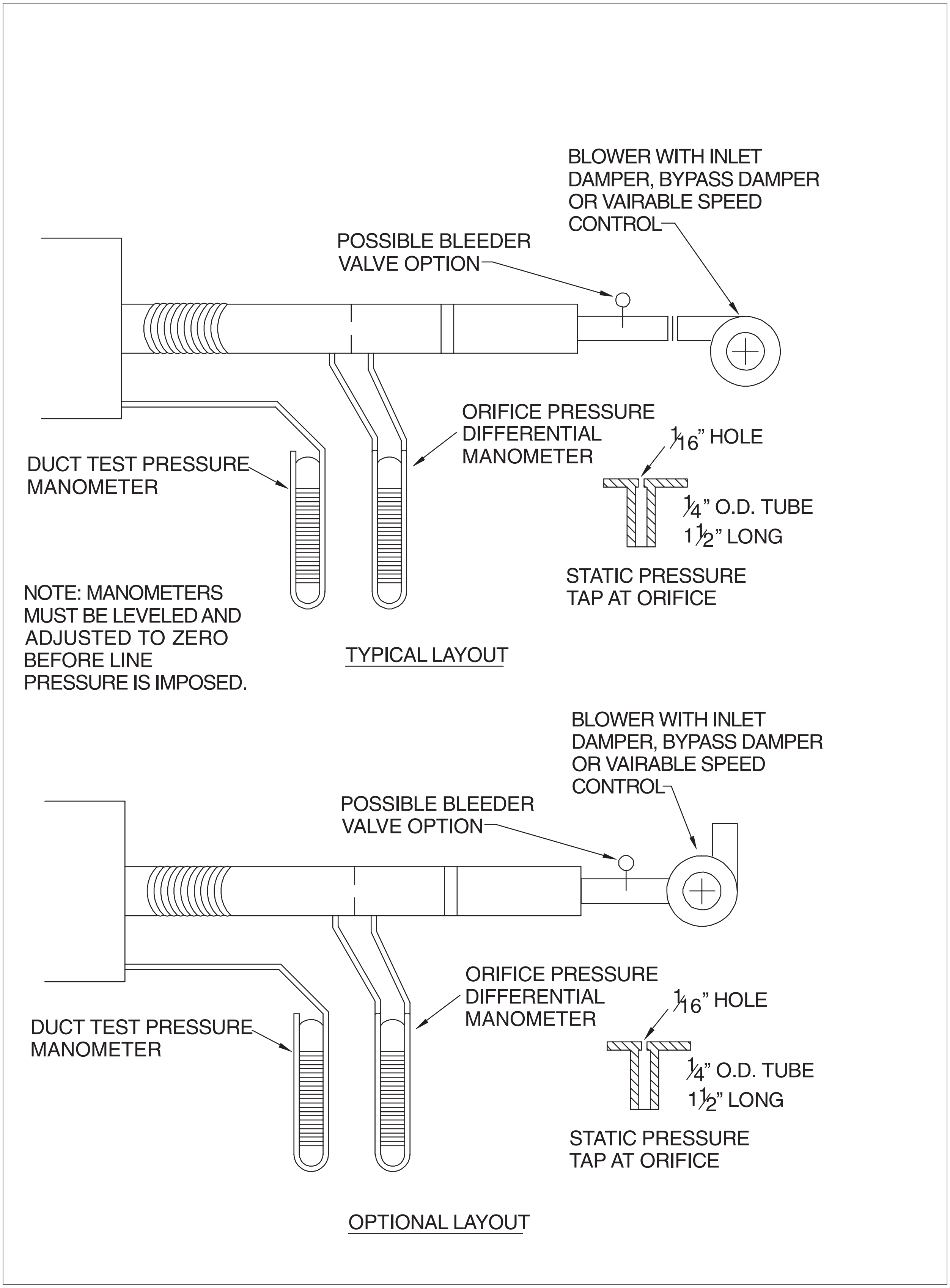
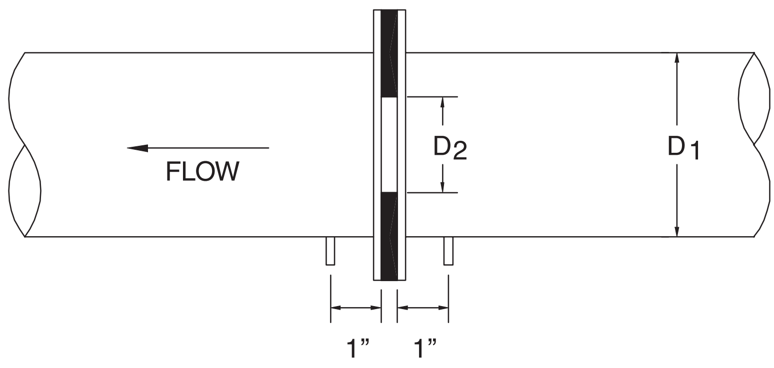
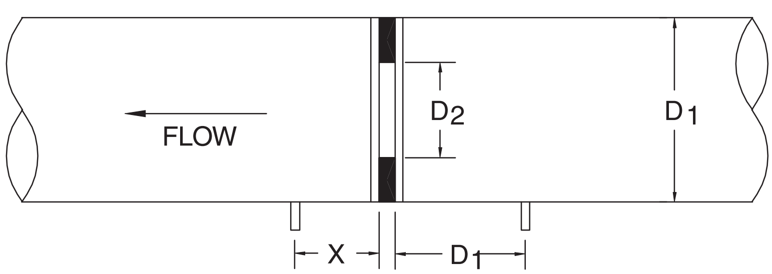


FIGURE 6–1 LEAKAGE TEST METER APPARATUS-FLANGE TAPS



LOCATION OF FLANGE TAPS
USE 3⁄32" OR 1⁄8" SQUARE EDGE ORIFICE PLATE



LOCATION OF VENA CONTRACTA TAPS
USE 3⁄32" OR 1⁄8" SQUARE EDGE ORIFICE PLATE

$\frac{D_2}{D_1}$	X
0.2	0.74 D_1
0.3	0.71 D_1
0.4	0.66 D_1
0.5	0.60 D_1
0.6	0.53 D_1
0.7	0.45 D_1
0.8	0.36 D_1

FIGURE 6–2 LEAKAGE TEST METER APPARATUS-VENA CONTRACTA TAPS

D_2/D_1 is less than 0.5. This assumes that there are no extraordinary pressure losses in the test meter and duct connecting it to the test specimen.

- Select the orifice tube from Figure 6-3 or use Table 6-1 and Equation 6-1 to size an orifice tube that will have a flow curve of the desired range and still be within the capacity of the blower. Characteristics of typical orifices are shown in Table 6-2.

Precautions that must be followed for test apparatus:

- Start the blower at low speed or with blocked suction or discharge to avoid over pressurizing ductwork.
- Use clean manometers.
- Heat manometers to avoid freezing fluid in cold weather. Or use a liquid and manometer combination for cold weather.
- If manometer fluid is blown out; refill with the appropriate fluid; it is permissible for convenience add a drop of water soluble dye to water-filled manometers. The dye must be the same specific gravity as the fluid
- Level position sensitive instruments and set them to zero scale reading.
- Read liquid levels by viewing them horizontally.
- Record instruments used for testing.

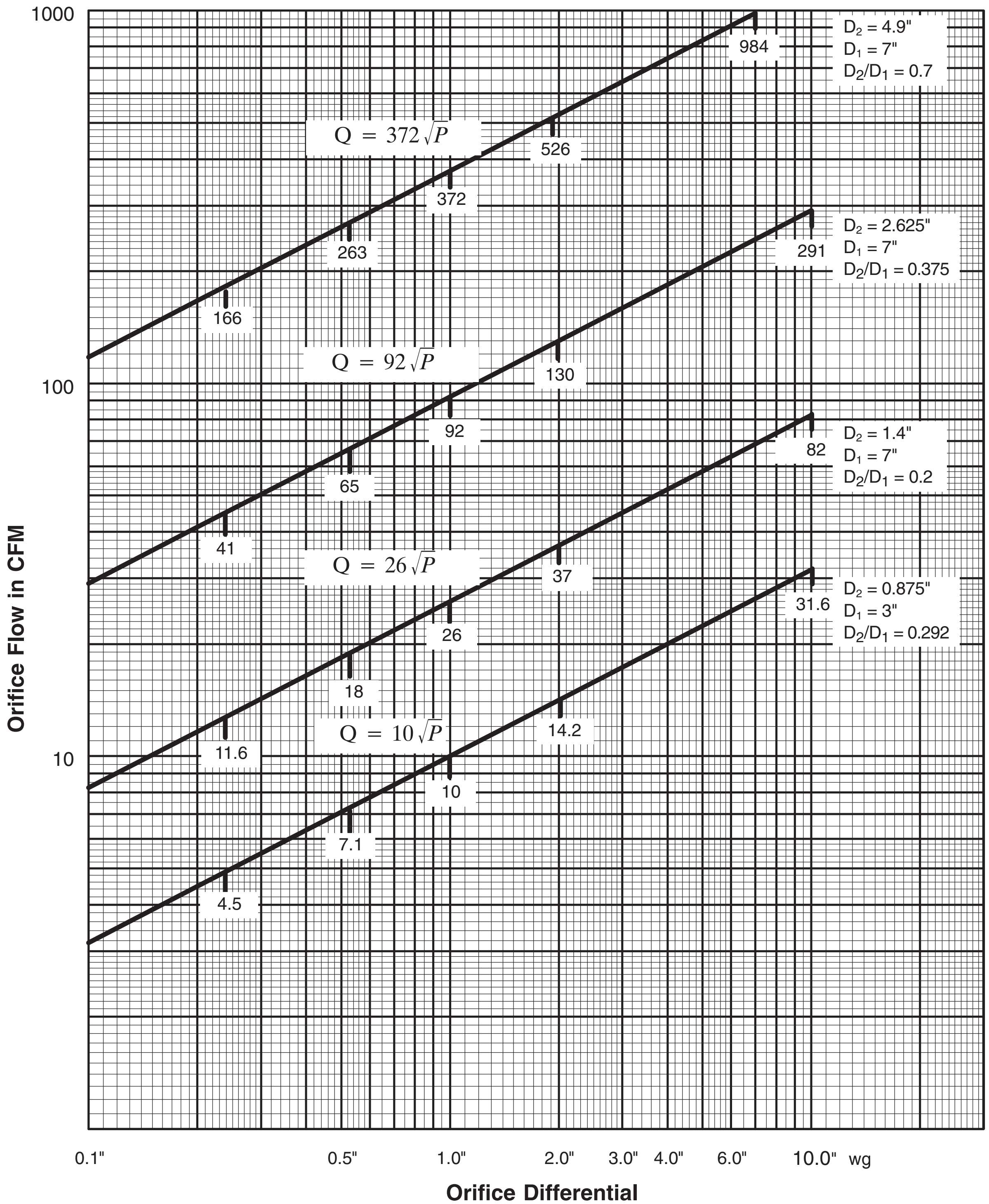


FIGURE 6–3 TYPICAL ORIFICE FLOW CURVES

ΔP in. wg	Orifice Size			ΔP in. wg	Orifice Size			ΔP in. wg	Orifice Size		
	1.4"	2.625"	4.90"		1.4"	2.625"	4.90"		1.4"	2.625"	4.90"
0.02			57.1	1.22	28.7	101.4	410.3	4.10	52.3	185.3	746
0.04		18.7	78.8	1.24	28.9	102.3	413.6	4.20	52.9	187.5	755
0.06		22.8	95.3	1.26	29.2	103.1	416.9	4.30	53.5	189.7	763
0.08		26.2	109.2	1.28	29.4	103.9	420.1	4.40	54.1	191.9	772
0.10		29.3	121.5	1.30	29.6	104.7	423.4	4.50	54.7	194.0	781
0.12		32.1	132.6	1.32	29.8	105.5	426.5	4.60	55.3	196.2	789
0.14		34.6	142.8	1.34	30.1	106.3	429.7	4.70	55.9	198.3	797
0.16		37.0	152.3	1.36	30.3	107.1	432.9	4.80	56.5	200.4	806
0.18		39.2	161.2	1.38	30.5	107.9	436.0	4.90	57.1	202.4	814
0.20		41.3	169.6	1.40	30.7	108.6	439.1	5.00	57.6	204.4	822
0.22		43.3	177.6	1.42	30.9	109.4	442.2	5.10	58.2	206.5	830
0.24		45.2	185.2	1.44	31.2	110.2	445.2	5.20	58.8	208.5	838
0.26		47.0	192.6	1.46	31.4	110.9	448.3	5.30	59.3	210.4	846
0.28		48.8	199.6	1.48	31.6	111.7	451.3	5.40	59.9	212.4	854
0.30		50.5	206.5	1.50	31.8	112.4	454.3	5.50	60.4	214.3	862
0.32		52.1	213.0	1.52	32.0	113.2	457.2	5.60	61.0	216.3	869
0.34		53.7	219.4	1.54	32.2	113.9	460.2	5.70	61.5	218.2	877
0.36		55.3	225.6	1.56	32.4	114.6	463.1	5.80	62.0	220.0	884
0.38		56.8	231.6	1.58	32.6	115.4	466.0	5.90	62.6	221.9	892
0.40		58.3	237.5	1.60	32.8	116.1	468.9	6.00	63.1	223.8	899
0.42		59.7	243.2	1.62	33.0	116.8	471.8	6.10	63.6	225.6	907
0.44		61.1	248.8	1.64	33.2	117.5	474.7	6.20	64.1	227.4	914
0.46		62.4	254.3	1.66	33.4	118.2	477.5	6.30	64.6	229.2	921
0.48		63.8	259.6	1.68	33.6	118.9	480.3	6.40	65.1	231.0	928
0.50	18.5	65.1	264.9	1.70	33.8	119.6	483.1	6.50	65.6	232.8	935
0.52	18.8	66.4	270.0	1.72	34.0	120.3	485.9	6.60	66.1	234.6	942
0.54	19.2	67.6	275.0	1.74	34.2	121.0	488.7	6.70	66.6	236.3	949
0.56	19.5	68.9	280.0	1.76	34.4	121.7	491.5	6.80	67.1	238.1	956
0.58	19.9	70.1	284.8	1.78	34.6	122.4	494.2	6.90	67.6	239.8	963
0.60	20.2	71.3	289.6	1.80	34.8	123.1	496.9	7.00	68.1	241.4	970
0.62	20.6	72.4	294.3	1.82	35.0	123.8	499.7	7.10	68.5	243.2	977
0.64	20.9	73.6	298.9	1.84	35.2	124.4	502.4	7.20	69.0	244.9	984
0.66	21.2	74.7	303.4	1.86	35.4	125.1	505.0	7.30	69.5	246.5	990
0.68	21.5	75.8	307.9	1.88	35.5	125.8	507.7	7.40	69.9	248.2	997
0.70	21.8	76.9	312.3	1.90	35.7	126.4	510.4	7.50	70.4	249.9	1003
0.72	22.1	78.0	316.7	1.92	35.9	127.1	513.0	7.60	70.9	251.5	1010
0.74	22.4	79.1	320.9	1.94	36.1	127.8	515.6	7.70	71.3	253.1	1017
0.76	22.7	80.2	325.2	1.96	36.3	128.4	518.2	7.80	71.8	254.7	1023
0.78	23.0	81.2	329.3	1.98	36.5	129.1	520.8	7.90	72.2	256.4	1029
0.80	23.3	82.2	333.5	2.00	36.6	129.7	523.4	8.00	72.7	257.9	1036
0.82	23.6	83.2	337.5	2.10	37.5	132.9	536.2	8.10	73,1	259.5	1042
0.84	23.9	84.2	341.6	2.20	38.4	136.0	548.6	8.20	73.6	261.1	1048
0.86	24.1	85.2	345.5	2.30	39.3	139.0	560.8	8.30	74.0	262.7	1055
0.88	24.4	86.2	349.4	2.40	40.1	142.0	572.6	8.40	74.5	264.2	1061
0.90	24.7	87.2	353.3	2.50	40.9	144.9	584.3	8.50	74.9	265.8	1067
0.92	25.0	88.1	357.2	2.60	41.7	147.8	595.7	8.60	75.3	267.3	1073
0.94	25.2	89.1	361.0	2.70	42.5	150.6	606.9	8.70	75.7	268.8	1079
0.96	25.5	90.0	364.7	2.80	43.3	153.3	617.9	8.80	76.2	270.4	1085
0.98	25.8	91.0	368.4	2.90	44.0	156.0	628.6	8.90	76.6	271.9	1091
1.00	26.0	91.9	372.1	3.00	44.8	158.7	639.2	9.00	77.0	273.4	1097
1.02	26.3	92.8	375.7	3.10	45.5	161.3	649.6	9.10	77.4	274.9	1103
1.04	26.5	93.7	379.3	3.20	46.2	163.8	659.9	9.20	77.9	276.4	1109
1.06	26.8	94.6	382.9	3.30	46.9	166.4	670.0	9.30	78.3	277.8	1115
1.08	27.0	95.5	386.4	3.40	47.6	168.8	679.9	9.40	78.7	279.3	1121
1.10	27.3	96.3	390.0	3.50	48.3	171.3	689.7	9.50	79.1	280.8	1127
1.12	27.5	97.2	393.4	3.60	49.0	173.7	699.3	9.60	79.5	282.2	1132
1.14	27.8	98.1	396.9	3.70	49.7	176.1	708.8	9.70	79.9	283.6	1138
1.16	28.0	98.9	400.3	3.80	50.3	178.4	718.2	9.80	80.3	285.1	1144
1.18	28.2	99.8	403.7	3.90	51.0	180.7	727.5	9.90	80.7	286.5	1150
1.20	28.5	100.6	407.0	4.00	51.6	183.0	736.6	10.00	81.1	287.9	1155

Table 6–2 Orifice Flow Rate (SCFM) Versus Pressure Differential (in. of Water)

Based on 7" Diameter Tube with Flange (Pipe) Taps.

Although the table gives cfm to the nearest 0.1, test reports should list numbers rounded to the nearest cfm. Accuracy to the nearest 0.1 is not implied. SCFM denotes air at standard conditions of 70°F and 0.075 lb/cf density.

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CHAPTER 7

TEST REPORTS

7.1 DUCT LEAKAGE TEST REPORT DETAILS

When leakage tests are required, preparation for these shall include the following:

- Review of the specification requirements for testing.
- Understanding of the acceptance criteria.
- Review of the general procedures outlined in Section 4.1.
- Familiarity with the leakage classification analysis in Section 5.1.
- Test scheduling.
- Test apparatus acquisition.
- Delivery of notices to concerned parties and witnesses.
- Preliminary data entry on report forms.

7.2 SPECIFIC REQUIREMENTS

The designer has adequately analyzed the systems and clearly specified the test parameters the reporting procedure is relatively simple. As discussed in previous sections the following requirements shall be clearly specified:

- Test Pressure (equivalent to the duct construction pressure class unless otherwise specified but never greater than the duct construction pressure class.)
- Leakage Class (class selected from Table 5-1).
- Amount of system to be tested (10%, 20%, 50%, all).
- If the test pressure or leakage class has not been provided, *see* Appendix C and Section 2.1.

7.3 TESTING SUB-SECTIONS

Verification of compliance consists of testing sections of duct at the specified pressure level, finding the leakage in CFM and comparing this with the allowable amount associated with the leakage class. When several separate segments within the same system and pressure class are tested for compliance, the aggregate leakage shall not exceed the allowable, even though the amount in one or more segments may somewhat exceed the cfm allowable indicated for each segment. In such case, to compensate, another segment would have to be tighter than required. If the duct is not in compliance refer to Section 4.1 of the general procedures.

7.4 DUCT LEAKAGE REPORTING PROCEDURE

A suggested test summary report form is provided on page 7-2, and a sample of a completed report is shown on page 7-3. The orifice tube data entries can be eliminated if a different type of test apparatus is used. In such cases, record the type of meter on the test report.

Procedure for completing a report.

- Log the project and system identification data.
- Enter the fan CFM (Q), the test pressure (P_T), and the leakage class (C_L) specified by the designer.
- Enter identification for each duct segment to be tested. Compute and enter the corresponding area of duct surface area excluding any equipment connected in-line.
- Look up the allowable leakage factor (F) from Figure 5-1 or Appendix E. Enter this number on the report for each test segment. (This value can also be computed as $F = C_L \times p^{0.65}$).
- Calculate the allowable leakage for each test segment by multiplying the surface area by the leakage factor, then dividing by 100.
- Conduct and record the field tests. If the sum of the CFM measured is less than or equal to the sum of the allowable leakage the test is passed. Record the date(s), presence of witnesses and flow meter characteristics.

Test reports shall be submitted as required by the project documents.

Project Name ____________ Project No. ____________ Page ______ of ______

AIR DUCT LEAKAGE TEST SUMMARY

Air System ____________ Duct Construction Pressure ____________

Fan CFM ____________ Specified Test Pressure ____________

Design Data					Field Test Data					
Subject Duct	Surface Area (ft^2)	Leakage Criteria			Equipment	Test Data	Date	Performed By:	Witnessed By:	Measured CFM
		Leakage Class	Leakage Factor ($CFM/100ft^2$)	CFM (section)	ID #	ΔP (in. w.g.)				
TOTALS										

Project Name Main St. Library Project No 3432 Page 1 of 1

AIR DUCT LEAKAGE TEST SUMMARY

Air System HVAC-2

Fan CFM 24,000

Duct Construction Pressure 6

Specified Test Pressure 6

Design Data					Field Test Data					
		Leakage Criteria			Equipment	Test Data				
Subject Duct	Surface Area (ft^2)	Leakage Class	Leakage Factor ($CFM/100ft^2$)	CFM (section)	ID #	ΔP (in. w.g.)	Date	Performed By:	Witnessed By:	Measured CFM
Total System	9600									
Test Sections										
Risers	840	4	12.8	108	91974	1.36	1/12/2010	MAT	EPH	103
3rd FL. Main	560	4	12.8	72	91974	0.58	6/22/2010	PEC	EPH	70
North Branch	410	4	12.8	52	91974	0.32	9/24/2010	MAT	EPH	52
East branch	480	4	12.8	61	91974	0.48	11/15/2010	MAT	EPH	64
TOTALS	**2290**			**293**						**289**

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APPENDIX A

Leakage Class (C_L)	Fan cfm Prorated* per ft^2	Static Pressure (in. wg)						
		½	1	2	3	4	6	10
48	2	15	24	38	Rates in this area do not apply to HVAC duct constructed to SMACNA standards			
	2.5	12	19	30				
	3	10	16	25				
	4	7.6	12	19				
	5	6.1	9.6	15				
16	2	5.1	8.0	13	16			
	2.5	4.1	6.4	10	13			
	3	3.4	5.3	8.4	11			
	4	2.5	4.0	6.3	8.2			
	5	2.0	3.2	5.0	6.5			
8	2	2.5	4.0	6.3	8.2	9.8		
	2.5	2.0	3.2	5.0	6.5	7.9		
	3	1.7	2.7	4.2	5.4	6.6		
	4	1.3	2.0	3.1	4.1	4.9		
	5	1.0	1.6	2.5	3.3	3.9		
4	2	1.3	2.0	3.1	4.1	4.9	6.4	8.9
	2.5	1.0	1.6	2.5	3.3	3.9	5.1	7.1
	3	0.8	1.3	2.1	2.7	3.3	4.3	6.0
	4	0.6	1.0	1.6	2.0	2.5	3.2	4.5
	5	0.5	0.8	1.3	1.6	2.0	2.6	3.6
2	2	0.6	1.0	1.6	2.0	2.5	3.2	4.5
	2.5	0.5	0.8	1.3	1.6	2.0	2.6	3.6
	3	0.4	0.7	1.0	1.4	1.6	2.1	3.0
	4	0.3	0.5	0.8	1.0	1.2	1.6	2.2
	5	0.3	0.4	0.6	0.8	1.0	1.3	1.8

Table A–1 Leakage as Percent of Flow in System

*Typically $\frac{FAN\_CFM}{DUCT\_SURFACE\_AREA}$ will be 2 to 5 cfm/square ft of duct surface.

Class 48 is average unsealed rectangular duct. Class 16 and lower are anticipated results for sealed ducts.

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APPENDIX B

B.1 SAMPLE LEAKAGE ANALYSIS

Since the system size and the impracticality of attempting to reach unrealistically low levels of leakage are such prominent considerations, the evaluation of leakage by the percentage method is not recommended. However, it is recognized that a percent of fan cfm or a percent of flow in a section of a system that passes through unconditioned space (considered as a heat loss or a heat gain) can be a useful parameter in energy conservation analysis. Leakage as a percent of flow entering one selected section of duct is not an adequate appraisal of the system performance. Five percent of the system flow is quite a different criterion than allowing 5% in each 100 ft of a 500 ft continuous run of duct. It should also be remembered that actual leakage will be less than that appraised for the maximum pressure, because the average pressure under operating conditions will be less.

Leakage as a percent of flow has been related to leakage class and pressure in Appendix A. As Appendix A is studied, the significance of seal classes A, B, and C as applicable to duct pressure classes, *see* Table 5–1 must be understood. An example of the application of leakage classes to a duct system is provided to aid a realistic approach to the use of seal class, leakage class and percentage method analysis. While other parameters such as cubic contents (of duct interior) or lineal feet of joint might be used for leakage evaluation they are less practical and should not be used unless the square footage analysis has already been made.

B.2 SYSTEM LEAKAGE CLASSIFICATION ANALYSIS

B.2.1 SYSTEM DATA

Leakage Evaluation for Supply Duct in Fig. B-1, page B.3.

8000 cfm fan
½ in. wg duct construction class
333 linear feet of duct
1926 ft^2 duct surface area

4.2 cfm/ft^2 of duct surface area. is average distribution

$$\left(i.e., \frac{8000\,cfm}{1926\,ft^2} = 4.15\frac{cfm}{ft^2} \right)$$

B.3 LEAKAGE ANALYSIS

- Unsealed duct at 1/2" static pressure. At ½ in. static pressure on Class 48 curve in Figure 5–1, $F = \frac{30\,cfm}{100\,ft^2}$.

  $$\frac{30\,cfm}{100\,ft^2} \times 1926\,ft^2 = 578\,cfm$$

  578 cfm is 7.2% of 8000 cfm fan capacity.

  Alternative Calculation (as in Appendix A)

  $$\frac{8000\,cfm}{1926\,ft^2} = 4.2 : 1 \text{ ratio}$$

  Allowable leakage factor $30x\frac{1}{4.2} = 7.1\%$

NOTE: The difference (7.1 vs 7.2) occurs because 4.2 is rounded from 4.154.

- Unsealed duct (1/2 in. static pressure class) operating at 0.3 in. static pressure. If the system actually operates with 0.3 in. average static pressure and is unsealed, $\frac{22\,cfm}{100\,ft^2}$ leakage is read from the Class 48 curve on Figure 5–1 at 0.3 in. pressure. This is 424 cfm or 5.3%.

- Leakage Class 16 Requirement, (1/2 in. Static Pressure)

  From Figure 5–1, $\frac{10\,cfm}{100\,ft^2}$ is read.

$$\frac{10\ cfm}{100\ ft^2} \times 1926\ ft^2 = 192.6\ cfm$$

192.6 cfm is 2.4% of fan capacity.

Alternative calculation

$$10 \times \frac{1}{4.2} = 2.4\%$$

- Leakage Class 8 Requirement, (1/2" Static Pressure)

From Figure 5–1, $\frac{5.1\ cfm}{100\ ft^2}$

$$\frac{5.1\ cfm}{100\ ft^2} \times 1926\ ft^2 = 98.2\ cfm$$

98.2 cfm is 1.2% of fan capacity

- Allowable leakage of 5% to fan capacity

If 5% of fan capacity is allowed for air leakage

$.05 \times 8000\ cfm = 400\ cfm$

$$\frac{400\ cfm}{1926\ ft^2} \times \frac{100 ft^2}{100 ft^2} = \frac{20.8\ cfm}{100\ ft^2}$$

To convert this to a leakage class C_L:

$$C_L = \frac{F}{P^{0.65}} = \frac{20.8}{0.5^{0.65}} = \frac{20.8}{0.64} = 32.5$$

- Figure B-1 shows a fire damper, volume dampers and a flexible connection (vibration isolation type). The designer should account for this air leakage (accessory air leakage) in addition to the duct air leakage. If testing through these devices allowances must be made to the allowable leakage rates. Consult the manufacturer for these leakage rates and at what pressure they were tested. If the data is not available then avoid testing through these devices.

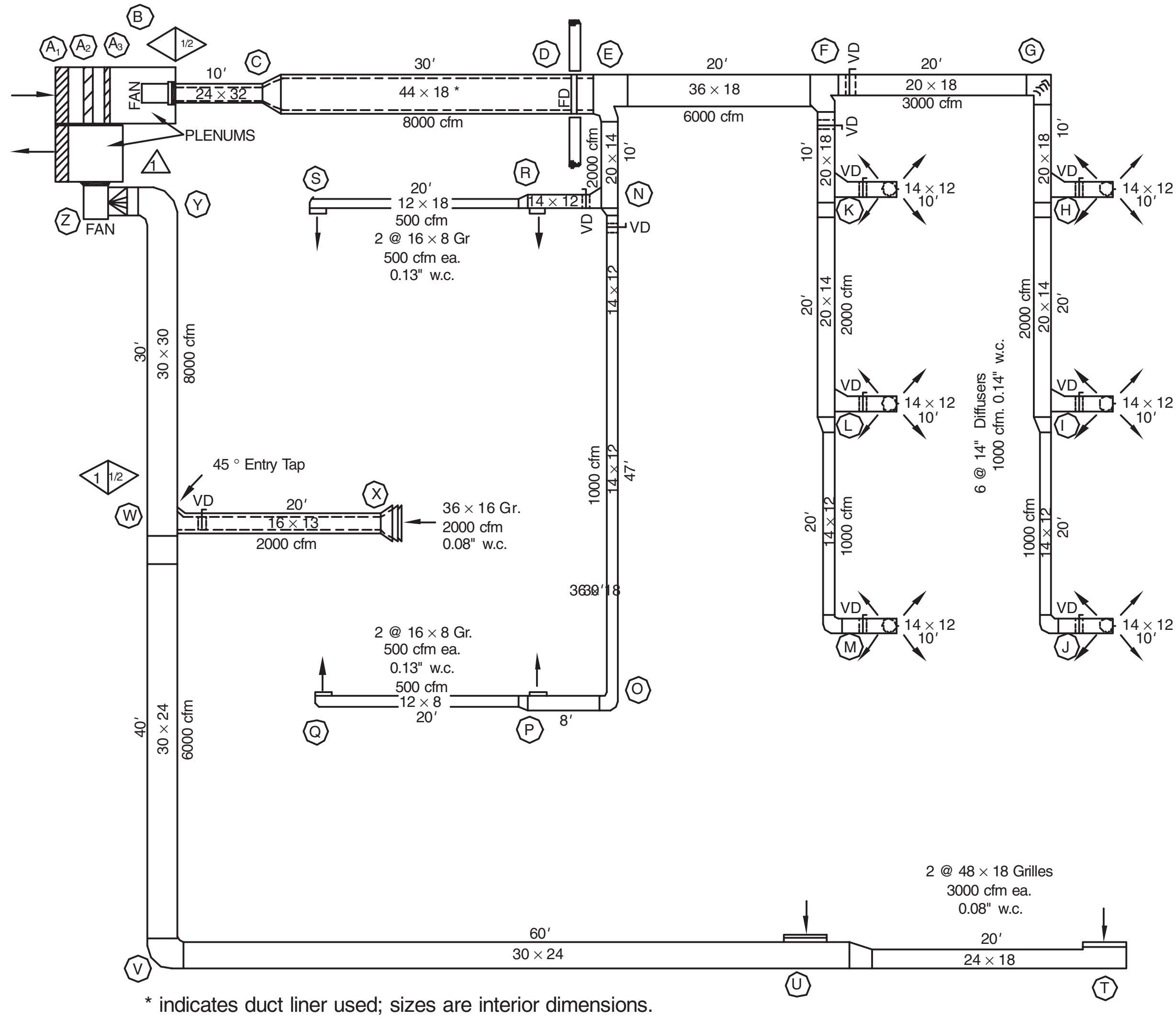

FIGURE B–1 DUCT SYSTEM EXAMPLE

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APPENDIX C

SUGGESTED ANALYSIS WHEN DESIGNER IS NOT USING THE SMACNA CRITERIA FOR SPECIFYING DUCT AIR LEAKAGE TESTING, DOES NOT PROVIDE LEAKAGE CLASS OR TEST PRESSURE AND ONLY REQUIRES TESTING TO MEET A PERCENTAGE AS ALLOWABLE LEAKAGE

C.1 LEAKAGE RATE DETERMINATION

When a leakage class is specified it is relatively simple to find the allowable leakage for a given test segment. However, when a total allowable leakage is expressed as a percent of total flow, it is somewhat more cumbersome to prorate the allowable leakage to any single test segment. A suggested method is as follows:

1. Calculate the total amount of allowable leakage by multiplying the percent allowable by the total flow of the fan.

2. Calculate the area of the entire duct system in square feet.

3. Divide the allowable leakage obtained in 1 by the total area obtained in 2 then multiply by 100 to obtain a leakage rate, F expressed as cfm/100 ft^2 of duct surface area. Enter this number on the report for each test segment.

4. Calculate the allowable leakage for each test segment by multiplying its surface area by the leakage factor obtained in 3. Remember to divide by 100 since F is expressed as leakage per 100 ft^2 of duct surface area.

At this point the contractor may find it informative to relate the contract requirements to the leakage suggested in Table 5.1. This can be done as follows:

$$C_L = \frac{F \times 100}{P^{0.65}}$$

In this formula F is the leakage rate obtained in paragraph 3. above expressed as cfm/100 ft^2, and P is the test pressure in inches water gauge.

Compare the numerical value of the leakage class obtained through this calculation with the suggested leakage classes for the type of duct construction and extent of sealing used. **If the calculated value is below the value suggested in Table 5–1 the contractor should anticipate some difficulty in obtaining satisfactory test results. The greater the difference is, the greater the difficulty will be. Resolve the issue under Sections 3.1(e) and 3.2(c) of the *HVAC AIR DUCT LEAKAGE TEST MANUAL*.**

Example:

The supply system has the following data:

8000 cfm
3 in. wg construction
1926 ft^2 of duct surface area (rectangular duct)
Allowable leakage rate of 5%

Step 1 $0.05 \times 8000\ cfm = 400\ cfm$ (total allowable leakage)

Step 2 Given above as 1926 ft^2

Step 3 $$F = \frac{400\ cfm}{1926\ ft^2} \times \frac{100\ ft^2}{100\ ft^2} = \frac{20.8\ cfm}{100\ ft^2}$$

Step 4 $$C_L = \frac{F}{P^{0.65}} = \frac{20.8}{3^{0.65}} = 10.2$$

Checking Table 5–1 for 3 in. wg, seal class B the expected leakage class for rectangular duct is 8 (16.3 cfm/100 ft^2). The air leakage rate required should be obtainable for the duct. If the leakage rate includes accessory air leakage and equipment air leakage this rate may or may not be obtainable. That would depend on the type and amount of accessories and equipment in the system. The example above would allow (20.8 – 16.3) 4.5 cfm/100ft^2 or 87 cfm or 1% of system air flow for other sources of air leakage.

C.2 TEST PRESSURE DETERMINATION

The duct will be constructed for the specified pressure class (or classes). It is not practical, or accurate to include duct from two different construction classes in the same leakage test segment. Ducts should never be leak tested at pressures greater than the construction class.

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APPENDIX D

D.1 SAMPLE PROJECT SPECIFICATION

NOTICE TO DESIGNERS:
WHEN TESTS ARE DEEMED NECESSARY, A TEST OF A REPRESENTATIVE SAMPLE OF THE DUCT IS RECOMMENDED. IF SAMPLE IS DEFECTIVE, THE CONTRACTOR SHOULD REPAIR OR MODIFY THE CONSTRUCTION. IF RESULTS OF SAMPLE TEST MEET THE SPECIFIED AIR LEAKAGE CRITERIA, CONTRACTOR SHALL BE PERMITTED TO PROCEED WITHOUT FURTHER TESTING. VISUAL INSPECTION AND EXAMINATION OF OPERATING CONDITIONS SHOULD SUFFICE TO JUSTIFY FAITH IN METHODS USED.

Contractor shall, at the beginning of the work construct, erect and leak test a representative sample of the duct construction to be used at the ____ pressure class. The sample specimen shall include at least five transverse joints, typical seams, and at least two typical branch connections plus an elbow.

The leakage amount shall not exceed the allotted amount for the pressure class or the allotted amount for that portion of the system, whichever is applicable.

Duct Construction Pressure Class	Leakage Class	
	Rectangular Duct	Round Duct
10 in. wg	4	2
6 in. wg	4	2
4 in. wg	4	2
3 in. wg	8	4

NOTE: See Chapter 5 of the SMACNA HVAC AIR DUCT LEAKAGE TEST MANUAL for normal classification.

Leakage test procedures shall follow the outlines and classifications in the SMACNA *HVAC AIR DUCT LEAKAGE TEST MANUAL*.

If specimen fails to meet specified air leakage criteria, the contractor shall modify fabrication methods to bring it into compliance and shall retest it until acceptable duct air leakage is demonstrated.

Tests and necessary repair shall be completed prior to concealment of ducts.

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APPENDIX E

Pressure (P) in. wg	$P^{0.65}$	Leakage Class (C_L)				Unsealed
		Class 2	Class 4	Class 8	Class 16	Class 48
0.05	0.143	0.3	0.6	1.1	2.3	6.8
0.1	0.224	0.4	0.9	1.8	3.6	10.7
0.2	0.351	0.7	1.4	2.8	5.6	16.9
0.3	0.457	0.9	1.8	3.7	7.3	21.9
0.4	0.551	1.1	2.2	4.4	8.8	26.5
0.5	0.637	1.3	2.5	5.1	10.2	30.6
0.6	0.717	1.4	2.9	5.7	11.5	34.4
0.7	0.793	1.6	3.2	6.3	12.7	38.1
0.8	0.865	1.7	3.5	6.9	13.8	41.5
0.9	0.934	1.9	3.7	7.5	14.9	44.8
1.0	1.00	2.0	4.0	8.0	16.0	48.0
1.5	1.30	2.6	5.2	10.4	20.8	62.5
2.0	1.57	3.1	6.3	12.6	25.1	75.3
2.5	1.81	3.6	7.3	14.5	29.0	87.1
3.0	2.04	4.1	8.2	16.3	32.7	98.0
3.5	2.26	4.5	9.0	18.1	36.1	108.4
4.0	2.46	4.9	9.8			
4.5	2.66	5.3	10.6			
5.0	2.85	5.7	11.4			
5.5	3.03	6.1	12.1			
6.0	3.20	6.4	12.8			
7.0	3.54	7.1	14.2	$F = C_L (P^{0.65})$		
8.0	3.86	7.7	15.5			
9.0	4.17	8.3	16.7			
10.0	4.47	8.9	17.9			

Table E–1 Leakage Factor *F* Expressed As cfm/100ft^2 of Duct Surface Area

These factors can be read from Figure 5–1.

See Table 5–1 for Seal Class and Pressure Class

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APPENDIX F

F.1 UNDER FLOOR AIR DISTRIBUTION SYSTEMS

Non-Ducted Under Floor Air Distribution (UFAD) systems present a unique set of circumstances that make leakage testing a very time consuming process not fully covered in this standard. UFAD systems have two types of leakage that contribute to the overall air leakage of the system. The first is referred to as Category 1 and includes air leaks that occur through 'general construction' items such as the building slabs, and walls. These items allow air to leak from the plenum to other building cavities. The other type of leakage encountered in UFAD systems is Category 2. Category 2 leakage includes air that leaks through the components of the UFAD system such as the air highway panels themselves and IT or Power boxes.

In addition to the issues associated with ducted systems, such as increased HVAC fan horsepower, leaks from UFAD systems can travel into the building's interior and exterior structure.

Testing by ASHRAE and the US General Services Administration (GSA) has shown that non ducted UFAD systems leak air in the range of 30% to 200% of the systems design airflow at a plenum static pressure of .07 in. wg. Results over 100% indicate that the volume of air required to achieve the test pressure is greater than the design air flow.

As mentioned earlier the leakage comes from two sources. Category 1 leakage is of particular concern because to reduce this type of air leakage would require a significant effort and close coordination of multiple building trades. Furthermore, testing shows that predictions of air leakage are unreliable.

To avoid problems designers have begun requiring full-scale mockups of the UFAD "system" so that it can be tested and used to educate all involved trades what its role is in the installation of the UFAD system.

The ducts used in ducted UFAD systems can be tested with the methods described in this manual.

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APPENDIX G

Leakage Rate CFM/100 SFD	Leak Test Rig Flow Capacity in cfm							
	25	**50**	**100**	**150**	**200**	**250**	**300**	**400**
1	2500	5000	10,000	15,000	20,000	25,000	30,000	40,000
2	1250	2500	5000	7500	10,000	12,500	15,000	20,000
3	833	1666	3333	5000	6666	8333	10,000	13,333
4	625	1250	2500	3750	5000	6250	7500	10,000
5	500	1000	2000	3000	4000	5000	6000	8000
6	417	833	1667	2500	3333	4167	5000	6667
10	250	500	1000	1500	2000	2500	3000	4000
12	208	417	833	1250	1667	2083	2500	3333
15	167	333	666	1000	1333	1667	2000	2667
20	125	250	500	750	1000	1250	1500	2000
25	100	200	400	600	800	1000	1200	1600
30	83	167	333	500	667	833	1000	1333
50	50	100	200	300	400	500	600	800

Table G–1 Amount of Duct to be Leak Tested (SFD)

SFD IS DUCT SURFACE AREA IN SQUARE FEET

NOTE: The static pressure for the test must develop within the cfm range of the test rig; if it does not the leakage in the amount of duct tested is (probably) greater than the estimated amount.

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APPENDIX H

DUCT DIMENSION (DEPTH)	Duct Dimension (Width)																						
	6"	8"	10"	12"	14"	16"	18"	20"	22"	24"	26"	28"	30"	36"	42"	48"	54"	60"	66"	72"	84"	96"	108"
6"	2.00	2.33	2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	15.00	17.00	19.00
8"		2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	7.33	8.33	9.33	10.33	11.33	12.33	13.33	15.33	17.33	19.33
10"			3.33	3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	6.67	7.67	8.67	9.67	10.67	11.67	12.67	13.67	15.67	17.67	19.67
12"				4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	6.67	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	16.00	18.00	20.00
14"					4.67	5.00	5.33	5.67	6.00	6.33	6.67	7.00	7.33	8.33	9.33	10.33	11.33	12.33	13.33	14.33	16.33	18.33	20.33
16"						5.33	5.67	6.00	6.33	6.67	7.00	7.33	7.67	8.67	9.67	10.67	11.67	12.67	13.67	14.67	16.67	18.67	20.67
18"							6.00	6.33	6.67	7.00	7.33	7.67	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	17.00	19.00	21.00
20"								6.67	7.00	7.33	7.67	8.00	8.33	9.33	10.33	11.33	12.33	13.33	14.33	15.33	17.33	19.33	21.33
22"									7.33	7.67	8.00	8.33	8.67	9.67	10.67	11.67	12.67	13.67	14.67	15.67	17.67	19.67	21.67
24"										8.00	8.33	8.67	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	18.00	20.00	22.00
26"											8.67	9.00	9.33	10.33	11.33	12.33	13.33	14.33	15.33	16.33	18.33	20.33	22.33
28"												9.33	9.67	10.67	11.67	12.67	13.67	14.67	15.67	16.67	18.67	20.67	22.67
30"													10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	19.00	21.00	23.00
36"														12.00	13.00	14.00	15.00	16.00	17.00	18.00	20.00	22.00	24.00
42"															14.00	15.00	16.00	17.00	18.00	19.00	21.00	23.00	25.00
48"																16.00	17.00	18.00	19.00	20.00	22.00	24.00	26.00
54"																	18.00	19.00	20.00	21.00	23.00	25.00	27.00
60"																		20.00	21.00	22.00	24.00	26.00	28.00
66"																			22.00	23.00	25.00	27.00	29.00
72"																				24.00	26.00	28.00	30.00
84"																					28.00	30.00	32.00
96"																						32.00	34.00
108"																							36.00

Table H–1 Duct Surface Area For Rectangular Duct in Square Feet per Linear Foot

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APPENDIX I

Diameter (inch)	Surface Area ft^2/ linear ft	Diameter (inch)	Surface Area ft^2/ linear ft	Diameter (inch)	Surface Area ft^2/ linear ft	Diameter (inch)	Surface Area ft^2/ linear ft
3	0.785	31	8.12	59	15.4	87	22.8
4	1.05	32	8.38	60	15.7	88	23.0
5	1.31	33	8.64	61	16.0	89	23.3
6	1.57	34	8.90	62	16.2	90	23.6
7	1.83	35	9.16	63	16.5	91	23.8
8	2.09	36	9.42	64	16.8	92	24.1
9	2.36	37	9.69	65	17.0	93	24.3
10	2.62	38	9.95	66	17.3	94	24.6
11	2.88	39	10.2	67	17.5	95	24.9
12	3.14	40	10.5	68	17.8	96	25.1
13	3.40	41	10.7	69	18.1	97	25.4
14	3.67	42	11.0	70	18.3	98	25.7
15	3.93	43	11.3	71	18.6	99	25.9
16	4.19	44	11.5	72	18.8	100	26.2
17	4.45	45	11.8	73	19.1	101	26.4
18	4.71	46	12.0	74	19.4	102	26.7
19	4.97	47	12.3	75	19.6	103	27.0
20	5.24	48	12.6	76	19.9	104	27.2
21	5.50	49	12.8	77	20.2	105	27.5
22	5.76	50	13.1	78	20.4	106	27.8
23	6.02	51	13.4	79	20.7	107	28.0
24	6.28	52	13.6	80	20.9	108	28.3
25	6.54	53	13.9	81	21.2	109	28.5
26	6.81	54	14.1	82	21.5	110	28.8
27	7.07	55	14.4	83	21.7	111	29.1
28	7.33	56	14.7	84	22.0	112	29.3
29	7.59	57	14.9	85	22.3	113	29.6
30	7.85	58	15.2	86	22.5	114	29.8

Table I-1 Duct Surface Area for Round Duct in Square Feet per Linear Foot

Minor Dimension (inches)	Major Dimension (inches)																						
	6	8	10	12	14	16	18	20	22	24	26	28	30	36	42	48	54	60	66	72	84	96	108
6	1.57	1.90	2.24	2.57	2.90	3.24	3.57	3.90	4.24	4.57	4.90	5.24	5.57	6.57	7.57	8.57	9.57	10.6	11.6	12.6	14.6	16.6	18.6
8		2.09	2.43	2.76	3.09	3.43	3.76	4.09	4.43	4.76	5.09	5.43	5.76	6.76	7.76	8.76	9.76	10.8	11.8	12.8	14.8	16.8	18.8
10			2.62	2.95	3.28	3.62	3.95	4.28	4.62	4.95	5.28	5.62	5.95	6.95	7.95	8.95	9.95	11.0	12.0	13.0	15.0	17.0	19.0
12				3.14	3.47	3.81	4.14	4.47	4.81	5.14	5.47	5.81	6.14	7.14	8.14	9.14	10.1	11.1	12.1	13.1	15.1	17.1	19.1
14					3.67	4.00	4.33	4.67	5.00	5.33	5.67	6.00	6.33	7.33	8.33	9.33	10.3	11.3	12.3	13.3	15.3	17.3	19.3
16						4.19	4.52	4.86	5.19	5.52	5.86	6.19	6.52	7.52	8.52	9.52	10.5	11.5	12.5	13.5	15.5	17.5	19.5
18							4.71	5.05	5.38	5.71	6.05	6.38	6.71	7.71	8.71	9.71	10.7	11.7	12.7	13.7	15.7	17.7	19.7
20								5.24	5.57	5.90	6.24	6.57	6.90	7.90	8.90	9.90	10.9	11.9	12.9	13.9	15.9	17.9	19.9
22									5.76	6.09	6.43	6.76	7.09	8.09	9.09	10.1	11.1	12.1	13.1	14.1	16.1	18.1	20.1
24										6.28	6.62	6.95	7.28	8.28	9.28	10.3	11.3	12.3	13.3	14.3	16.3	18.3	20.3
26											6.81	7.14	7.47	8.47	9.47	10.5	11.5	12.5	13.5	14.5	16.5	18.5	20.5
28												7.33	7.66	8.66	9.66	10.7	11.7	12.7	13.7	14.7	16.7	18.7	20.7
30													7.85	8.85	9.85	10.9	11.9	12.9	13.9	14.9	16.9	18.9	20.9
36														9.42	10.4	11.4	12.4	13.4	14.4	15.4	17.4	19.4	21.4
42															11.0	12.0	13.0	14.0	15.0	16.0	18.0	20.0	22.0
48																12.6	13.6	14.6	15.6	16.6	18.6	20.6	22.6
54																	14.1	15.1	16.1	17.1	19.1	21.1	23.1
60																		15.7	16.7	17.7	19.7	21.7	23.7
66																			17.3	18.3	20.3	22.3	24.3
72																				18.8	20.8	22.8	24.8
84																					22.0	24.0	26.0
96																						25.1	27.1
108																							28.3

Table I-2 Duct Surface Area for Flat Oval Duct in Square Feet per Linear Foot

Bold boxes indicate round duct (minor = major)

APPENDIX J

COMMENTARY ON FLOW CALCULATION FOR ORIFICE METERS

J.1 FLOW EQUATION DERIVATION

The basic flow equation is $Q = AV$ for which Q is in cfm, A is in ft^2 and V is in fpm. Velocity pressure head $h = \frac{V^2}{2g}$ and velocity $V = \sqrt{2gh}$ where g is the gravitational factor of 32.17 lb/ft-sec/sec. To use basic formula in inches of water gage pressure it is necessary to multiply the velocity head in feet by 12 in/ft and by the ratio of air density to water density $\frac{\rho \text{lb/ft}^3}{62.3 \text{ lb/ft}^3}$. To use velocity in fpm divide by 3600 s^2/m^2.

Thus, $h = \frac{V^2}{2(32.17)} \times \frac{12}{3600} \times \frac{\rho}{62.3}$

and $V = 1096.7 \sqrt{\frac{h}{\rho}}$

When $\rho = 0.075$, $V = 4005 \sqrt{h}$

Fluid flow texts indicate that for temperatures below 500°F thermal expansion effects in the orifice meter need not be accounted for. Also, for the normal range pressures in HVAC system testing, the effects of air compressibility are negligible. A combined coefficient K is used for various effects due to approach, contraction, discharge and pressure tap locations.

Standard airflow across a sharp edge orifice with $\rho = 0.075$ lb/ft^3 is calculated from

Equation J-1

$$Q = KAV = K\frac{\pi}{4}\frac{D^2}{144}1096.7\sqrt{\frac{\Delta P}{0.075}}$$

$$= 21.8KD^2\sqrt{\Delta P}$$

For densities other than standard, the following equation can be used as a good approximation:

Equation J–2

$$Q = 6KD^2\sqrt{\frac{\Delta P}{0.075\,d}}$$

where Q = air volume, cfm
K = coefficient of air flow
D = orifice diameter, inches
ΔP = pressure drop across orifice, in. wg
d = density factor from Appendix L

J.2 FLOWMETER ACCURACY

The coefficient K is affected by the Reynolds number, a dimensionless value expressing flow conditions in a duct. Appendix K relates Reynolds number, Beta ratio, and K. The following equation gives a simplified method of calculating Reynolds number for standard air:

$$R = 8.4\,DV$$

Where R = Reynolds number
D = Orifice diameter, inches
V = Velocity of air through orifice, fpm

The coefficient K is read from Appendix K for the type of meter taps used. It varies more below R values of 10^5 than for higher values. Some texts such as *Fan Engineering*, copyrighted by Buffalo Forge Co., use K coefficients for Reynolds number of 10^6 (with pipe diameter as the reference) as reasonably accurate for normal flow in 1½" to 16" diameter pipes, whether flange or vena contracta taps are used. Fisher and Porter Company reports in their *Flowmeter Orifice Sizing Handbook* that ASME publications and other research indicate that regardless of pipe size and standard orifice tap locations, only ±1% error is likely over a beta range of 0.12 to 0.72 if the equation for K is

$$K_c = 0.5930 + 0.4\beta^4 + (0.0015\sqrt{\beta} + 0.012\beta^4)\sqrt{\frac{1000}{R}}$$

The terms with β in this equation are relatively small and the practice of using $K = 0.60$ is fairly common. Flow approaching the orifice must be uniform to maintain accuracy. Straightening vanes or other flow straightening means must be used upstream. However, ASME and other texts point out that the basic orifice flow coefficients need modification for the effects of gas expansion if the pressure drop across the orifice is more than a few percent of the absolute pressure upstream of the orifice. Appendix L may be used to evaluate the effects of a gas expansion factor Y in terms of β the upstream pressure P_1, the ratio of specific heat at constant pressure to constant volume ($k = 1.4$ for air) and orifice pressure drop. The Y factor would reduce the apparent flow by becoming a multiplier in the formula $Q = K_c YAV$. The Y factor should be considered when determining the beta ratio to be used in a meter that is to be highly accurate.

Manometer scales are calibrated for fluids of specific density. Fluids with density corresponding to scale calibration must be used. Recalibration is not necessary. Densities of various manometer fluids are given in Appendix N.

The accuracy of the K coefficients in Figure 5–1 can be compared with those varying with Reynolds number in the following manner.

With 100 cfm in a 2.625” diameter orifice

$$R = 8.4\,DV = 8.4\,D\frac{Q}{A}$$

$$R = 8.4(2.625)\frac{100}{0.03758} = 5.87 \times 10^4$$

If $\frac{D_2}{D_1} = 0.375$, Figure K-1 gives $K = 0.61$ and Figure K-2 gives $K = 0.615$.

Observe that 0.623 from Table 6–1 is 102% of 0.61. With 30 cfm in a 1" diameter orifice,

$$R = 8.4(1)\frac{30}{0.00545} = 4.6 \times 10^4$$

If $\frac{D_2}{D_1} = 0.33$, Figure K-1 gives $K = 0.605$ and Figure K-2 gives $K = 0.61$.

Table 6–1 (interpolated) gives $K = 0.6024$ which is 98.8% of 0.61.

Various authorities agree that orifice meters that are precisely built to conform to ASME specifications do not require calibration. In Chapter 9 of *Industrial Ventilation*, ACGIH discusses orifice calibration with a standard Pitot tube and states that orifices conforming to meters indicated in Table 6–2 of this manual do not require calibration. Otherwise, the nominal values for K that are given in Table 6–1 are deemed suitable for flow measurement under field conditions. Table 6–1 is usable for vena contracta taps at all D_2/D_1 ratios and for flange taps when D_2/D_1 is 0.50 or less. Vena contracta taps or flange taps are acceptable for Figure 5–3 except that $Q = 372\sqrt{P}$ (with $K = 0.711$) may have 10% error with flange taps when Reynolds number is less than 10^5.

J.3 OVERALL METER LOSS

Where test apparatus fan capacity is marginal overall pressure loss through the orifice meter may contribute to difficulty in obtaining the required test pressure level in the duct. The overall loss in relation to the diameter ratio β is indicated in Table 6–1 and in Figure J-1.

J.4 METER CAPACITY FOR TESTED DUCT SIZE

A test meter must have a fan that can produce the target cfm at a static pressure that is a combination of the duct test pressure plus other “system” losses. The required capacity of a leakage test meter should be examined in relation to the duct leakage classification chart. The orifice relates cfm to pressure according to $Q = C \times P^{0.5}$. Leakage class is a plot of $Q = C \times P^{0.5}$. However, the orifice capacity needs to relate only to one pressure level on the leakage class curve, the test pressure. An orifice conforming to $10\sqrt{\Delta P}$ will, for example, have the capacity to register only 24 cfm at 6” orifice differential. If the test is at 6 static pressure for Leakage Class 3 compliance, *i.e.*, 9.6 cfm per 100 sf, with 6” orifice differential and 6” duct test pressure, the meter could only indicate 24 cfm. However, the blower for the test apparatus *would have to produce 24 cfm at 10” to 12” static*. Observe that with a β ratio of 0.29, as in a 3” tube with ⅞” orifice, the meter loss is 88% of the orifice differential. Assuming that the duct leaked at Class 3 and the test

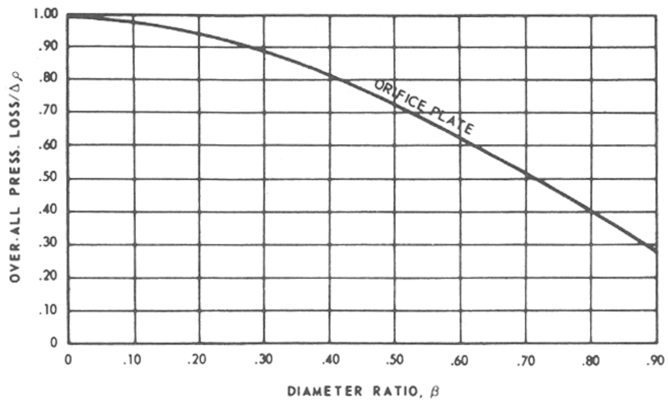

FIGURE J–1 RATIO OF OVER-ALL PRESSURE LOSS TO METERED DIFFERENTIAL VERSUS DIAMETER RATIO β

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apparatus could generate the static pressure to indicate 24 cfm, 250 square feet of duct (24/9.6 × 100 = 250) could be tested at one time. A larger meter, for example, $Q = 26\Delta P$, could test 666 sf of duct (64/9.6 × 100) with 6" ΔP. If the 10 $\sqrt{\Delta P}$ meter were used to test Class 24 duct at 1 ½" static and it could not develop more than about 10" orifice drop while maintaining 1 ½" in the tested duct; the 32 cfm metered could only handle 32/31 × 100 or 103 sf of duct (unless the leakage rate was below the allowable). Comparing Figure 6–3 with Figure 5–1 can facilitate testing. Excess fan pressure can be controlled with inlet dampers, bypass, variable speed motors or other means.

J.5 STANDARD AIR

Air density varies with barometric pressure, temperature, and the amount of moisture present. Moist air is less dense than dry air at a given temperature. At a barometric pressure of 29.92 in. Hg and 70° F *dry air* has a density of 0.07495 lb/ft^3. At 60°F dry air is 0.764 lb/ft^3. Federal agency documents define "standard atmosphere"; at sea level standard temperature is 59° F with 29.921 in. Hg barometric pressure. Industry documents define "standard air" in different ways. ASHRAE uses a standard value of 0.075 lb of dry air per cubic foot for 70° F dry at 14.696 psia. The ASHRAE Fundamentals Handbook chapter on duct design states that no corrections to their duct friction chart are needed for ±30° F from 70° F, elevations to 1500 ft and duct pressures from +20 in. wg to –20 in. wg. These limits result in only ±5% variation. Comparable limits should be acceptable for field tests. Other variations can be observed in Appendix L.

Those who test air handling systems will occasionally be concerned with the designations ACFM and SCFM. The "A" refers to "actual"; the "S" refers to standard (CFM). Chapter 10 of the *Industrial Ventilation Manual*, published by ACGIH, defines three equivalent methods of calculating ACFM. The SCFM basis is 0.075 lb/ft^3 at 70° F at sea level.

a. $ACFM = SCFM \times \frac{460 + T}{530}$ where T is actual dry bulb air temperature in °F, moisture is negligible and pressure is less than ±20 in. wg.

b. $ACFM = SCFM \times \frac{0.075}{d}$ where d is air density taken from psychrometric charts.

c. $ACFM$ = lb per min. of dry air × humid volume ft^3 per min. per pound of dry air.

These evaluations are rarely applied on commercial projects but are common in the industrial sector. For example, outdoor air at 95° db and 75° wb has a humid air volume of 14.3 ft^3/lb of dry air. The density is 0.07 lb/ft^3. By formula b. above an actual flow measurement of 100 cfm would mean a standard airflow of 93.3 cfm.

For additional information on flowmeters *see* references in Appendix O.

J.6 OTHER LEAK TEST METHODS

Various methods of leak testing are used for shafts, building compartments, door cracks, windows, curtain walls, critical ducts in safety related criteria zones in nuclear power plants and other circumstances. ASME/ANSI Standard N510, *Testing of Nuclear Air-Cleaning Systems*, covers requirements for field testing of engineered safety feature systems and high efficiency air cleaning systems. Bubble, spray DOP, liquid penetrant, pressure decay rate and other methods are found in N510. Several levels of tightness for ducts in contamination zones and other applications are addressed in N510 and also in ASME/ANSI Standard N509, *Nuclear Power Plant Air-Cleaning Units and Components*. Provisions in both of these documents are reviewed in the ERDA 76–21, *Nuclear Air Cleaning Handbook*, available from the U.S. Department of Commerce National Technical Information Service.

Tracer gas methods have been used frequently by researchers investigating the leakage in houses and commercial building compartments. NBS has used the method and numerous ASHRAE transactions report this method and fan pressurization methods. Transaction H1-85-03 No. 2 lists many of the references. ASHRAE *Fundamentals Handbook* on ventilation and infiltration, reports leakage rates for various building elements. Key standards for such tests are:

ASTM E283, *Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors*

ASTM E741, *Measuring Air Leakage by the Tracer Dilution Method*

ASTM E779, *Measuring Air Leakage by the Fan Pressurization Method*

ASTM E783, *Field Measurement of Air Leakage Through Installed Exterior Windows and Doors*

Measurement techniques, field studies, and the significance of infiltration are comprehensively reviewed in ASTM STP 719–1980, *Building Air Change Rate and Infiltration Measurements*.

Typical leakage rates for walls and floors of commercial buildings are reported in *Design of Smoke Control Systems for Buildings*, available from ASHRAE. This document has an extensive bibliography on stairwell, shaft, and building leakage. At the present it appears that insufficient knowledge exists about the leakage rates in ceilings, interior partitions and corridor construction to document rates for design purposes.

Damper leakage is lab tested by AMCA Standard 500. Several classifications of damper leakage are published in UL Standard 555S, *Leakage Rated Dampers for Use in Smoke Control Systems*. Higher integrity classifications of damper leakage are in ANSI N509.

Tests of HVAC systems and building compartments for smoke control performance may involve flow direction study, air change rate and leakage evaluation by means other than orifice meters.

APPENDIX K

K.1 FLOW COEFFICIENTS

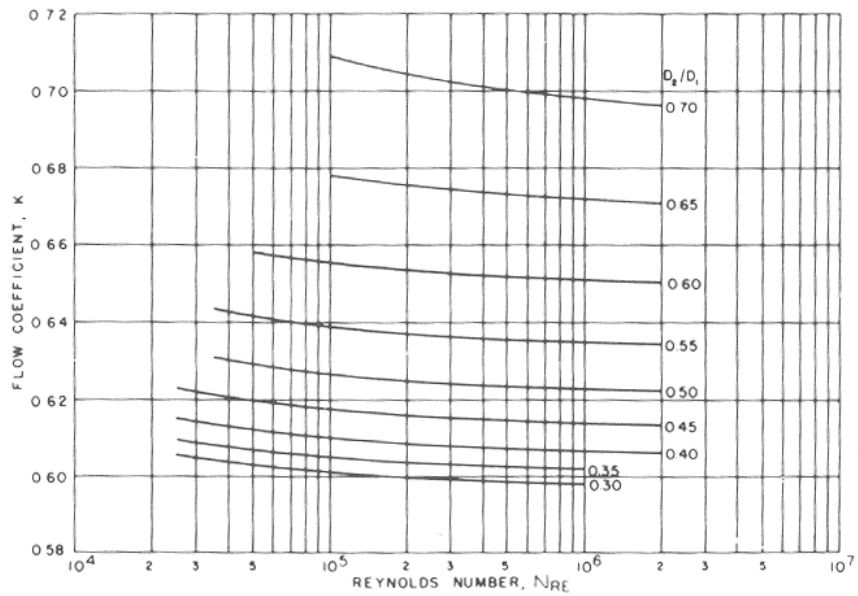

FIGURE K–1 FLOW COEFFICIENTS K FOR SQUARE/EDGED ORIFICE PLATES AND VENA CONTRACTA TAPS IN SMOOTH PIPE

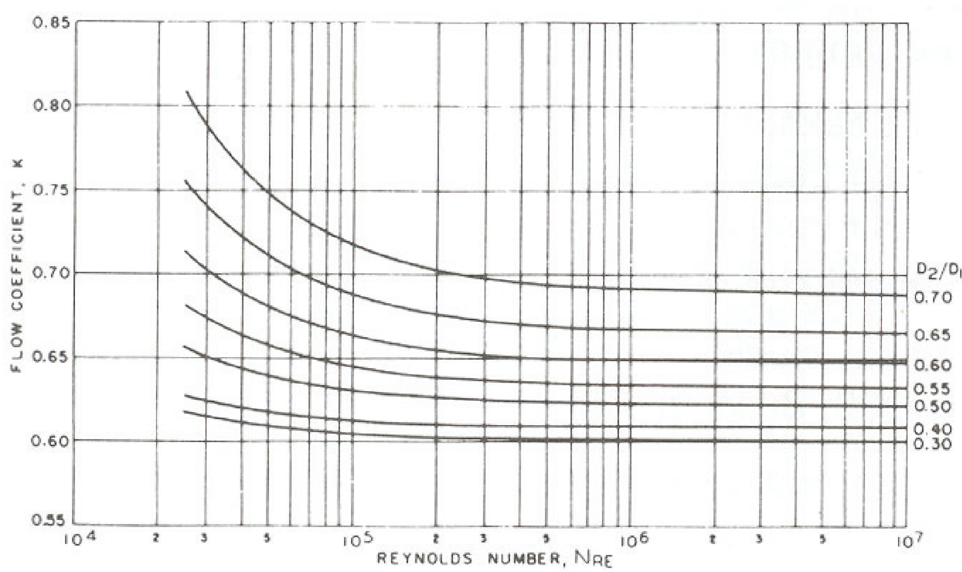

FIGURE K–2 FLOW COEFFICIENTS K FOR SQUARE-EDGED ORIFICE PLATES AND FLANGE TAPS IN SMOOTH PIPE

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APPENDIX L

Altitude	(ft)	Sea Level	1000	2000	3000	4000	5000	6000	7000	8000	9000	10,000
Barometer	(in. Hg)	**29.92**	**28.86**	**27.82**	**26.82**	**25.84**	**24.90**	**23.98**	**23.09**	**22.22**	**21.39**	**20.58**
	(in. wg)	**407.5**	**392.8**	**378.6**	**365.0**	**351.7**	**338.9**	**326.4**	**314.3**	**302.1**	**291.1**	**280.1**
Air Temp, °F	-40°	1.26	1.22	1.17	1.13	1.09	1.05	1.01	0.97	0.93	0.90	0.87
	0°	1.15	1.11	1.07	1.03	0.99	0.95	0.91	0.89	0.85	0.82	0.79
	40°	1.06	1.02	0.99	0.95	0.92	0.88	0.85	0.82	0.79	0.76	0.73
	70°	1.00	0.96	0.93	0.89	0.86	0.83	0.80	0.77	0.74	0.71	0.69
	100°	0.95	0.92	0.88	0.85	0.81	0.78	0.75	0.73	0.70	0.68	0.65
	150°	0.87	0.84	0.81	0.78	0.75	0.72	0.69	0.67	0.65	0.62	0.60
	200°	0.80	0.77	0.74	0.71	0.69	0.66	0.64	0.62	0.60	0.57	0.55
	250°	0.75	0.72	0.70	0.67	0.64	0.62	0.60	0.58	0.56	0.58	0.51
	300°	0.70	0.67	0.65	0.62	0.60	0.58	0.56	0.54	0.52	0.50	0.48
	350°	0.65	0.62	0.60	0.58	0.56	0.54	0.52	0.51	0.49	0.47	0.45
	400°	0.62	0.60	0.57	0.55	0.53	0.51	0.49	0.48	0.46	0.44	0.42
	450°	0.58	0.56	0.54	0.52	0.50	0.48	0.46	0.45	0.43	0.42	0.40
	500°	0.55	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.39	0.38
	550°	0.53	0.51	0.49	0.47	0.45	0.44	0.42	0.41	0.39	0.38	0.36
	600°	0.50	0.48	0.46	0.45	0.43	0.41	0.40	0.39	0.37	0.35	0.34
	700°	0.46	0.44	0.43	0.41	0.39	0.38	0.37	0.35	0.34	0.33	0.32
	800°	0.42	0.40	0.39	0.37	0.36	0.35	0.33	0.32	0.31	0.30	0.29
	900°	0.39	0.37	0.36	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27
	1000°	0.36	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.25
Standard Air Density, Sea Level, 70°F = 0.075 Ib/cu ft at 29.92 in. Hg												

Table L–1 Air Density Correction Factor, d

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APPENDIX M

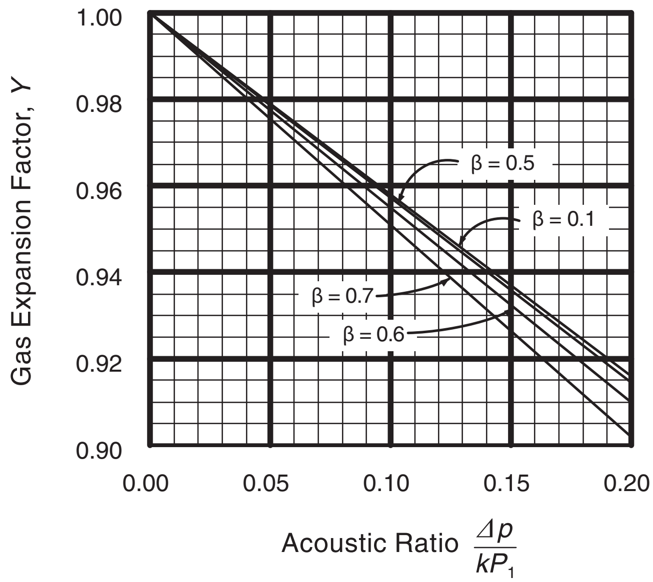

FIGURE M–1 GAS EXPANSION FACTOR, *Y*, VERSUS ACOUSTIC RATIO, $\Delta P/KP_1$

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APPENDIX N

	Liquid	Specific Gravity 20/20	Action with Water Vapor	Vapor Pressure at 68°F	Coefficient of Thermal Expansion per deg F × 10^6	per deg C × 10^6	Range deg F	Melting Point deg F	Boiling Point deg F	Flash Point deg F
				mm Hg						
1.	Ethyl Alcohol, C_2H_6O	0.7939	absorbs	43.9	600	1080	50-86	–179	173	55
2.	Kerosine, 41 API at 60°F	0.8200 60/60	negligible	—	480	864	30-100	–20	300+	120
3.	Ellison Gage Oil	0.8340 60/60	negligible	—	466	839	30-100	—	300+	140
4.	Benzene (Benzol), C_6H_6	0.8794	negligible	74.7	687	1237	68	42	176	12
5.	Butyl Cellosolve $C_6H_{14}O_2$ (Ethylene Glycol Monobutyl Ether)	0.9019	absorbs	0.85				–100	340	165
6.	Water	1.000	—	17.5	115	2070	68	32	212	non-inflam.
7.	Alcohol Glycol	1.000	absorbs	—	427	769	30-100	–60	173	70
8.	Carbitol, $C_6H_{14}O_3$ (Diethylene Glycol Monoethly Ether)	1.024-30	absorbs					–76	202	210
9.	n-Butyl Phthalate, $C_{16}H_{22}O_4$	1.0477	negligible	10^{-4}	433	780	—	–31	644	340
10.	Ethylene Glycol (Glycol), $C_2H_6O_2$	1.1155 20/4	absorbs slowly	0.09	354	638	68	+0.8	387	241
11.	Halowax Oil	1.19–1.25	—	0.3-50°C	367	660	—	–24-–42		203
12.	Glycerine (Glycerol), $C_3H_8O_3$	1.260 20/4	absorbs	low	281	505	68	64	554	320
13.	o-Dibromobenzene, $C_6H_4Br_2$	1.956 20/4	negligible	—	432	778	30-100	35.2	430	150+
14.	1, 1-Dibromoethane, $C_2H_4Br_2$	2.089 20/4	negligible	34.7	532	958	30-100	40	230	75+
15.	Acetylene tetrabromide (Tetrabromoethane), $C_2H_2Br_4$	2.964 20/4	absorbs slightly	—	370	660	—	–4	—	non-inflam.
16.	Mercury	13.570	negligible	0.0012	101	181.8	–20 to 250	–38	679	non-inflam.

Table N–1 Properties of Manometric Liquids

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APPENDIX O

O.1 REFERENCES AND ADDITIONAL SOURCES OF INFORMATION

1. ASHRAE *Fundamentals Handbook* Chapter on Measurement and Instruments

2. ASHRAE Standard 193 Method of Test for Determining Airtightness of HVAC Equipment

3. ASHRAE Standard 130 Methods of Testing Air Terminal Units

4. ASME, *Fluid Meters, Their Theory and Application*

5. ASME *Power Test Code PTC 19.5*

6. ASME MFC-3M (Part 1, Orifices) *Measurement of Fluid Flow in Pipes*, 1984

7. *Principles and Practices of Flowmeter Engineering*, L.K. Spink, Foxboro, Co.

8. ANSI/API 2530, *Orifice Metering of Natural Gas* (AGA Report #3)

9. *Flow Measurement Engineering Handbook*, R.W. Miller, McGraw Hill (1982)

10. ISA-RP 3.2 *Flange Mounted Sharp Edged Orifice Plates for Flow Measurement (For ANSI B16 flanges)*

11. *The Measurement of Gas Flow*, January '83 Journal of the Air Pollution Control Association

12. *Fan Engineering*, Buffalo Forge Co.

13. Fischer & Porter Company Handbook No 1OB9000, *Flowmeter Orifice Sizing*, 1978

14. *Industrial Ventilation*, ACGIH, Chapter 9, Monitoring and Testing of Ventilation Systems, (24TH AND 25TH EDITIONS).

15. *Nondestructive Testing Handbook*, 2nd ed., 1982 Volume 1, Leak Testing, American Society for Nondestructive Testing and American Society for Metals.

ACGIH, American Conference of Governmental Industrial Hygienists, Cincinnati, OH

AGA, American Gas Association, Arlington, VA

ANSI, American National Standards Institute, New York, NY

APCA, Air Pollution Control Association, Pittsburgh, PA

API, American Petroleum Institute, Washington, DC

ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA

ASME, American Society of Mechanical Engineers, New York, NY

See building element leak test references and instrumentation in Appendix J.

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