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Chapter 9

Duct and Ventilation Systems

Topics

1.0.0 Duct Systems

2.0.0 Balancing Duct Systems

3.0.0 Ventilation Systems

To hear audio, click on the box.

Overview

As a Utilitiesman (UT), you can expect to become involved in the installation of duct and/or ventilation systems designed to provide conditioned air or to remove less desirable air from a given space or facility. When sheet metal is to be fabricated into system components, the Steelworker (SW) provides the expertise. When duct board is used, fabrication and installation may be tasked to the UT exclusively.

This chapter provides some key knowledge to aid you in the identification of types of duct and ventilation systems, their installation, and factors you must be aware of in determining the sizes required to meet specified building requirements. Keep in mind that the term *air conditioned* refers to air that has been cooled, heated, dehumidified or humidified, or any combination of these.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of duct systems.
2. Describe procedures for balancing duct systems.
3. Describe the different types of ventilation systems.

Prerequisites

None.

1.0.0 DUCT SYSTEMS

To deliver air to the conditioned space, you need air carriers. These carriers are called ducts. They are made of sheet metal or some structural material that is noncombustible.

Duct systems are also classified as high-pressure or high-velocity ductwork and low-pressure or low-velocity ductwork. The term *high-pressure* or *high-velocity* ductwork includes ductwork systems and ***plenums*** from the fan discharge to the final high-velocity mixing boxes, or other final pressure-reducing devices or any air supply system served by a fan operating with a static pressure range of 3 inches to 7 inches of water column (WC).

High-velocity or high-pressure systems with fan static pressures of 3 inches WC or greater are defined as high pressure. Usually the static pressure is limited to a maximum of 7 inches WC, and duct velocities are limited to 4,000 feet per minute (fpm). Systems requiring pressures more than 7 inches WC are normally unwarranted and could result in very high operating costs. Systems with velocities more than 4,000 fpm performs satisfactorily when all duct fittings are carefully designed and installed. However, velocity pressure losses are excessive and velocities more than 4,000 fpm are not recommended.

A high-velocity double-duct system begins with a high-pressure fan of class II or III design any conveys air through sound-treated high-velocity ductwork connected to sound and pressure-attenuating mixing units. Connections to the outlets of the reduction units are treated as low velocity.

Smaller sized ductwork, using higher velocities, permits conveyance of air to areas limited by construction and reduces floor-to-floor height. Round ductwork generally provides the greatest strength, tightness, and economy, while oval and rectangular ducts can be used when large risers are involved. *Figure 9-1* shows the three types of ductwork.

A necessary component of the high-pressure system is the mixing box or unit. Its function is to blend air at two different temperatures for proper delivery to the rooms. This requires special pressure-reducing air valves at both hot and cold inlets, mixing baffles to prevent stratification of air, and sound attenuation treatment to absorb noise generated by the air valves.

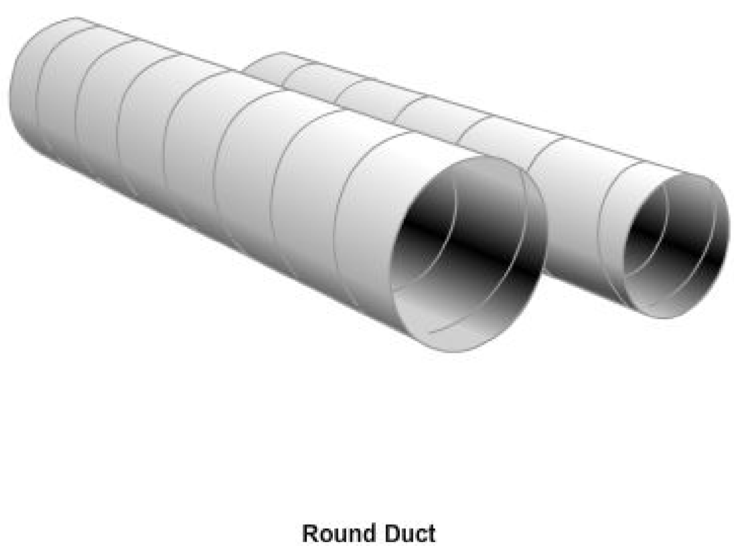

Figure 9-1 — Types of ductwork.

The term *low-pressure* or *low-velocity* ductwork applies to systems with fan static pressures less than 3 inches WC. Generally, duct velocities are less than 2,000 feet per minute.

The choice between using low versus high-velocity systems requires you to study architectural, mechanical, and structural considerations. Installation cost, temperature control, and operating cost should also be studied.

Low-velocity double duct systems are many years old. It was not until after World War II that their use became extensive. Space for the installation of the double ducts is a main consideration for this system and must be provided during initial planning. Difficulties in providing for this space in modern structures with low floor-to-floor heights and flush ceilings, together with the need for developing a compact distribution system for existing buildings, has brought about the development of high-velocity double duct systems. High velocity saves ceiling space and duct shaft space, but requires greater attention in the selection of fans and equipment with regard to sound levels.

Also, higher duct velocities require increased fan static pressures; therefore, increased operating costs. On the other hand, high-velocity systems are easy to balance and control and have much greater flexibility for partition changes and so forth.

Generally, high-velocity systems are applicable to large multistory buildings; primarily because the advantage of saving in duct shafts and floor-to-floor heights is more substantial. Small two- and three-story buildings are normally low velocity; however, both systems should be analyzed for each building. *Table 9-1* shows outlet velocities for the range of optimum performance of typical ventilation fans.

Ducts are made of many types of materials. Pressure in the ducts is small, so materials with a great deal of strength are not needed. Originally, hot air ducts were thin, tin sheet steel. Later, galvanized sheet steel, aluminum sheet, and finally, insulated ducts made from materials, such as asbestos and fiberboard, were developed. Passageways, formed by studs or joists, are sometimes used for return air when a fire hazard does not exist.

Ducts made of asbestos are no longer legal. Asbestos may still be encountered when performing preventative and corrective maintenance in older facilities. If you have any doubt, inform you COC immediately. Naval guidance for asbestos handling, demolition, and disposal are covered by OPNAVINST 5100.23(series), *Navy Safety and Occupational Health (SOH) Program Manual*. However, you should also learn the local laws and restrictions pertinent to your work location. These federal, state, and local laws are important. In an overseas location, the laws of the host country must be researched and clearly understood in the construction planning phase. It is inevitable that somewhere in the disposal cycle, transporting of this type of material to a disposal site will take place over roads not directly under Navy control.

Table 9-1 — Outlet Velocities for Optimum Performance of Fans

Static Pressure Inches of Water	Centrifugal Fans Outlet Velocity fpm	Tube Axial and Vane Axial Fans Outlet Velocity at Wheel Dia. fpm
1/4	400 - 100	950 – 1,500
1/2	550 – 1,450	1,350 – 1,900
3/4	700 – 1,750	1,650 – 2,350
1	800 – 2,000	1,900 – 2,700
1 1/2	1,000 – 2,500	2,350 – 3,300
2	1,150 – 2,800	2,700 – 3,800
2 1/2	1,250 – 3,200	3,000 – 4,300
3	1,400 – 3,500	3,300 – 4,700
4	1,600 – 4,050	
6	2,000 – 4,950	
8	2,300 – 5,700	
10	2,500 – 6,400	

The material you use for the construction of ductwork depends on the application of the duct. Use *Table 9-2* as a guide in the selection of duct material. The thickness of the material depends primarily on the pressure developed within the duct, the length of the individual sections, and the cross-sectional area of the duct. The developed length of a section for a particular gauge can be increased if you install angle bracing around the duct.

It is beyond the scope of this chapter to include the technical details necessary for the selection of proper metal thickness and section length for different pressures and for different cross-sectional areas of duct material. However when you make repairs, the same thickness and type of metal that was originally included in the system must be installed. Where the original ductwork was destroyed by pressure, repairs may include increasing metal thickness or adding of angle bracing.

Ducts are either round or rectangular in cross section. Rectangular ducts usually have the advantage of saving room space and being easier to install in walls. However, whenever possible you should use round ducts, which provide less resistance to air flow.

Additionally, round ducts require less material to construct; thus, by using round ducts, you can save both money and material during installation.

Initially, an air-handling duct is usually sized for round ducts. Then, if rectangular ducts are wanted or required, duct sizes can be selected to provide flow rates equivalent to those of the round ducts originally selected.

Table 9-2 — Materials for Ductwork

Application	Material
Normal system handling dray air: 1. Air conditioning 2. Ventilating	Galvanized steel Fiberboard
Systems handling air at very high temperature: 1. Kitchen exhaust	Black steel
System handling partially saturated air: 1. Outside air intake ductwork 2. Exhaust ductwork near discharge outlet 3. Ductwork exposed to weather elements	Aluminum
Systems handling completely saturated air: 1. Shower exhaust 2. Dishwasher exhaust 3. Ductwork exposed to salty atmosphere	Copper

Table 9-3 is a ready reference to determine the size of a rectangular duct that equals the carrying capacity of a predetermined round duct. To use this chart, convert a rectangular duct with sides of 17 inches by 16 inches, respectively. First, come down the left-hand column until you reach 17 inches; then trace the line horizontally across the columns until you reach the column headed by 16 inches. At the center of these intersecting lines is 18.0 inches. This is the round duct size equivalent. In the second example, following the same procedure, it is clearly shown that a 22-inch by 17-inch rectangular duct has a 21-inch round duct equivalent.

Table 9-3 — Duct Capacity Conversions

(The dimensions in this chart are in inches)

Side Rectangular duct	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
3.0	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1	5.2	5.5	5.7	6.0	6.2	6.4	6.6	6.8	7.0
3.5	4.1	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.4	7.6
4.0	4.4	4.6	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4	6.8	7.1	7.3	7.6	7.8	8.1	8.3
4.5	4.6	4.9	5.2	5.4	5.6	5.9	6.1	6.3	6.5	6.9	7.2	7.5	7.8	8.1	8.4	8.6	8.9
5.0	4.9	5.2	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.3	7.6	8.0	8.3	8.6	8.9	9.1	9.4
5.5	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.6	8.0	8.4	7.8	9.0	9.4	9.6	9.8

Side Rectangular duct	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30
6	6.6																			
7	7.1	7.7																		
8	7.5	8.2	8.8																	
9	8	8.6	9.3	9.9																
10	8.4	9.1	9.8	10.4	10.9															
11	8.8	9.5	10.2	10.8	11.4	12														
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1													
13	9.5	10.3	11.1	11.8	12.4	13	13.6	14.2												
14	9.8	10.7	10.5	12.2	12.9	13.5	14.2	14.7	15.3											
15	10.1	11	11.8	12.6	13.3	14	14.6	15.3	15.8	16.4										
16	10.4	11.4	12.2	13	13.7	14.4	15.1	15.7	16.3	16.9	17.5									
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6								
18	11	11.9	12.9	13.7	14.5	15.3	16	16.6	17.3	17.9	18.5	19.1	19.7							
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19	19.5	20.2	20.8						
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	17.5	18.2	18.8	19.5	20.1	20.7	21.3	21.9					
22	12	13.1	144.1	15	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21	21.7	22.3	22.9	24.1				
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2	23.9	25.1	26.2			
26	12.8	14.1	15.2	16.2	17.2	18.1	19	19.8	20.6	21.4	22.1	22.8	23.5	24.1	24.8	26.1	27.2	28.4		
28	13.2	14.5	15.6	16.7	17.7	19	18.7	19.6	200.8	21.3	2.1	22.9	23.6	24.4	25	25.7	27.1	28.2	29.5	30.6
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22	22.9	23.7	24.4	25.2	25.9	26.7	28	29.3	30.5	31.6	32.8
32	14	15.3	16.5	17.7	18.8	20.8	20.8	21.8	22.7	23.6	24.4	25.2	26	26.7	27.5	28.9	31	32.3	33.6	33.8
34	14.4	15.7	17	18.2	19.3	19.3	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	32.3	33.6	33.8	34.8
36	14.7	16.1	17.4	18.6	19.8	19.8	21.9	23	23.9	24.8	25.8	26.6	27.4	28.3	29	30.5	32	33	34.6	35.8

This chart depicts sizes of rectangular duct that are equal in carrying capacity to round ducts. To use this chart find the diameter of round duct in the chart. Then find one side of rectangular duct by reading up. Find the other side by reading left to the first row of numbers representing the other side of the rectangular duct.

1.1.0 Types of Duct Systems

In this section, the advantages and disadvantages of a double-duct system are discussed. Since there are many possibilities for an adequate duct system, one such system is modified to fit the needs of two different residential configurations.

A double duct system generally consists of a blow-through fan unit discharging filtered air through stacked or adjacent heating and cooling coils into separate plenums and ductwork with thermostatically controlled mixing dampers at various room locations.

The inherent advantage of a double duct system is that individual room conditions can be maintained from a central system, within the limitations of supply air temperatures. This is done by the blending of hot and cool air through automatically controlled mixing devices. Another important credit is flexibility. In this regard, individually controlled rooms can be easily incorporated, at modest cost, after the building is completed.

In modern buildings of multiple exposures designed for variable functions and changing occupancy, individual room control is essential and a double duct system should be seriously considered.

Double duct systems for low pressure are usually tiered hot and cold ducts within the furred space. They are generally located above corridors. The manner of distributing proper temperature air to the room is through right angle, interlinked mixing dampers operated by motors controlled through thermostats. In general, this type of system uses the same corridor plenum area around the ducts for conveyance of return or exhaust air. The residual volume of space left for this purpose is too often neglected. Inevitably, this results in insufficient relief for the rooms.

The main disadvantage of a double duct system is lack of stability of air quantities supplied to areas (rooms) because of varying duct static pressures.

All duct elbows, including supply, exhaust, and return, should be made with a center line radius of 1.5 times the duct width, parallel to the radius wherever possible. In no case should the center line radius be less than the width of the duct parallel to the radius. Where space does not permit the above radius, or where square elbows are indicated on plans, turning vanes of an approved type should be used.

Additionally, there are numerous adaptations and modifications of duct systems. *Figure 9-2* shows a residential duct system with the furnace and central air unit located in the basement.

In *Figure 93*, the same basic system is shown in a single-story house. The duct system is located in the overhead and the return air enters through the bottom of the central air-handling unit. When the duct system is located in a crawl space, basement, or attic, it should be insulated to maintain the existing temperature.

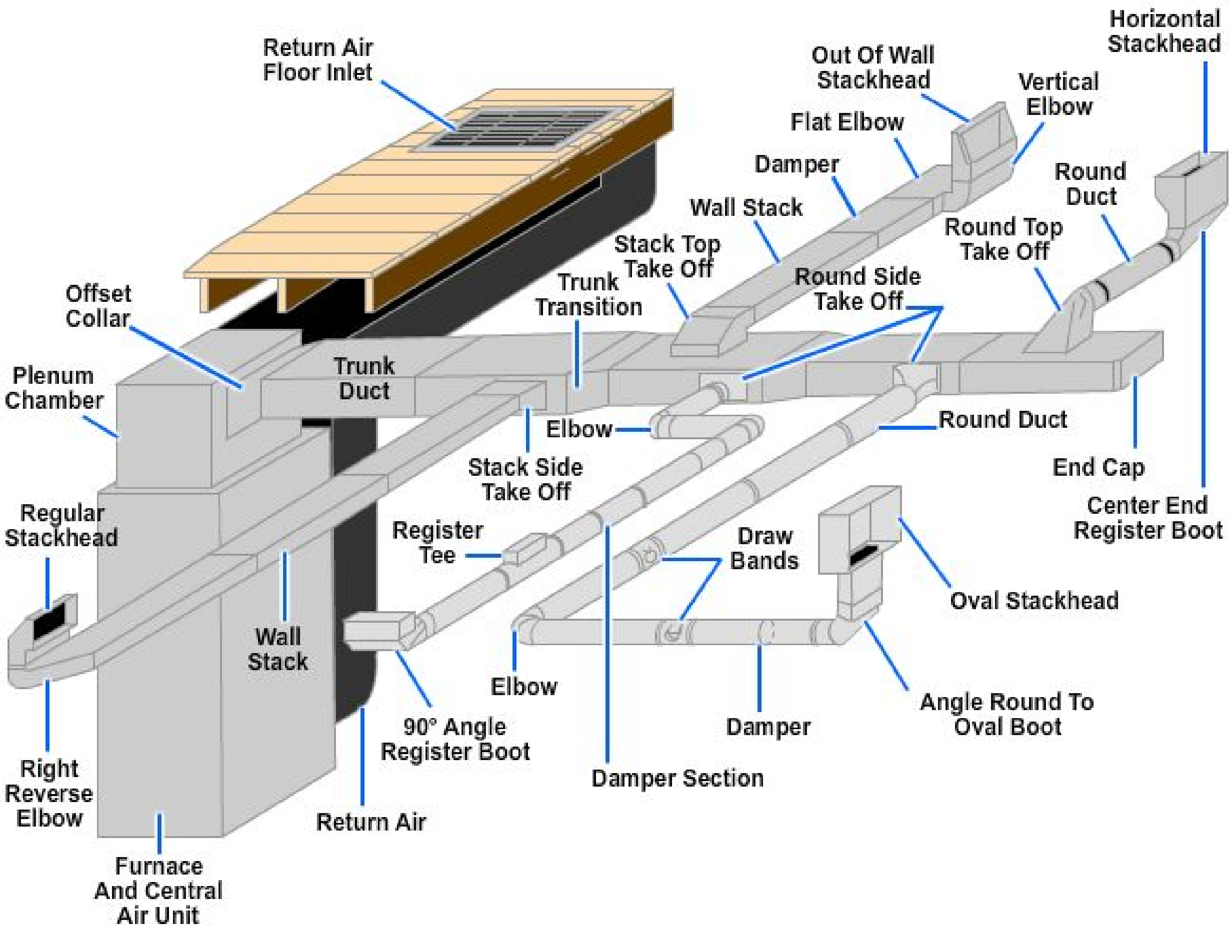

Figure 9-2 — Basement residential duct system.

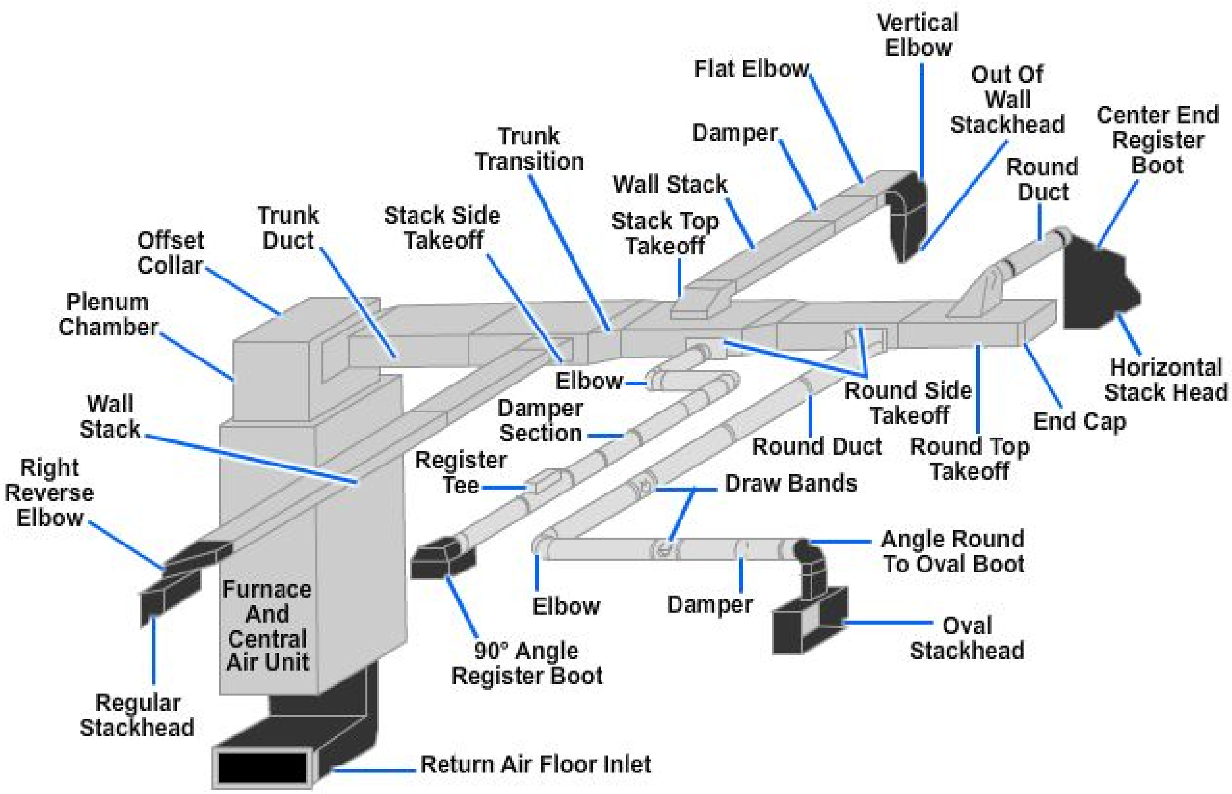

Figure 9-3 — Overhead residential duct system.

1.2.0 Duct Construction

This section will discuss the basic round and rectangular sheet metal ducts. Emphasis is placed on layout and pattern requirements. Fiberboard duct construction and its use will also be discussed.

1.2.1 Round Duct

Straight sections of round duct are usually formed from sheets rolled to a proper radius and assembled with a longitudinal grooved seam. Each end of a round section is swaged and assembled with the larger end of the adjoining section butting against the swage. Sections are held together by rivets, by sheet metal screws, or by solder. Where solder is not used, duct tape or liquid rubber (duct sealer) should be used as a covering at all joints. Rectangular ducts are generally constructed by bending corners and by grooving along the longitudinal seam.

The duct system should be constructed in a way that avoids abrupt changes in size, direction, or other resistance conditions that can create unnecessary noise and reduce the air volume. The normal noise level of air flowing through a duct depends on the velocity of the air moving through the duct. This can be further reduced by lining or covering the duct with sound absorbing material. The exterior of ducts that carry conditioned air can be covered with heat insulation materials to prevent heat transfer between ducts and the surrounding air. All materials used for duct lining and coverings must be noncombustible.

Ducts should be constructed for easy maintenance. They should have access plates or doors included to facilitate cleaning and inspection (*Figure 9-4*). It is important that the correct size duct (as specified on the prints or drawings) be used for the construction of the duct system.

Figure 9-4 — Duct access door.

The amount of air to be carried depends on the size of the duct. This determines the pressure loss in the system—the larger the quantity of air moving through a duct of a given cross-sectional area, the greater the friction loss. Similarly, with a given quantity of air to be delivered, the friction loss increases in inverse proportion to the sizes of ducts provided to carry the air. Therefore, the power required at the fan for delivering a given quantity of air increases rapidly as the duct size is decreased. It is important to keep these facts in mind, when you have to replace or change sections of ducts. The same size new duct should be used unless proper design provisions are made for a change in size.

1.2.2 Rectangular Duct

Straight sections of rectangular duct are normally formed by personnel in the Steelworker rating. This is normally accomplished on bending-brake type of equipment. Then the rectangular ductwork is joined together as mentioned earlier. Straight sections of ducts can usually be laid out without a pattern. However, a pattern is required for elbows, transitions, and jump fittings. Steelworkers perform the task, but you are the planner, so you need to be aware of the time required to draw and fabricate the required patterns. Also bear in mind that if this is a one-time job, you can make the pattern of paper or cardboard. If there are large numbers of fittings to be constructed with the same size and dimension, you should make the pattern of sheet metal.

1.2.3 Fiber Glass Duct

A fiber glass duct is constructed of molded glass fibers covered with a thin film coating. This coating is usually of aluminum, but vinyl or other plastic coatings are sometimes used. Since they are made of glass fibers, the ducts are inherently insulated. Also, they are primarily used where insulation is a factor. Fiber glass meets military specifications for a flame spread rating of less than 25 and a smoke development rating of less than 50 for insulating material. The fiber glass ducts allowed for use on Navy installations must range between 3/4 inch to 2 inches thick, depending upon the size of the duct.

The nature of a fiber glass duct requires that it be supported with 1-inch by 1/16-inch galvanized steel strap hangers shaped to fit the duct. For round ducts, these supports must be on not less than 6-foot centers. Rectangular and square ducts up to 24-inch spans may be supported on 8-foot centers. Ducts larger than 24 inches require support on 4-foot centers.

The applicability of fiber glass ducts on heating systems is sometimes limited by the adhesive used on the protective outer covering to cause it to adhere to the fiber glass material. Unless aluminum surface duct is used, the specification of the duct should be checked carefully to ensure that it does not fail when heated over 250°F.

Fiber glass ducts can be molded into a variety of shapes for special uses. Round ducts and reducers are available from manufacturers' stock. For most purposes, however, the duct is supplied flat in the form of a board, with V-grooves cut into the inner surface to allow folding to make a rectangular section. The ends of the boards are molded so that when the rectangular duct is formed, two sections of the same size fit together in a shiplap joint to ensure a tight joint in positive alignment. It is important to exercise care in selecting a board of adequate size to complete the desired duct before beginning cutting and grooving operation. In all cases, the inside diameter of the duct is the determining factor for board size. To determine board size, see *Table 9-4*.

Table 9-4 — Duct Board Length Selection Chart

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76
7	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78
8	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
9	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82
10	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
11	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86
12	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
13	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
14	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
15	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94
16	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96
17	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98
18	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100
19	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102
20	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104
21	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106
22	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108
23	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
24	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112
25	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114
26	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116
27	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118
28	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120
29	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	
30	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	102		
31	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120			
32	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120				
33	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120					
34	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120						
35	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120							
36	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120								
37	94	96	98	100	102	104	106	108	110	112	114	116	118	120									
38	96	98	100	102	104	106	108	110	112	114	116	118	120										
39	98	100	102	104	106	108	110	112	114	116	118	120											
40	100	102	104	106	108	110	112	114	116	118	120												
41	102	104	106	108	110	112	114	116	118	120													
42	104	106	108	110	112	114	116	118	120														
43	106	108	110	112	114	116	118	120															
44	108	110	112	114	116	118	120																
45	110	112	114	116	118	120																	
46	112	114	116	118	120																		
47	114	116	118	120																			
48	116	118	120																				
49	118	120																					
50	120																						

* For 1 1/2 -inch board – ADD 4 INCHES to these dimensions.
* for 2-inch board – ADD 8 INCHES to these dimensions.

To form a rectangular duct, the flat duct board is measured accurately and grooves are cut at the proper locations. The board is then folded into a rectangular shape. When the board is cut, an overlapping tab is left and this is then pulled tight and stapled. Tape is applied and the joint is heat sealed. Joints between sections are made by pulling the shiplap end sections together. The joint is then completed by stapling, taping, and heat sealing the junction (*Figure 9-5*).

Sheet metal ducts expand as they become hot and contract as they become cold. The degree to which expansion and contraction becomes an installation factor depends upon the temperature of the air surrounding the ducts and the temperature of the air moving through the ducts. Fabric joints are often used to absorb this duct movement. Additionally, fan noise and furnace or air-conditioner noise tends to travel along the metal ducts. Therefore, fabric joints (usually constructed of heavy canvas) are used to join the branch ducts to the plenum.

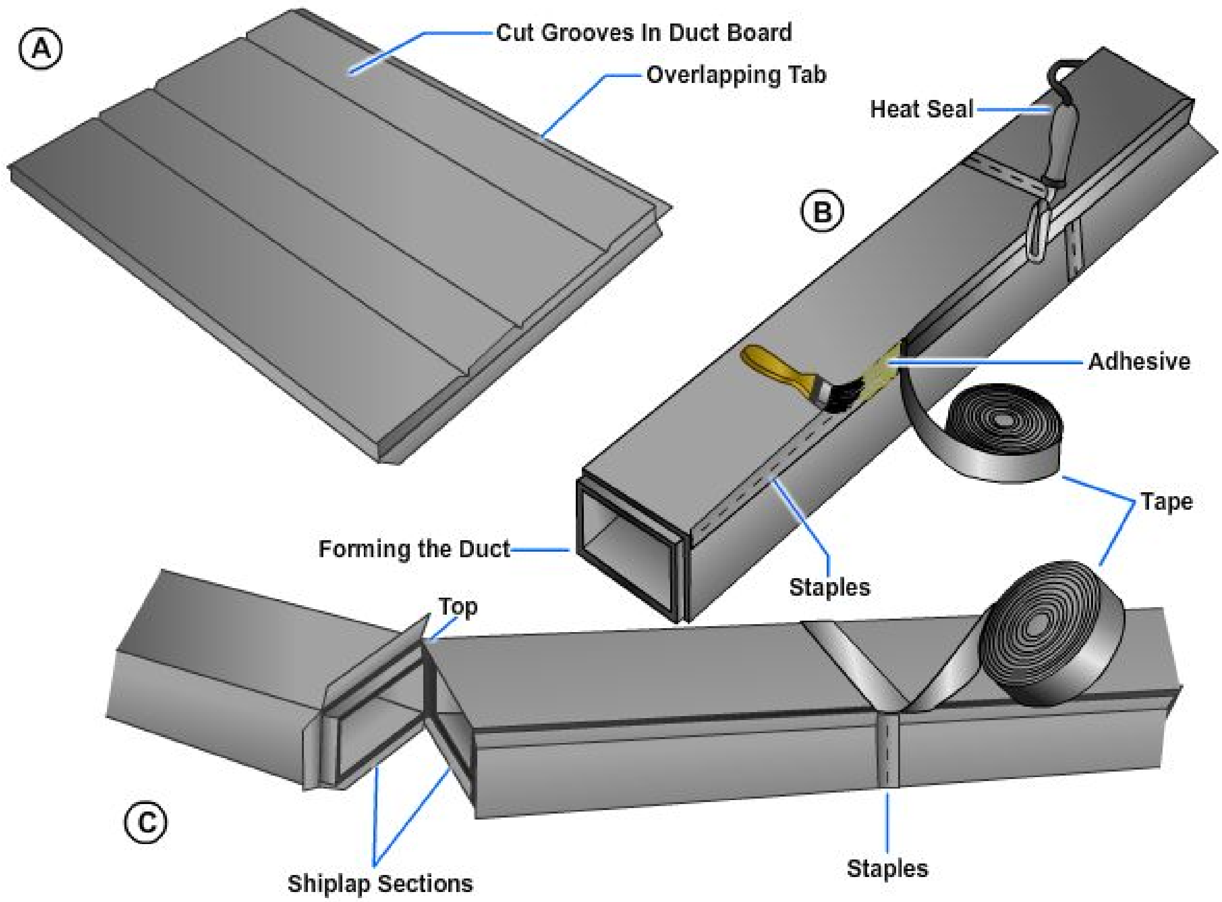

Figure 9-5 — Forming rectangular fiberglass ducts from duct board.

1.3.0 Sizing Duct Systems

There are numerous factors that you need to consider when sizing duct systems. These factors cause you to make modifications and adjustments throughout the planning and installation process to develop an efficient working system. First, you must calculate the air volume required for heating and cooling the required space. This will assist you in determining the necessary duct size, fan size, fan speed, and so forth, that is needed to circulate the conditioned air. While determining the heating and the cooling factors, you should think in terms of air circulation throughout the building and in each individual room or space. Remember, air movement is determined by the type of return airflow that you use.

Four other important duct system components are diffusers, grilles, registers, and dampers. Each of these components has a direct correlation between functional design, amount of air accommodated, and the air movement pattern.

The elbows within the duct system are a major source of airflow restriction. Whenever possible, you can gain efficiency by installing long sweeping elbows. Short 90-degree elbows should be used sparingly on long duct runs. However, they can be used very effectively with a minimum of air turbulence and airflow restriction when installed just before diffusers, grilles, and registers.

Your final duct calculations involve taking unit pressure drops and total pressure drops throughout the system. Some of the major contributing factors to these pressure drops are as follows:

- Length of duct
- Duct material and interior finish
- Changes in duct size
- Number of elbows

Normally, you will be installing a duct system according to pre-established blueprints and drawings. Occasionally you may need to refer to other sources and review trade association standards. The *ASHRAE Handbook of Fundamentals* has three chapters dedicated to methods and procedures for selecting proper duct sizes. You should become familiar with the contents of these three chapters; particularly, if you are involved in the design phase of an air-conditioning system.

Test your Knowledge (Select the Correct Response)

1. It is now illegal to use what type of material for making ducts?

   A. Steel
   B. Aluminum
   C. Asbestos
   D. Fiber glass

2. **(True or False)** The first step to follow, when sizing a duct systems, is to calculate the air volume required for heating and cooling the required space.

   A. True
   B. False

2.0.0 BALANCING DUCT SYSTEMS

A duct system is always installed to fulfill specific requirement features related in some way to the health and welfare of human beings. Equally important is the fact that a properly balanced operating system results in lower operating costs and significant utilities conservation. Consequently, it is important that these systems, regardless of the function, operate properly. When a duct system is initially installed, the required pressures and performance data are available from the construction drawings and the manufacturer's instructions. After installation, pressures and performance requirements should be measured to ensure proper airflow at different locations. Once the proper airflows are established, little change should take place within the system. Maintenance personnel must ensure that the system is operating correctly by conducting certain periodic tests. Tests are used for the initial and subsequent setting of grilles, diffusers, dampers, and registers to obtain the necessary airflow required by specifications, codes, regulations, or trade association standards.

It is important to understand the pressure in a duct carrying a moving stream of air. Certain changes in an existing duct system are often necessary and you should be able to accomplish these changes. In addition, malfunctioning duct systems require immediate attention, and an understanding of the basic elements of the system is required before troubleshooting and corrective action can be undertaken. Furthermore, you need to have an essential knowledge of airflow, before a duct system can be properly balanced.

Static pressure is a measure of the outward push of air on the walls of a duct. When air is not moving within a duct because a damper at the outlet is closed, the static pressure can be measured by means of a pressure gauge installed in the wall of the duct. If the damper in the duct is then opened and the air is flowing, static pressure continues to be present. It will be reduced when the damper is opened, but the static pressure can still be read on the gauge.

When air is flowing in a duct, there is another pressure that can be measured, in addition to the static pressure. This is the pressure exerted by the moving airstream. This pressure acts in a plane perpendicular to the direction of airflow. To illustrate, imagine a horizontal duct without any air flowing in it. When a thin, flat piece of metal is suspended with a movable hinge from the top of the duct, it will hang straight down when air is not moving. When air is flowing, the hinged piece of metal swings upward toward the top of the duct. The velocity pressure is the force that causes the deflection of the hinged vane (obviously, the greater the air velocity, the greater the pressure acting on the hinged vane and the greater its deflection from the perpendicular).

The velocity pressure cannot be measured as easily as the static pressure. When a hollow tube is inserted in the moving airstream, and a gauge is connected to the end of the tube, the gauge registers a certain pressure. This pressure is larger than the static pressure because the gauge indicates the sum of the static and the velocity pressure. This sum is known as the total pressure. Since total and static pressure can be easily measured, the velocity pressure can be found by subtracting static from total pressure. In most problems concerning duct systems, air pressure is expressed in terms of inches of water (1 pound per square inch = 27.74 inches of water.)

It is important that the design data be recorded when the duct system is initially installed. After initial start-up, the system should be balanced so that each air outlet is adjusted to the design rate of flow. During the initial balancing procedure, the actual design rate of flow is sometimes not achieved, but the flow is within the range of acceptable standards. When such conditions exist, they should be noted on the design data sheet where they may be considered by maintenance personnel during repairs or the rebalancing of the system.

Static pressure measurements should be taken throughout the system after the system is balanced and proper operation is assured. Also, the total pressure difference across the fan (the difference between the suction total pressure and the discharge total pressure) is noted. Although these initial measurements can be used for checking the design of the system, their main function is to serve as reference data for future tests. If the system fails to function properly at any time, another set of measurements should be taken and compared to the original set.

2.1.0 Air Balancing Instruments

There are numerous instruments designed for air balancing requirements which are available from different manufacturers. The ones most commonly used will be discussed in this section.

2.1.1 Velometer

This instrument is particularly adaptable to maintenance work because of its portability, wide scale range, and instantaneous reading features. Its accuracy is suitable for most air velocity and static pressure readings. Since velometers are made by several manufacturers, the instruction sheets for any instrument should be thoroughly understood before attempting to use it. A functional velometer set consists of the basic meter with hoses and accessories (*Figure 9-6*).

Figure 9-6 — Velometer set.

2.1.2 Manometer

A manometer is an instrument that indicates air pressure by employing the principle of balancing a column of liquid of known weight against air pressure. The units of measure used are pounds per square inch, inches of mercury using mercury as the fluid, and inches of water using water as the fluid.

The simplest form of manometer is the basic U-tube type. Several variations of the basic type are presently used in air movement applications, for example, the inclined type (draft gauge) and the combination inclined and vertical type. *Figure 9-7* shows an inclined manometer with a pitot probe. Many commercially installed central duct systems have permanently mounted manometers connected to duct interiors with static pressure tips.

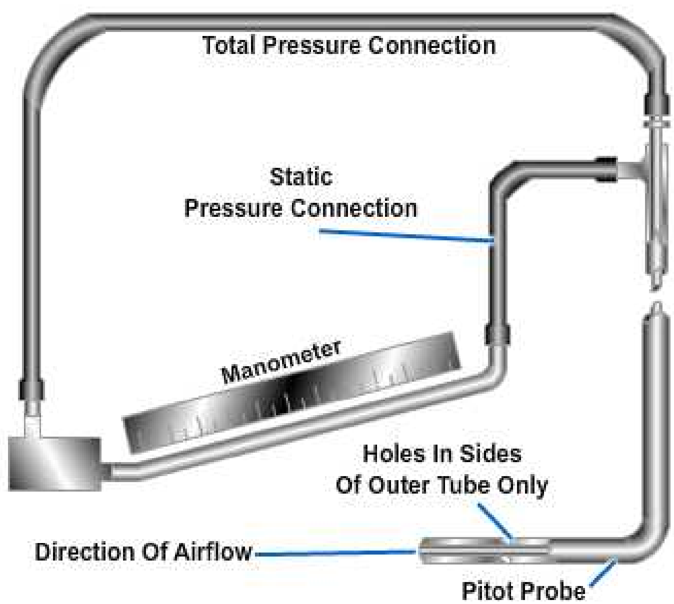

Figure 9-7 — Inclined monometer with pitot probe.

2.1.3 Rotating Vane Anemometer

The rotating vane anemometer (*Figure 9-8*) consists of a propeller or revolving vane connected through a gear train to a set of recording dials that indicate the number of linear feet of air passing in a measured length of time. It requires correction factors and frequent calibrations, and it is not as accurate as the velometer.

The primary application for a rotating vane anemometer is the measurement of grille velocities on heating, cooling, and ventilating installations; however, it may not be suitable for exhaust measurements or for measurements on very small grilles.


Figure 9-8 — Rotating vane anemometer.

2.1.4 Miscellaneous Instruments

In addition to the air balancing instruments, there are other miscellaneous devices required. Thermometers are necessary for making temperature measurements at various duct and room locations; a tachometer is needed to determine fan speeds; and a multimeter is needed to check fan motors for proper operation.

2.2.0 Preparation for Balancing

The following preliminary procedure is necessary before proper balancing can begin. These steps are general in nature and should apply to most situations.

1. Review applicable mechanical drawings and job specifications. This review will provide necessary data on the ducts, air handlers, and outlets. Information pertaining to design airflow can also be taken from these drawings.
2. Prepare a simple working sketch of the entire duct system showing dimensions, airflow volumes and velocities, and the location of all components such as dampers, fans, coils, and filters. Duct outlets should be numbered on the sketch starting at the farthest one from the fan and working back toward the fan. (*See Figure 9-9*) The type of diffuser and the air delivery design of each outlet should be noted.
3. Obtain data pertinent to motors, fans, diffusers, and grilles that are not given on drawings. This can usually be taken from the manufacturer's identification plate located on the component. This information is useful during the balancing process for comparing measured results with design conditions.

4. Make a visual check of the system to ascertain that all fans are rotating correctly. Also, that air filters are clean and properly installed.
5. Place all dampers in the open position. This includes volume balancing dampers, splitter dampers, outlet dampers, and fire dampers.
6. Check all necessary instruments *prior* to starting the balancing procedure. Always follow the manufacturer's recommendations for checking the calibration of instruments.

2.3.0 Procedures for Balancing

The procedures required for balancing most systems are similar. Balancing is a rigorous technique that, if properly done, yields excellent results. As with any set of procedures, each operation is necessary and must be performed in the correct sequence. The following procedures are general in nature and apply to most systems.

2.3.1 Determine Fan Performance

The first step of the procedure is to determine fan performance. The purpose for this is to ensure that there is sufficient static pressure and air volume being handled at the fan before balancing is started. The fan's revolutions per minute (rpm), the voltage and amperage of the fan motor, the fan static pressure, and the system's total airflow are indications of fan performance.

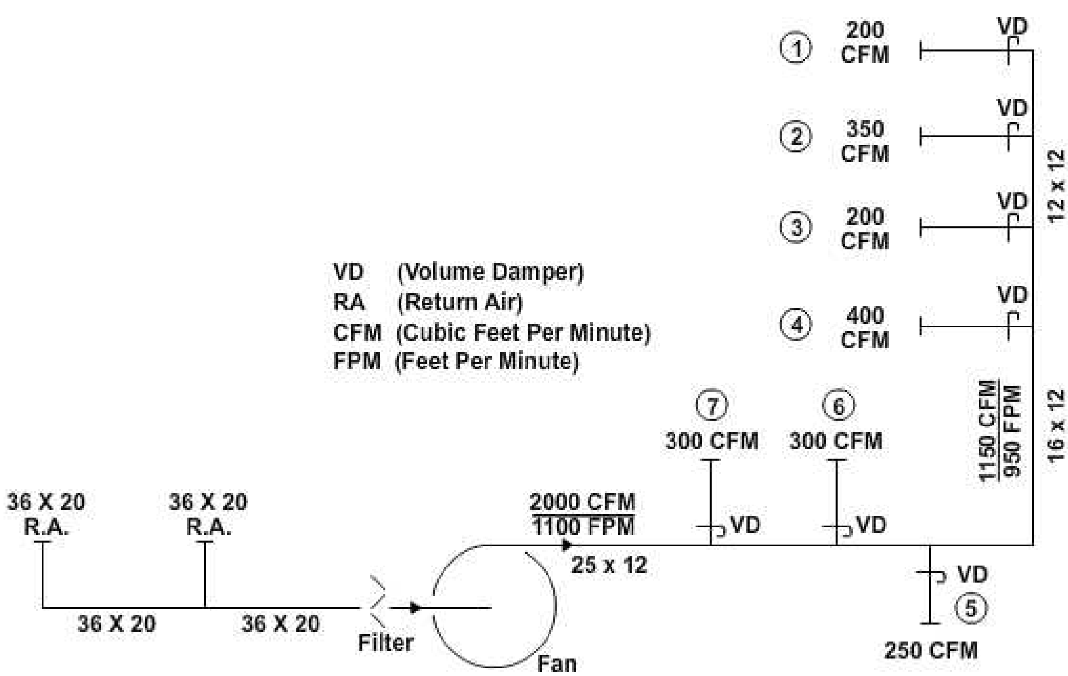

Figure 9-9 — Duct system working sketch.

The fan rpm can be measured by a tachometer (*Figure 9-10*). You should take several readings to ensure an accurate reading. The results can be compared with the design conditions to determine performance.

You should use a multimeter to determine if the operating voltage and amperage of the fan motor are within the range of rated voltage and amperage indicated on the motor nameplate. The measured results can either be compared or used to calculate the brake horsepower. Use the manufacturer's recommended calculation to determine the brake horsepower.

You can determine the fan static pressure by attaching a velometer and static pressure probe to test tap holes located on the inlet and discharge duct of the fan (*Figure 9-11*). Fan static pressure is the static pressure at the outlet minus the total pressure in the fan inlet. This test may not be necessary in the field; however, if it is, the results can be compared with the manufacturer's fan curve and system specifications to determine fan performance.

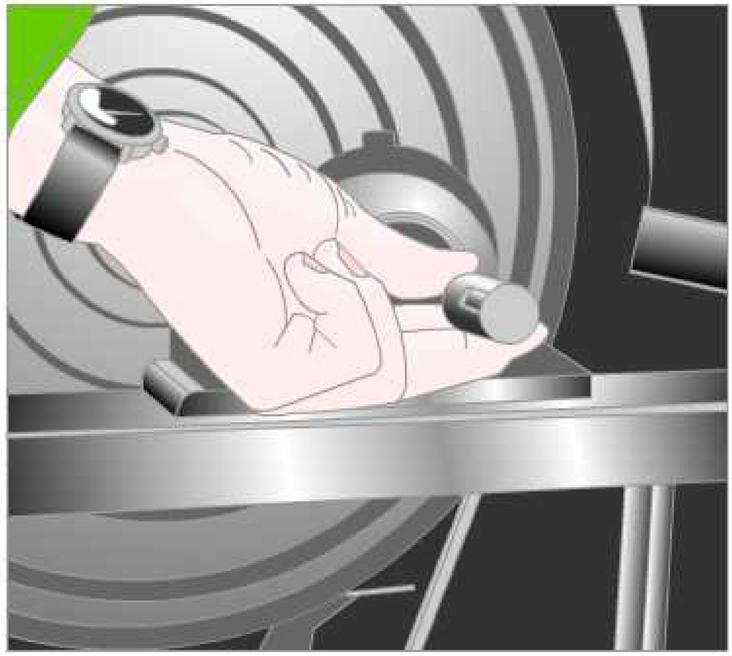

Figure 9-10 — Measuring fan rpm.

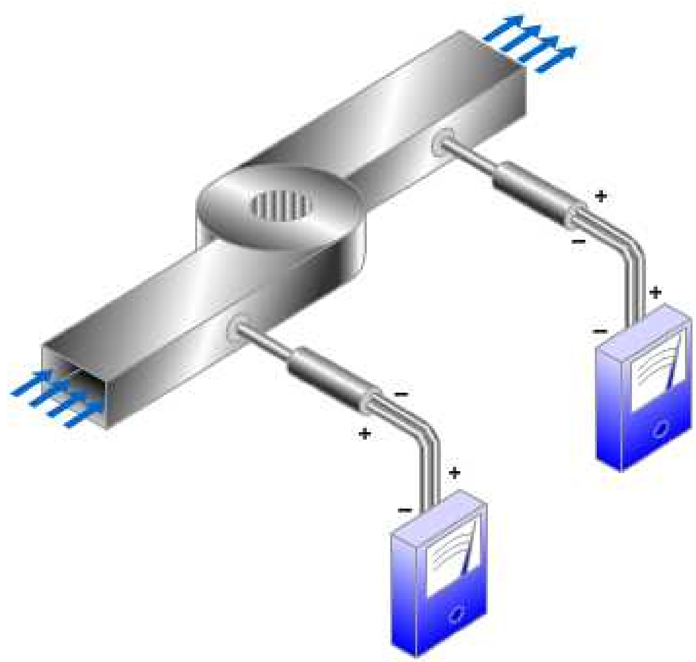

Figure 9-11 — Fan static pressure measurement.

You can quickly locate problems caused by blockages in duct systems by performing static pressure readings. The total air volume in cubic feet per minute (cfm) for a fan can be determined by the following procedures:

1. Downstream of the air handler, establish a point along the duct that has the longest straight run and drill test holes into the duct. Holes should be far enough downstream from any elbows or from the fan discharge to minimize the effect of turbulence. The holes must be closed and sealed after the test is completed.
2. Take velocity pressure readings using a pitot probe and manometer or velometer. For rectangular ducts, velocity readings are taken at the center of equally divided areas. On round ducts, readings are taken across each of two diameters on lines at right angles to each other. (*See Figure 9-12*)
3. Calculate the cubic feet of air per minute by multiplying the average velocity pressure in feet per minute found in the above reading by the cross-sectional area of the duct in square feet. Total airflow in cfm = Average velocity in fpm x duct cross-sectional area in square feet.

The results are compared with design conditions to determine performance. Measured cfm should be approximately equal to design cfm plus 10 percent to allow for leakage.

In the event that fan performance is not consistent with design conditions, the necessary adjustments or repairs should be made at this point in the balancing procedure. For example, the fan speed can be changed by adjusting the variable diameter motor pulley. Be careful to avoid operating the fan at a speed that overloads the motor. After adjustments or repairs, tests should be repeated to verify that the design conditions have been attained. Total air volume measurements should be repeated for all air-handling units on branch, return, and exhaust duct systems.

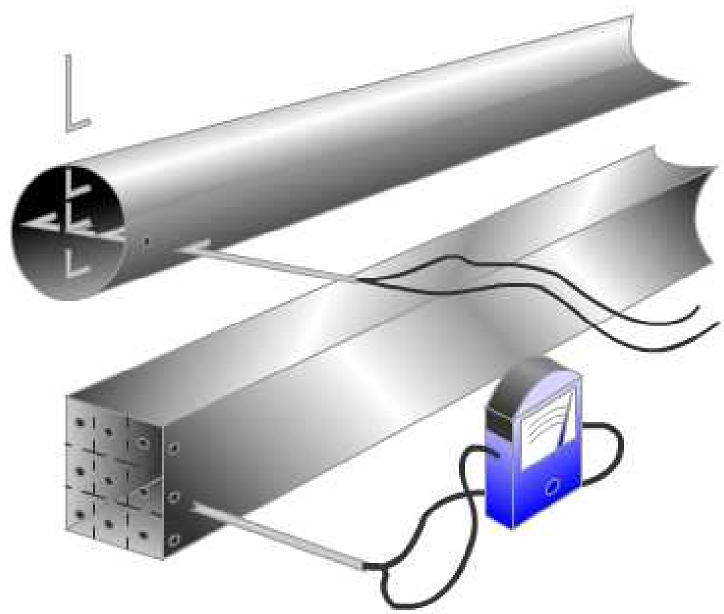

Figure 9-12 — Velocity pressure measurement.

2.4.0 Duct and Outlet Adjustments

You should use the same procedure for measuring total air volume to set the main splitter dampers on systems containing branch ducts. When main ducts, zone ducts, and branches are set for design air, the tests necessary for adjusting individual outlets can begin. When available, always follow the manufacturer’s recommended procedure.

The final balancing procedure involves the adjustment of individual outlets to correspond with the manufacturer's design flow and system specifications. Begin with the last outlet on the branch farthest from the fan discharge and measure the velocity (or cfm). You can use either a velometer with the diffuser probe or an anemometer. If the cfm is below design, leave the damper open and proceed to the next outlet. If the cfm is greater than design, close the damper to obtain the desired results. In the same branch go to the next closest outlet and repeat the procedure. Then continue the process with each outlet, until you reach the main duct.

If applicable, you should complete the same procedure on the remaining branch ducts. Finally, total cfm of all outlets should agree with total cfm of all branches, and this grand total should agree with the air volume for the fan or fans. These figures should be within 3 to 7 percent of design conditions. You should check fan outputs and motor amperages to ensure that the motor is not in an overloaded condition. At this point, fan speed and horsepower, fan total air by velocity measurement, and total air by outlet volume measurements have been established for the specific operating condition of the system during the procedure. The system should be balanced for those conditions.

Test your Knowledge (Select the Correct Response)

3. What air balancing instrument can be permanently connected to duct interiors using static pressure tips?

   A. Manometer
   B. Velometer
   C. Tachometer
   D. Rotating van anemometer

4. **(True or False)** When balancing a duct system, the first step is to determine the type of fan that is being used in the system.

   A. True
   B. False

3.0.0 VENTILATION SYSTEMS

Normally air contains about 21 percent oxygen. The air in a ventilation system that serves human beings must have a certain oxygen content to maintain life and to ensure comfort.

If a room is tightly sealed, any person in that room would slowly consume the oxygen and increase the amounts of carbon dioxide, water vapor, and various impurities. This could cause that person to become drowsy or even result in death.

You must remember that the space where people live must have air with good oxygen content and be kept at a reasonable temperature. It is of utmost importance that fresh air be admitted to provide the oxygen.

In the past, this fresh air entered the space by infiltration (leakage) from the outside at door and window openings and through cracks in the structure. However, modern construction is reducing this air leakage, which means air conditioning systems must provide fresh air. Modern units have a controlled fresh-air intake. This fresh air is conditioned and mixed with the re-circulated air before it reaches the room.

Some conditioned air leaves a building through doors, windows, and other construction joints. Some also leaves by ***exfiltration***. Any kind of exhaust fan removes conditioned air. Some of this air is replaced by infiltration on those sides of the building exposed to wind pressure. It is best to bring in replacement fresh air through a makeup air system. The following occurs when this is done:

- The makeup air can be cleaned, cooled and heated
- A positive pressure can be maintained in the building to keep out airborne dirt, dust, and pollen. (A negative pressure reduces the efficiency of exhaust fans and fuel-fired furnaces.)
- A definite amount of fresh air is brought into the building for health purposes (oxygen content).

Certain areas of a building should have a slightly less positive pressure (5 to 10 percent) than the rest of the building to reduce the spread of odors. Such areas would include the kitchen, lavatories, and where certain industrial operations produce fumes.

The amount of fresh air required depends on the use of the space and the amount of fresh air admitted by infiltration. One basic rule is to provide at least 4 cfm of fresh air per person to provide enough oxygen and to remove carbon dioxide. If six people occupy a 1,000-square foot space with a 10-foot ceiling, there is 10,000 ÷ 6, or 1,667 cubic feet per hour for each person, or 1,667 ÷ 60 = 27.7 cfm (.78m3 /min). This meets or exceeds ventilating code requirements.

It is important for you to remember that the air can be handled either to produce positive pressure (higher than atmospheric pressure) in a building or negative pressure (below atmospheric pressure). A positive pressure eliminates infiltration of air from the outside or from other spaces. Positive pressure is produced by using special air intakes to the blowers. A positive pressure assures -that all air entering a building can be filtered and cleaned before reaching the occupied space. For example, hospitals use positive air pressure and require a 100- percent fresh air intake.

Negative pressure increases the infiltration at windows and doors. This air is untreated and may be dirty. If the amount of impurities in the inside air-such as odor, smoke, and bacteria—is great enough to require air cleaning, the remedy may be either more ventilation (using fresh air) or improved air cleaning.

Ventilation for a conditioned space is usually based on air changes per hour. If the space is 10,000 cubic feet there would be three changes per hour at 3,000 cubic feet per hour or 50 cfm. Three changes every hour is the minimum for a residence during the heating season. As high as 12 changes per hour (in the above case, 200 cfm), are recommended for cooling.

It is a good practice to keep the air blowers running at all times to provide good ventilation to all parts of the building. When heating and cooling systems are turned off, variable speed blowers are sometimes used to provide more air movement.

An adequate air supply is the best way to control comfort. Body comfort is controlled by evaporation, convection, radiation, and respiration. That means you must control the temperature of the walls, floors, or ceilings to make sure they are not too warm or too cold (radiation). You must also supply enough air to promote good respiration, evaporation, and convection.

If the specified conditions are not known, it is best to design for 2 cubic feet per minute per square foot and/or 12 changes of air per hour. It is also very important to remember that people occupying a closed space give off considerable heat. A sleeping person gives off about 200 Btu/hr; a person doing heavy work gives off up to 2,400 Btu/hr.

Another way to determine ventilation requirements is to design for 4 cfm to 6 cfm of fresh air per person and for about 25 cfm to 40 cfm of re-circulated air per person. This means the system should handle a total of 29 cfm to 46 cfm per person. (1 cfm = 0.0283 cu m/min.)

3.1.0 Natural Ventilation

Natural ventilation, or gravity ventilation, uses the natural forces of wind, stack effect, and breathing of structures caused by the interior-exterior temperature difference to induce air circulation and removal. Generally, air enters through openings at or near the floor level in a building and escapes through openings high in the walls or ventilators on the roof.

Natural ventilation is used only where the necessary quantity of ventilation can be induced by natural forces. Applications that require a continuous supply of outdoor air for human comfort, or the safe use of space (or process) should not be designed for natural ventilation. In such cases, natural ventilation is not reliable because of wide variations in the natural forces, such as wind velocity and direction and the inside-outside temperature difference.

For an installation using natural ventilation, you should consider the location and control of ventilation openings. Locate the air inlet openings on the side of the building facing directly into the prevailing winds. Locate the air outlets where prevailing winds movements would create low-pressure areas; that is, on the side directly opposite the prevailing wind direction.

Outlets may also be placed on a roof in the form of individual gravity ventilators or ridge ventilators. Calculate the ventilation rate due to wind velocity and the stack effect as detailed in criteria established by the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE). When natural ventilation is provided for temperature control, you should provide a means for closing the openings during the heating season.

The use of gravity ventilators is another method. A roof-mounted gravity ventilator may be a stationary, a pivoting wind-directional, or a rotating-turbine type of ventilator. You should select gravity ventilators based on the rating tables for the mounting height involved and a wind velocity of 4 miles per hour. Natural ventilation has limited uses. In general, natural ventilation is inadequate for the following examples:

- Offices having an open window area less than 5 percent of the floor area
- Offices over 24 feet deep and without cross ventilation
- Offices having cross ventilation but having occupied space more than 35 feet from a window or an air inlet
- Dining rooms having a window area less than 6 percent of the floor area

In using natural ventilation, you should consider local building and safety codes and the minimum requirements of the *Occupational Safety and Health Standards, part 1910*.

3.2.0 Mechanical Ventilation

Mechanical ventilation uses mechanical forces to induce air circulation within buildings or spaces. Air movement is created by fans or by fans combined with a supply air and/or exhaust air duct system. You should provide mechanical ventilation equipment when the necessary quantity of outside air cannot be supplied continuously by natural forces. The quantity of air supplied should be kept to an acceptable minimum. You should install mechanical ventilation equipment in the following cases:

You should provide mechanical ventilation equipment when the necessary quantity of outside air cannot be supplied continuously by natural forces. The quantity of air supplied should be kept to an acceptable minimum. You should install mechanical ventilation equipment in the following cases:

- For a supply of outside air and the removal of bad air or air contaminated by smoke, body odors, and so forth, in areas having a high occupancy level (auditoriums, assembly halls, and cafeterias).
- For processes giving off noxious or hazardous fumes, dust, or vapor, resulting in unsafe or unhygienic conditions (paint spray booths, electroplating plants, welding booths, and other similar applications).
- For limited comfort of operators as in laundries, projection booths, and kitchens.
- For spaces containing fumes and vapor with specific gravity higher than air, such as garages and some refrigeration rooms. In these cases, provide exhaust intakes at floor level.
- For electronic or electric equipment installed in confined spaces where the operating temperatures of the equipment may exceed the safe limit.
- For spaces having explosive vapors or dust, use explosion proof ventilation equipment regardless of the concentration of explosive substances.
- For odor removal in bathrooms.

Test your Knowledge (Select the Correct Response)

5. How many ventilation air changes are considered the minimum for a residence during the heating season?

   A. 1
   B. 2
   C. 3
   D. None of the above

6. **(True or False)** Hospitals use positive air pressure and require a 75- percent fresh air intake.

   A. True
   B. False

Summary

In this chapter you were introduced to the types of duct systems, duct system construction, and how duct systems are sized. This chapter also provided you with information on how duct systems are balanced , the two types of ventilation systems, and the tools and materials used to evaluate system operation.

Trade Terms Introduced In This Chapter

Exfiltration	This means leaking out or being blown out by mechanical means.
Plenums	A space within the building created by building components, designed for the movement of environmental air (a space above a suspended ceiling or below an access floor).

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Navy Safety and Occupational Health (SOH) Program Manual, OPNAVINST 5100.23 (series), Naval Safety Center, Norfolk, Va.

American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE), Handbook of Fundamentals.

Occupational Safety and Health Standards (Part 1910), Occupational Safety & Health Administration (OSHA).