CHAPTER 16

DUCT CONSTRUCTION

THIS CHAPTER covers the construction of heating, ventilating, air-conditioning, 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. While 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 United States 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 the design and construction of HVAC duct systems; however, Figure 1 may not list all applicable regulations and standards for a specific locality. Specifications for the U.S. federal government construction are promulgated by such agencies as the Federal Construction Council, the General Services Administration, the Department of the Navy, and the Veterans Administration.

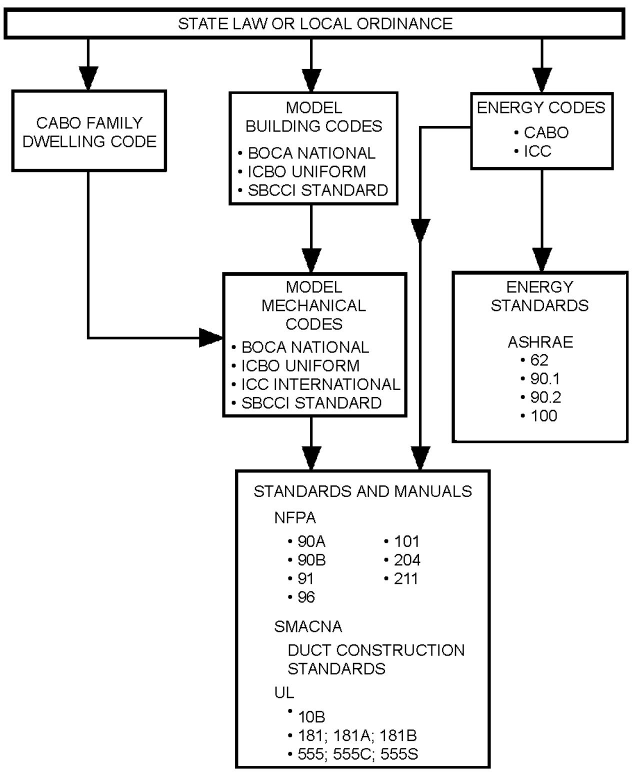

Fig. 1 Hierarchy of Building Codes and Standards

Since the development of safety codes, energy codes and standards proceed 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 equivalency that are incorporated into codes. Staff engineers from the model code agencies are available to assist in the resolution of conflicts, ambiguities, and equivalencies.

Smoke management is covered in Chapter 52 of the *ASHRAE Handbook—Applications*. The designer should consider flame spread, smoke development, combustibility, and toxic gas production from duct and duct insulation materials. Code documents for ducts in certain locations within buildings rely on a criterion of limited combustibility (see definitions, 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 duct materials that are aged or of systems that are poorly maintained for cleanliness.

CLASSIFICATION OF DUCTS

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 systems. Air pollution control systems, industrial exhaust systems, and systems outside the pressure range of commercial system standards are classified as industrial systems.

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

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

Air conveyed by a duct imposes both air pressure and velocity pressure loads on the duct's structure. The load resulting from mean static pressure differential across the duct wall normally dominates and is generally used for duct classification. Turbulent airflow introduces 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 taken into account, especially systems used for smoke management and those with fire dampers that must close with the system running.

DUCT CLEANING

Ducts may collect dirt and moisture, which can harbor or transport microbial contaminants. Ducts should be designed, constructed, and maintained to minimize the opportunity for growth and dissemination of microorganisms. Recommended control measures include providing access for cleaning, providing proper filtration, and preventing moisture and dirt accumulation. NADCA (1992) and NAIMA (1993) have specific information and procedures for cleaning ducts. Owners should routinely conduct inspections for cleanliness.

DUCT LEAKAGE

Predicted leakage rates for unsealed and sealed ducts are reviewed in Chapter 34 of the *ASHRAE Handbook—Fundamentals*. Project specifications should define allowable duct leakage, specify the need for leak testing, and require the ductwork 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 ductwork in conditioned spaces should be seal level A to prevent dirt smudges. Leakage classifications for ductwork are given in Table 6 in Chapter 34 of the *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.

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 1 Recommended Duct Seal Levels[a]

	Duct Type			
	Supply			
Duct Location	**≤ 2 in. water**	**> 2 in. water**	**Exhaust**	**Return**
Outdoors	A	A	A	A
Unconditioned spaces	B	A	B	B
Conditioned spaces (concealed ductwork)	C	B	B	C
Conditioned spaces (exposed ductwork)	A	A	B	B

[a]See Table 2 for definition of seal level.

Table 2 Duct Seal Levels[a]

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

[a]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 prior to assembly, but may be coated after assembly to reduce leakage. 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.

Table 3 Residential Metal Duct Construction

Shape of Duct and Exposure	Galvanized Steel Minimum Thickness, in.	Aluminum (3003) Nominal Thickness, in.
Enclosed rectangular ducts[a]		
14 in. or less	0.0127	0.016
Over 14 in.	0.0157	0.020
Rectangular and round ducts	Consult SMACNA (1995)	

[a]Data based on nominal thickness, NFPA *Standard* 90B.

RESIDENTIAL DUCT CONSTRUCTION

NFPA *Standard* 90B, CABO's *One- and Two-Family Dwelling Code*, 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 constructed of minimum thickness as shown in Table 3 and installed in accordance with *HVAC Duct Construction Standards—Metal and Flexible* (SMACNA 1995). Fibrous glass ducts should be installed in accordance with the *Fibrous Glass Duct Construction Standards* (SMACNA 1992, NAIMA 1997). For return ducts, the use of alternate materials, and other exceptions, consult NFPA *Standard* 90B.

COMMERCIAL DUCT CONSTRUCTION

Materials

NFPA *Standard* 90A is used as a guide standard by many building code agencies. 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 temperature higher than 250°F. Many manufactured flexible and fibrous glass ducts are UL approved and listed as Class 1. For galvanized ducts, a G90 coating is recommended (see ASTM *Standard* A 653). 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 1995) 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 are designed to reinforce the duct system. Ducts 85 in. and larger at a pressure of 6 in. of water and greater require

Table 4A Galvanized Sheet Thickness

Galvanized Sheet Gage[a]	Thickness, in. Nominal	Thickness, in. Minimum[b]	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

[a]Galvanized sheet gage is used for convenience. A metric series would conform to ASME *Standard* B32.3M, and the tolerances in ASTM *Standard* A 924 apply.
[b]Minimum thickness is based on thickness tolerances of hot-dip galvanized sheets in cut lengths and coils (per ASTM *Standard* A 924). Tolerance is valid for 48 in. and 60 in. wide sheets.

Table 4B Uncoated Steel Sheet Thickness

Manufacturers' Standard Gage[b]	Thickness, in. Nominal	Minimum[a] Hot-Rolled	Minimum[a] 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.
[a]Minimum thickness is based on thickness tolerances of hot-rolled and cold-rolled sheets in cut lengths and coils (per ASTM *Standards* A 366, A 568, and A 569).
[b]Manufacturers' standard gage is used for convenience. A metric series would conform to ASME *Standard* B32.3M, and the tolerances in ASTM *Standard* A 568 apply.

Table 4C Stainless Steel Sheet Thickness

Gage[a]	Thickness, in. Nominal	Thickness, in. Minimum[b]	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

[a]Stainless sheet gage is not standardized. A metric series would conform to ASME *Standard* B32.3M, and the tolerances in ASTM *Standard* A 480 apply.
[b]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* A 480).

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

internal tie rods to maintain their structural integrity. For ducts over 36 in. wide, internal midpanel tie rods are an alternative to external reinforcement. *Rectangular Industrial Duct Construction Standards* (SMACNA 1980) gives construction details for ducts up to 168 in. wide at a pressure up to ±30 in. of water and higher.

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.

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 ability of the material to withstand the physical abuse of installation and negative pressure requirements. SMACNA (1995) lists construction requirements as a function of static pressure, type of seam (spiral or longitudinal), and diameter.

Nonferrous Ducts. SMACNA (1995) 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 (1995) also lists flat oval duct construction requirements. Seams and transverse joints are generally the same as those permitted 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 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 barrier. 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* (SMACNA 1992, NAIMA 1997) and manufacturers' installation instructions give details on fibrous glass duct construction. SMACNA (1992) 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, and electric heaters). AIA (1996) includes guidelines for the use of 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 (1995) has an installation standard and a specification for joining, attaching, and supporting flexible duct. ADC (1996) has another installation standard. Because unnecessary length, offsetting, and compression of these ducts significantly increase airflow resistance, they should be kept as short and straight as possible, fully extended, and supported to minimize sagging (see Chapter 34 of the *ASHRAE Handbook—Fundamentals*).

UL *Standard* 181 covers testing of materials used to fabricate flexible ducts that are separately categorized as air ducts or connectors. NFPA *Standard* 90A defines the 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 *Gas and Oil Directory*, published annually.

Plenums and Apparatus Casings

SMACNA (1995) 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 1980).

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 suction side of a fan, plenums and apparatus casings are normally constructed to withstand negative air pressure at least equal to the total upstream static pressure loss. The accidental stoppage of 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, the transmission of fan noise 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-wall panel with an acoustical liner and a perforated metal inner liner. Double-wall 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 aerodynamic 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-wall construction using a perforated metal inner liner is frequently specified. Chapter 47 of the *ASHRAE Handbook—Applications* addresses design considerations, including external lagging. ASTM *Standard* C 423 covers laboratory testing of duct liner materials to determine their sound absorption coefficients. ASTM *Standard* E 477 covers laboratory testing of the acoustical insertion loss of duct liner materials. Designers should review all of the tests incorporated in ASTM *Standard* C 1071. A wide range of performance attributes, including erosion resistance, vapor adsorption, temperature resistance, bacteria resistance, and fungi resistance, is covered in the standard. Health and safety precautions are addressed, and manufacturer's certifications of compliance are also covered. AIA (1996) includes guidelines for the use of 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 1995). Adhesives should be Type I, in conformance to ASTM *Standard* C 916, and should be applied to the duct, with at least 90% coverage of mating surfaces. Quality 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. If a designer wants systems to switch on and off frequently (as an energy conservation measure) during the times in which buildings are occupied, duct construction that reduces objectionable noise should be specified.

Hangers

SMACNA (1995) 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 (1989) and AISI (1989) design manuals should be consulted. To hang or support fibrous glass ducts, the methods detailed in *Fibrous Glass Duct Construction Standards* (SMACNA 1992, NAIMA 1997) are recommended. UL *Standard* 181 involves 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 for corrosive applications such as acid fumes has been introduced by SMACNA.

For contaminant abrasiveness ratings, see *Round Industrial Duct Construction Standards* (SMACNA 1999). Consult the *ASHRAE Handbook—Applications* for specific processes and uses.

Materials

Galvanized steel, uncoated carbon steel, or aluminum are most frequently used for industrial air handling. Aluminum ductwork is not used for systems conveying abrasive materials; when temperatures exceed 400°F, galvanized steel is not recommended. Ductwork material for systems 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 the publications of the National Association of Corrosion Engineers (NACE) and ASM International.

Round Ducts

SMACNA (1999) gives information for the selection of 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 the construction requirements for diameters greater than 96 in.

Software is also available from SMACNA for design with steel, stainless steel, and aluminum. For other spiral duct applications, consult manufacturer's 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 1980) 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. Usually, the four sides of a rectangular duct are built of material with the same thickness. Ducts are sometimes built with the bottom plate thicker than the other three sides (usually in ducts with heavy particulate accumulation) 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 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 1998), NFPA *Standard* 91, and *Accepted Industry Practice for Industrial Ventilation* (SMACNA 1975). For industrial duct Classes 2, 3, and 4, the 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 *Manual of Steel Construction* (AISC 1989) and the *Cold-Formed Steel Design Manual* (AISI 1989) give design information for industrial duct hangers and supports. The SMACNA standards for rectangular and round industrial ducts (SMACNA 1980, 1999) and manufacturers' schedules include duct design information for supporting ducts at intervals of up to 35 ft.

DUCT CONSTRUCTION FOR GREASE- AND MOISTURE-LADEN VAPORS

The installation and construction of ducts used for the removal of smoke or grease-laden vapors from cooking equipment should be in accordance with NFPA *Standard* 96 and SMACNA's rectangular and round industrial duct construction standards (SMACNA 1980, 1999). Kitchen exhaust ducts that conform to NFPA *Standard* 96 must (1) be constructed from carbon steel with a minimum thickness of 0.054 in. or stainless steel sheet with a minimum thickness of 0.043 in.; (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. Since 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 corrosion of metals. Chemical concentrations affect corrosion rate significantly. Chapter 48 of the *ASHRAE Handbook—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 (1998) covers hood design.

PLASTIC DUCTS

The *Thermoplastic Duct (PVC) Construction Manual* (SMACNA 1994) covers thermoplastic (polyvinyl chloride, polyethylene, polypropylene, acrylonitrile butadiene styrene) and thermosetting (glass-fiber-reinforced polyester) ducts used in commercial and industrial installations. SMACNA's manual provides comprehensive construction details for positive or negative 2, 6, and 10 in. of water polyvinyl chloride ducts. 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.

Fiberglass reinforced thermosetting plastic (FRP) ducts are described in the *Thermoset FRP Duct Construction Manual* (SMACNA 1997). The manual covers physical properties, manufacture, construction, installation, and methods of testing. 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 gage and duct sizes from 4 to 72 in. round and 12 to 96 in. rectangular.

UNDERGROUND DUCTS

No comprehensive standards exist for the construction of underground air ducts. 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 (1995). Thickness above the minimum may be needed for individual applications. Specifications for the 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 prior to backfill, and code compliance. Chapter 11 has information on cathodic protection of buried metallic conduits. *Criteria and Test Procedures for Combustible Materials Used for Warm Air Ducts Encased in Concrete Slab Floors* (NRC) provides criteria and test procedures for fire resistance, crushing strength, bending strength, deterioration, and odor. *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

The 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
- Susceptibility to physical damage
- Hazards at air inlets and discharges
- Maintenance needs

In addition, support systems 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 1997) and the Department of Defense (NAVFAC 1982). Ducts, duct hangers, fans, fan supports, and other duct-mounted equipment are generally evaluated independently. Chapter 54 of the *ASHRAE Handbook—Applications* gives design details. SMACNA (1998) provides guidelines for seismic restraints of mechanical systems. The manual gives bracing details for ducts, pipes, and conduits that apply to the model building codes and ASCE *Standard* 7, Minimum Design Loads for Buildings and Other Structures.

SHEET METAL WELDING

AWS (1990) covers sheet metal arc welding and braze welding procedures. This specification 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 *ASHRAE Handbook—Fundamentals*. Codes generally limit factory-insulated ducts to UL *Standard* 181, Class 0 or Class 1. *Commercial and Industrial Insulation Standards* (MICA 1993) gives insulation details. ASTM *Standard* C 1290 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 documents are *Masterspec* by the American Institute of Architects (AIA) and *SPECTEXT* by the Construction Sciences Research Foundation (CSRF). These documents are model project specifications that require little editing to customize each application for a project.

Nationally recognized model specifications provide several benefits, including the following:

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

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