

HVAC AIR DUCT LEAKAGE TEST MANUAL



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**

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**FIRST EDITION
1985**



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NATIONAL ASSOCIATION, INC.**

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FOREWORD

SMACNA has 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.

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 has 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 the keynote of new SMACNA duct leakage classifications. It is expected that in the future industry will have correlated leakage classes with performance of particular sealant methods used on individual joint systems.

Leakage testing on job sites disrupts productivity, is costly and is generally not as beneficial as one might expect. Relatedly, industry fails to recognize the extent that equipment that is inserted in-line in duct leaks. Few ratings for this are published. 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.

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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LEAKAGE TESTING

SECTION 1 INTRODUCTION

- 1.1 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 routine use of testing. Leakage testing is generally an unjustified major expense that is unnecessary when proper methods of assembly and sealing are used. 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.
- 1.2 The sealing provisions contained in the SMACNA HVAC Duct Construction Standards—Metal and Flexible, 1985 edition, are reproduced here for convenient understanding of use of prescriptive measures. Consult the SMACNA Fibrous Glass Duct Construction Standards for fibrous glass duct assembly. Closures of joints and seams in fibrous glass ducts rely on taped adhesive systems to make connections, in contrast with metal ducts which use mechanical locks for connection and use sealants for supplemental leakage control.
- 1.3 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 loss will be. Key variables that affect the amount of leakage are:
- Static pressure, not velocity pressure. (The higher the pressure the more leakage will occur.)
 - The amount of duct (the more duct the more opportunity for leakage there will be).
 - The openings in the duct surface (the major contributors are joints and seams although access doors, rod penetrations and fastener penetrations also contribute).
 - 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 simplest parameter by which to evaluate system 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.

$$F = C_L P^N \text{ where}$$

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

C_L 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 new 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.

DUCT CONSTRUCTION AND INSTALLATION STANDARDS

S1.0 General Requirements

S1.1 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 independent of illustrations stated as depicting items representative of a class of items too broad to comprehensively illustrate.

S1.2 Regardless of the category designations in 1.1, nothing herein is intended to preclude the use of products or methods demonstrated to the satisfaction of specifying authorities to be equivalent in performance for the application.

S1.3 Requirements herein 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 herein are shown on the contract drawings, are not of proprietary manufacture and are illustrated with friction loss coefficients in either the SMACNA HVAC Duct System Design manual or the ASHRAE Fundamentals Handbook chapter on duct design, such fittings shall be fabricated from materials, assembly techniques and sealing provisions herein as though they were illustrated herein.

S1.4 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" WATER GAGE PRESSURE CLASS IS THE BASIS OF COMPLIANCE WITH THESE STANDARDS, REGARDLESS OF VELOCITY IN THE DUCT, EXCEPT WHEN THE DUCT IS VARIABLE VOLUME: ALL VARIABLE VOLUME DUCT UPSTREAM OF VAV BOXES

HAS A 2" W.G. BASIS OF COMPLIANCE WHEN THE DESIGNER DOES NOT GIVE A PRESSURE CLASS.

S1.5 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.

S1.6 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.

S1.7 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.

S1.8 Ducts shall be sealed in accordance with Table 1-2.

S1.9 Where sealing is required in Table 1-2 and otherwise herein it shall mean 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
- b) the use of continuous welds;
- c) 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;
- d) that these provisions are applicable to duct connections to equipment and to apparatus but are not for

TABLE 1-2
DUCT SEALING REQUIREMENTS

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

In addition to the above any variable air volume system duct of 1" and 1/2" w.g. construction class that is upstream of the VAV boxes shall also meet Seal Class C.

- equipment and apparatus.
- e) that where distinctions between seams and joints are made herein, a seam is defined as joining of two longitudinally (in the direction of air-flow) 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;
- f) that sealing requirements herein do not contain provisions to:
1. resist chemical attack.
 2. be dielectrically isolated.
 3. be waterproof, weatherproof or ultraviolet ray resistant.
 4. withstand temperatures higher than 120°F or lower than 40°F.
 5. contain atomic radiation or serve in other safety-related construction.
 6. be electrically grounded.
 7. maintain leakage integrity at pressures in excess of the duct classification herein.
 8. be underground below the water table.
 9. be submerged in liquid.
 10. withstand continuous vibration visible to the naked eye.
 11. be totally leak-free within an encapsulating vapor barrier.
 12. create closure in portions of the building structure used as ducts, e.g., ceiling plenums, shafts, pressurized compartments.
- The exclusions in this section (f) shall mean "not defined or prescribed herein" and that the prescription of the designer is required independently of this standard if obligatory;
- 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.

DUCT SEALING COMMENTARY

Ducts must be sufficiently airtight to insure economical and quiet performance of the system. It must be recognized that airtightness in ducts as a practical matter cannot, 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 airtightness can normally be assured by a) selecting a static pressure construction class suitable for the actual operating condition, and b) 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 1/2" 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 1/2" pressure class is not required by this construction 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 1/2" pressure class duct the designer must require this in his project specification. The designer should assume that unsealed ducts may leak at the following rates per 100 square feet of duct surface:

Duct Pressure in inches w.g.	CFM/100 s.f.
0.1	11
0.25	20
0.5	31
1.0	48

Since seven pressure classes exist (1/2, 1, 2, 3, 4, 6 and 10" w.g.) the designer is also reminded that if he does not designate pressure class for duct construction on the contract drawings the basis of compliance with the SMACNA HVAC Duct Construction Standards is as follows: 2" w.g. for all duct between the supply fan and variable volume control boxes; 1" w.g. for all other duct of any application.

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. It is not recommended that duct systems constructed to 3" w.g. class or lower be tested since it is generally recognized as not being cost effective. For duct systems constructed to 4" w.g. class and higher, the designer must determine if any justification for testing exists. If it does, he must clearly designate in the contract documents the portions of the system(s) to be tested and he must 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. Potential accuracy of flow 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 1,000 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.

Experience indicates that certain types of paint may form reliable seals particularly for small cracks and holes. Further research and confirmation is needed in this area.

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 his employees have become familiar with. Costs related to restoration of systems not receiving the required sealing or of those haphazardly sealed can greatly exceed the modest 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 lockseam 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, 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.

Liquids

Many manufacturers market liquid sealants specifically for ducts. They have the consistency of heavy syrup and can be applied either by brush or with a cartridge gun or powered pump. Liquid sealants normally contain 30 to 60 percent volatile solvents; 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 1/16 inch, several applications may be necessary to fill the voids caused by shrinkage or runout of the sealant. They are normally brushed on to round slip joints and are pumped into rectangular slip joints.

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. Although not marketed specifically for ductwork, good quality curtain wall sealants have been used for this application. Oil base caulking and glazing compounds should not be used.

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.

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 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 nonmetal 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.

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.

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.

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.

Sealant Strength

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

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.

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.

SECTION 2 RESPONSIBILITIES

2.1 The duct system designer should:

- 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. He 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.
- e) Reconcile all significant inconsistencies between his performance specifications and his prescription specifications before releasing contract documents for construction.
- f) Avoid ambiguity created by references to non-specific editions of SMACNA or other documents he has specified.
- g) Have his contract documents reflect a clear scope of work known by him 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.

2.2 The ductwork installer should:

- 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 where and as specified.
- 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.

SECTION 3 GENERAL PROCEDURES

- 3.1 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.
- 3.2 Select a test pressure not in excess of the pressure class rating of the duct.
- 3.3 Calculate the allowable or allocated leakage using leakage factors related to the duct surface area.
- 3.4 Select a limited section of duct for which the estimated leakage will not exceed the capacity of the test apparatus.
- 3.5 Connect the blower and flowmeter to the duct section and provide temporary seals at all open ends of the ductwork.
- 3.6 To prevent overpressurizing of the ducts, start the blower with the variable inlet damper closed. Controlling pressure carefully, pressurize the duct section to the required level.
- 3.7 Read the flowmeter and compare the leakage in cfm per square foot with the allowable rate determined in step 3.3. If it meets the allowable rate proceed to step 3.8. If it does not meet the allowable rate follow steps 3.7a through 3.7c.
 - 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.
 - c) Allow repaired seals to cure and retest until the leakage rate is acceptable.
- 3.8 Complete test reports and, if required, obtain witness' signature.
- 3.9 Remove temporary blanks and seals.
- 3.10 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) Consider acquiring experience with leakage rates in the type of construction used before formally conducting field tests. This is especially advisable 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 should 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 overpressurize ducts. Provide pressure control or pressure relief if test apparatus behavior is unfamiliar; 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 panic by informing occupants and bystanders when you will conduct smoke tests.
- 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.

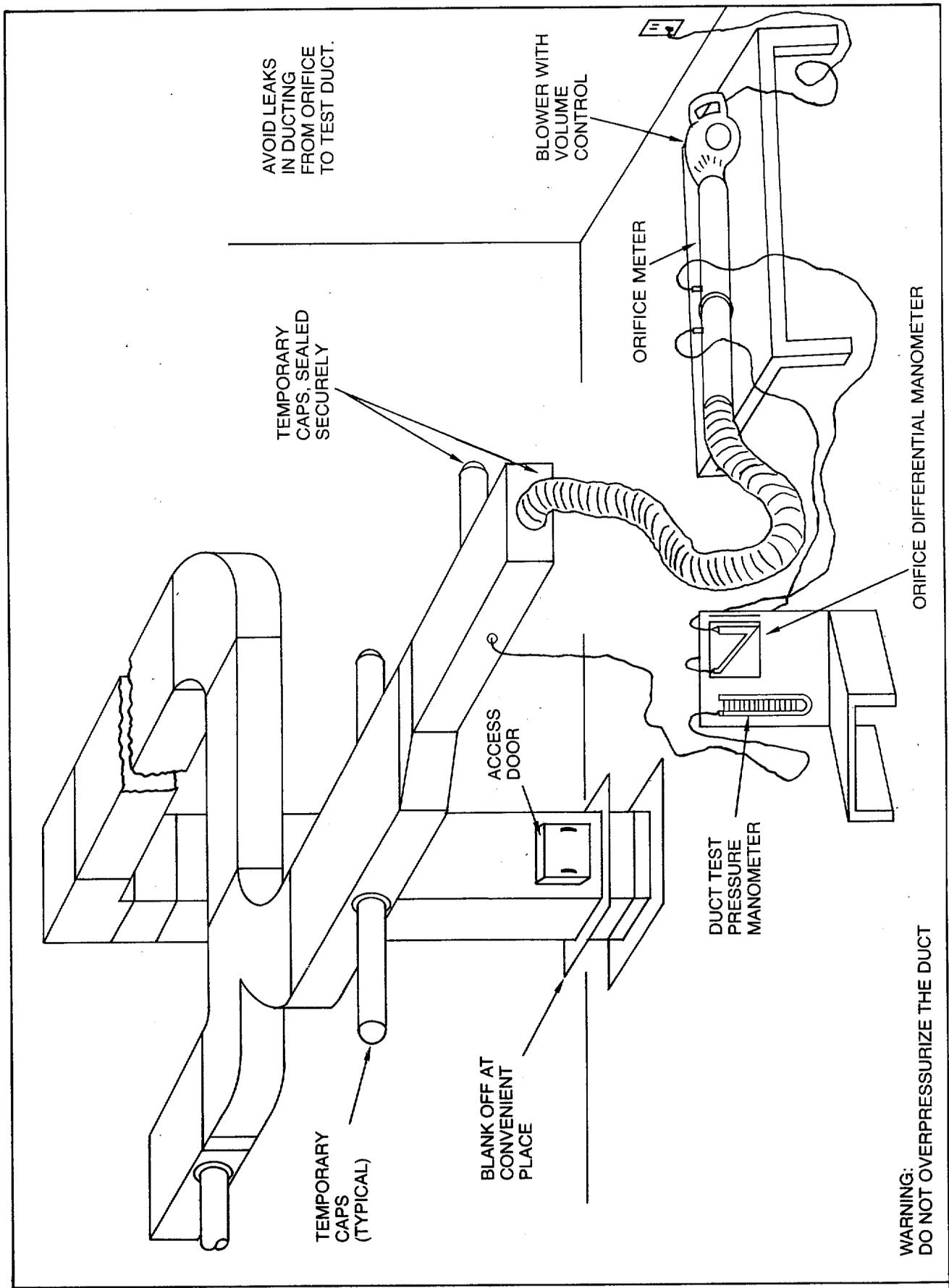


ILLUSTRATION OF TESTING

FIG. 3-1

SECTION 4 LEAKAGE CLASSIFICATION

4.1 Leakage classification identifies a permissible leakage rate in cfm per 100 square feet of duct surface according to the relationship $C_L = F \div (P)^{.65}$ as defined in Section 1.3.

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

P is the static pressure. Values for $(P)^{.65}$ are given in Appendix E. When $P = 1$, $C_L = F$.

C_L is the leakage class and is a constant.

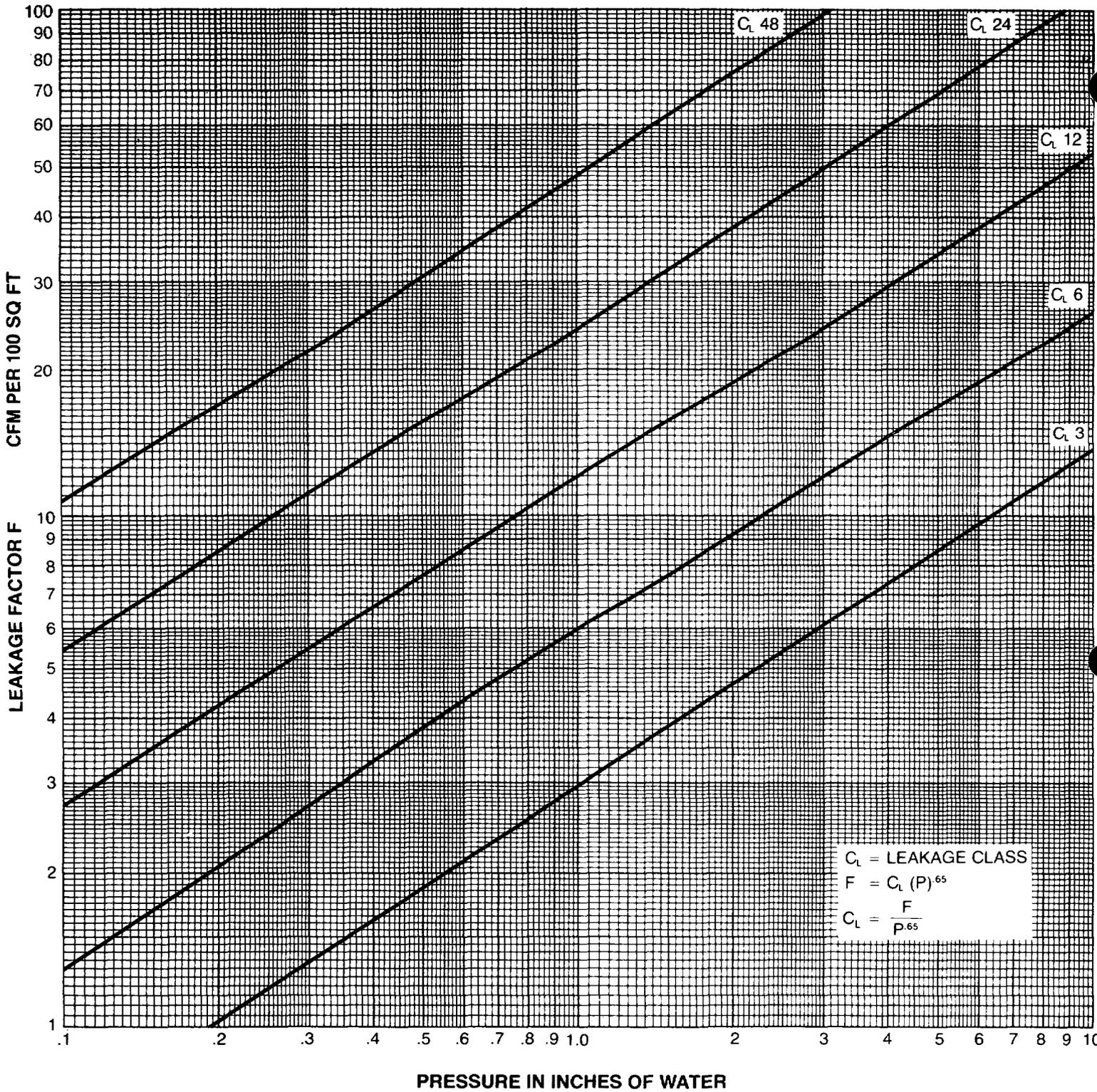
4.2 Leakage classifications 3, 6, 12, 24 and 48 are shown in Figure 1 for pressures up to 10" w.g. They are associated with duct type, seal classes, and construction pressure classes in Table 4-1. Table 4-1 is the basis of evaluating duct conforming to the SMACNA duct construction standards unless a specifier gives other limits.

4.3 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.

4.4 Assignment of leakage classes involves careful consideration of system size, duct location, sealing and construction class. Arbitrary assignment of an allowable % of leakage in disregard of these factors can indicate unobtainable results. A 1/2% allowance, for example, on a 3900 cfm system with 1300 s.f. of duct or on a 39,000 cfm system with 13,000 s.f. of duct would mean an unrealistic leakage factor of 1.5 cfm/100 s.f. in each case. Similarly, arbitrary assignment of 10" w.g. class construction for a system operating at 1" w.g. in order to get leak class 3 rectangular duct would not be cost effective. Assigning a leakage class 3 to a 1" w.g. rectangular duct system may address an achievable result but the associated difficulty and costs will be excessive. Table 4-1 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 4-1. 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 4-1 should be carefully weighed against the costs of achieving them.

4.5 A sample leakage classification analysis is given in Appendix B.

4.6 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 Duct Leakage Test Manual for verification that the leakage classifications in Table 1 have been met (and has given no other criteria and scope), he is deemed to have not fulfilled the responsibilities outlined in Section 2.1 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 2.2 in regard to leakage are deemed to be waived by defective specification.



SEE TABLE 4-1 FOR ASSOCIATED DUCT CONSTRUCTION CLASS

SEE APPENDIX E FOR TABULAR FORM OF FIGURE 4-1

DUCT LEAKAGE CLASSIFICATION

FIG. 4-1

**TABLE 4-1
APPLICABLE LEAKAGE CLASSES**

DUCT CLASS	1/2", 1", 2" W.G.	3" W.G.	4", 6", 10" W.G.
SEAL CLASS	C	B	A
SEALING APPLICABLE	TRANSVERSE JOINTS ONLY	TRANSVERSE JOINTS AND SEAMS	JOINTS, SEAMS AND ALL WALL PENETRATIONS
LEAKAGE CLASS			
RECTANGULAR METAL	24	12	6
ROUND METAL	12	6	3

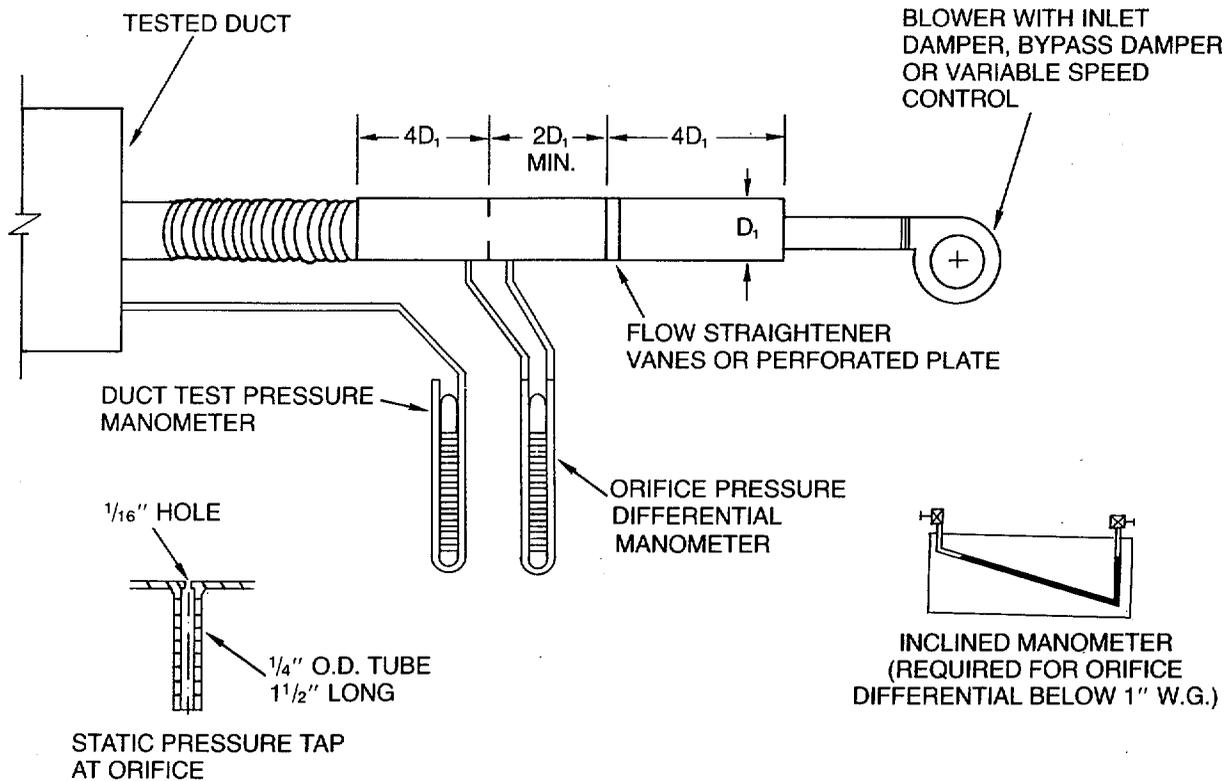
NOTES:

- Leakage classes in Table 4-1 apply when the designer does not designate other limits and has specified Seal Class C for 1/2" and 1" w.g. See text on sealing in the HVAC-DCS manual.
- Unsealed rectangular metal duct may follow Leakage Class 48.
- Fibrous glass duct may follow Leakage Class 6 (at 2" w.g. or less).
- Unsealed flexible duct leakage average is estimated to be Class 30. Sealed nonmetal flexible duct is an average of Class 12.
- See SMACNA HVAC Duct Systems Design manual Table 5-1 for longitudinal seam leakage rates.
- 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.
- Leakage Class (C_L) is defined as being the leakage rate (CFM/100 S.F.) divided by $P^{0.65}$ where P is the static pressure (IN. W.G.). When P is numerically equal to 1" the leakage rate is C_L . See Figure 4-1.
- 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 his contract documents. Unless construction class is otherwise specified it means a static pressure classification in the SMACNA HVAC-DCS. Those classifications pertain to maximum operating pressure in the duct as follows:

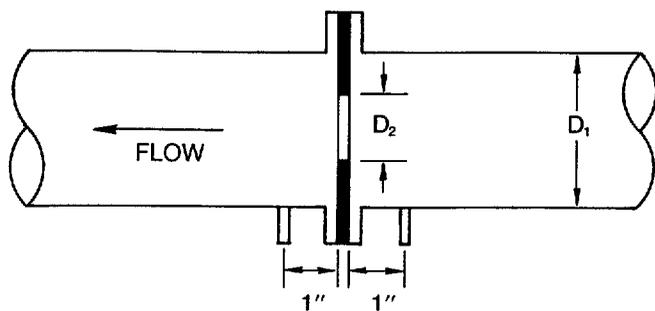
0.5" w.g. maximum	3.1" to 4" w.g. maximum
0.6" to 2" w.g. maximum	4.1" to 6" w.g. maximum
1.1" to 2" w.g. maximum	6.1" to 10" w.g. maximum
2.1" to 3" w.g. maximum	

SECTION 5 TEST APPARATUS

- 5.1 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.
- 5.2 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.
- 5.3 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.
- 5.4 Unless otherwise specified, test apparatus shall be used as outlined in this section, as described in Section 3 and as recommended for good practice.
- 5.5 Typical construction and use of orifice meters is indicated in Figures 5-1 and 5-2. Typical orifice selections are shown in Figure 5-3.
- 5.6 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.
- 5.7 The recommended minimum thicknesses for orifice plates in tubes of various diameters are 1/16" to 6" diameter, 3/32" to 12" diameter and 1/8" for larger diameters. Steel or stainless steel plate material is preferable. 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.
- 5.8 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.
- 5.9 Pressure differential sensing instruments shall be readable to 0.05" scale division for flow rates below 10 cfm or below 0.5" w.g. differential. For higher flow scale divisions of 0.1" are appropriate. U-tube manometers should not be used for readings less than 1" of water.
- 5.10 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.
- 5.11 The duct test pressure shall be sensed only from an opening in the duct.
- 5.12 The illustration of the flowmeter on test blower discharge does not preclude use of it on the suction side.
- 5.13 Instruments must be adjusted to zero reading before pressure is applied.



NOTE: MANOMETERS MUST BE LEVELED AND ADJUSTED TO ZERO BEFORE LINE PRESSURE IS IMPOSED.

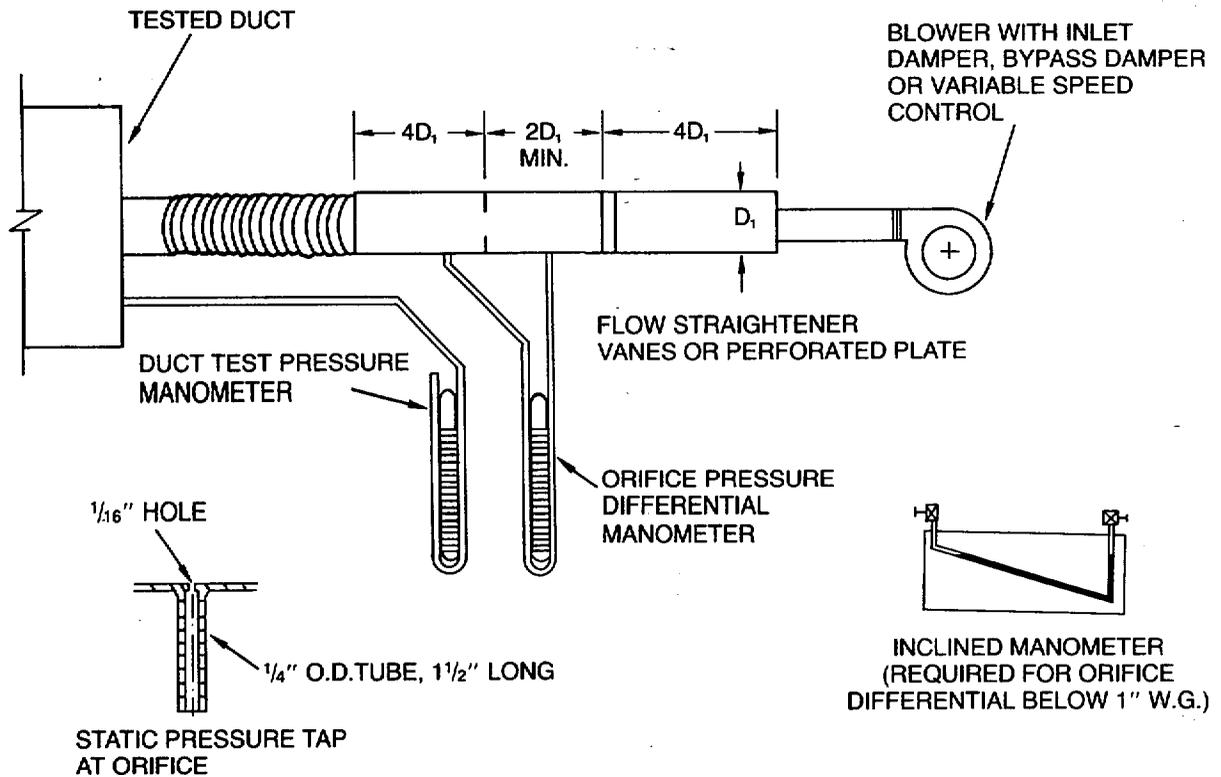


LOCATION OF FLANGE (PIPE) TAPS

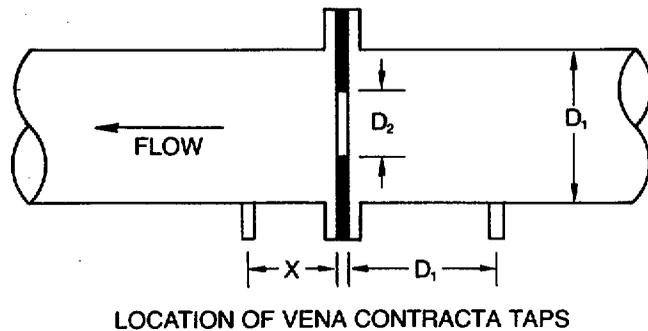
USE $3/32''$ OR $1/8''$ STEEL SQUARE EDGE ORIFICE PLATE

LEAKAGE TEST METER APPARATUS— FLANGE TAPS

FIG. 5-1



NOTE: MANOMETERS MUST BE LEVELED AND ADJUSTED TO ZERO BEFORE LINE PRESSURE IS IMPOSED.



LOCATION OF VENA CONTRACTA TAPS

USE $\frac{3}{32}$ " OR $\frac{1}{8}$ " STEEL 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

**LEAKAGE TEST METER APPARATUS—
VENA CONTRACTA TAPS**

FIG. 5-2

5.14 Airflow across a sharp edge orifice with standard air density of .075 #/ft³ is calculated from

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

(Equation 1)

Where

Q = air volume, cfm

K = coefficient of airflow from Table 5-1 or Appendix J

D = orifice diameter, inches (D₂)

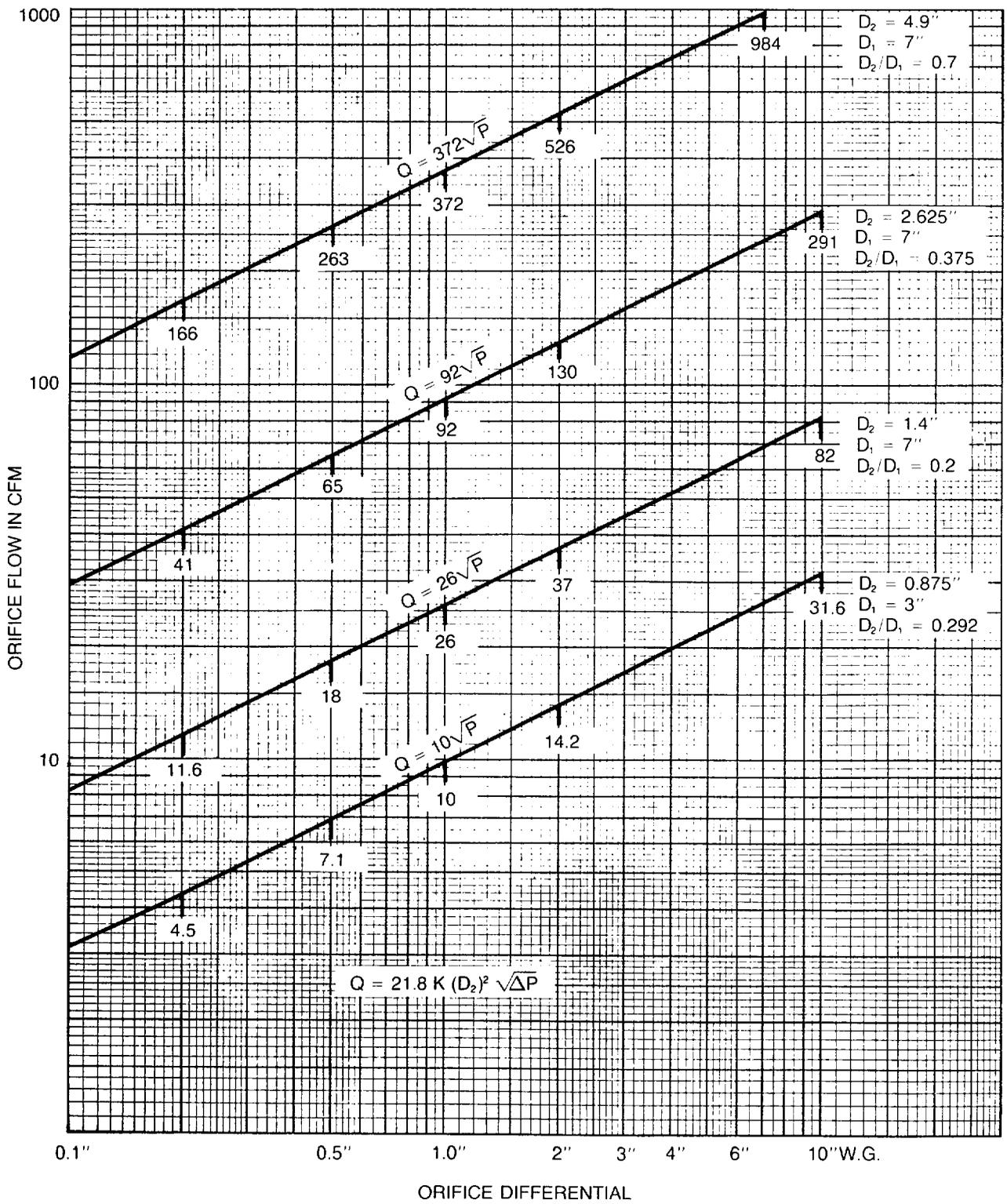
ΔP = pressure drop across orifice, inches w.g.

TABLE 5-1 ORIFICE COEFFICIENTS					
D ₂ /D ₁	.70	.60	.50	.40	.30
A ₂ /A ₁	.490	.36	.250	.160	.090
K	.699	.650	.623	.608	.600
K _p	.52	.63	.73	.82	.88

The ratio of orifice diameter D₂ to meter tube interior diameter D₁ 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 (A₂/A₁) is an indication of the contraction of flow. K_p in Table 5-1 is the overall pressure loss that occurs from contracting and expanding the flow. Thus, the orifice causes a K_p × ΔP loss that affects blower capacity.

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

- a) Using the target leakage rate (cfm/100 s.f.) 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" w.g. if D₂/D₁ 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.
- b) Select the meter from Figure 5-3 or use Table 5-1 and Equation 1 to size a meter 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 5-2.



TYPICAL ORIFICE FLOW CURVES

FIG. 5-3

TABLE 5-2
ORIFICE FLOW RATE (SCFM) VERSUS PRESSURE DIFFERENTIAL (in. of Water)

ΔP in. w.g.	Orifice Size			ΔP in. w.g.	Orifice Size			ΔP in. w.g.	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

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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5.16 Precautions to be followed for test apparatus:

- a) Start the blower with blocked suction or discharge to avoid overpressurizing ductwork.
- b) Use clean manometers.
- c) Heat manometers to avoid freezing fluid in cold weather.
- d) If manometer fluid is blown out; refill with the appropriate fluid; for convenience add a drop of water soluble dye to water-filled manometers.
- e) Level position sensitive instruments and set them to zero scale reading.
- f) Read liquid levels by viewing them horizontally.
- g) Record instruments used for testing.

SECTION 6 TEST REPORTS

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

- a) Review of the specification requirements for testing.
- b) Understanding of the acceptance criteria.
- c) Review of the general procedures outlined in Section 3.
- d) Familiarity with the leakage classification analysis in Section 5.
- e) Test scheduling.
- f) Test apparatus acquisition.
- g) Delivery of notices to concerned parties and witnesses.
- h) Preliminary data entry on report forms.

6.2 When 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 should be clearly specified:

Test Pressure (equivalent to the duct construction pressure class is suggested).

Leakage Class (class selected from Table 4.1).

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.

6.3 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 should 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 3.7 of the general procedures.

6.4 A suggested test summary report form is provided on page 6-2, and a sample of a completed report is shown on page 6-3. The orifice tube data entries can be eliminated if a different type of test apparatus is used. In such case record the type of meter on the test report.

6.5 Procedure for completing a report.

- a) Log the project and system identification data.
- b) Enter the fan CFM (Q), the test pressure (P_T), and the leakage class (C_L) specified by the designer.
- c) Enter an identification for each duct segment to be tested. Compute and enter the corresponding area of duct surface area excluding any equipment connected in-line.
- d) Look up the allowable leakage factor (F) from Figure 4-1 or Appendix E. Enter this number on the report for each test segment. (This value can also be computed as $F = C_L \times P^{.65}$).
- e) Calculate the allowable leakage for each test segment by multiplying the surface area by the leakage factor, then dividing by 100.
- f) 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.

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

AIR DUCT LEAKAGE TEST SUMMARY

AIR SYSTEM HVAC - 2

LEAKAGE CLASS (C₁) 3

FAN CFM (Q) 24,000

SPECIFIED TEST PRESSURE (P₁) 6"

DUCT CONSTRUCTION PRESSURE CLASS (P₂) 6"

DESIGN DATA				FIELD TEST DATA RECORD						
SUBJECT DUCT	SURFACE AREA IN FT ²	ALLOWABLE LEAKAGE		DIAMETER		PRESSURE "W.G.		PERFORMED BY	WITNESSED BY	ACTUAL CFM
		FACTOR CFM/100 FT ²	CFM (TEST SECTION)	ORIFICE	TUBE	DUCT	ACROSS ORIFICE			
TOTAL SYSTEM	9600			****	****	**	*****	****	****	
TEST SECTION(S)										
RISERS	840	4.4	81	2.625"	7"	6	0.6	3-7-85	UNGS	71
3RD FL. MAIN	560	9.6	54	1.4"	7"	6	3.2	3-13-85	UNGS	46
NORTH BRANCH	410	9.4	39	1.4"	7"	6	3.5	4-16-85	UNGS	48
EAST BRANCH	480	9.6	46	1.4"	7"	6	1.8	4-19-85	UNGS	35
TOTAL	2290		220							200
(SEGMENTS TESTED)										

APPENDIX

APPENDIX A

LEAKAGE AS % OF FLOW IN SYSTEM

LEAKAGE CLASS	FAN CFM PRORATED* PER S.F.	STATIC PRESSURE (IN. W.G.)					
		1/2	1	2	3	4	6
48	2	15	24	38			
	2-1/2	12	19	30			
	3	10	16	25			
	4	7.7	12	19			
	5	6.1	9.6	15			
24	2	7.7	12	19			
	2-1/2	6.1	9.6	15			
	3	5.1	8.0	13			
	4	3.8	6.0	9.4			
	5	3.1	4.8	7.5			
12	2	3.8	6	9.4	12		
	2-1/2	3.1	4.8	7.5	9.8		
	3	2.6	4.0	6.3	8.2		
	4	1.9	3.0	4.7	6.1		
	5	1.5	2.4	3.8	4.9		
6	2	1.9	3	4.7	6.1	7.4	9.6
	2-1/2	1.5	2.4	3.8	4.9	5.9	7.7
	3	1.3	2.0	3.1	4.1	4.9	6.4
	4	1.0	1.5	2.4	3.1	3.7	4.8
	5	.8	1.2	1.9	2.4	3.0	3.8
3	2	1.0	1.5	2.4	3.1	3.7	4.8
	2-1/2	.8	1.2	1.9	2.4	3.0	3.8
	3	.6	1.0	1.6	2.0	2.5	3.2
	4	.5	.8	1.3	1.6	2.0	2.6
	5	.4	.6	.9	1.2	1.5	1.9

*TYPICALLY $\frac{\text{FAN CFM}}{\text{DUCT SURFACE AREA}}$ WILL BE 2 to 5 CFM/SQUARE FOOT.

% OF FLOW = LEAKAGE FACTOR (IN CFM/100 AT THE PRESSURE)

$$\text{DIVIDED BY } \frac{\text{FAN CFM}}{\text{S.F. SURFACE}} = \frac{\text{CFM}_A}{100 \text{ S.F.}} \times \frac{\text{S.F.}}{\text{CFM}_F}$$

CLASS 48 IS AVERAGE UNSEALED RECTANGULAR DUCT. CLASS 24 AND LOWER ARE ANTICIPATED RESULTS FOR SEALED DUCTS.

APPENDIX B

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 should be a secondary consideration.* 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 criteria than allowing 5% in each 100 ft of a 500 ft continuous run of duct. It should also be remembered that actual leakage will tend to 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 4-1) 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.

SYSTEM LEAKAGE CLASSIFICATION ANALYSIS

SYSTEM DATA

Leakage Evaluation for
Supply Duct in Fig. 8-1,
page 8-4 of the SMACNA
HVAC Duct Design Manual

8000 cfm fan
1/2" w.g. duct construction class
320 l.f. of duct
2,074 ft² duct

3.9 cfm/s.f. is average distribution (i.e., $\frac{8000 \text{ cfm}}{2074 \text{ s.f.}} = 3.857$)

6.3 ft² duct per l.f. of duct

LEAKAGE ANALYSIS

A. *Unsealed duct at 1/2" static pressure. At 1/2" s.p. on Class 48 curve in Figure 4-1, 30 cfm/100 s.f. is read.*

$$\frac{30}{100} \times 2074 \text{ ft}^2 = 622 \text{ cfm}$$

622 cfm is 7.8% of 8000 cfm fan capacity.

Alternative Calculation (as in Appendix A)

$$\frac{8000 \text{ cfm}}{2074 \text{ ft}^2} = 3.9 \text{ to } 1 \text{ ratio}$$

$$\text{Allowable leakage factor } 30 \times \frac{1}{3.9} = 7.7\%$$

NOTE: The difference (7.7 vs 7.8) occurs because 3.9 is rounded from 3.857.

B. *Unsealed duct (1/2" s.p. class) operating at 0.3" s.p.* If the system actually operates with 0.3" average static pressure and is unsealed, 22 cfm/100 s.f. leakage is read from the Class 48 curve on Figure 4-1 at 0.3" pressure. This is 456 cfm or 5.7%.

C. *Leakage Class 24 Requirement, (1/2" Static Pressure)*

From Figure 4-1, 16 cfm/100 s.f. is read.

$\frac{16}{100} \times 2074 \times 322$ cfm, which is 4.1% of fan cfm.

Alternative method: $16 \times \frac{1}{3.9} = 4.1$

D. *Leakage Class 12 Requirement, (1/2" Static Pressure)*

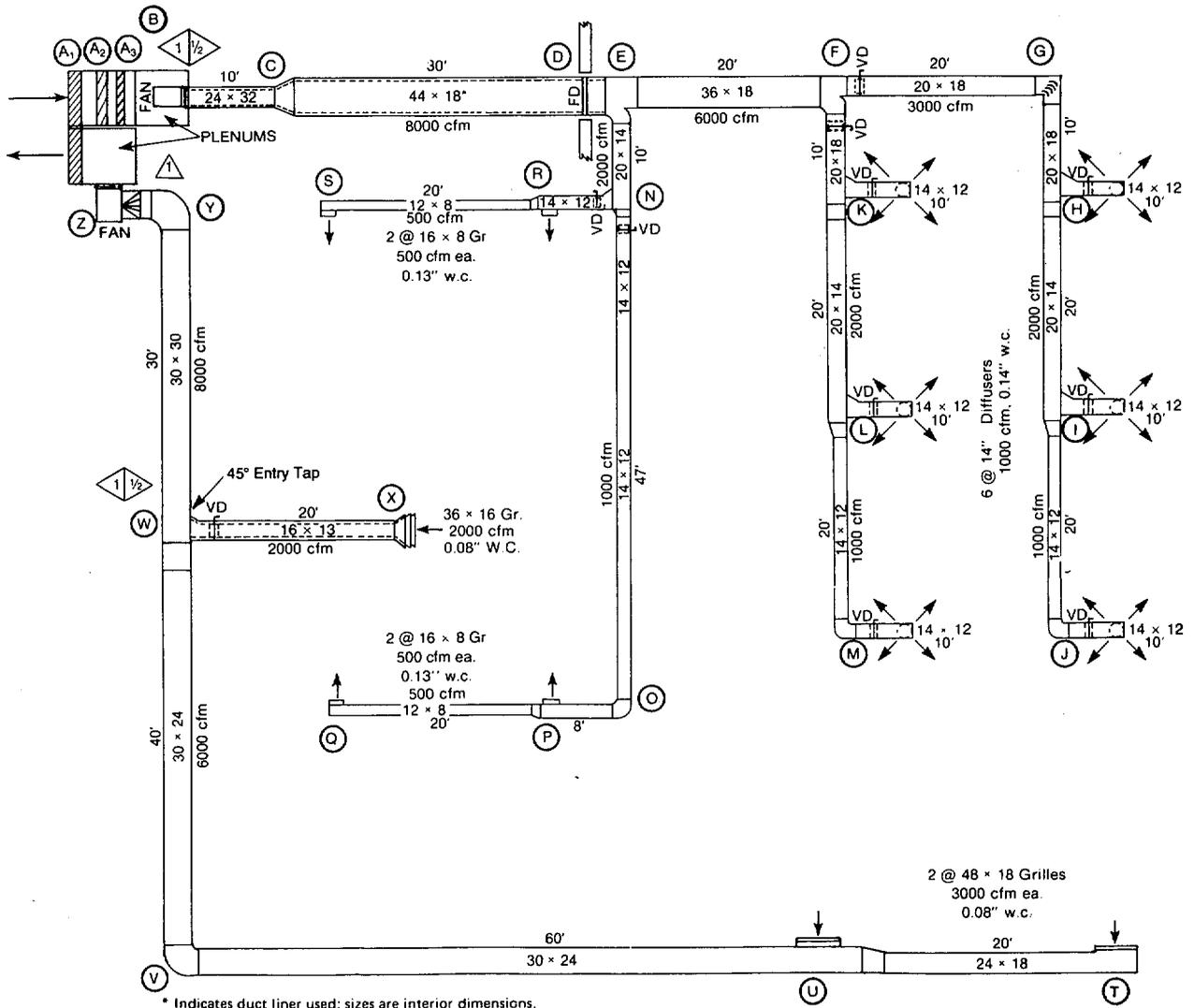
From Figure 4-1, $7.5/100 \times 2074 = 156$ cfm or 1.94%

E. *Allowable leakage of 5%*

If 5% is allowed (i.e., 400 cfm) this is $\frac{400}{2074}$ or 19.3 cfm/100 s.f. allowable;

Leakage class if $C_L = \frac{F}{P^{.65}} = \frac{19.3}{0.64} = 30$

The plan on page 8-5 of the duct design manual shows an access door, two volume dampers and a flexible connection (vibration isolation type); leakage allowance for these is prorated to duct surface.



* Indicates duct liner used; sizes are interior dimensions.

DUCT SYSTEM EXAMPLE

APPENDIX B

APPENDIX C

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

A. 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) to obtain a prorated leakage rate (F). 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).

At this point the contractor may find it informative to relate the contract requirements to the leakage suggested in Table 4.1. This can be done as follows:

$$CL = \frac{F \times 100}{P^{.65}}$$

In this formula (F) is the leakage rate obtained in paragraph (3) above, and P is the test pressure.

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 4-1 the contractors 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 2.1(e) and 2.2(c) of the leakage test manual.

B. Test Pressure Determination

The duct will be constructed for some pressure class (or classes). It is not practical to include duct from two different construction classes in the same leakage test segment. Ducts should not be leak tested at pressures greater than the construction class.

APPENDIX D

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 ARE GOOD, CONTRACTOR CAN BE PERMITTED TO PROCEED WITHOUT FURTHER TESTING. VISUAL INSPECTION AND EXAMINATION OF OPERATING CONDITIONS SHOULD SUFFICE TO JUSTIFY FAITH IN METHODS USED.

- 1.1 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, an access door and at least two typical branch connections plus an elbow.
- 1.2 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 CLASS	LEAKAGE CLASS
10" w.g.	3
6" w.g.	6
4" w.g.	6
3" w.g.	12

NOTE: See Section 4 of the SMACNA leakage test manual for normal classification.

- 1.3 Leakage test procedures shall follow the outlines and classifications in the SMACNA HVAC Duct Leakage Test manual.
- 1.4 If specimen fails to meet allotted leakage level, the contractor shall modify to bring it into compliance and shall retest it until acceptable leakage is demonstrated.
- 1.5 Tests and necessary repair shall be completed prior to concealment of ducts.

APPENDIX E

LEAKAGE FACTOR (F) IN CFM/100 S.F. DUCT

PRESSURE W.G.		LEAKAGE CLASS (C _L)					UNSEALED
P ^{.65}	P"	CLASS 3	CLASS 6	CLASS 12	CLASS 24	CLASS 48	
.143	.05	.4	.9	1.7	3.4	6.7	
.224	.10	.7	1.3	2.7	5.4	10.7	
.351	.20	1.1	2.1	4.2	8.4	16.8	
.457	.30	1.4	2.7	5.5	11.0	21.9	
.551	.40	1.7	3.3	6.6	13.2	26.4	
.637	.50	1.9	3.8	7.6	15.3	30.6	
.717	.60	2.2	4.3	8.6	17.2	34.4	
.793	.70	2.4	4.8	9.5	19.0	38.1	
.865	.80	2.6	5.2	10.4	20.8	41.5	
.934	.90	2.8	5.6	11.2	22.4	44.8	
1	1	3	6	12	24	48	
1.30	1.5	3.9	7.8	15.6	31.2	62.4	
1.57	2.0	4.7	9.4	18.8	37.7	75.4	
1.81	2.5	5.4	10.9	21.7	43.4	86.8	
2.04	3.0	6.1	12.2	24.5	49.0	98.0	
2.26	3.5	6.7	13.6	27.1	54.2	108.5	
2.46	4.0	7.4	14.8	29.5	59.0	118.1	
2.66	4.5	8.0	16.0				
2.85	5.0	8.6	17.1				
3.03	5.5	9.1	18.2				
3.20	6.0	9.6	19.2				
3.54	7.0	10.6	21.2				
3.86	8.0	11.6	23.2				
4.17	9.0	12.5	25.0				
4.47	10.0	13.4	26.8				
4.75	11.0	14.3	28.5				
5.03	12.0	15.1	30.2				

$$C_L = \frac{F}{P^{.65}}$$

When P = 1

$$C_L = F$$

$$F = C_L(P)^{.65}$$

These factors may also be read from Figure 4-1.
See Table 4-1 for seal class and pressure class.

APPENDIX F

AMOUNT OF DUCT TO BE LEAK TESTED (SFD)

LEAKAGE RATE CFM/100 SFD	LEAK TEST RIG FLOW CAPACITY IN CFM							
	25	50	100	150	200	250	300	400
1	2,500	5,000	10,000	15,000	20,000	25,000	30,000	40,000
2	1,250	2,500	5,000	7,500	10,000	12,500	15,000	20,000
3	833	1,666	3,333	5,000	6,666	8,333	10,000	13,333
4	625	1,250	2,500	3,750	5,000	6,250	7,500	10,000
5	500	1,000	2,000	3,000	4,000	5,000	6,000	8,000
6	417	833	1,667	2,500	3,333	4,167	5,000	6,667
10	250	500	1,000	1,500	2,000	2,500	3,000	4,000
12	208	417	833	1,250	1,667	2,083	2,500	3,333
15	167	333	666	1,000	1,333	1,667	2,000	2,667
20	125	250	500	750	1,000	1,250	1,500	2,000
25	100	200	400	600	800	1,000	1,200	1,600
30	83	167	333	500	667	833	1,000	1,333
50	50	100	200	300	400	500	600	800

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.

APPENDIX G

DUCT SURFACE AREA IN SQUARE FEET PER LINEAR FOOT

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"	2.0	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

APPENDIX H

AREAS AND CIRCUMFERENCES OF CIRCLES

Diameter Inches	Area		Circumference		Diameter Inches	Area		Circumference	
	Sq. In.	Sq. Ft.	In.	Ft.		Sq. In.	Sq. Ft.	In.	Ft.
1	0.7854	.00545	3.142	.2618	51	2042.82	14.19	160.22	13.35
2	3.1416	.0218	6.283	.5236	52	2123.72	14.75	163.36	13.61
3	7.0686	.0491	9.425	.7854	53	2206.18	15.32	166.50	13.88
4	12.5664	.0873	12.566	1.047	54	2290.22	15.90	169.65	14.14
5	19.6350	.1364	15.708	1.309	55	2375.83	16.50	172.79	14.40
6	28.2743	.1964	18.850	1.571	56	2463.01	17.10	175.93	14.66
7	38.4845	.2673	21.991	1.833	57	2551.76	17.72	179.07	14.92
8	50.2655	.3491	25.133	2.094	58	2642.08	18.35	182.21	15.18
9	63.6173	.4418	28.274	2.356	59	2733.97	18.99	185.35	15.45
10	78.5398	.5454	31.416	2.618	60	2827.43	19.63	188.50	15.71
11	95.0332	.6600	34.558	2.880	61	2922.47	20.29	191.64	15.97
12	113.097	.7854	37.699	3.142	62	3019.07	20.97	194.78	16.23
13	132.732	.9218	40.841	3.403	63	3117.25	21.65	197.92	16.49
14	153.938	1.069	43.982	3.665	64	3216.99	22.34	201.06	16.76
15	176.715	1.227	47.124	3.927	65	3318.31	23.04	204.20	17.02
16	201.062	1.396	50.265	4.189	66	3421.19	23.76	207.35	17.28
17	226.980	1.576	53.407	4.451	67	3525.65	24.48	210.49	17.54
18	254.469	1.767	56.549	4.712	68	3631.68	25.22	213.63	17.80
19	283.529	1.969	59.690	4.974	69	3739.28	25.97	216.67	18.06
20	314.159	2.182	62.832	5.236	70	3848.45	26.73	219.91	18.33
21	346.361	2.405	65.973	5.498	71	3959.19	27.49	223.05	18.69
22	380.133	2.640	69.115	5.760	72	4071.50	28.27	226.19	18.85
23	415.476	2.885	72.257	6.021	73	4185.39	29.07	229.34	19.11
24	452.389	3.142	75.398	6.283	74	4300.84	29.87	232.48	19.37
25	490.874	3.409	78.540	6.545	75	4417.86	30.68	235.62	19.63
26	530.929	3.687	81.681	6.807	76	4536.46	31.50	238.76	19.90
27	572.555	3.976	84.823	7.069	77	4656.63	32.34	241.90	20.16
28	615.752	4.276	87.965	7.330	78	4778.36	33.18	245.04	20.42
29	660.520	4.587	91.106	7.592	79	4901.67	34.04	248.19	20.68
30	706.859	4.909	94.248	7.854	80	5026.55	34.91	251.33	20.94
31	754.768	5.241	97.389	8.116	81	5153.00	35.78	254.47	21.21
32	804.248	5.585	100.531	8.378	82	5281.02	36.67	257.61	21.47
33	855.299	5.940	103.673	8.639	83	5410.61	37.57	260.75	21.73
34	907.920	6.305	106.814	8.901	84	5541.77	38.48	263.89	21.99
35	962.113	6.681	109.956	9.163	85	5674.50	39.41	267.04	22.25
36	1017.88	7.069	113.097	9.425	86	5808.80	40.34	270.18	22.51
37	1075.21	7.467	116.239	9.686	87	5944.68	41.28	273.32	22.78
38	1134.11	7.876	119.381	9.948	88	6082.12	42.24	276.46	23.04
39	1194.59	8.296	122.522	10.21	89	6221.14	43.20	279.60	23.30
40	1256.54	8.727	125.66	10.47	90	6361.73	44.18	282.74	23.56
41	1320.25	9.168	128.81	10.73	91	6503.88	45.17	285.88	23.82
42	1385.44	9.621	131.95	10.99	92	6647.61	46.16	289.03	24.09
43	1452.20	10.08	135.09	11.26	93	6792.91	47.17	292.17	24.35
44	1520.53	10.56	138.23	11.52	94	6939.78	48.19	295.31	24.61
45	1590.43	11.04	141.37	11.78	95	7088.22	49.22	298.45	24.87
46	1661.90	11.54	144.51	12.04	96	7238.23	50.27	301.59	25.13
47	1734.94	12.05	147.65	12.30	97	7389.81	51.32	304.73	25.39
48	1809.56	12.51	150.80	12.57	98	7542.96	52.38	307.88	25.66
49	1885.74	13.09	153.94	12.83	99	7699.69	53.46	311.02	25.92
50	1963.50	13.64	157.08	13.09	100	7853.98	54.54	314.16	26.18

The surface area (per lineal foot) of flat oval duct can be calculated from $3.14D + 2L$, where L is the flat span and D is the depth. The value $3.14D$ or πD may be read in the circumference column of the above table. The flat width is equal to the difference between the major and minor dimensions.

APPENDIX I

COMMENTARY ON FLOW CALCULATION FOR ORIFICE METERS

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 .

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

$$\text{and } V = 1096.7 \sqrt{\frac{h}{\rho}} \quad \text{When } \rho = 0.075 \quad V = 4005 \sqrt{h}$$

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 of 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 $\rho = .075 \text{ \#/ft}^3$ is calculated from

$$\begin{aligned} Q &= KAV = K \frac{\pi}{4} \frac{D^2}{144} 1096.7 \sqrt{\frac{\Delta P}{.075}} \\ &= 21.8 K D^2 \sqrt{\Delta P} \end{aligned} \quad (\text{Equation 1})$$

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

$$Q = 6KD^2 \sqrt{\frac{\Delta P}{0.075 d}} \quad (\text{Equation 2})$$

where Q = air volume, cfm

K = coefficient of air flow

D = orifice diameter, inches

ΔP = pressure drop across orifice, "wg

d = density factor from Appendix K

Flowmeter Accuracy

The coefficient K is affected by the Reynolds number, a dimensionless value expressing flow conditions in a duct. Appendix J 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 J 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 K 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 $Q = K_c Y A V$. 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 M.

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

$$R = 8.4 DV = 8.4 D \frac{Q}{A} \text{ or } R = 8.4 (2.625) \frac{100}{.03758} = 5.87 \times 10^4$$

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

Observe that 0.623 from Table 5-1 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 $\frac{D_2}{D_1} = 0.33$ Fig. 1 gives $K = 0.605$ and Fig. 2 gives $K = 0.61$.

Table 5-1 (interpolated) gives $K = .6024$ 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 5-2 of this manual do not require calibration. Otherwise, the nominal values for K that are given in Table 5-1 are deemed suitable for flow measurement under field conditions. Table 5-1 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 .

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 5-1 and in Figure 1.

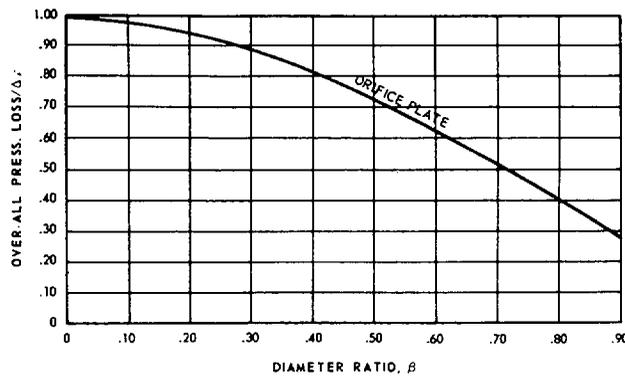


FIG. 1* RATIO OF OVER-ALL PRESSURE LOSS TO METERED DIFFERENTIAL VERSUS DIAMETER RATIO β .

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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 $Q = C \times P^{.5}$. Leakage class is a plot of $Q = C \times P^{.65}$. 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 s.f., 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 7/8" orifice, the meter loss is 88% of the orifice differential. Assuming that the duct leaked at Class 3 and the test apparatus could generate the static pressure to indicate 24 cfm, 250 square feet of duct ($24/9.6 \times 100 = 250$) could be tested at one time. A larger meter, for example, $Q = 26\Delta P$, could test 666 s.f. of duct ($64/9.6 \times 100$) with 6" ΔP . If the $10\sqrt{\Delta P}$ meter were used to test Class 24 duct at 1-1/2" static and it could not develop more than about 10" orifice drop while maintaining 1-1/2" in the tested duct; the 32 cfm metered could only handle $32/31 \times 100$ or 103 s.f. of duct (unless the leakage rate was below the allowable). Comparing Figure 5-3 with Figure 4-1 can facilitate testing. Excess fan pressure can be controlled with inlet dampers, bypass, variable speed motors or other means.

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/ft³. At 60° F dry air is 0.764 lb/ft³. 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 60° F at saturation and for 69° F dry at 14.7 psia. The ASHRAE Fundamentals Handbook chapter on duct design states that no corrections to their duct friction chart are needed for $\pm 30^\circ$ F from 70° F, elevations to 1500 ft and duct pressures from +20" w.g. to -20" w.g. These limits result in only $\pm 5\%$ variation. Comparable limits should be acceptable for field tests. Other variations can be observed in Appendix K.

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/ft³ 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 $\pm 20''$ w.g.
- b) $ACFM = SCFM \times \frac{0.075}{d}$ where d is air density taken from psychrometric charts.
- c) $ACFM = \text{lb per min. of dry air} \times \text{humid volume ft}^3 \text{ per min. per pound of dry air.}$

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 ft³/lb of dry air. The density is .07 lb/ft³. 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 N.

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 NTIS.

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 Chapter 22, on ventilation and infiltration, reports leakage rates for various building elements. Key standards for such tests are:

- ASTM E-283, Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors
- ASTM E-741, Measuring Air Leakage by the Tracer Dilution Method
- ASTM E-779, Measuring Air Leakage by the Fan Pressurization Method
- ASTM E-783, 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 J

FLOW COEFFICIENTS

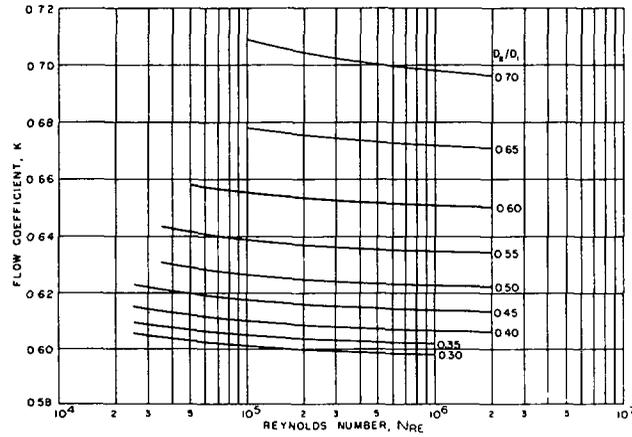


FIG. 1 FLOW COEFFICIENTS K FOR SQUARE/EDGED ORIFICE PLATES AND VENA CONTRACTA TAPS IN SMOOTH PIPE

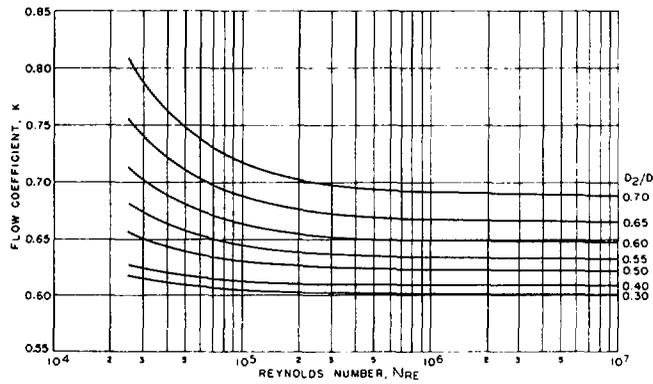


FIG. 2 FLOW COEFFICIENTS K FOR SQUARE-EDGED ORIFICE PLATES AND FLANGE TAPS IN SMOOTH PIPE

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APPENDIX K

AIR DENSITY CORRECTION FACTOR, d

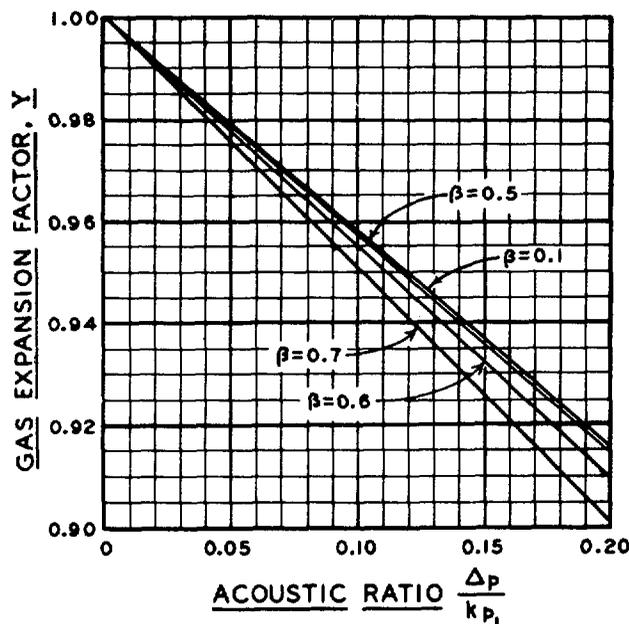
Altitude (ft)	Sea Level	1000	2000	3000	4000	5000	6000	7000	8000	9000	10,000
Barometer (in.Hg)	29.92	28.86	27.82	26.82	25.84	24.90	23.98	23.09	22.22	21.39	20.58
Barometer (in.w.g.)	407.5	392.8	378.6	365.0	351.7	338.9	326.4	314.3	302.1	291.1	280.1
Air Temp. -40°	1.26	1.22	1.17	1.13	1.09	1.05	1.01	0.97	0.93	0.90	0.87
°F 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	0.54	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 lb/cu ft at 29.92 in. Hg

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APPENDIX L

GAS EXPANSION FACTOR, Y, VERSUS ACOUSTIC RATIO, $\Delta p/kp_1$



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APPENDIX M

PROPERTIES OF MANOMETRIC LIQUIDS

Liquid	Specific Gravity 20/20	Action with Water Vapor	Vapor Pressure at 68 F	Coefficient of Thermal Expansion per deg F $\times 10^6$	Melting Point deg F	Boiling Point deg F	Flash Point deg F
1. Ethyl Alcohol, C ₂ H ₆ O	0.7939	absorbs	43.9 mm Hg	600	-179	173	55
2. Kerosine, 41 API at 60 F	0.8200 60/60	negligible	—	480	-20	300+	120
3. Ellison Gage Oil	0.8340 60/60	negligible	—	466	—	300+	140
4. Benzene (Benzol), C ₆ H ₆	0.8794	negligible	74.7	687	42	176	12
5. Butyl Cellosolve (Ethylene Glycol Monobutyl Ether), C ₈ H ₁₈ O ₂	0.9019	absorbs	0.85	—	-100	340	165
6. Water	1.000	—	17.5	115	32	212	non-inflam.
7. Alcohol Glycol	1.000	absorbs	—	427	-60	173	70
8. Carbitol, C ₆ H ₁₄ O ₃ (Diethylene Glycol Monoethyl Ether)	1.024-30	absorbs	—	—	-76	202	210
9. n-Butyl Phthalate, C ₁₆ H ₂₂ O ₄	1.0477	negligible	10 ⁻⁴	433	-31	644	340
10. Ethylene Glycol (Glycol), C ₂ H ₆ O ₂	1.1155 20/4	absorbs slowly	0.09	354	+0.8	387	241
11. Halowax Oil	1.19-1.25	—	0.3-50 C	367	-24-42	—	203
12. Glycerine (Glycerol), C ₃ H ₈ O ₃	1.260 20/4	absorbs	low	281	64	554	320
13. o-Dibromobenzene, C ₆ H ₄ Br ₂	1.956 20/4	negligible	—	432	35.2	430	150+
14. 1, 1-Dibromoethane, C ₂ H ₄ BR ₂	2.089 20/4	negligible	34.7	532	40	230	75+
15. Acetylene tetrabromide (Tetrabromoethane), C ₂ H ₂ Br ₄	2.964 20/4	absorbs slightly	—	370	-4	—	non-inflam.
16. Mercury	13.570	negligible	0.0012	101	-38	679	non-inflam.

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APPENDIX N

FLUID METER INSTRUMENTATION REFERENCES

1. ASHRAE Fundamentals Handbook Chapter on Measurements and Instruments
2. ASME, Fluid Meters, Their Theory and Application
3. ASME Power Test Code PTC 19.5
4. ASME MFC-3M (Part 1, Orifices) Measurement of Fluid Flow in Pipes, 1984
5. Principles and Practices of Flowmeter Engineering, L.K. Spink, Foxboro, Co.
6. ANSI/API 2530, Orifice Metering of Natural Gas (AGA Report #3)
7. Flow Measurement Engineering Handbook, R.W. Miller, McGraw Hill (1982)
8. ISA-RP 3.2 Flange Mounted Sharp Edged Orifice Plates for Flow Measurement (For ANSI B16 flanges)
9. The Measurement of Gas Flow, January '83 Journal of the Air Pollution Control Association
10. ASHRAE Standard 41.5, Standard Measurement Guide—Engineering Analysis of Experimental Data
11. Fan Engineering—Buffalo Forge Co.
12. Fischer & Porter Company Handbook No 10B9000, Flowmeter Orifice Sizing, 1978
13. Industrial Ventilation, ACGIH, Chapter 9, Testing of Ventilation Systems.
14. 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, Lansing, MI

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 I.



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