CHAPTER 18

DUCT CONSTRUCTION

THIS chapter covers construction of HVAC and exhaust duct systems for residential, commercial, and industrial applications. Technological advances in duct construction should be judged relative to the construction requirements described here and to appropriate codes and standards. Although the construction materials and details shown in this chapter may coincide, in part, with industry standards, they are not in an ASHRAE standard.

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 illustrates 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). Specifications for U.S. federal government construction are promulgated by agencies such as the Federal Construction Council, the General Services Administration, the Department of the Navy, and the Veterans Administration.

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 code compliance obligations affect 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

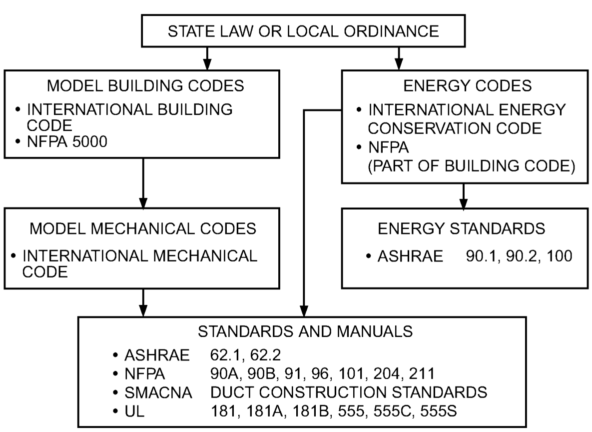

Fig. 1 Hierarchy of Building Codes and Standards

equivalency incorporated into codes. Staff engineers from the model code agencies are available to assist in resolving conflicts, ambiguities, and equivalencies.

Smoke management is covered in Chapter 52 of the 2007 *ASHRAE Handbook—HVAC Applications*. The designer should consider flame spread, smoke development, combustibility, and toxic gas production from ducts and duct insulation materials. Code documents for ducts in certain locations in buildings rely on a criterion of limited combustibility (see NFPA *Standard* 90A), which is independent of the generally accepted criteria of 25 flame spread and 50 smoke development; however, certain duct construction protected by extinguishing systems may be accepted with higher levels of combustibility by code officials.

Combustibility and toxicity ratings are normally based on tests of new materials; little research is reported on ratings of aged duct materials or of dirty, poorly maintained systems.

CLASSIFICATIONS

Duct construction is classified by application and pressure. HVAC systems in public assembly, business, educational, general factory, and mercantile buildings are usually designed as *commercial*. Air pollution control systems, industrial exhaust systems, and systems outside the pressure range of commercial system standards are classified as *industrial*.

Classifications are as follows:

Residences	±0.5 in. of water
	±1 in. of water
Commercial Systems	±0.5 in. of water
	±1 in. of water
	±2 in. of water
	±3 in. of water
	±4 in. of water
	±6 in. of water
	±10 in. of water
Industrial Systems	Any pressure

Air conveyed by a duct adds both static pressure and velocity pressure loads on the duct's structure. The load from mean static pressure differential across the duct wall normally dominates and is generally used for duct classification. Turbulent airflow adds relatively low but rapidly pulsating loading on the duct wall.

Static pressure at specific points in an air distribution system is not necessarily the static pressure rating of the fan; the actual static pressure in each duct section must be obtained by computation. Therefore, the designer should specify the 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.

The preparation of this chapter is assigned to TC 5.2, Duct Design.

Table 1 Recommended Duct Seal Levels*

	Duct Type			
	Supply			
Duct Location	≤2 in. water	>2 in. water	Exhaust	Return
Outdoors	A	A	A	A
Unconditioned spaces	A	A	B	B
Conditioned spaces	A	A	B	B

*See Table 2 for definition of seal level.

Table 2 Duct Seal Levels*

Seal Level	Sealing Requirements
A	All transverse joints, longitudinal seams, and duct wall penetrations
B	All transverse joints and longitudinal seams

*Transverse joints are connections of two ducts oriented perpendicular to flow. Longitudinal seams are joints oriented in the direction of airflow. Duct wall penetrations are openings made by screws, non-self-sealing fasteners, pipe, tubing, rods, and wire. Round and flat oval spiral lock seams need not be sealed. All other connections are considered transverse joints, including but not limited to spin-ins, taps and other branch connections, access door frames, and duct connections to equipment.

DUCT CLEANING

Ducts may collect dirt and moisture, which can harbor or transport microbial contaminants. Design, construct, and maintain ducts to minimize the opportunity for growth and dissemination of microorganisms. Recommended control measures include using access for cleaning, using proper filtration, and preventing moisture and dirt accumulation. NADCA (2006) and NAIMA (2002a) have specific information and procedures for cleaning ducts. Owners should routinely conduct inspections for cleanliness.

LEAKAGE

Predicted leakage rates for unsealed and sealed ducts are reviewed in Chapter 35 of the 2005 *ASHRAE Handbook—Fundamentals*. Project specifications should define allowable duct leakage, specify the need for leak testing, and require the duct installer to perform a leak test after installing an initial portion of the duct. Ducts should be sealed in compliance with Table 1; duct seal levels are defined in Table 2. Exposed supply ducts in conditioned spaces should be seal level A to prevent dirt smudges. Leakage classifications for ducts are given in Table 6 in Chapter 35 of the 2005 *ASHRAE Handbook—Fundamentals.* Procedures in the *HVAC Air Duct Leakage Test Manual* (SMACNA 1985) should be followed for leak testing. If a test indicates excess leakage, corrective measures should be taken to ensure quality.

ASHRAE Research Project RP-1132 (Sahu and Idem 2003) established baseline data on the effects of sealing ducts to diffusers and supply and return grilles. Test setups were designed to simulate typical field conditions. For flow rates from 250 to 1300 cfm, the leakage flow rate generally varied from 1 to 8% of the total approach flow rate, depending on sealing conditions. Moderate sealing of the connection between the air terminal collar and the duct significantly reduced leakage. In general, for rigid ducts, mounting the terminal collar to the duct with sheet metal screws (as prescribed by the terminal manufacturer) reduced leakage by more than 50%. Likewise, using draw bands to mount air terminals to flexible ducts can reduce leakage at the collar to virtually zero. It is recommended that all rigid duct/terminal connections be sealed.

Responsibility for proper assembly and sealing belongs to the installing contractor. The most cost-effective way to control leakage is to follow proper installation procedures. However, the incremental cost of achieving 1% or less leakage becomes prohibitively high, particularly for large duct systems. Because access for repairs is usually limited, poorly installed duct systems that must later be resealed can cost more than a proper installation.

Table 3 Residential Metal Duct Construction[1]

Shape of Duct and Exposure	Galvanized Steel Minimum Thickness, in. (gage)	Aluminum[2] Minimum Thickness, in.
Round and enclosed rectangular ducts		
14 in. or less	0.013 (30)	0.014
Over 14 in.	0.016 (28)	0.0175
Exposed rectangular ducts		
14 in. or less	0.016 (28)	0.0175
Over 14 in.	0.019 (26)	0.0215

[1]NFPA *Standard* 90B.
[2]ASTM B-209; Alloy 3003-H14

RESIDENTIAL DUCT CONSTRUCTION

NFPA *Standard* 90B, ICC's (2006) *International Residential Code for One- and Two-Family Dwellings*, or a local code is used for duct systems in single-family dwellings. Generally, local authorities use NFPA *Standard* 90A for multifamily homes.

Supply ducts may be steel, aluminum, or a material with a UL *Standard* 181 listing. Sheet metal ducts should be of the minimum thickness shown in Table 3 and installed in accordance with *HVAC Duct Construction Standards—Metal and Flexible* (SMACNA 2005). Fibrous glass ducts should be installed in accordance with the *Fibrous Glass Duct Construction Standards* (NAIMA 2002b; SMACNA 2003). For return ducts, alternative materials, and other exceptions, consult NFPA *Standard* 90B.

COMMERCIAL DUCT CONSTRUCTION

Materials

Many building code agencies use NFPA *Standard* 90A as a guide. NFPA *Standard* 90A invokes UL *Standard* 181, which classifies ducts as follows:

Class 0: Zero flame spread, zero smoke developed
Class 1: 25 flame spread, 50 smoke developed

NFPA *Standard* 90A states that ducts must be iron, steel, aluminum, concrete, masonry, or clay tile. However, ducts may be UL *Standard* 181 Class 1 materials when they are not used as vertical risers of more than two stories or in systems with air temperatures higher than 250°F. Many manufactured flexible and fibrous glass ducts are UL listed as Class 1. For galvanized ducts, a G60 coating is recommended (see ASTM *Standard* A653). The minimum thickness and weight of sheet metal sheets are given in Tables 4A, 4B, and 4C.

External duct-reinforcing members are formed from sheet metal or made from hot-rolled or extruded structural shapes. The size and weights of commonly used members are given in Table 5.

Rectangular and Round Ducts

Rectangular Metal 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 2007) gives construction details for ducts up to 144 in. wide at a pressure up to ±150 in. of 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.

Table 4A Galvanized Sheet Thickness

Galvanized Sheet Gage	Thickness, in. Nominal	Thickness, in. Minimum*	Nominal Weight, lb/ft²
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

*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 4B Uncoated Steel Sheet Thickness

Manufacturers' Standard Gage	Thickness, in. Nominal	Minimum* Hot-Rolled	Minimum* Cold-Rolled	Nominal Weight, lb/ft²
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.
*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 4C Stainless Steel Sheet Thickness

Gage	Thickness, in. Nominal	Thickness, in. Minimum*	Nominal Weight, lb/ft², Stainless Steel 300 Series	Nominal Weight, lb/ft², Stainless Steel 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

*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).

Round Metal 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 5 Steel Angle Weight per Unit Length (Approximate)

Angle Size, in.	Weight, lb/ft
3/4 × 3/4 × 1/8	0.59
1 × 1 × 0.0466 (minimum)	0.36
1 × 1 × 0.0575 (minimum)	0.44
1 × 1 × 1/8	0.80
1 1/4 × 1 1/4 × 0.0466 (minimum)	0.45
1 1/4 × 1 1/4 × 0.0575 (minimum)	0.55
1 1/4 × 1 1/4 × 0.0854 (minimum)	0.65
1 1/4 × 1 1/4 × 1/8	1.01
1 1/2 × 1 1/2 × 0.0575 (minimum)	0.66
1 1/2 × 1 1/2 × 1/8	1.23
1 1/2 × 1 1/2 × 3/16	1.80
1 1/2 × 1 1/2 × 1/4	2.34
2 × 2 × 0.0575 (minimum)	0.89
2 × 2 × 1/8	1.65
2 × 2 × 3/16	2.44
2 × 2 × 1/4	3.19
2 1/2 × 2 1/2 × 3/16	3.07
2 1/2 × 2 1/2 × 1/4	4.10

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. of water.

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 duct is for positive-pressure applications only, unless special designs are used. Hanger designs and installation details for rectangular ducts generally also apply to flat oval ducts.

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. This material is 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. of water. Molded round ducts are available in higher pressure ratings. *Fibrous Glass Duct Construction Standards* (NAIMA 2002b; 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 duct in hospital and health care facilities.

Flexible Ducts

Flexible ducts connect mixing boxes, light troffers, diffusers, and other terminals to the air distribution system. SMACNA (2005) has an installation standard and a specification for joining, attaching, and supporting flexible duct. ADC (2003) has another installation standard.

The routing, the number and sharpness of bends, and the amount of sag allowed between support joints significantly affect system performance because of the increased resistance each introduces. Use the minimum length of flexible duct needed to make connections. Excess length of flexible ducts should not be installed to allow for possible future relocations of air terminal devices. Constructability-related flow restrictions should be avoided (e.g., duct-hanging wires should not reduce the effective duct diameter). Avoid bending ducts across sharp corners or incidental contact with metal fixtures, pipes, or conduits. The turn radius at duct centerline should not be less than one duct diameter.

At terminal units, splices, and collars, pull back the jacket and insulation from the core and connect to the collar in accordance with ADC (2003) or SMACNA (2005) installation standards. After the flexible duct is connected to a collar or splice by appropriate duct tape and/or clamps, pull the jacket and insulation back over the core. For a collar, tape the jacket with at least two wraps of duct tape. A clamp may be used in place of or in combination with the duct tape. For a splice, tape jackets together with at least two wraps of duct tape.

UL *Standard* 181 covers testing materials used to fabricate flexible ducts that are separately categorized as air ducts or connectors. NFPA *Standard* 90A defines acceptable use of these products. The flexible duct connector has less resistance to flame penetration, has lower puncture and impact resistance, and is subject to many restrictions listed in NFPA *Standard* 90A. Only flexible ducts that are air duct rated should be specified. Tested products are listed in the UL *Online Certifications Directory.*

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 2007).

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 end 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 47 of the 2007 *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 *Standard* 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. Avoid uneven edge alignment at butted 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.

Hangers

SMACNA (2005) covers commercial HVAC system hangers for rectangular, round, and flat oval ducts. When special analysis is required for larger ducts or loads or for other hanger configurations than are given, AISC and AISI design manuals should be consulted. To hang or support fibrous glass ducts, the methods detailed by NAIMA (2002b) and SMACNA (2003) are recommended. UL *Standard* 181 discusses maximum support intervals for UL listed ducts.

INDUSTRIAL DUCT CONSTRUCTION

NFPA *Standard* 91 is widely used for duct systems conveying particulates and removing flammable vapors (including paint-spraying residue), and corrosive fumes. Particulate-conveying 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 breeching, 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 *Round Industrial Duct Construction Standards* (SMACNA 1999). Consult Chapters 12 to 31 of the 2007 *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 1975), the *Pollution Engineering Practice Handbook* (Cheremisinoff and Young 1975), and publications of the National Association of Corrosion Engineers (NACE) and ASM International (asminternational.org).

Round Ducts

SMACNA (1999) gives information on selecting material thickness and reinforcement members for spiral and nonspiral industrial ducts. (Spiral-seam ducts are only for Class 1 and 2 applications.) The tables in this manual are presented as follows:

Class. *Steel*: Classes 1, 2, 3, 4, and 5. *Aluminum*: Class 1 only. *Stainless steel*: Classes 1 and 5.

Pressure classes for steels and aluminum. ±2 to ±30 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 available for calculating construction requirements for diameters over 96 in.

Software is also available from SMACNA for design with steel, stainless steel, and aluminum. For other spiral duct applications, consult manufacturers' construction schedules, such as those listed in the *Industrial Duct Engineering Data and Recommended Design Standards* (United McGill Corporation 1985).

Rectangular Ducts

Rectangular Industrial Duct Construction Standards (SMACNA 2007) is available for selecting material thickness and reinforcement members for industrial ducts. The data in this manual give the duct construction for any pressure class and panel width. Each side of a rectangular duct is considered a panel, each of which is usually built of material with the same thickness. Ducts (usually those with heavy particulate accumulation) are sometimes built with the bottom plate thicker than the other three sides to save material.

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 2007), NFPA *Standard* 91, and *Accepted Industry Practice for Industrial Ventilation* (SMACNA 1975). 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 2006) and the *Cold-Formed Steel Design Manual* (AISI 2002) give design information for industrial duct hangers and supports. SMACNA standards for round and rectangular industrial ducts (SMACNA 1999, 2007) and manufacturers' schedules include duct design information for supporting ducts at intervals of up to 35 ft.

ANTIMICROBIAL-TREATED DUCTS

Antimicrobial-treated ducts are made of steel that is coated (as a precoating, or after fabrication) with a substance that inhibits the growth of bacteria, mold, and fungi (including mildew). Either galvanized or stainless steel ducts can be used, if service temperatures of the antimicrobial compound are not exceeded. Prefabricated coatings allow the metal to be pressed, drawn, bent, and rollformed without coating loss. Some coatings are still effective even with small scratches. Large imperfections, such as spot welds and welded joints, can be repaired with a touch-up paint of the antimicrobial compound.

All antimicrobial coatings or touch-up paint should be an EPA-registered antimicrobial compound, should be tested under 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.

DUCT CONSTRUCTION FOR GREASE- AND MOISTURE-LADEN VAPORS

Installation and construction of ducts for removing smoke or grease-laden vapors from cooking equipment should be in accordance with NFPA *Standard* 96 and SMACNA's round and rectangular industrial duct construction standards (SMACNA 1999, 2007). 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. 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

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 48 of the 2007 *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 (2007) covers hood design.

RIGID PLASTIC DUCTS

The *Thermoplastic Duct (PVC) Construction Manual* (SMACNA 1995) 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 and duct sizes from 4 to 72 in. round and 12 to 96 in. rectangular.

FABRIC DUCTS

Fabric ducts can distribute air through built-in diffusers or (with a permeable fabric) can diffuse air directly. Use is limited to areas where the fabric duct is exposed within an environment.

Consult the manufacturer for design criteria for selecting air dispersion type (vents, orifices, or porous 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 1800 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 regain, reduce turbulence, reduce abrupt inflation, and balance airflow into branch ducts.

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 air-tightness, inspection or testing before backfill, and code compliance. Chapter 11 has information on cathodic protection of buried metallic conduits. *Installation Techniques for Perimeter Heating and Cooling* (ACCA 1990) covers residential systems and gives five classifications of duct material related to particular performance characteristics. Residential installations may also be subject to the requirements in NFPA *Standard* 90B. Commercial systems also normally require compliance with NFPA *Standard* 90A.

DUCTS OUTSIDE BUILDINGS

Location and construction of ducts exposed to outdoor atmospheric conditions are generally regulated by building codes. 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.

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 2000a, 2000b). Ducts, duct hangers, fans, fan supports, and other duct-mounted equipment are generally evaluated independently. Chapter 54 of the 2007 *ASHRAE Handbook—HVAC Applications* gives design details. SMACNA (1998) 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 (2002, 2004a, 2004b) 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.

SHEET METAL WELDING

AWS (2006) 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.

THERMAL INSULATION

Insulation materials for ducts, plenums, and apparatus casings are covered in Chapter 24 of the 2005 *ASHRAE Handbook—Fundamentals*. Codes generally limit factory-insulated ducts to UL *Standard* 181, Class 0 or 1. *Commercial and Industrial Insulation Standards* (MICA 2006) gives insulation details. ASTM *Standard* C1290 gives specifications for fibrous glass blanket external insulation for ducts.

MASTER 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 2004) is the organization standard for specifications. These documents are model project specifications that require little editing to customize each application for a project.

Nationally recognized model specifications

- Focus industry practice on a uniform set of requirements in a widely known format
- Reduce the need to prepare new specifications for each project
- Remain relatively current and automatically incorporate new and revised editions of construction, test, and performance standards published by other organizations
- Are adaptable to small or large projects
- Are performance- or prescription-oriented as the designer desires
- Provide lists of products and equipment by name and number or descriptions that are deemed equal
- Are divided into subsections that are coordinated with other sections of related work
- Are increasingly being used by government agencies to replace separate and often different agency specifications

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