

CHAPTER 19. DUCT CONSTRUCTION

THIS chapter covers construction of HVAC and exhaust duct systems for residential, commercial, and industrial applications.

1. BUILDING CODE REQUIREMENTS

In the U.S. private sector, each new construction or renovation project is normally governed by state laws or local ordinances that require compliance with specific health, safety, property protection, and energy conservation regulations. [Figure 1](#) shows relationships between laws, ordinances, codes, and standards that can affect design and construction of HVAC duct systems (note that it may not list all applicable regulations and standards for a specific locality). Typically, local building ordinances invoke NFPA *Standards* 90A and 90B or some variation thereof along with one or more of the national codes (see [Figure 1](#)) for HVAC duct system construction and installation.

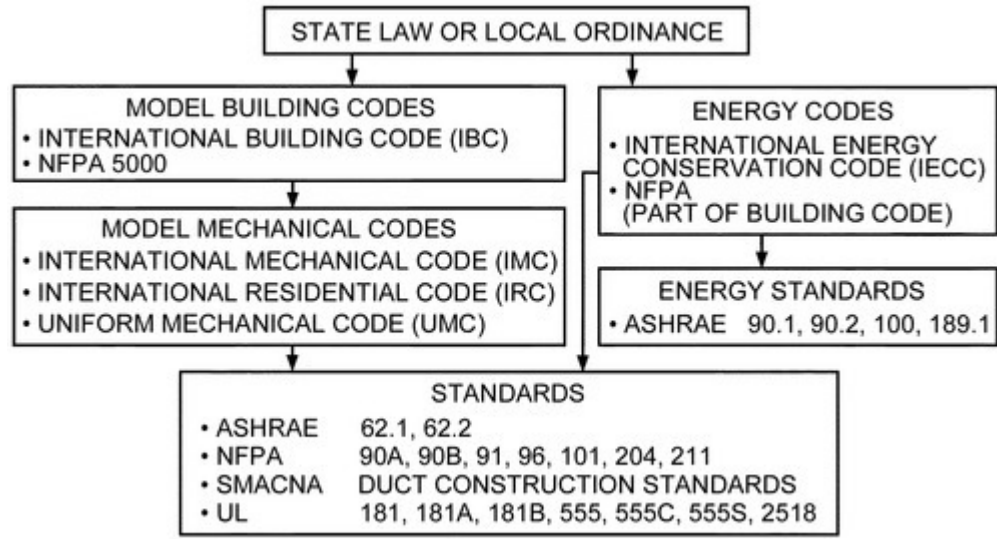


Figure 1. Hierarchy of Building Codes and Standards

Because safety codes, energy codes, and standards are developed independently, the most recent edition of a code or standard may not have been adopted by a local jurisdiction. HVAC designers must know which codes apply to their designs. If a provision conflicts with the design intent, the designer should resolve the issue with local building officials. New or different construction methods can be accommodated by the provisions for equivalency incorporated into codes. codes. Local jurisdictions may also include amendments and additions to various sections of a referenced building code.

2. PRESSURE CLASSIFICATIONS

Duct construction static pressure classifications typically used on contract drawings and specifications are summarized by [Table 1](#). The classifications are from SMACNA (2005) for sheet metal ductwork, and NAIMA (2002a) for fibrous glass duct board. Negative-pressure flat oval duct systems can be designed by using +10 in. of water sheet gages with the negative-pressure rectangular duct reinforcement members mechanically attached or welded to the duct. The most common flexible air ducts and air connectors are listed up to 10 in. of water maximum positive-pressure ratings and anywhere from 0.5 to 2.0 in. of water negative-pressure ratings, but there are listed flexible ducts with pressures as high as 16 in. of water and as low as -12 in. of water. Air conveyed by a duct adds both static pressure and velocity pressure loads on the duct's structure. The load from static pressure differential across the duct wall normally dominates and the mean static pressure is generally used for duct pressure classification. Turbulent airflow adds relatively low but rapidly pulsating loading on the duct wall. Duct design is based on **total pressure** calculations as discussed in [Chapter 21 of the 2013 ASHRAE Handbook—Fundamentals](#). From these calculations, the designer should specify the static pressure classification of the various duct sections in the system. All modes of operation must be considered, especially in systems used for smoke management and those with fire dampers that must close when the system is running.

Table 1. Pressure Classification for Ductwork¹

Type Duct	+1/2	-1/2	+1	-1	+2	-2	+3	-3	+4	-4	+6	-6	+10	-10
Rectangular	*			*	*	*	*		*	*	*	*	*	*
Round														
Flat oval														
Fibrous glass duct board ²	*		*	*	*	*	*		*	*	*	*	*	*
Flexible duct ³ (wire: helix type)	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Notes:
 * Columns with a dot indicate that construction standards are available for the pressure classes shown. Arrows in the table indicate that a construction standard is not available for that pressure class and one should use the indicated next available standard for construction.
¹ Same reinforcement as rectangular duct, except reinforcement mechanically attached to duct.
² Fibrous glass duct board must be UL Standard 181 listed.
³ Flexible duct must be UL Standard 181 listed and labeled.
 The preparation of this chapter is assigned to TC 5.2, Duct Design.

3. DUCT CLEANING

Ducts can collect dirt and moisture, which can contribute to microbial growth. Design, construct, and maintain ducts and attached HVAC system components to minimize the opportunity for growth and dissemination of microorganisms. As described by NIH (2015), recommended control measures to reduce duct contamination include (1) locating air intakes away from contaminant sources, (2) providing and maintaining proper air filtration, (3) sealing ductwork during construction to prevent debris from entering, (4) inspecting new ductwork for air or debris prior to system startup and cleaning if needed, and (5) implementing good housekeeping in occupied spaces. Owners should routinely inspect ducts for cleanliness. If cleaning is needed, contaminant sources should be identified and controlled before cleaning is performed. NADCA (2013) and NAIMA (2002b) provide specific information and procedures for cleaning ducts. Fabric duct systems should be cleaned (washed) in accordance with manufacturer's instructions. To minimize air leakage after duct sections are opened or disconnected, attention should be given to properly closing, connecting, and resealing them (see the section on HVAC System Leakage). Also, any duct insulation removed must be replaced, and vapor barriers (if used) must be resealed.

4. HVAC SYSTEM LEAKAGE

For the purposes of this chapter, **ductwork** includes straight duct, flexible duct, sheet metal and rigid fiberglass plenums, and fittings (e.g., elbows, transitions, tees, wyes) for distribution and extraction of air. It does not include duct-mounted components (e.g., terminal units, access doors/panels, attenuators, coils, fire/smoke dampers, balancing and control dampers). A **system** consists of the supply air handler, return fan, exhaust fan, plenums, and all ductwork that connects the air handler to the conditioned space. The system also includes duct-mounted components where leaks through joints or penetrations can occur. However, leakage from the occupied space into a return air plenum is not included.
Commentary: Return air plenums are part of the air path from the conditioned space back to the air handler. Therefore, they are part of the system. As described in the examples that follow in this section, the thermal effects of unintended leakage directly from the supply system into the return plenum must be accounted for differently than if the supply system leaked directly to the conditioned space.
 HVAC system air leakage increases building energy consumption. It also reduces the system's ability to control and deliver intended flows and pressures, and to manage the extraction and dilution of contaminants. Also, leakage can cause noise problems, drafts in the conditioned space, and dirt and dust deposits on the duct exterior. Leakage energy impacts depend on building and system type. For small buildings with single-zone air distribution systems served by equipment such as packaged rooftop cooling units and furnaces (e.g., houses, commercial buildings with floor area less than 25,000 ft²), 75 to 95% of the HVAC site energy is used for space heating and cooling (Thornton et al. 2010; Walker and Sherman 2008; Zhang et al. 2010), and the impacts are mostly on the thermal side. For large buildings with central multizone air distribution systems served by equipment such as central chillers and boilers (e.g., mid- and high-rise offices, supermarkets and retail stores with a floor area of 25,000 ft² or more), 20 to 80% of HVAC site energy is used by fans (Huang et al. 1991; Leach et al. 2009, 2010) and the impacts are also on fan power. All of these effects are strongly influenced by the location of leaks relative to conditioned space.
 If supply air leaks to an unconditioned attic or crawlspace, or to the outdoors, the lost heating or cooling must be replaced. In this case, heating or cooling fluid flows or temperature differences must increase, or the system must run longer to meet the load. If, instead, supply air leaks to a ceiling return plenum adjacent to conditioned spaces, the fan must run faster or longer, and the largest impact may be on fan power. The heat associated with this added fan power also creates an additional cooling load. The effects of return leakage can also be significant. For example, leaks from a hot attic into a return duct heat the return air, which in turn reduces system cooling capacity.
 Because the relationship between fan power and airflow is somewhere between a quadratic and cubic function depending on the system type (Sherman and Wray 2010), an increase in airflow to provide the desired service and compensate for system leakage means that fan energy consumption increases significantly. Field measurements by Diamond et al. (2003) showed that a leaky VAV system (10% leakage upstream and 10% downstream of terminal box inlet dampers at operating conditions) uses 25 to 35% more fan energy than a tight system (2.5% upstream and 2.5% downstream at operating conditions). For an exhaust system with 20% leakage, the fan has to move 25% more air to meet the specified flows at the grilles, which causes fan power to increase 95%.

System Sealing
 It is recommended that all ductwork and plenum transverse joints, longitudinal seams, and duct penetrations, including damper shafts, be sealed. Longitudinal seams are joints in the direction of airflow. Transverse joints are connections of two duct sections, with the connections oriented perpendicular to airflow. Openings for rotating shafts, wires, and pipes or tubes should be sealed with bushings or other devices that minimize air leakage but that do not interfere with shaft rotation or prevent thermal expansion. Sealing that meets these requirements is in compliance with ASHRAE *Standards* 90.1-2013 and 189.1-2014, the *International Mechanical Code*[®] (IMC 2015), the *International Energy Conservation Code*[®] (IECC 2015), the *International Residential Code*[®] (IRC 2015), and the *Uniform Mechanical Code*[®] (UMC 2015). Spiral lock seams need not be sealed. Duct-mounted equipment, such as terminal units, reheat coils, and access doors, should be specified as low leakage so that the combined HVAC system can meet air leakage criteria set by the designer, the *ASHRAE Handbook*, standards, and codes.
 Sealing that would void product listings, such as for fire/smoke dampers, is not recommended. It is, however, recommended that the design engineer specify low-leakage duct-mounted components. For example, some manufacturers of UL-listed and -labeled fire/smoke dampers allow sealing and gasketing of breakaway duct/sleeve connections; all can provide sealed non-breakaway duct/sleeve connections.

Sealants
General. All tape, mastic, rolled sealants, aerosol/spray applied sealants, gaskets, and nonmetallic mechanical fasteners should

- Be used in compliance with the manufacturer's instructions
- Be tested to UL *Standard* 723 (ASTM *Standard* E84) and have a flame spread index equal to or less than 25 and a smoke developed index equal to or less than 50
- Maintain their airtightness over the service life of the component to which they are applied

Sheet Metal Ductwork. All joints, longitudinal and transverse seams, and connections in sheet metal ductwork should be securely fastened and sealed with welds, gaskets, tapes, mastics, mastic-plus-embedded-fabric systems, rolled sealants, or aerosol sealants. Sealants should be (1) UL listed, labeled, and used in accordance with their listing; and (2) tested for durability using the accelerated aging procedure in ASTM *Standard* E2342. Sherman (2005) recommended that the time-to-failure acceptance criterion should be at least 60 days, because this time period delineated which tapes failed early using accelerated aging compared to tapes that lasted much longer.
 Tapes should be used only on joints between parallel surfaces, or on right-angle flat joints. If mastic or tape is used to seal openings greater than 1/4 in., the combination of mastic or either mesh or tape should be used. Heat-sensitive and heat-activated tapes, which are designed specifically to seal fibrous glass ductboard, should not be used as a sealant on metal ducts. Cloth-backed, rubber-adhesive duct tape should not be used, regardless of UL designation, unless such tape is used in combination with mastic and draw bands or it has been approved by the authority having jurisdiction for use without mastic.
 For exterior applications, mastics should be tested using ASTM *Standard* C732 artificial weathering tests and show no signs of visible degradation (e.g., washout, slump, cracking, loss of adhesion) after being exposed to artificial weathering.
Commentary: Apart from UL *Standard* 723, there is no UL standard for sealant performance when it is applied to sheet metal ductwork. It is recommended that a standard be developed for sheet metal applications and it should include or refer to a durability test.

Rigid Fiberglass Ductwork. Rigid fiberglass ductboard should be sealed following the NAIMA (2002a) standard using materials listed and labeled to the UL *Standard* 181A standard. There are three closure and air sealing systems for fiberglass duct board. The first two use tapes (marked "181A-P" or "181A-H"); the third system is a fiberglass mesh and mastic system (marked "181A-M"). In the latter case, a layer of mastic is applied to the joint, a strip of fiberglass mesh is embedded into the mastic, and then a finish coat of mastic is applied over the mesh.
Flexible Duct. Tapes and mastics used to close flexible air ducts and air connectors should be listed and labeled to UL *Standard* 181B, Part 1 or Part 2; be marked "181B-FX" or "181B-M," respectively; and be used in accordance with their listing.
 Mechanical fasteners for use with nonmetallic flexible air ducts and air connectors should be either stainless steel worm-drive gear performance or non-metallic straps listed and labeled to UL *Standard* 181B, Part 3, and be marked "181B-C." Nonmetallic fasteners should have a minimum tensile strength rating of 150 lb and be suitable for continuous use at the maximum temperature to which they will be exposed. When nonmetallic fasteners are used, beaded fittings are required, and the maximum duct positive operating pressure should be limited to 6 in. of water.
Commentary: Sherman (2005) showed that some nonmetallic flexible duct cone-to-collar clamps have unacceptable high-temperature performance. Most of the standard nylon straps failed before the two-year test period was completed. Sherman concluded that UL *Standard* 181B testing of these clamps does not adequately address this issue, and recommended that straps be rated for continuous use at 200°F. A more flexible requirement is that they be suitable for continuous use at the maximum temperature to which they will be exposed. A new test method for determining the durability of clamping systems should be developed to test the actual failure modes found in the field. Such a test could be incorporated in UL testing or be a separate ASTM (or equivalent ANSI) test method.

Leakage Testing
Rationale. System leakage testing, including ducts and duct-mounted components, is recommended, because leakage data collected by researchers over several years (1998 through 2004) for 10 systems in nine U.S. large commercial buildings (see [Figure 2](#) in Wray et al. (2005)) showed that seven had substantial leakage flows (10 to 26%). The other three systems had much smaller leakage flows (3 to 4%). These data include variable-air-volume (VAV), constant-air-volume (CAV), and dual-duct systems, and both high-pressure (main) and low-pressure (branch) systems. The distinction between main and branch sections is their location relative to terminal box inlet dampers. For VAV systems, data include fan-powered and cooling-only boxes. Most systems supplied air through square diffusers, but some used slot diffusers. Ductwork pressurization tests conducted by Lawrence Berkeley National Laboratory (LBNL) on the same nine buildings at a test pressure of 1 in. of water also showed that, on average, the leakage area for branches was about three times more than for mains (see [Figure 1](#) in Wray et al. (2005)).
Scope. It is recommended that supply air (both upstream and downstream of the VAV box primary air inlet damper), return air, and exhaust air systems be tested for leakage during construction to verify (1) good workmanship, and (2) the use of low-leakage components as required to achieve the design allowable system leakage.
 Systems may be tested at operating conditions and/or during construction before the installation of insulation and concealment of ductwork, but after the system section to be tested is fully assembled. As a minimum, 25% of the system, based on duct surface area, should be tested during construction and another 25% if any of the initial sections fail. If any section of the second 25% fails, the entire system should be leakage tested. Sections should be selected randomly by the owner's representative. Leakage tests should be conducted by an independent party responsible to the owner's representative.
Procedures. Leakage test setups and test procedures should be in compliance with industry practice (e.g., AABC 2002, Chapter 5; ASHRAE *Standard* 126-2016: Section 7; EUROVENT 2/2 1996; SMACNA 2012: Sections 4, 6, and 7).

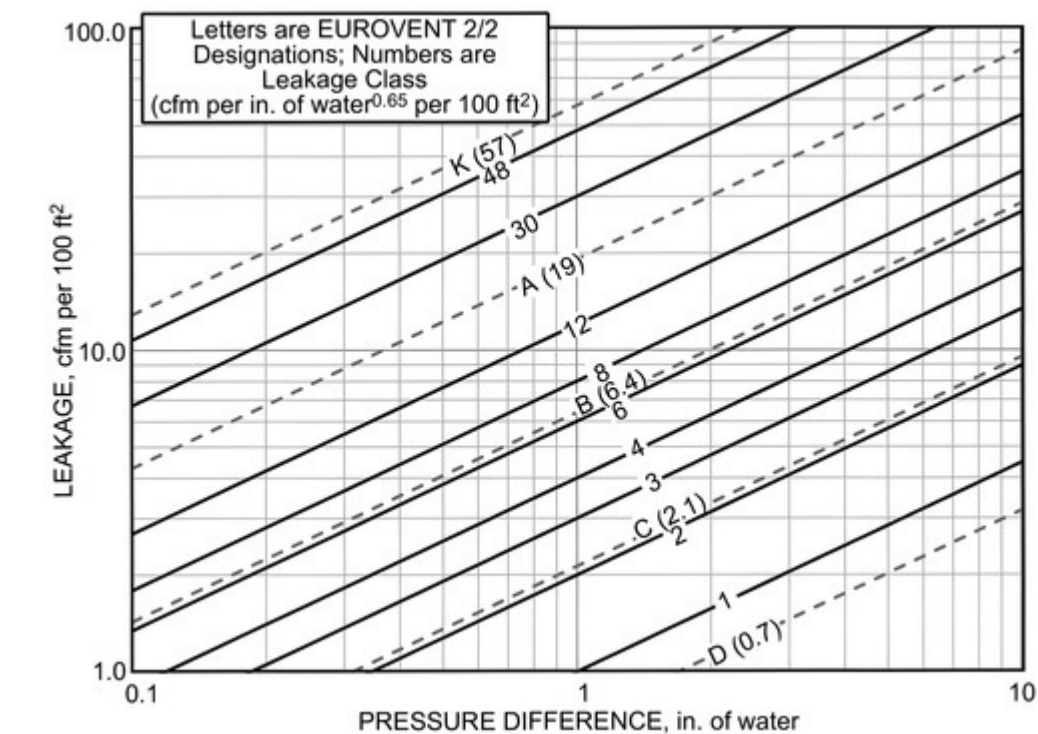


Figure 2. Relationship Between Leakage Class and EUROVENT (1996) Airtightness Classes used by European Countries

Instrumentation. Temperature and pressure measurement should be in compliance with ASHRAE *Standards* 41.1 and 41.3. Flow measurement devices (e.g., fan inlet flow stations, flow capture hoods) should have an accuracy of 3% or better over the operating range of interest. The size of the tested system section should be large enough that the instrumentation can measure leakage flow with the required accuracy.
Acceptance Criteria. The design engineer should establish the allowable system leakage rate for each fan system as a percentage of fan airflow at the design (maximum) system operating conditions. Recommended test pressures and maximum system leakage rates are shown in [Table 2](#), except as noted otherwise (supply and return system sections that leak directly to/from the outdoors, exhaust systems that draw air directly from the indoors, and air-handling units).
Commentary: Five percent system leakage is attainable in large commercial buildings, as evidenced by the supply systems with low leakage (2 to 4%) reported by Wray et al. (2005). Also, Wray and Matson (2003) indicate that system leakage operating cost impacts are about \$0.14 to \$0.18 per square foot of duct surface area for a 20% leaky supply system compared to a 5% leaky system in a large commercial building with ceiling return plenums. System sealing costs vary with fitting-to-straight-duct ratio, pressure class, and other system variables. According to Tsai et al. (1998), an upper bound for the one-time cost of duct sealing is \$0.25/ft² of duct surface area. Using these costs, the payback period for achieving 5% leakage compared to 20% leakage is about 1 to 2 years. The recommended 5% value may be modified when further life-cycle cost analysis data become available.
 Supply and return sections that leak to/from outdoors should be tighter than indoor sections, because the added thermal losses/gains from these leaks increase energy impacts. For example, an airtight VAV supply system with a design fan pressure rise of 4 in. of water, a design fan flow of 14,000 cfm, and a total efficiency of 60% will require about 11,000 W of power. With 5% leakage and applying an exponent of 2.4 to the flow ratio (1.05), the fan power increases by about 12% or 1400 W. Assuming that 55°F air is supplied to maintain a room temperature of 74°F, the supply air energy lost to outdoors by the 740 cfm of leakage is about 4600 W and the total energy impact of the leakage is about 6000 W. To achieve the same total energy impact as only the fan power increase with 5% leakage, leakage for the outdoor sections would need to be limited to about 1%.
 However, this analysis is overly simplified, because it ignores the thermal impacts of leakage if the supply sections were located indoors instead. In some cases, the thermal impacts of leakage from indoor sections may be as much as the related fan power impacts. Accounting for these thermal effects is more complicated because of interactive system effects (e.g., supply-leakage-related cooling of a ceiling return plenum, which in turn reduces ceiling heat transfer to adjacent cooler conditioned spaces, and thus reduces supply airflows needed to manage space cooling loads). Energy simulation programs can be used to conduct detailed analyses of the thermal and fan power effects of supply leakage (Wray and Sherman 2010).
 For buildings without static pressure control of the conditioned space (e.g., a midrise apartment building), exhaust sections that draw in indoor air through leaks need to be tighter than outdoor exhaust sections because the leakage flow also tends to depressurize the building and increase building air infiltration (assuming that the fan has been adjusted to still provide the design airflow at the exhaust inlets). The ratio of the change in infiltration flow to the change in exhaust flow from leakage depends on environmentally driven pressures, which can vary widely depending on weather. A reasonable average for this ratio is about 0.6 (Woolley et al. 2014). For example, an exhaust system with a design fan pressure rise of 2 in. of water, a design fan flow of 5000 cfm, and a total efficiency of 60% requires about 2300 W of power. With 5% leakage and applying an exponent of 3 to the flow ratio (1.05), the fan power increases by about 16%, or 310 W. Using a ratio of 0.6, the change in infiltration due to the 5% leakage (about 160 cfm) will be about 160 cfm. Assuming that the outdoor design temperature is 32°F and the conditioned space is heated to a temperature of 72°F, the energy associated with increased infiltration is about 3900 W and the total energy impact of the leakage is about 4200 W. To achieve the same total energy impact as only the fan power increase with 5% leakage, leakage in this case will need to be limited to about 0.4%. Even tighter systems are required for colder outdoor design temperatures, whereas outdoor temperatures closer to the conditioned space temperature will allow more leakage (to a maximum of 5%).
 As a compromise so that the designer does not need to carry out additional calculations for supply and return sections that leak to/from outdoors and for exhaust sections that draw in indoor air through leaks, it is recommended that leakage for these sections be limited to 2%.
Leakage Class. Leakage class, as specified by ASHRAE *Standard* 90.1-2013, can be translated to fractional (%) leakage using [Equation \(1\)](#) or [Table 3](#).

$$Q_{leak,frac} = \left[\frac{(C_L/100)A_p^{0.65}}{Q_{fan,norm}} \right] 100 \tag{1}$$

where

$Q_{leak,frac}$ = leakage fraction of fan airflow, %
 C_L = leakage class, cfm per in. of water^{0.65} per 100 ft² of duct surface area
 p = system pressure difference, in. of water
 $Q_{fan,norm}$ = normalized fan airflow, cfm per ft² of duct surface area

For example, for a leakage class of 4 cfm per in. of water^{0.65} per 100 ft² of duct surface area with a pressure difference of 3 in. of water and an inlet flow of 2 cfm/ft² of duct surface area, the fractional leakage is 4.1%. For a pressure difference of 6 in. of water, the fractional leakage is 6.4%.

Table 2 Recommended Maximum System Leakage Percentages

Type of System	System Condition	Test Pressure, ^{1,2} In. of water	Maximum Fan System ³ Leakage
1. Fractional horsepower systems, small exhaust/return systems, residential systems	Operating	Operating pressure	5%
	During construction	0.5	5%
	Operating	Operating pressure	5%
2. Single-zone supply, return, or exhaust systems	During construction	2.0	5%
	Operating	Operating pressure	5%
	During construction	2.0	5%
3. Multizone supply, return, or exhaust systems	Operating	Operating pressure	5%
	During construction	2.0	5%
	Operating	Operating pressure	5%
4. Dual-duct supply systems, both hot and cold ducts	During construction	6.0	5%
	Operating	Operating pressure	5%
	During construction	Upstream box: 4.0	5%
5. VAV ⁴ and CAV ⁴ supply systems	Operating	Operating pressure	5%
	During construction	Downstream box: 1.0	5%
	Operating	Operating pressure	5%
6. VAV ⁴ or CAV ⁴ return systems	During construction	Downstream box: 3.0	5%
	Operating	Operating pressure	5%
	During construction	Upstream box: 1.0	5%
7. Chilled-beam systems	Operating	Operating pressure	5%
	During construction	4.0	5%
	Operating	Operating pressure	5%
8. High-pressure induction systems	During construction	6.0	5%
	Operating	Operating pressure	2%
	During construction	3.0	2%
9. Supply and return ductwork located outdoors	Operating	Operating pressure	2%
	During construction	3.0	2%
	Operating	Operating pressure	2%
10. Exhaust ductwork located indoors	During construction	3.0	2%
	Operating	Operating pressure	2%
	During construction	3.0	2%
11. Air-handling units	Site test by manufacturer	Specified design pressure	1%

Notes:
¹ Test pressure should not exceed duct pressure rating.
² It is recommended that duct pressure rating equal fan shutoff pressure if possibility of fan shutoff exists either in VAV systems or in systems with smoke/fire damper control.
³ A fan system includes ductwork upstream and downstream of the fan. The fan system also includes components mounted to that ductwork where leaks through joints or penetrations can occur. However, leakage from the occupied space into a return air plenum is not included. Separate leakage specifications should be used for upstream and downstream sections.
⁴ Assuming primary air damper located at box inlet. If damper is at box outlet, then box should be included in upstream leakage testing.

Table 3 Leakage as Percentage of Flow

Leakage Class*			Static Pressure, in. of water								
cfm per 100 ft ² per in. of water ^{0.65}	Q_{leak}/A_s , cfm/ft ² Duct Surface Area		0.5	1	2	3	4	5	6	8	10
12	2		3.8	6.0	9.4	12.3	14.8	17.1	19.2	23.2	26.8
	2.5		3.1	4.8	7.5	9.8	11.8	13.7	15.4	18.5	21.4
	3		2.5	4.0	6.3	8.2	9.8	11.4	12.8	15.5	17.9
	4		1.9	3.0	4.7	6.1	7.4	8.5	9.6	11.6	13.4
	5		1.5	2.4	3.8	4.9	5.9	6.8	7.7	9.3	10.7
6	2		1.9	3.0	4.7	6.1	7.4	8.5	9.6	11.6	13.4
	2.5		1.5	2.4	3.8	4.9	5.9	6.8	7.7	9.3	10.7
	3		1.3	2.0	3.1	4.1	4.9	5.7	6.4	7.7	8.9
	4		1.0	1.5	2.4	3.1	3.7	4.3	4.8	5.8	6.7
	5		0.8	1.2	1.9	2.5	3.0	3.4	3.8	4.6	5.4
4	2		1.3	2.0	3.1	4.1	4.9	5.7	6.4	7.7	8.9
	2.5		1.0	1.6	2.5	3.3	3.9	4.6	5.1	6.2	7.1
	3		0.8	1.3	2.1	2.7	3.3	3.8	4.3	5.2	6.0

Leakage Class ^a	cfm per 100 ft ² per in. of water ^{a,b}	Q_{lm}/A_s , cfm/ft ² Duct Surface Area	Static Pressure, in. of water									
			0.5	1	2	3	4	5	6	8	10	
3		4	0.6	1.0	1.6	2.0	2.5	2.8	3.2	3.9	4.5	
		5	0.5	0.8	1.3	1.6	2.0	2.3	2.6	3.1	3.6	
		2	1.0	1.5	2.4	3.1	3.7	4.3	4.8	5.8	6.7	
		2.5	0.8	1.2	1.9	2.5	3.0	3.4	3.8	4.6	5.4	
		3	0.6	1.0	1.6	2.0	2.5	2.8	3.2	3.9	4.5	
		4	0.5	0.8	1.2	1.5	1.8	2.1	2.4	2.9	3.4	
		5	0.4	0.6	0.9	1.2	1.5	1.7	1.9	2.3	2.7	
		2	0.6	1.0	1.6	2.0	2.5	2.8	3.2	3.9	4.5	
2		2.5	0.5	0.8	1.3	1.6	2.0	2.3	2.6	3.1	3.6	
		3	0.4	0.7	1.0	1.4	1.6	1.9	2.1	2.6	3.0	
		4	0.3	0.5	0.8	1.0	1.2	1.4	1.6	1.9	2.2	
		5	0.3	0.4	0.6	0.8	1.0	1.1	1.3	1.5	1.8	

^aConsult [Figure 2](#) for the relationship of leakage class and airtightness class used by European countries.

Calculating Test Section Allowable Leakage. Determine from the drawings the airflow and duct surface area in each section and then calculate the allowable leakage (see Example 1).
If an entire system or section of ductwork is not to be tested, determine the allowed leakage in the test section. To do this, determine the surface area of the test section, and divide that by the total surface area of the entire section. Multiply this test section leakage percentage by the section airflow to determine the test section leakage airflow.
Example 1. A system consists of three sections, with airflow and surface areas as summarized in [Table 4](#). Determine the allowable leakage for a 5000 ft² surface area section of Section 1 identified by the owner's representative. Branch 3 is located outdoors.
Solution. [Table 5](#) summarizes the calculations. By test, the 5000 ft² test section cannot exceed 700 cfm at 4.0 in. of water.

Responsibilities
(Refer to definitions of terms **ductwork** and **system** found at beginning of HVAC System Leakage section.)
The **engineer** should

- Specify HVAC system components, duct-mounted equipment, accessories, sealants, and sealing procedures that together can meet the system airtightness design objective
- Specify leakage test standard
- Specify allowable system leakage percentage
- Select a test pressure that does not exceed the pressure class rating of the ductwork
- Review or verify that the system meets the leakage specification

The **building owner or owner's representative** should

- Select sections for test once the contractor reports that at least three sections are fully assembled and ready for testing

The **sheet metal contractor** should

- Separate duct sections from each other as required so the test apparatus capacity is not exceeded
- Provide connections for the test apparatus
- Take corrective action where required to seal ductwork

The **test contractor** should

- Measure and record results of duct leakage tests
- Report test results

5. AIR-HANDLING UNIT LEAKAGE

Custom-designed air-handling units (AHUs) should be leak tested after the AHU is reassembled on site with all penetrations (e.g., for controls, electrical, and piping) in place and sealed. Leakage tests should be conducted by the AHU manufacturer in accordance with ASHRAE *Standard* 126-2015, Section 7, at design operating pressures (positive and negative) specified by the design engineer, and be witnessed by a representative of the owner. AHUs should be shipped with blankoffs and a round flanged opening for the flow meter/blower leakage test unit. It is recommended that packaged AHUs also be leak tested.
The casing leakage for AHUs should not exceed 1% of design airflow at the specified design pressure.

6. RESIDENTIAL AND COMMERCIAL DUCT CONSTRUCTION

Air connector. A rigid or flexible duct tested to 13 of the 16 UL *Standard* 181 tests required for "air ducts." Flame penetration, impact, and puncture testing are not required for air connector approval. Flexible air connectors are identified with a round listing mark indicating the product is a Class 0 or Class 1 "Air Connector."
Air duct. A flexible duct that passes all applicable UL *Standard* 181 tests to be listed as an "Air Duct." These tests include surface burning characteristics (ASTM *Standard* E84), flame penetration, burning, corrosion, mold growth and humidity, temperature, puncture, static load, impact, erosion, pressure, collapse, tension, torsion, bending, and leakage. Flexible air ducts are identified with a square or rectangular listing mark indicating the product is a Class 0 or Class 1 "Air Duct."
Class 0. Air duct or air connector having a flame spread index and smoke developed index of "zero" determined in accordance with UL *Standard* 723 (ASTM *Standard* E84).
Class 1. Air duct or air connector having a flame spread index not over 25 without evidence of continued progressive combustion and a smoke developed index of not over 50 determined in accordance with UL *Standard* 723 (ASTM *Standard* E84).
Flexible air connector. See *air connector*.
Flexible air duct. See *air duct*.
Flexible duct. A flexible air duct or flexible air connector.

Commentary:
1. Listed flexible air ducts and flexible air connectors are required by UL 181 to have a listing label applied every 10 ft or fraction thereof during the manufacturing process as part of their listing. However, installed ducts can be shorter than 10 ft; thus, a label might not be present under the current labeling requirements.
2. It is recommended that UL 181 markings be increased in size, prominence, and frequency to facilitate verification of duct classification between flexible air duct and flexible air connector.
3. Specifications should indicate the requirement for the use of flexible air ducts or flexible air connectors as appropriate for the conditions under which they are to be installed.

Buildings and Spaces
Typically, codes (IMC, IRC, UMC, IAPMO) and local ordinances invoke NFPA *Standards* 90A and 90B or some variation thereof. NFPA *Standard* 90A covers the following buildings and spaces:

- Buildings of combustible construction [Types III, IV and IV; for definition of construction types, see IBC (2015), Chapter 6] over three stories in height, regardless of volume
- Spaces over 25,000 ft³ in volume
- Buildings and spaces not covered by other applicable NFPA standards

NFPA *Standard* 90B covers the following dwellings and spaces:

- One- and two-story dwellings
- Spaces not exceeding 25,000 ft³ in volume in any occupancy

NFPA 90A Materials. Ducts must be constructed of steel, aluminum, copper, concrete, masonry, clay tile, or Class 0 or Class 1 flexible air duct tested in accordance with UL *Standard* 181 and installed in conformance with the conditions of their listing. Flexible ducts must not be used as vertical ducts serving more than two adjacent stories in height and must not penetrate fire-resistance-rated assemblies or construction.
Steel and aluminum construction must comply with SMACNA *Duct Construction Standards—Metal and Flexible* (2005). Refer to [Tables 6A, 6B, and 6C](#) for the relationship between gage and nominal/minimum thickness for galvanized steel, uncoated steel, and stainless steel sheet thickness. For galvanized ducts, a G60 (Z180) coating (ASTM *Standard* A653) is commonly used for dry indoor applications because the small amount of corrosion that may occur causes only discoloration in 20 to 30 years. For outdoor exposures or wet indoor applications, the galvanized duct coating should be G90 (Z270) minimum. The average years to first rust for G90 (Z275) coatings located outdoors depends on the environment: 3 to 7 years for severe industrial, 15 to 20 for rural, 7 to 10 for Atlantic coast marine, 12 for suburban, and 10 for urban (Stratton 2000).
NFPA 90B Materials. Supply ducts must be made of the following materials:

- Galvanized steel or aluminum having a minimum thickness per the standard/code having jurisdiction (NFPA 90B (2015: Table 4.1.1.1); IMC (2015: 603.4); IRC (2015: Table M1601.1.1); UMC (2015: Article 602.1)), or
- Class 0 or Class 1 rigid or flexible air duct tested in accordance with UL 181 and installed in conformance with the conditions of their listing. Rigid or flexible ducts must not be used as a vertical duct that is more than two stories in height and must not penetrate fire-resistance-rated assemblies or construction.

Return ducts governed by NFPA 90B (2015) must be constructed of metal, 1 in. nominal wood boards, or other material provided that the material is not more flammable than 1 in. wood boards. Return ductwork under the jurisdiction of a code is commonly constructed in accordance with SMACNA (2005). For galvanized ducts, a G60 (Z180) coating is recommended (ASTM *Standard* A653).

Commentary. UMC (2015) and IAPMO (2015) do not have steel duct construction requirements for single-dwelling units.
For spaces not exceeding 25,000 ft³ in volume (light commercial), it is recommended that duct systems be G60 (Z180) minimum galvanized steel, aluminum, or stainless steel in compliance with SMACNA (2005) or flexible duct in compliance with UL 181.

Round, Flat Oval, and Rectangular Ducts

Round Ducts. Round ducts are inherently strong and rigid, and are generally the most efficient and economical ducts for air systems. The dominant factor in round duct construction is the material's ability to withstand the physical abuse of installation and negative pressure requirements. SMACNA (2005) lists construction requirements as a function of static pressure, type of seam (spiral or longitudinal), and diameter. Proprietary joint systems are available from several manufacturers.

Table 4 Example 1 System Parameters

Section	Airflow, cfm	Surface Area, ft ²	cfm/ft ²	Allowable Leakage, %	Allowable Leakage, cfm
1 (main)	25,000	9000	2.8	5	1250
2 (branch)	10,000	4000	2.5	5	500
3 (branch)	15,000	5000	3.0	2	300
Total	50,000	18,000	2.8	4.1	2050

Table 5 Solution for Example 1

Test Section Leakage, %					
Test Section Area Fraction, ft ²					
Section Surface Area, ft ²					
Section	Surface Area, ft ²		Section Airflow, cfm	Allowable Leakage, %	Allowable Leakage, cfm
1 (main)	Under test	9000	14,000	5	700
	Not tested	4000	11,000	5	550
Total	9000	1.00	25,000	5	1250

Flat Oval Ducts. SMACNA (2005) also lists flat oval duct construction requirements. Seams and transverse joints are generally the same as those allowed for round ducts. However, proprietary joint systems are available from several manufacturers. Flat oval positive- and negative-pressure ducts should meet the functional requirements of Section 3.3 of SMACNA (2005). Hanger designs and installation details for rectangular ducts generally also apply to flat oval ducts.
Rectangular Ducts. *HVAC Duct Construction Standards—Metal and Flexible* (SMACNA 2005) lists construction requirements for rectangular steel ducts and includes combinations of duct thicknesses, reinforcement, and maximum distance between reinforcements. Transverse joints (e.g., standing drive slips, pocket locks, and companion angles) and, when necessary, intermediate structural members and tie rods are designed to reinforce the duct system. Proprietary joint systems are available from several manufacturers. *Rectangular Industrial Duct Construction Standards* (SMACNA 2004) gives pressures up to ±150 in. water.
Fittings must be reinforced similarly to sections of straight duct. On size change fittings, the greater fitting dimension determines material thickness. Where fitting curvature or internal member attachments provide equivalent rigidity, such features may be credited as reinforcement.
Nonferrous Ducts. SMACNA (2005) lists construction requirements for rectangular (±3 in. of water) and round (±2 in. of water) aluminum ducts. *Round Industrial Duct Construction Standards* (SMACNA 1999) gives construction requirements for round aluminum duct systems for pressures up to ±30 in. water.

Table 6A Galvanized Sheet Thickness

Galvanized Sheet Gage	Thickness, in.		Nominal Weight, lb/ft ²
	Nominal	Minimum ¹	
30	0.0157	0.0127	0.656
28	0.0187	0.0157	0.781
26	0.0217	0.0187	0.906
24	0.0276	0.0236	1.156
22	0.0336	0.0296	1.406
20	0.0396	0.0356	1.656
18	0.0516	0.0466	2.156
16	0.0635	0.0575	2.656
14	0.0785	0.0705	3.281
13	0.0934	0.0854	3.906
12	0.1084	0.0994	4.531
11	0.1233	0.1143	5.156
10	0.1382	0.1292	5.781

¹ Minimum thickness is based on thickness tolerances of hot-dip galvanized sheets in cut lengths and coils per ASTM *Standard* A924. Tolerance is valid for 48 and 60 in. wide sheets.

Table 6B Uncoated Steel Sheet Thickness

Thickness, in.				
Manufacturers' Standard Gage	Nominal	Minimum ¹		Nominal Weight, lb/ft ²
		Hot-Rolled	Cold-Rolled	
28	0.0149		0.0129	0.625
26	0.0179		0.0159	0.750
24	0.0239		0.0209	1.000
22	0.0299		0.0269	1.250
20	0.0359		0.0329	1.500
18	0.0478	0.0428	0.0438	2.000
16	0.0598	0.0538	0.0548	2.500
14	0.0747	0.0677	0.0697	3.125
13	0.0897	0.0827	0.0847	3.750
12	0.1046	0.0966	0.0986	4.375
11	0.1196	0.1116	0.1136	5.000
10	0.1345	0.1265	0.1285	5.625

Note: Table is based on 48 in. width coil and sheet stock; 60 in. coil has same tolerance, except that 16 gage is ±0.007 in. in hot-rolled coils and sheets.

¹ Minimum thickness is based on thickness tolerances of hot- and cold-rolled sheets in cut lengths and coils per ASTM *Standards* A568, A1008, and A1011.

Table 6C Stainless Steel Sheet Thickness

Gage	Thickness, in.		Nominal Weight, lb/ft ²	
	Nominal	Minimum ¹	Stainless Steel	
			300 Series	400 Series
28	0.0151	0.0131	0.634	0.622
26	0.0178	0.0148	0.748	0.733
24	0.0235	0.0205	0.987	0.968
22	0.0293	0.0253	1.231	1.207
20	0.0355	0.0315	1.491	1.463
18	0.0480	0.0430	2.016	1.978
16	0.0595	0.0535	2.499	2.451
14	0.0751	0.0681	3.154	3.094
13	0.0900	0.0820	3.780	3.708
12	0.1054	0.0964	4.427	4.342
11	0.1200	0.1100	5.040	4.944
10	0.1350	0.1230	5.670	5.562

¹ Minimum thickness is based on thickness tolerances of hot-rolled sheets in cut lengths and cold-rolled sheets in cut lengths and coils per ASTM *Standard* A480.

Fibrous Glass Ducts
Fibrous glass ducts are a composite of rigid fiberglass and a factory-applied facing (typically aluminum or reinforced aluminum), which serves as a finish and vapor retarder. Fibrous glass ducts must be constructed from UL Class 1 air duct material in accordance with the manufacturer's instructions and meet the requirements of UL *Standard* 181 for rigid air ducts. Fibrous glass duct are available in molded round sections or in board form for fabrication into rectangular or polygonal shapes.
Duct systems of round and rectangular fibrous glass are generally limited to 2400 fpm and ±2 in. water. Molded round ducts are available in higher pressure ratings. *Fibrous Glass Duct Construction Standards* (NAIMA 2002a; SMACNA 2003) and manufacturers' installation instructions give details on fibrous glass duct construction. SMACNA (2003) also covers duct and fitting fabrication, closure, reinforcement, and installation, including installation of duct-mounted HVAC appurtenances (e.g., volume dampers, turning vanes, register and grille connections, diffuser connections, access doors, fire damper connections, electric heaters). AIA (2006) includes guidelines for using fibrous glass ducts in health care facilities.

Phenolic Ducts
A phenolic duct system comprises phenolic panels, fabrication methods, coupling systems, and accessories to produce preinsulated rectangular ductwork in sections up to 13 ft long. Phenolic panels are 7/8 in. thickness and 1 3/16 in. thickness (SMACNA 2015). Phenolic ducts must be UL Class1 and meet the requirements of UL *Standard* 181 for rigid air ducts.
Phenolic panels comprise a fiber-free rigid thermoset phenolic insulation core faced with silver aluminum foil on one side and plain silver aluminum foil on the other. In addition, there are several transverse joint systems available to suit different installation and project specification requirements. They include panel fastener systems, aluminum grip type flange systems, and a four-bolt system.

Flexible Ducts
Flexible ducts are categorized by their UL listing as either **air duct** or **air connector** (see the section on Definitions). Air ducts and air connectors may be metallic or nonmetallic and are listed and labeled as Class 0 or Class 1 by UL *Standard* 181. These ducts must be installed per the conditions of their listing and the manufacturer's installation instructions provided. The maximum allowed temperature inside flexible ducts (air ducts and air connectors) is 250°F per their listing and NFPA 90A and 90B requirements.
Commentary: The IMC (2015), IRC (2015), and UMC (2015) require installation instructions on or within the package or there must be specific directions referring to the manufacturer's web site for instructions. Generally, minimum instructions are provided on or inside the package, with reference to the website for more detailed instructions. Also see the section on Installation.
Flexible Air Connectors. Air connectors are limited-use flexible ducts that can be used in lieu of air ducts in NFPA 90A and 90B buildings provided that they comply with the following limitations:

1. Length does not exceed 14 ft. Connecting multiple sections of flexible air connectors using sheet metal couplings to obtain a total air connector run greater than that allowed by code is not allowed.
2. The flexible air connector does not pass through any wall, partition, or enclosure of a vertical shaft having a fire resistance rating of 1 h or more.
3. The flexible air connector does not pass through floors.

Commentary:

- Uniform Mechanical Code (UMC 2015) limits flexible air ducts and flexible air connectors to no longer than 5 ft in length for nonresidential systems and does not allow their use in lieu of rigid elbows or fittings.
- In addition to NFPA 90A (2015) and 90B (2015), the International Mechanical Code (IMC 2015) also limits flexible air connectors to 14 ft in length.

Hangers and Supports
SMACNA (2005) covers HVAC system hangers for rectangular, round, and flat oval ducts. When special analysis is required for larger ducts, loads, or other hanger configurations, AISC and AISI design manuals should be consulted. To hang or support fibrous glass ducts, the methods detailed by NAIMA (2002a) and SMACNA (2003) are recommended. Flexible air ducts and flexible air connectors should be supported at intervals not exceeding 4 ft when installed horizontal and 6 ft when installed as vertical risers. Flexible duct supports should be minimum 1 1/2 in. wide and of sufficient rigidity to maintain this width to prevent any restriction of the internal duct diameter when the weight of the supported section rests on the hanger. Cloth hangers should not be used.

- Installation**
Sheet metal ducts must be installed in accordance with *HVAC Duct Construction Standards—Metal and Flexible* (SMACNA 2005). Fibrous glass ducts must be installed in accordance with the industry fibrous glass duct construction standards (NAIMA 2002a; SMACNA 2003). Flexible ducts must be installed in accordance with *Flexible Duct Performance and Installation Standards* (ADC 2010), and as follows:
1. Owner's representative should review flexible duct markings to verify that the flexible duct is (1) a UL listed "Air Duct" or "Air Connector," and (2) installed per applicable code limitations.
 2. Flexible air ducts and flexible air connectors should be installed fully extended with minimal compression. Excess length should not be allowed for future relocation of VAV boxes, registers, or other system components.
 3. Install flexible ducts so that bends equal or exceed one duct diameter bend radius based on the inside duct diameter. Ducts should not be bent across sharp corners such as pipes, wires, posts, joists, or trusses.
 4. For recommended flexible air duct and flexible air connector spacing, refer to the section on Hangers and Supports.
 5. The maximum sag between horizontal duct supports should be 1/2 in. per ft.
 6. Tape and mastic used for sealing flexible duct to metal fittings should be listed and labeled to UL *Standard* 181B. For details, consult the HVAC System Leakage, Sealants sections "General" and "Flexible Duct."
 7. Do not install flexible duct upstream of VAV boxes. Instead, use rigid ducts in these locations as described by Taylor (2015).
 8. When installing flexible air ducts and flexible air connectors in inaccessible spaces, the use of metal worm-gear clamps is recommended. Nonmetallic fasteners (plastic straps) are not recommended.
 9. Do not penetrate nonmetallic flexible duct inner core with sheet metal screws unless the flexible duct manufacturer's installation instructions specifically allow the use of screws as part of the closure method.
 10. When installing flexible air ducts and flexible air connectors in inaccessible spaces, attention should be given to the ability to clean the flexible duct (see the section on Duct Cleaning).
 11. For insulated ducts, the outer vapor barrier should be pulled back over the core and fitting and secured using two wraps of UL 181B-FX tape. A clamp may be used in place of or in combination with the tape.
 12. Fittings used in combination with flexible air ducts and air connectors should have a 2 in. minimum rigid attaching collar with a bead. Flexible duct inner cores should be installed at least 1 in. onto the fitting and past the bead prior to taping and application of the mechanical fastener past the bead. Beaded fittings are not required when metal worm-gear clamps are used.

Plenums and Apparatus Casings
SMACNA (2005) shows details on field-fabricated plenum and apparatus casings. Sheet metal thickness and reinforcement for plenum and casing pressure outside the range of -3 to 10 in. of water can be based on *Rectangular Industrial Duct Construction Standards* (SMACNA 2004). Carefully analyze plenums and apparatus casings on the discharge side of a fan for maximum operating pressure in relation to the construction detail being specified. On the fan's suction side, plenums and apparatus casings are normally constructed to withstand negative air pressure at least equal to the total upstream static pressure loss. Accidentally stopping intake airflow can apply a negative pressure as great as the fan shutoff pressure. Conditions such as malfunctioning dampers or clogged louvers, filters, or coils can collapse a normally adequate casing. To protect large casing walls or roofs from damage, it is more economical to provide fan safety interlocks, such as damper and switches or pressure limit switches, than to use heavier sheet metal construction. Apparatus casings can perform two acoustical functions. If the fan is completely enclosed within the casing, fan noise transmission through the fan room to adjacent areas is reduced substantially. An acoustically lined casing also reduces airborne noise in connecting ductwork. Acoustical treatment may consist of a single metal wall with a field-applied acoustical liner or thermal insulation, or a double-walled panel with an acoustical liner and a perforated metal inner liner. Double-walled casings are marketed by many manufacturers, who publish data on structural, acoustical, and thermal performance and also prepare custom designs.

Acoustical Treatment
Metal ducts are frequently lined with acoustically absorbent materials to reduce noise. Although many materials are acoustically absorbent, duct liners must also be resistant to erosion and fire and have properties compatible with the ductwork fabrication and erection process. For higher-velocity ducts, double-walled construction using a perforated metal inner liner is frequently specified. [Chapter 48 of the 2015 ASHRAE Handbook—HVAC Applications](#) addresses design considerations, including external lagging. *ASTM Standard* C423 covers laboratory testing of duct liner materials to determine their sound absorption coefficients, and *ASTM Standard* E477 covers acoustical insertion loss of duct liner materials. Designers should review all of the tests in *ASTM Standard* C1071. A wide range of performance attributes (e.g., vapor adsorption and resistance to erosion, temperature, bacteria, and fungi) is covered. Health and safety precautions are addressed, and manufacturers' certifications of compliance are also covered. AIA (2006) includes guidelines for using duct liner in hospital and health care facilities. Rectangular duct liners should be secured by mechanical fasteners and installed in accordance with *HVAC Duct Construction Standards—Metal and Flexible* (SMACNA 2005). Adhesives should be Type I, in conformance to *ASTM Standards* C916, and should be applied to the duct, with at least 90% coverage of mating surfaces. Good workmanship prevents delamination of the liner and possible blockage of coils, dampers, flow sensors, or terminal devices. Rough edges should be sealed to prevent airborne fibers and erosion of lining. Avoid uneven edge alignment at buttled joints to minimize unnecessary resistance to airflow (Swim 1978). Rectangular metal ducts are susceptible to rumble from flexure in the duct walls during start-up and shutdown. For a system that must switch on and off frequently (for energy conservation) while buildings are occupied, duct construction that reduces objectionable noise should be specified.

7. INDUSTRIAL DUCT CONSTRUCTION

NFPA *Standard* 91 is widely used for design, construction, installation, and maintenance of duct systems conveying particulates and removing flammable vapors (including paint-spraying residue), and corrosive fumes. Industrial duct systems are generally classified as follows:

- **Class 1** covers nonparticulate applications, including makeup air, general ventilation, and gaseous emission control.
- **Class 2** is imposed on moderately abrasive particulate in light concentration, such as that produced by buffing and polishing, woodworking, and grain handling.
- **Class 3** consists of highly abrasive material in low concentration, such as that produced from abrasive cleaning, dryers and kilns, boiler breaching, and sand handling.
- **Class 4** is composed of highly abrasive particulates in high concentration, including materials conveying high concentrations of particulates listed under Class 3.
- **Class 5** covers corrosive applications such as acid fumes.

For contaminant abrasiveness ratings, see SMACNA's (1999, 2004) round or rectangular industrial duct construction standards.Consult [Chapters 14 to 23 of the 2015 ASHRAE Handbook—HVAC Applications](#) for specific processes and uses.

Materials
Galvanized steel, uncoated carbon steel, or aluminum are most frequently used for industrial air handling. Aluminum ducts are not used for conveying abrasive materials; when temperatures exceed 400°F, galvanized steel is not recommended. Duct material for handling corrosive gases, vapors, or mists must be selected carefully. For the application of metals and use of protective coatings in corrosive environments, consult *Accepted Industry Practice for Industrial Duct Construction* (SMACNA 2008a), the *Pollution Engineering Practice Handbook* (Cheremisinoff and Young 1975), and publications of the National Association of Corrosion Engineers (NACE) and ASM International (www.asminternational.org).

Round Ducts
SMACNA (1999) provides information on selecting material thickness and reinforcement members for spiral and nonspiral industrial ducts. Spiral-seam ducts are only for industrial duct Class 1 and 2 applications. The tables in this standard are as follows:
Class (Industrial Duct). Steel: Classes 1, 2, 3, 4, and 5. Aluminum: Class 1 only. Stainless steel: Classes 1 and 5.
Pressure classes for steels and aluminum. -30 to +50 in. of water, in increments of 2 in. of water.
Duct diameter for steels and aluminum. 4 to 96 in., in increments of 2 in. Equations are provided for calculating construction requirements for diameters over 96 in.

Rectangular Ducts
Rectangular Industrial Duct Construction Standards (SMACNA 2004) is available for selecting hot-rolled steel, galvanized steel, or stainless steel thickness and reinforcement members for industrial ducts. The data in this standard give the duct construction for any pressure class and panel width. The designer selects a combination of panel thickness, reinforcement, and reinforcement member spacing to limit the deflection of the duct panel to a design maximum. Any shape of transverse joint or intermediate reinforcement member that meets the minimum requirement of both section modulus and moment of inertia may be selected. The SMACNA data, which may also be used for designing apparatus casings, limit the combined stress in either the panel or structural member to 24,000 psi and the maximum allowable deflection of the reinforcement members to 1/360 of the duct width.

Construction Details
Recommended manuals for other construction details are *Industrial Ventilation: A Manual of Recommended Practice* (ACGIH 2013), *NFPA Standard* 91, and *Accepted Industry Practice for Industrial Duct Construction* (SMACNA 2008a). For industrial duct Classes 2, 3, and 4, transverse reinforcing of ducts subject to negative pressure below -3 in. of water should be welded to the duct wall rather than relying on mechanical fasteners to transfer the static load.

Hangers
The *Steel Construction Manual* (AISC 2011) and the *Cold-Formed Steel Design Manual* (AISI 2008) give design information for industrial duct hangers and supports. SMACNA standards for round and rectangular industrial ducts (SMACNA 1999, 2004) and manufacturers' schedules include duct design information for supporting ducts at intervals of up to 35 ft.

8. ANTIMICROBIAL-TREATED DUCTS

Antimicrobial-treated ducts are coated (as a precoat or after fabrication) with a substance that inhibits the growth of bacteria, mold, and fungi (including mildew). Antimicrobial-treated galvanized steel, stainless steel, and aluminum ducts can be used when the service temperature of the antimicrobial compound is not exceeded. Prefabricated coatings allow metal to be pressed, drawn, bent, and roll-formed without coating loss. Imperfections in metal ducts, such as spot welds and welded joints, can be repaired with a touch-up paint of the antimicrobial compound. Fabrics can be made inherently antimicrobial by combining the antimicrobial chemistry into the polymer fibers of the product. Glass fiber duct liners can be made resistant to bacterial and fungal growth using a biocide that protects the airstream surface from microbial growth. All antimicrobial coatings or touch-up paints should be EPA-registered antimicrobial compounds, tested per *ASTM Standard* E84, survive minimum and maximum service temperature limits, and comply with *NFPA Standards* 90A and 90B. Coatings should have flame spread/smoke developed ratings not exceeding 25/50, and meet local building code requirements.

9. DUCT CONSTRUCTION FOR GREASE- AND MOISTURE-LADEN VAPORS

Factory-Built Grease Duct Systems
Manufactured grease duct systems are made in accordance with UL *Standard* 1978 and are UL or ETL listed. These systems are also classified in accordance with UL *Standard* 2221 for clearance to combustibles. Factory-built grease duct systems must be assembled in accordance with manufacturers' recommended instructions but are not required to be welded. Component assembly is by bands/sleeves, and the systems are watertight. The gages for metal ducts used in these systems are considerably lighter than for welded site-fabricated grease ducts, and there may be substantial installation savings because components are assembled with tools instead of welding. System segments classified for clearance to combustibles are typically provided as a metal liner and outer shell, with insulation or an air gap in the annular space.

Site-Built Grease Duct Systems
Installation and construction of ducts for removing smoke or grease-laden vapors from cooking equipment should be in accordance with *NFPA Standard* 96. Kitchen exhaust ducts that conform to *NFPA Standard* 96 must (1) be constructed from carbon steel with a minimum thickness of 0.054 in. (16 gage) or stainless steel sheet with a minimum thickness of 0.043 in. (18 gage); (2) have all longitudinal seams and transverse joints continuously welded; and (3) be installed without dips or traps that may collect residues, except where traps with continuous or automatic removal of residue are provided. Test ports should not be installed in grease-rated ductwork, except for temporary measuring test holes, which are sealed by welding before equipment use. Because fires may occur in these systems (producing temperatures in excess of 2000°F), provisions are necessary for expansion in accordance with the following table. Ducts that must have a fire resistance rating are usually encased in materials with appropriate thermal and durability ratings.

Kitchen Exhaust Duct Material	Duct Expansion at 2000°F, in/ft
Carbon steel	0.19
Type 304 stainless steel	0.23
Type 430 stainless steel	0.13

Duct Systems for Moisture-Laden Air
Ducts that convey moisture-laden air must have construction specifications that properly account for corrosion resistance, drainage, and waterproofing of joints and seams. No nationally recognized standards exist for applications in areas such as kitchens, swimming pools, shower rooms, and steam cleaning or washdown chambers. Galvanized steel, stainless steel, aluminum, and plastic materials have been used. Wet and dry cycles increase metal corrosion. Chemical concentrations affect corrosion rate significantly. [Chapter 49 of the 2015 ASHRAE Handbook—HVAC Applications](#) addresses material selection for corrosive environments. Conventional duct construction standards are frequently modified to require welded or soldered joints, which are generally more reliable and durable than sealant-filled, mechanically locked joints. The number of transverse joints should be minimized, and longitudinal seams should not be located on the bottom of the duct. Risers should drain and horizontal ducts should pitch in the direction most favorable for moisture control. ACGIH (2013) covers hood design.

10. RIGID PLASTIC DUCTS
The *Thermoplastic Duct (PVC) Construction Manual* (SMACNA 1999) covers thermoplastic (polyvinyl chloride, polyethylene, polypropylene, acrylonitrile butadiene styrene) ducts used in commercial and industrial installations. SMACNA's manual provides comprehensive polyvinyl chloride duct construction details for positive or negative 2, 4, 6, and 10 in. of water. *NFPA Standard* 91 provides construction details and application limitations for plastic ducts. Model code agencies publish evaluation reports indicating terms of acceptance of manufactured ducts and other ducts not otherwise covered by industry standards and codes. Physical properties, manufacture, construction, installation, and methods of testing for fiberglass-reinforced thermosetting plastic (FRP) ducts are described in the *Thermoset FRP Duct Construction Manual* (SMACNA 1997). These ducts are intended for air conveyance in corrosive environments as manufactured by hand lay-up, spray-up, and filament winding fabrication techniques. The term *FRP* also refers to fiber-reinforced plastic (fibers other than glass). Other terms for FRP are reinforced thermoset plastic (RTP) and glass-reinforced plastic (GRP), which is commonly used in Europe and Australia. SMACNA (1997) has construction standards for pressures up to +30 in. of water, temperatures up to 180°F, and duct sizes from 4 to 72 in. round and 12 to 96 in. rectangular.

11. AIR DISPERSION SYSTEMS

Air dispersion systems are designed to both convey and disperse air in the space being conditioned. Diffusion options include linear vents, nozzles, orifices, and porous fabrics. There are three typical cross-sectional shapes: semicircular D-shape, quarter round, and cylindrical (most common). D-shape and quarter round are normally mounted to a surface (wall or ceiling), whereas cylindrical are suspended from the ceiling. The cross-sectional area is based on the interior air velocity.

Typically, these systems are made of fabric, but also include sheet metal or plastic film, including porous and nonporous options. UL *Standard* 2518 is the recognized standard to evaluate fabric air dispersion systems and their materials for safety and building code requirements.

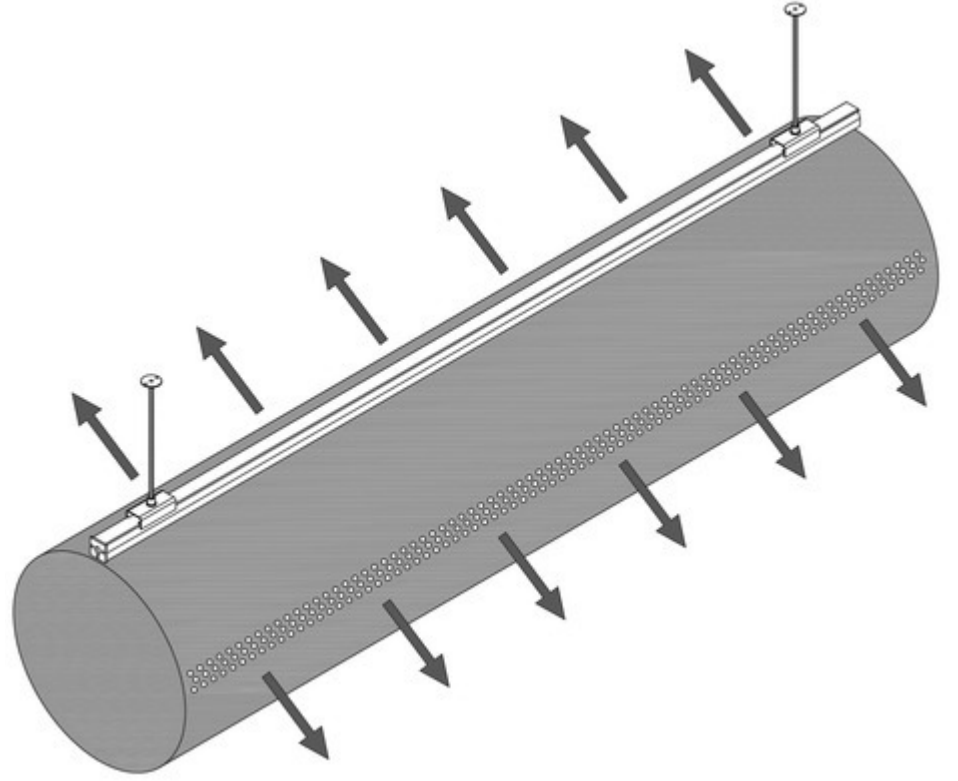


Figure 3. Fabric Duct with Nozzle Outlets

Consult the manufacturer for design criteria for selecting air dispersion type [linear vents, orifices, nozzles, microperforated (porous weave) fabric], fabric (porous or nonporous, color, weight, and construction), suspension options (cable or track options), and installation instructions. In design, consider velocities of 1000 to 1600 fpm at static pressures of 0.3 to 1.0 in. of water to ensure proper airflow performance. Excessively turbulent airflow (from metal fittings or fans) or higher inlet velocities can cause fabric fluttering, excessive noise, premature material failure, and poor air dispersion. Fabric airflow restriction devices are available to help balance static pressures, reduce turbulence, reduce abrupt inflation, and balance airflow into branch ducts.

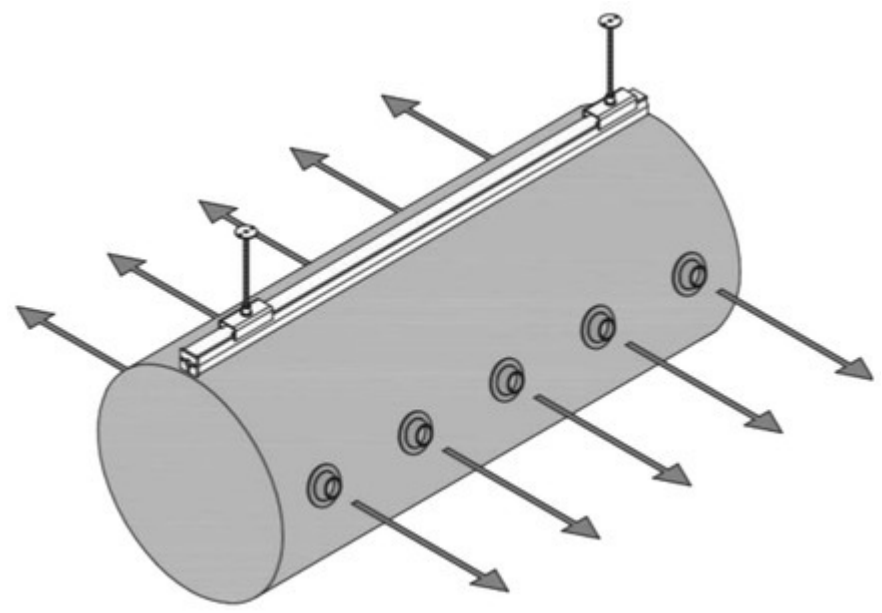


Figure 4. Fabric Duct with Nozzle Outlets

Dispersion Types
Linear Vent Outlets. Air is delivered through linear vents providing linear air flow. This vent typically consists of small openings (0.25 to 1 in. diameter) set in an array that is long and narrow ([Figure 3](#)). Airflow typically ranges from 5 to 60 cfm per linear foot of vent at 0.5 in. of water and is usually installed far enough away from a surface that it is a free-air jet. These linear vents normally run the length of the product on both sides.
Orifice and Nozzle Outlets. Air is delivered through orifices or nozzles ([Figure 4](#)), providing jet-type air distribution. Typical applications are gymsnasiums, pools, and manufacturing facilities. Nozzles can direct air perpendicularly away from the surface of the duct. Adjustable nozzles allow for changing flow direction, rate, and throw. Nozzles generally have the least entrainment of long-throw outlets. The sizes of orifices and nozzles typically range from 0.5 to 5 in. diameter.
Porous-Duct-Surface Air Distribution System. Airflow is discharged through a porous weave or microperforated fabric ([Figure 5](#)), resulting in air velocities 30 to 80 fpm at the surface of the fabric duct to minimize mixing between supply and room air. This air distribution system is typically used for food processing, cleanrooms, and laboratories where draft elimination and uniform air distribution are required.
NFPA Standard 90B and IMC requirements for fabric air distribution systems are as follows:

1. Install systems in entirely exposed locations.
2. Always operate these systems under positive pressure.
3. Do not allow any system component to pass through or penetrate fire-resistance-rated construction.
4. All systems and components must be listed and labeled in accordance with UL 2518.

12. UNDERGROUND DUCTS

No comprehensive standards exist for underground air duct construction. Coated steel, asbestos cement, plastic tile, concrete, reinforced fiberglass, and other materials have been used. Underground duct and fittings should always be round and have a minimum thickness as listed in SMACNA (2005), although greater thickness may be needed for individual applications. Specifications for construction and installation of underground ducts should account for the following: water tables, ground surface flooding, the need for drainage piping beneath ductwork, temporary or permanent anchorage to resist flotation, frost heave, backfill loading, vehicular traffic load, corrosion, cathodic protection, heat loss or gain, building entry, bacterial organisms, degree of water- and airtightness, inspection or testing before backfill, and code compliance. [Chapter 14](#) has information on cathodic protection of direct-buried conduits. Residential installations may also be subject to the requirements in *NFPA Standard* 90B. Commercial systems also normally require compliance with *NFPA Standard* 90A.

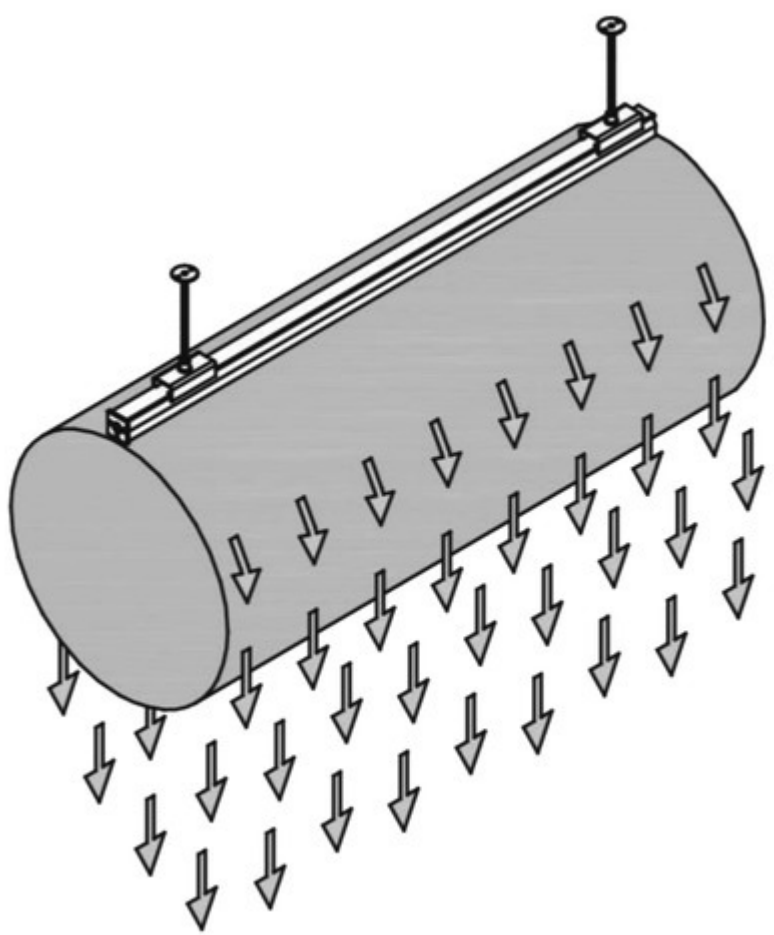


Figure 5. Fabric Duct with Porous Material as Air Outlet

13. DUCTS OUTSIDE BUILDINGS

Exposed ducts and their sealant/joining systems must be evaluated for the following:

- Waterproofing
- Resistance to external loads (wind, snow, and ice)
- Degradation from corrosion, ultraviolet radiation, or thermal cycles
- Heat transfer, solar reflectance, and thermal emittance
- Susceptibility to physical damage

- Hazards at air inlets and discharges
 - Maintenance needs
- In addition, supports must be custom-designed for rooftop, wall-mounted, and bridge or ground-based applications. Specific requirements must also be met for insulated and uninsulated ducts.

14. SEISMIC QUALIFICATION

Seismic analysis of duct systems may be required by building codes or federal regulations. Provisions for seismic analysis are given by the Federal Emergency Management Agency (FEMA 2009). Ducts, duct hangers, fans, fan supports, and other duct-mounted equipment are generally evaluated independently. [Chapter 55 of the 2015 ASHRAE Handbook—HVAC Applications](#) gives design details. SMACNA (2008b) provides guidelines for seismic restraints of mechanical systems and gives bracing details for ducts, pipes, and conduits that apply to the model building codes and ASCE *Standard* 7. FEMA (2013a, 2013b, 2014) has three fully illustrated guides that show equipment installers how to attach mechanical and electrical equipment or ducts and pipes to a building to minimize earthquake damage.

15. SHEET METAL WELDING

AWS (2012) covers sheet metal arc welding and braze welding procedures. It also addresses the qualification of welders and welding operators, workmanship, and the inspection of production welds.

16. THERMAL INSULATION

Insulation materials for ducts, plenums, and apparatus casings are covered in [Chapter 23 of the 2013 ASHRAE Handbook—Fundamentals](#). Codes generally limit factory-insulated ducts to UL *Standard* 181, Class 0 or 1. *Commercial and Industrial Insulation Standards* (MICA 2014) gives insulation details. ASTM *Standard* C1290 gives specifications for fibrous glass blanket external insulation for ducts.

17. SPECIFICATIONS

Master specifications for duct construction and most other elements in building construction are produced and regularly updated by several organizations. Two examples are *MASTERSPEC* by the American Institute of Architects (AIA) and *SPECTEXT*® by the Construction Sciences Research Foundation (CSRF). *MasterFormat*™ (CSI 2014) is the organization standard for specifications. These documents are model project specifications that require editing to customize each application for a project. It is the design engineer's responsibility to create clear construction specifications.

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