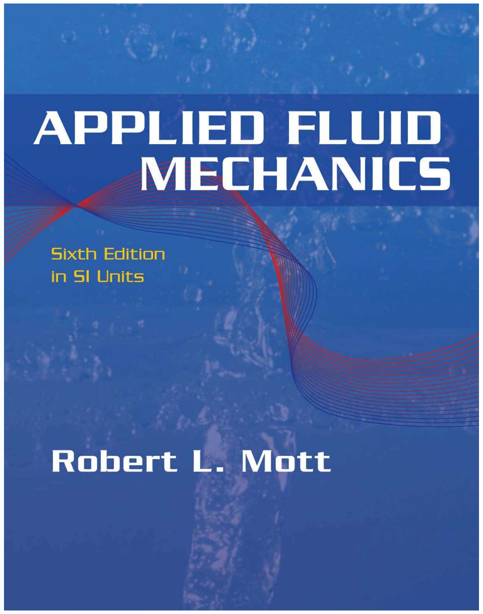
Applied Fluid Mechanics



1. The Nature of Fluid and the Study of Fluid Mechanics
2. Viscosity of Fluid
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5. Buoyancy and Stability
6. Flow of Fluid and Bernoulli's Equation
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Applied Fluid Mechanics

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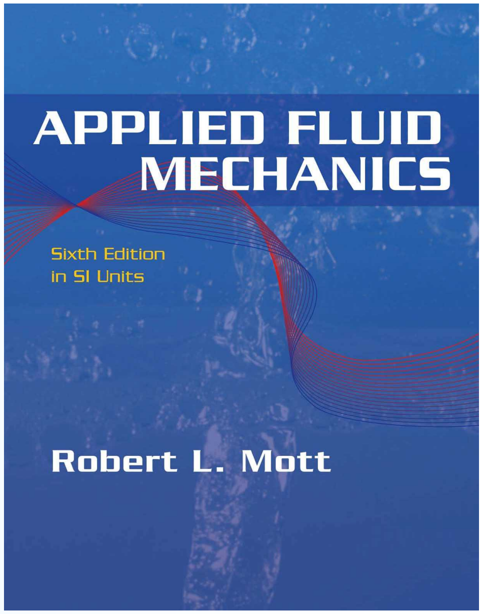
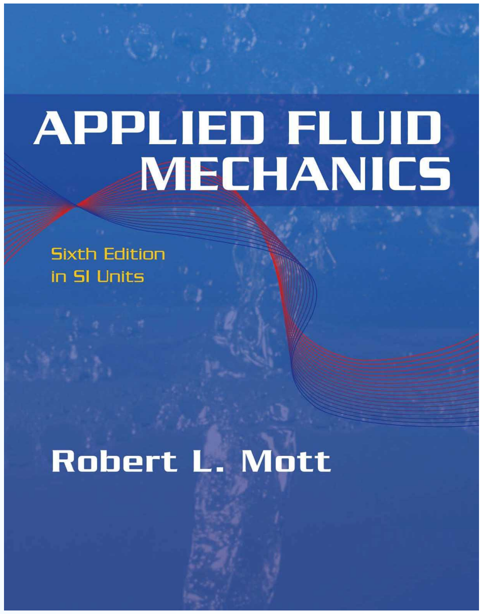


Applied Fluid Mechanics

17. Drag and Lift
18. Fans, Blowers, Compressors and the Flow of Gases
19. Flow of Air in Ducts



19. Flow of Air in Ducts

Chapter Objectives

- Describe the basic elements of an air distribution system that may be used for heating, ventilation, or air conditioning.
- Determine energy losses in ducts, considering straight sections and fittings.
- Determine the circular equivalent diameters of rectangular ducts.
- Analyze and design ductwork to carry air to spaces needing conditioning and to achieve balance in the system.
- Identify the fan selection requirements for the system.

19. Flow of Air in Ducts

Chapter Outline

1. Introductory Concepts
2. Energy Losses in Ducts
3. Duct Design
4. Energy Efficiency and Practical Considerations in Duct Design

19. Flow of Air in Ducts

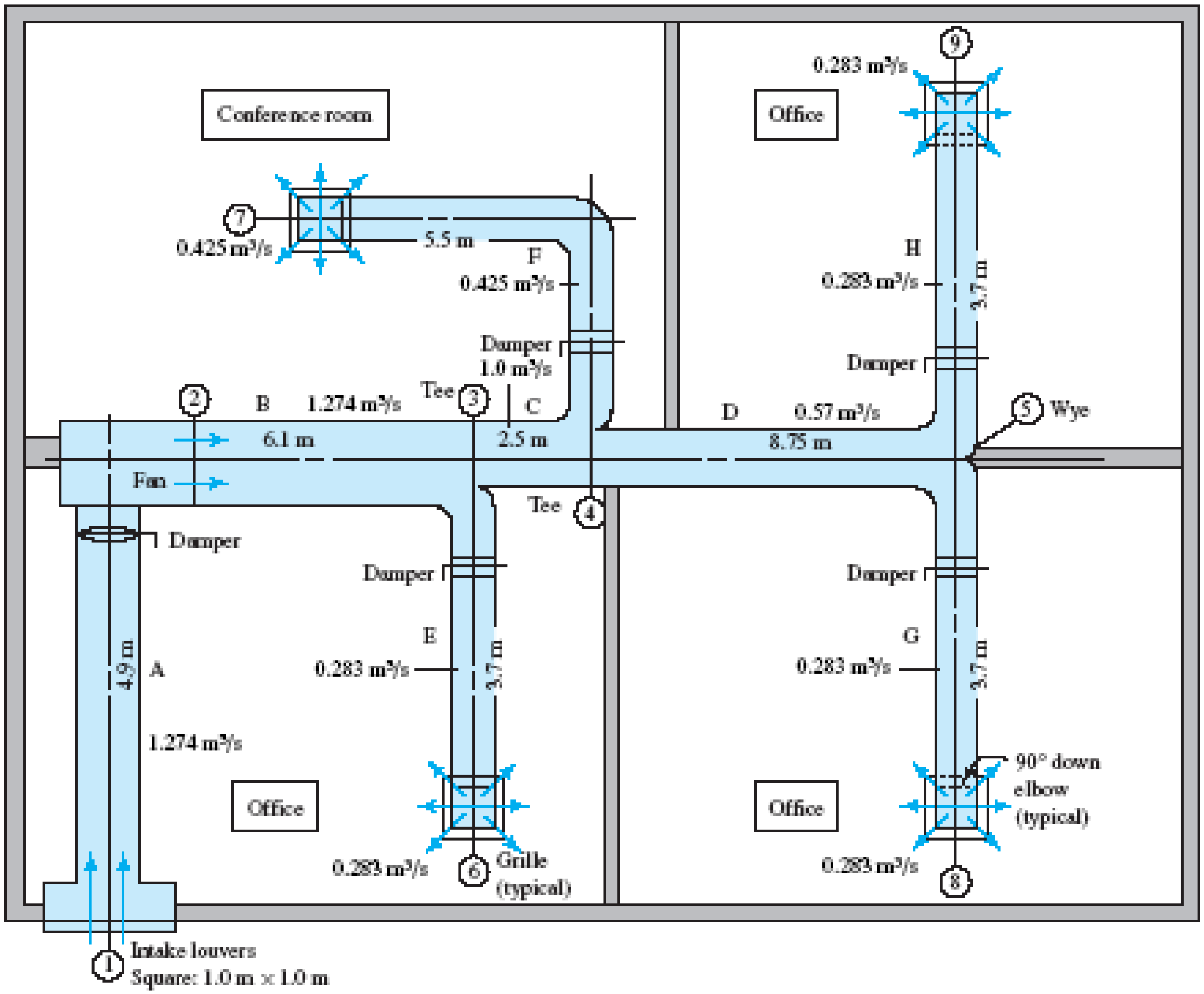
19.1 Introductory Concepts

An Example Air Distribution System

- Figure 19.1 is a sketch of the layout of an air distribution system.
- Outside air enters the building at point 1 through louvers that protect the ductwork from wind and rain.
- The velocity of the air flow through the louvers should be relatively low, approximately 2.5 m/s (500 ft/min), to minimize entrainment of undesirable contaminants.
- The duct then reduces to a smaller size to deliver the air to the suction side of a fan.
- A sudden contraction of the duct is shown, although a more gradual reduction would have a lower pressure loss.

19. Flow of Air in Ducts

19.1 Introductory Concepts



19.2 Energy Losses in Ducts

- Two kinds of energy losses in duct systems cause the pressure to drop along the flow path.
- *Friction losses* occur as the air flows through straight sections, whereas *dynamic losses* occur as the air flows through such fittings as tees and wyes and through flow control devices.
- The units used for the various quantities and the assumed conditions are summarized in Table 19.1.

19. Flow of Air in Ducts

19.2 Energy Losses in Ducts

	U.S. Customary System Units	SI Units
Flow rate	ft^3/min (cfm)	m^3/s
Friction loss h_L	in of water per 100 ft (inH_2O/100 ft)	Pa/m
Velocity	ft/min	m/s
Duct diameter	in	mm
Specific weight of air	0.075 lb/ft^3	11.81 N/m^3
Duct surface roughness	5×10^{-4} ft	1.5×10^{-4} m
Condition of air	14.7 psia; 68°F	101.3 kPa; 20°C

19. Flow of Air in Ducts

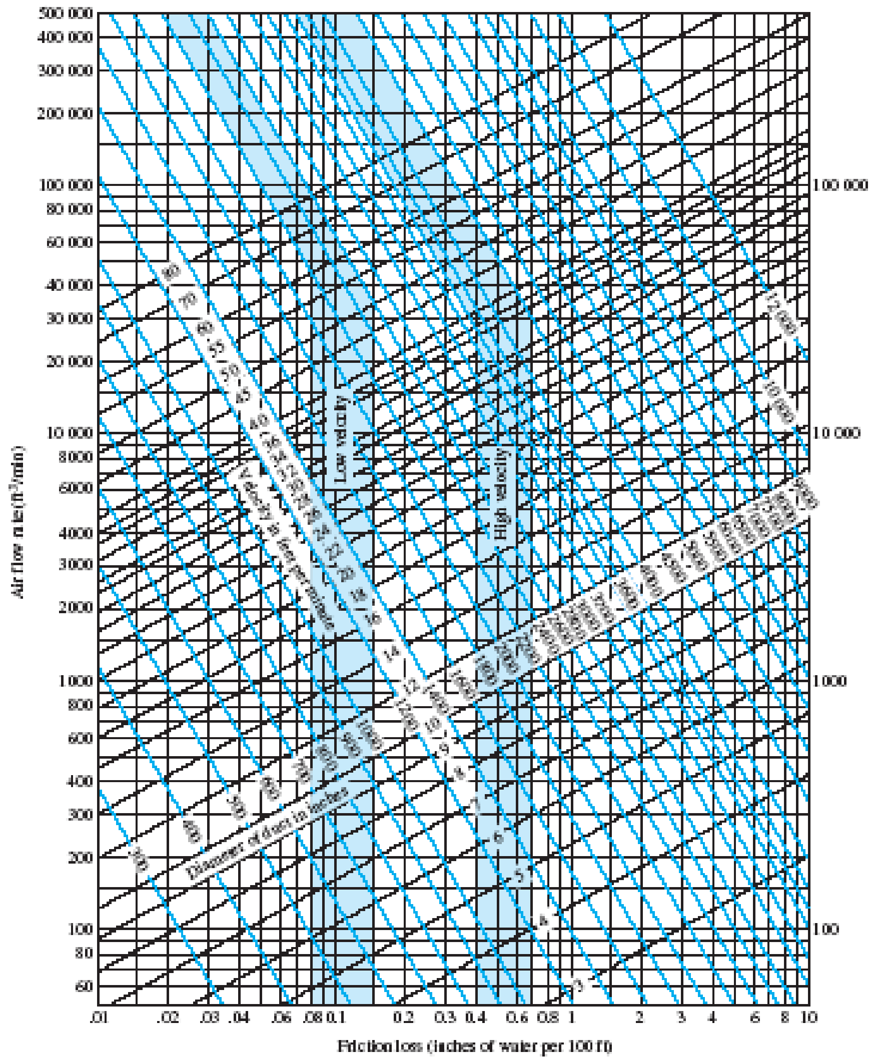
19.2 Energy Losses in Ducts

- Figures 19.2 and 19.3 show friction loss h_L as a function of volume flow rate, with two sets of diagonal lines showing the diameter of circular ducts and the velocity of flow.
- The total energy loss for a given duct length L is called H_L and is found from

$$HL = h_L(L) \text{ Pa}$$

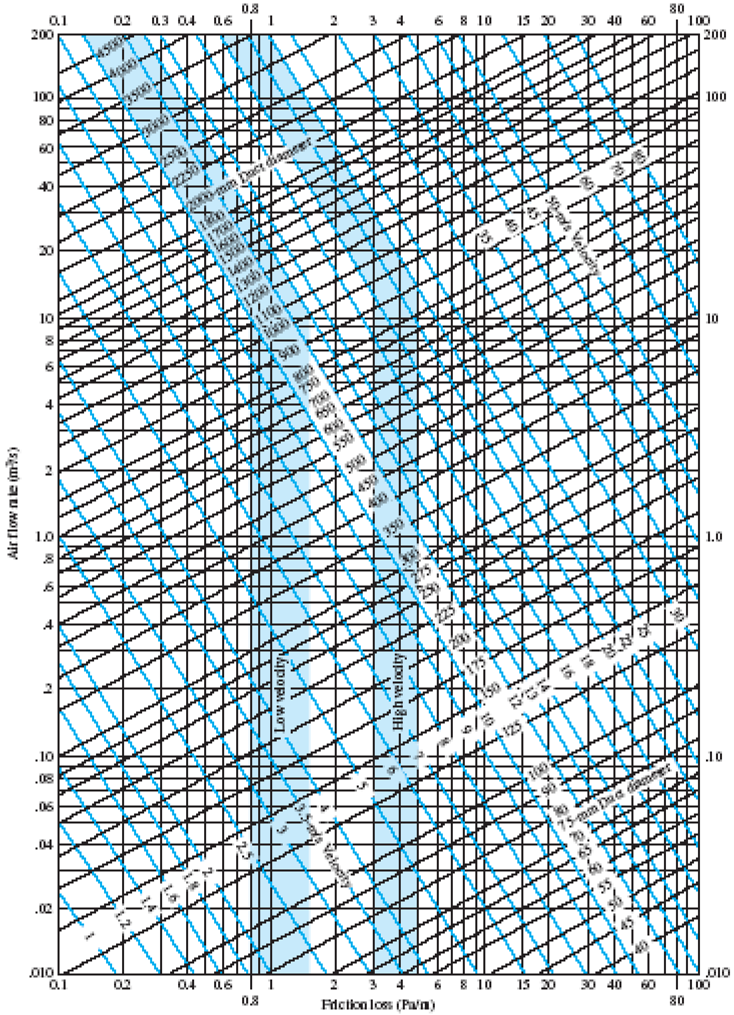
19. Flow of Air in Ducts

19.2 Energy Losses in Ducts



19. Flow of Air in Ducts

19.2 Energy Losses in Ducts



19.2.1 Rectangular Ducts

- When the necessary substitutions of the hydraulic radius for the diameter are made in relationships for velocity, Reynolds number, relative roughness, and the corresponding friction factor, we see that the *equivalent diameter* for a rectangular duct is

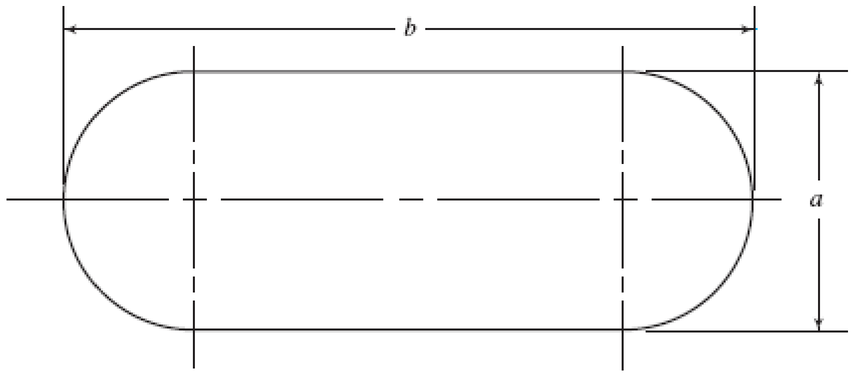
$$D_e = \frac{1.3(ab)^{5/8}}{(a + b)^{1/4}} \qquad (19\text{–}1)$$

where *a* and *b* are sides of the rectangle.

19. Flow of Air in Ducts

19.2.2 Flat Oval Ducts

- Another popular shape for air ducts is the flat oval shown in Fig. 19.4.



- The cross-sectional area is the sum of a rectangle and a circle, found from

$$A = \pi a^2/4 + a(b - a) \qquad (19\text{–}2)$$

where *a* is the length of the minor axis of the duct and *b* is the length of the major axis.

19.2.2 Flat Oval Ducts

- The equivalent diameter of a circular duct is needed to use Figs. 19.2 and 19.3 to determine friction loss:

$$D_e = \frac{1.55A^{0.625}}{WP^{0.250}} \qquad (19\text{–}3)$$

where *WP* is the wetted perimeter as defined in Chapter 9, found from

$$WP = \pi a + 2(b - a) \qquad (19\text{–}4)$$

- Table 19.3 shows some examples of the circular equivalent diameters for flat oval ducts.

19.2.2 Flat Oval Ducts

TABLE 19.3. Circular equivalent diameters of flat oval ducts

Minor Axis mm (in)	Major Axis mm (in) 203 (8)	254 (10)	305 (12)	356 (14)	406 (16)	457 (18)	508 (20)	559 (22)	610 (24)	660 (26)	711 (28)	762 (30)
152 (6)	180 (7.1)	206 (8.1)	226 (8.9)	244 (9.6)	259 (10.2)	274 (10.8)	287 (11.3)	300 (11.8)	312 (12.3)	323 (12.7)	333 (13.1)	343 (13.5)
203 (8)		234 (9.2)	259 (10.2)	279 (11.0)	300 (11.8)	318 (12.5)	335 (13.2)	351 (13.8)	366 (14.4)	378 (14.9)	391 (15.4)	404 (15.9)
254 (10)			284 (11.2)	310 (12.2)	335 (13.2)	356 (14.0)	376 (14.8)	394 (15.5)	411 (16.2)	427 (16.8)	442 (17.4)	457 (18.0)
305 (12)				335 (13.2)	363 (14.3)	389 (15.3)	409 (16.1)	432 (17.0)	449 (17.7)	470 (18.5)	488 (19.2)	503 (19.8)
356 (14)					386 (15.2)	414 (16.3)	439 (17.3)	465 (18.3)	485 (19.1)	505 (19.9)	526 (20.7)	544 (21.4)
406 (16)						437 (17.2)	465 (18.3)	493 (19.4)	516 (20.3)	538 (21.2)	561 (22.1)	582 (22.9)
457 (18)							488 (19.2)	518 (20.4)	544 (21.4)	569 (22.4)	592 (23.3)	615 (24.2)
508 (20)								538 (21.2)	569 (22.4)	597 (23.5)	622 (24.5)	645 (25.4)
559 (22)									592 (23.3)	620 (24.4)	648 (25.5)	673 (26.5)
610 (24)										642 (25.3)	671 (26.4)	699 (27.5)
660 (26)											693 (27.3)	721 (28.4)
711 (28)												744 (29.3)

Example 19.1

Determine the velocity of flow and the amount of friction loss that would occur as air flows at 1.42 m^3/s through 24.4 m of circular duct having a diameter of 0.6 m (22 in).

We can use Fig. 19.3 to determine that the velocity is approximately 5.8 m/s and that the friction loss Pa/m of duct (h_L) is 0.61 Pa/m. Then, by proportion, the loss for 24.4 m is

$$H_L = h_L(L) = 0.61 \frac{\text{Pa}}{\text{m}} (24.4 \text{ m}) = 14.9 \text{ Pa}$$

Example 19.2

Specify the dimensions of a rectangular duct that would have the same friction loss as the circular duct described in Example Problem 19.1.

From Table 19.2 we can specify a 0.36-by-0.76 m (14-by-30-in) rectangular duct that would have the same loss as the 0.56-m (22.0-in) diameter circular duct. Others that will have approximately the same loss are 0.4-by-0.7 m (16-by-26-in), 0.46-by-0.56 m (18-by- 22-in), and 0.51-by-0.51 m (20-by-20-in) rectangular ducts. Such a list gives the designer many options when fitting a duct system into given spaces.

Example 19.3

Specify the dimensions of a flat oval duct that would have approximately the same friction loss as the circular duct described in Example Problem 19.1.

From Table 19.3 we can specify a 0.41-by-0.71 m (16-by-28-in) flat oval duct that would have approximately the same friction loss as a 0.56-m (22.0-in) diameter circular duct. Others with approximately the same loss are 0.46-by-0.66 m (18-by-26-in) and 0.51-by-0.61 m (20-by-24-in) flat oval ducts.

19.2.2 Flat Oval Ducts

- *Dynamic losses* can be estimated by using published data for loss coefficients for air flowing through certain fittings.
- The dynamic loss for a fitting is calculated from

$$H_L = C(H_v) \qquad (19\text{–}5)$$

where *C* is the loss coefficient from Table 19.4 and H_v is the *velocity pressure* or *velocity head*.

19.2.2 Flat Oval Ducts

Dynamic Loss Coefficient *C*						
	90°elbows					
	Smooth, round	0.22				
	5-piece, round	0.33				
	4-piece, round	0.37				
	3-piece, round	0.42				
	Mitered, round	1.20				
	Smooth, rectangular	0.18				
	Tee, branch	1.00				
	Tee, flow through main	0.10				
	Symmetrical wye	0.30				
Damper Position	0° (wide open)	10°	20°	30°	40°	50°
C	0.20	0.52	1.50	4.5	11.0	29
Outlet grille: Assume total pressure drop through grille is 0.06 inH_2O (15 Pa).						
Intake louvers: Assume total pressure drop across louver is 0.07 inH_2O (17 Pa).						

Note: Dynamic loss for fittings is $C(H_v)$, where H_v is the velocity pressure upstream of the fitting. Values shown are examples, for use only in solving problems in this book. Many factors affect the actual values for a given style of fitting. Refer to Reference 2 or manufacturers' catalogs for more complete data.

19.2.2 Flat Oval Ducts

- In U.S. Customary System units, pressure levels and losses are typically expressed in inches of water, which is actually a measure of pressure head. Then,

$$H_v = \frac{\gamma_a v^2}{2g\gamma_w} \qquad (19\text{–}6)$$

where γ_a is the specific weight of air, v is the flow velocity, and γ_w is the specific weight of water.

19.2.2 Flat Oval Ducts

- When the velocity is expressed in feet per minute and the conditions of standard air are used, Eq. (19–6) reduces to

$$H_v = \left(\frac{v}{4005}\right)^2 \qquad (19\text{–}7)$$

- When we use SI units, pressure levels and losses are measured in the pressure unit of Pa. Then,

$$H_v = \frac{\gamma_a v^2}{2g} \qquad (19\text{–}8)$$

19.2.2 Flat Oval Ducts

- When the velocity is expressed in m/s and the conditions of standard air are used, Eq. (19–8) reduces to

$$H_v = \left(\frac{v}{1.289}\right)^2 \text{Pa} \qquad (19\text{–}9)$$

19. Flow of Air in Ducts

Example 19.4

Estimate the pressure drop that occurs when 1.42 m^3/s of air flows around a smooth, rectangular, 90° elbow with side dimensions of 0.36 x 0.61 m (14 x 24 in).

Use Table 19.2 to find that the equivalent diameter for the duct is 500 mm (19.9 in.). From Fig. 19.3 we find the velocity of flow to be 7.1 m/s. Then, using Eq. (19–9), we compute

$$H_v = \left(\frac{v}{1.289}\right)^2 = \left(\frac{7.1}{1.289}\right)^2 \text{ Pa} = 30.4 \text{ Pa}$$

Example 19.4

From Table 19.4, we find C = 0.18. Then the pressure drop is

$$H_L = C(H_v) = (0.18)(30.4 \text{ Pa}) = 5.5 \text{ Pa}$$

19.3 Duct Design

- The goals of the design process are to specify reasonable dimensions for the various sections of the ductwork, to estimate the air pressure at key points, to determine the requirements to be met by the fan in the system, and to balance the system.
- Balance requires that the pressure drop from the fan outlet to each outlet grille is the same when the duct sections are carrying their design capacities.

19.3 Duct Design

- Several different techniques are used by air distribution designers, such as the following:

1. *Equal-friction method*
2. *Static regain method*
3. *T-Method*
4. *Industrial exhaust systems for vapors and particulates*

19. Flow of Air in Ducts

19.3 Duct Design

- Space limitations in the design of large office buildings and certain industrial applications make “high-velocity systems” attractive.
- The name comes from the practice of using smaller ducts to carry a given flow rate.
- However, several consequences arise:

1. Noise is usually a factor, and special noise-attenuation devices must be employed.
2. Duct construction must be more substantial, and sealing is more critical.
3. Operating costs are generally higher because of greater pressure drops and higher fan total pressures.

19. Flow of Air in Ducts

19.3 Duct Design

- Below is the general procedure for designing air ducts using the equal-friction method:

1. Generate a proposed layout of the air distribution system:

a) Determine the air flow desired into each conditioned space (cfm or m^3/s).

b) Specify the location of the fan.

c) Specify the location of the outside air supply inlet.

d) Propose the layout of the ductwork for the intake duct.

e) Propose the layout of the air delivery system to each space including fittings such as tees, elbows, dampers, and grilles. Dampers should be included in the final run to each delivery grille to facilitate final balance of the system.

19.3 Duct Design

2. For the intake duct and the fan outlet duct, determine the total airflow requirement as the sum of all of the air flows delivered to conditioned spaces.
3. Use Fig. 19.2 or Fig. 19.3 to specify the nominal friction loss (or Pa/m). Low-velocity design is recommended for typical commercial or residential systems.

19.3 Duct Design

5. Specify the nominal flow velocity for each part of the duct system. For the intake duct and the final runs to occupied spaces, use approximately 3–4 m/s (600–800 ft/min). For main ducts away from occupied spaces, use approximately 6 m/s (1200 ft/min).
6. Specify the size and shape of each part of the duct system. The diameters for circular ducts are found directly from Fig. 19.2 or Fig. 19.3. Rectangular ducts can be sized using Table 19.2 and Eq. (19–1). Use Table 19.3 and Eq. (19–3) for flat oval ducts.

19.3 Duct Design

6. Compute the energy losses in the intake duct and in each section of the delivery duct.
7. Compute the total energy loss for each path from the fan outlet to each delivery grille.
8. Determine whether the energy losses for all paths are reasonably balanced, that is, the pressure drop from the fan to each outlet grille is approximately equal.
9. If significant unbalance occurs, redesign the ductwork by typically reducing the design velocity in those ducts where high pressure drops occur. This requires using larger ducts.

19.3 Duct Design

10. Reasonable balance is achieved when all paths have small differences in pressure drop such that modest adjustment to dampers will achieve a true balance.
11. Determine the pressure at the fan inlet and outlet and the total pressure rise across the fan.
12. Specify a fan that will deliver the total air flow at this pressure rise.
13. Plot or chart the pressure in the duct for each path and inspect for any unusual performance.

Example 19.5

The system shown in Fig. 19.1 is being designed for a small office building. The air is drawn from outside the building by a fan and delivered through four branches to three offices and a conference room. The air flows shown at each outlet grille have been determined by others to provide adequate ventilation to each area. Dampers in each branch permit final adjustment of the system.

Example 19.5

Complete the design of the duct system, specifying the size of each section of the ductwork for a low-velocity system. Compute the expected pressure drop for each section and at each fitting. Then, compute the total pressure drop along each branch from the fan to the four outlet grilles and check for system balance. If a major imbalance is predicted, redesign appropriate parts of the system to achieve a more nearly balanced system. Then, determine the total pressure required for the fan. Use Fig. 19.2 for estimating friction losses and Table 19.4 for dynamic loss coefficients.

Example 19.5

First, treat each section of the duct and each fitting separately. Then, analyze the branches.

1. Intake duct A: Q=1.274 m^3/s; L=4.9 m.
Let v L 4.1 m/s.
From Fig. 19.3, required *D*=0.6 m.
h_L=0.3 Pa/m
H_L=0.3 Pa/m (4.9 m)=1.47 Pa

Example 19.5

2. Damper in duct A: C = 0.20 (assume wide open) (Table 19.4).

$$\text{For } 4.1 \text{ m/s}, H_v = (4.1/1.289)^2 = 10.1 \text{ Pa}$$

$$H_L = 0.20(10.1 \text{ Pa}) = 2.02 \text{ Pa}$$

3. Intake louvers: The 1.0 by 1.0 m (40-by-40-in) size has been specified to give approximately a velocity of 3.1 m/s through the open space of the louvers. Use H_L=17 Pa from Table 19.4.

Example 19.5

4. Sudden contraction between louver housing and intake duct: From Fig. 10.7, we know that the resistance coefficient depends on the velocity of flow and the ratio D_1/D_2 for circular conduits. Because the louver housing is a 1-by-1-m (40-by-40-in) square, we can compute its equivalent diameter from Eq. (19–1):

$$D_e = \frac{1.3(ab)^{5/8}}{(a+b)^{1/4}} = \frac{1.3(1.0 \times 1.0)^{5/8}}{(1.0+1.0)^{1/4}} = 1.1 \text{ m}$$

Example 19.5

Then, in Fig. 10.7,

$$D_1/D_2 = 1.1/0.63 = 1.75$$

and K = C = 0.31. Then,

$$H_L = C(H_v) = 0.31(10.1 \text{ Pa}) = 3.13 \text{ Pa}$$

5. Total loss in intake system:

$$H_L = 1.47 \text{ Pa} + 2.02 \text{ Pa} + 17 \text{ Pa} + 3.13 \text{ Pa} = 23.62 \text{ Pa}$$

Example 19.5

Because the pressure outside the louvers is atmospheric, the pressure at the inlet to the fan is –23.62 Pa, a negative gage pressure. An additional loss may occur at the fan inlet if a geometry change is required to mate the intake duct with the fan. Knowledge of the fan design is required, and this potential loss is ignored in this example.

Note: All ducts on the fan outlet side are rectangular.

Example 19.5

6. Fan outlet, duct B: Q=1.274 m^3/s; L=6.1 m.

Let $v \approx 6.1$ m/s; $h_L = 0.9$ Pa/m.

$D_e = 0.5$ m (20 in); use 0.3-by-0.76-m (12-by-30-in) size to minimize overhead space required

$H_L = 0.9$ Pa/m (6.1 m) $= 5.49$ Pa

$H_v = (6.1/1.289)^2 = 22.4$ Pa

Example 19.5

7.

Duct E: $Q = 0.283\ m^3/s$; $L = 3.7$ m.

Let $v \approx 4$ m/s; $h_L = 0.7$ Pa/m.

$D_e = 0.31$ m (12 in); use 0.31-by-0.25-m (12-by-10-in) size

$H_L = 0.7$ Pa/m (3.7 m) $= 2.6$ Pa

$H_v = (4/1.289)^2 = 9.6$ Pa

Example 19.5

7.

Duct E: $Q = 0.283\ m^3/s$; $L = 3.7$ m.

Let $v \approx 4$ m/s; $h_L = 0.7$ Pa/m.

$$D_e = 0.31 \text{ m (12 in); use 0.31-by-0.25-m (12-by-10-in) size}$$

$$H_L = 0.7 \text{ Pa/m } (3.7 \text{ m}) = 2.6 \text{ Pa}$$

$$H_v = (4/1.289)^2 = 9.6 \text{ Pa}$$

8. Damper in duct E: C = 0.20 (assume wide open).

$$H_L = 0.20(9.6 \text{ Pa}) = 1.93 \text{ Pa}$$

9. Elbow in duct E: smooth rectangular elbow; C = 0.18

$$H_L = 0.18(9.6 \text{ Pa}) = 1.73 \text{ Pa}$$

Example 19.5

10. Grille 6 for duct E: H_L=1.5 Pa.

11. Tee 3 from duct B to branch E, flow in branch: C = 1.00. H_L based on velocity ahead of tee in duct B:

$$H_L = 1.00(22.4\ \text{Pa}) = 22.4\ \text{Pa}$$

12. Duct C: $Q = 1.0\ \text{m}^3/\text{s}$; $L = 2.4$ m.
Let $v \approx 6.1$ m/s; $h_L = 0.93$ Pa/m.

$$D_e = 0.5\ \text{m (18.5 in)};\ \text{use 0.31-by-0.6-m (12-by-24-in) size}$$

$$H_L = 0.93\ \text{Pa/m}\ (2.4\ \text{m}) = 2.2\ \text{Pa}$$

$$H_v = (6.1/1.289)^2 = 22.4\ \text{Pa}$$

Example 19.5

13. Tee 3 from duct B to duct C, flow through main:
C = 0.10

$$H_L = 0.10(22.4 \text{ Pa}) = 2.24 \text{ Pa}$$

14. Duct F: $Q = 0.425 \text{ m}^3/\text{s}$; $L = 5.5$ m.
Let $v \approx 4$ m/s; $h_L = 0.55$ Pa/m.

$$D_e = 0.36 \text{ m (14.3 in); use 0.31-by-0.35-m (12-by-14-in) size}$$

$$H_L = 0.55 \text{ Pa/m } (5.5 \text{ m}) = 3.0 \text{ Pa}$$

$$H_v = (4/1.289)^2 = 9.6 \text{ Pa}$$

Example 19.5

15. Damper in duct F: C = 0.20 (assume wide open).

$$H_L = 0.20(9.6 \text{ Pa}) = 1.93 \text{ Pa}$$

16. Two elbows in duct F: smooth rectangular elbow;
C = 0.18

$$H_L = 2(0.18)(9.6) = 3.5 \text{ Pa}$$

17. Grille 7 for duct F H_L=15 Pa.

18. Tee 4 from duct C to branch F, flow in branch:
C = 1.00

H_L based on velocity ahead of tee in duct C:

$$H579_L = 1.00(22.4 \text{ Pa}) = 22.4 \text{ Pa}$$

19. Flow of Air in Ducts

Example 19.5

19. Duct D: $Q = 0.57\ m^3/s$; $L = 8.75$ m.
Let $v \approx 5.1$ m/s; $h_L = 0.8$ Pa/m.

$$D_e = 0.37 \text{ m (14.7 in); use 0.31-by-0.41-m (12-by-16-in) size}$$
$$\text{Actual } D_e = 0.38 \text{ m; new } h_L = 0.78 \text{ Pa/m}$$
$$H_L = 0.78 \text{ Pa/m } (8.75 \text{ m}) = 6.8 \text{ Pa}$$
$$\text{New } v = 4.9 \text{ m/s}$$
$$H_v = (4.9/1.289)^2 = 14.5 \text{ Pa}$$

20. Tee 4 from duct C to duct D, flow through main: C = 0.10

$$H_L = 0.10(22.4 \text{ Pa}) = 2.24 \text{ Pa}$$

21. Wye 5 between duct D and ducts G and H: C = 0.3

$$H_L = 0.30(14.5 \text{ Pa}) = 4.3 \text{ Pa}$$

Example 19.5

22. Ducts G and H are identical to duct E, and losses from Steps 7–10 can be applied to
these paths.
This completes the evaluation of the pressure drops through components in the
system. Now we can sum the losses through any path from the fan outlet to the outlet grilles.

a. Path to grille 6 in duct E: sum of losses from Steps 6–11:

$$H_6 = 5.49 \text{ Pa} + 2.6 \text{ Pa} + 1.93 \text{ Pa} + 1.73 \text{ Pa} + 1.5 \text{ Pa} + 22.4 \text{ Pa}$$
$$= 36 \text{ Pa}$$

Example 19.5

b. Path to grille 7 in duct F: sum of losses from Steps 6 and 12–18:

$$H_7 = 5.49 \text{ Pa} + 2.2 \text{ Pa} + 2.24 \text{ Pa} + 3.0 \text{ Pa} + 1.93 \text{ Pa} + 3.5 \text{ Pa} + 15 \text{ Pa} + 22.4 \text{ Pa}$$
$$= 55.8 \text{ Pa}$$

c. Path to either grille 8 in duct G or grille 9 in duct H: sum of losses from Steps 6, 12, 13, 19–21, and 7–10:

$$H_8 = 5.49 + 2.2 + 2.24 + 6.8 + 2.24 + 4.3 + 2.6 + 1.93 + 1.73 + 1.5$$
$$= 31.0 \text{ Pa}$$

Example 19.5

Redesign to Achieve a Balanced System

The ideal system design would be one in which the loss along any path, a, b, or c, is the same. Because that is not the case here, some redesign is called for. The loss in path b to grille 7 in duct F is much higher than the others. The component losses from steps 12, 14–16, and 18 affect this branch, and some reduction can be achieved by reducing the velocity of flow in ducts C and F.

Example 19.5

12a. Duct C: $Q = 1.0\ m^3/s$; $L = 2.4$ m.
Let $v \approx 5$ m/s; $h_L = 0.55$ Pa/m.

$$D_e = 0.5 \text{ m (19.6 in); use 0.31-by-0.71-m (12-by-28-in) size}$$

$$H_L = 0.55 \text{ Pa/m } (2.4 \text{ m}) = 1.32 \text{ Pa}$$

$$H_v = (5/1.289)^2 = 15.1 \text{ Pa}$$

14a. Duct F: $Q = 0.425\ m^3/s$; $L = 5.5$ m.
Let $v \approx 3.1$ m/s; $h_L = 0.25$ Pa/m.

$$D_e = 0.42 \text{ m (16.5 in); use 0.31-by-0.46-m (12-by-18-in) size; } D_e = 0.41 \text{ m}$$

$$\text{Actual } v = 3.3 \text{ m/s; } h_L = 0.33 \text{ Pa/m}$$

$$H_L = 0.33 \text{ Pa/m } (5.5) = 1.8 \text{ Pa}$$

$$H_v = (3.3 \text{ m}/1.289)^2 = 6.6 \text{ Pa}$$

19. Flow of Air in Ducts

Example 19.5

15a. Damper in duct F: $C = 0.20$ (assume wide open).

$$H_L = 0.20(6.6 \text{ Pa}) = 1.3 \text{ Pa}$$

16a. Two elbows in duct F: smooth rectangular elbow; $C = 0.18$.

$$H_L = 2(0.18)(6.6 \text{ Pa}) = 2.40 \text{ Pa}$$

18a. Tee 4 from duct C to branch F, flow in branch: $C = 1.00$. H_L based on velocity ahead of tee in duct C.

$$H_L = 1.00(15.1 \text{ Pa}) = 15.1 \text{ Pa}$$

Example 19.5

Now we can recompute the total loss in path B to grille 7 in duct F. As before, this is the sum of the losses from steps 6, 12a, 13, 14a, 15a, 16a, 17, and 18a:

$$H_7 = 5.49 + 1.32 + 2.24 + 1.8 + 1.3 + 2.4 + 15 + 15.1$$
$$= 44.7 \text{ Pa}$$

This is a significant reduction, which results in a total pressure drop less than that of path a. Therefore, let's see if we can reduce the loss in path a by also reducing the velocity of flow in duct E. Steps 7–9 are affected.

Example 19.5

7a. Duct E: $Q = 0.283\ m^3/s$; $L = 3.7$ m.
Let $v \approx 3.0$ m/s.

$$D_e = 0.35 \text{ m (13.8 in); use 0.31-by-0.36-m (12-by-14-in) size}$$

$$\text{Actual } v = 0.36 \text{ m; } h_L = 0.26 \text{ Pa/m; } v = 2.8 \text{ m/s}$$

$$H_L = 0.26 \text{ Pa/m (3.7 m)} = 0.96 \text{ Pa}$$

$$H_v = (2.8/1.289)^2 = 4.7 \text{ Pa}$$

8a. Damper in duct E: $C = 0.20$ (assume wide open).

$$H_L = 0.20(4.7 \text{ Pa}) = 0.94 \text{ Pa}$$

Example 19.5

9a. Elbow in duct E: smooth rectangular elbow; $C = 0.18$.

$$H_L = 0.18(4.7 \text{ Pa}) = 0.85 \text{ Pa}$$

Now, we can recompute the total loss in path a to grille 6 in duct E. As before, this is the sum of the losses from steps 6, 7a, 8a, 9a, 10, and 11:

$$\begin{aligned} H_6 &= 5.49 + 0.96 + 0.94 + 0.85 + 1.5 + 22.4 \\ &= 32.1 \text{ Pa} \end{aligned}$$

Example 19.5

This value is very close to that found for the redesigned path b, and the small difference can be adjusted with the dampers. Now, note that path c to either grille 8 or grille 9 still has a lower total loss than either path a or path b. We could either use a slightly smaller duct size in branches G and H or depend on the adjustment of the dampers here also. To evaluate the suitability of using the dampers, let’s estimate how much the dampers would have to be closed to increase the total loss to 32.1 Pa (to equal that in path a). The increased loss is

$$H_6 - H_8 = 32.1 - 31.0 = 1.1 \text{ Pa}$$

Example 19.5

With the damper wide open and with 0.283 m^3/s passing at a velocity of approximately 4 m/s, the loss was 1.93 Pa, as found in the original Step 8. The loss now should be

$$H_L = 1.93 + 1.1 = 3.03 \text{ Pa}$$

For the damper, however,

$$H_L = C(H_v)$$

Solving for *C* gives

$$C = \frac{H_L}{H_v} = \frac{3.03}{9.6} = 0.32$$

Example 19.5

Referring to Table 19.4, you can see that a damper setting of less than 10° would produce this value of *C*, a very feasible setting. Thus, it appears that the duct system could be balanced as redesigned and that the total pressure drop from the fan outlet to any outlet grille will be approximately 32 Pa. This is the pressure that the fan would have to develop.

Example 19.5

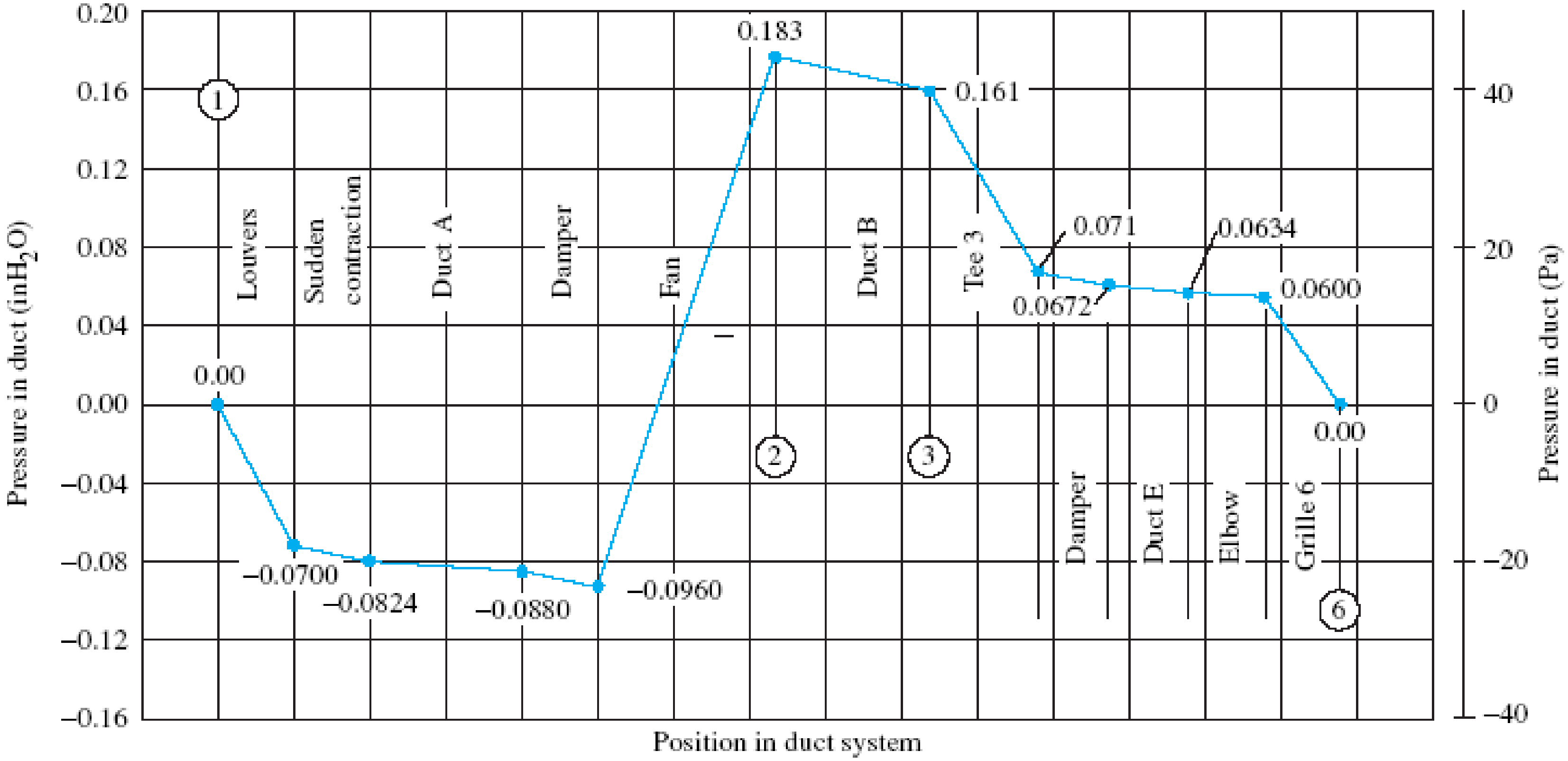
SUMMARY OF THE DUCT SYSTEM DESIGN

- Intake duct A: round; $D = 0.6$ m (25.0 in)
- Duct B: rectangular; 0.3 m × 0.76 m (12 in × 30 in)
- Duct C: rectangular; 0.31 m × 0.71 m (12 in × 28 in)
- Duct D: rectangular; 0.31 m × 0.41 m (12 in × 16 in)
- Duct E: rectangular; 0.31 m × 0.35 m (12 in × 14 in)
- Duct F: rectangular; 0.31 m × 0.46 m (12 in × 18 in)
- Duct G: rectangular; 0.31 m × 0.25 m (12 in × 10 in)
- Duct H: rectangular; 0.31 m × 0.25 m (12 in × 10 in)
- Pressure at fan inlet: −23.6 Pa
- Pressure at fan outlet: 32.1 Pa
- Total pressure rise by the fan: 32.1 + 23.6 = 55.7 Pa
- Total delivery by the fan: 1.274 m^3/s

Example 19.5

It is helpful to visualize the pressure changes that occur in the system. Figure 19.5 shows a plot of air pressure versus position for the path from the intake louvers, through the fan, through ducts B and E, to outlet grille 6. Similar plots could be made for the other paths.

Example 19.5



Pressure in duct (inH$_2$O)
0.20
0.16
0.12
0.08
0.04
0.00
−0.04
−0.08
−0.12
−0.16
Pressure in duct (Pa)
40
20
0
−20
−40
Position in duct system
1
2
3
6
Louvers
Sudden contraction
Duct A
Damper
Fan
Duct B
Tee 3
Damper
Duct E
Elbow
Grille 6
0.00
−0.0700
−0.0824
−0.0880
−0.0960
0.183
0.161
0.071
0.0672
0.0634
0.0600
0.00

19.4 Energy Efficiency and Practical Considerations in Duct Design

- Additional considerations must be addressed when designing air distribution systems for HVAC systems and industrial exhausts.
- Listed below are some recommendations.

1. Lower velocities tend to produce lower energy losses in the system, which reduce fan energy usage and may permit using a smaller, less expensive fan. However, ducts will tend to be larger, affecting space requirements and leading to higher installed costs.
2. Locating as much of the duct system as practical within the conditioned space will save energy for heating and cooling systems.

19.4 Energy Efficiency and Practical Considerations in Duct Design

3. Ductwork should be well sealed to stop leaks.
4. Ducts passing through unconditioned spaces should be well insulated.
5. The fan capacity should be well matched to the air supply requirement to avoid excessive control by dampers, which tends to waste energy.

19.4 Energy Efficiency and Practical Considerations in Duct Design

6. When loads vary significantly over time, variable-speed drives should be installed on the fan and connected into the control system to lower the fan speed at times of low demand. The fan laws indicate that lowering speed reduces power required by the cube of the speed reduction ratio. (See Chapter 13.) For example, reducing fan speed by 20 percent will reduce the required power by approximately 50 percent.

19.4 Energy Efficiency and Practical Considerations in Duct Design

7. Ducts can be made from sheet metal, rigid fiberglass duct board, fabric, or flexible nonmetallic duct. Some come with insulation either inside or outside to reduce energy losses and to attenuate noise. Smooth surfaces are preferred for long runs to minimize friction losses.
8. Return air ducts should be provided to maintain consistent flow into and out from each room in the conditioned space.

19.4 Energy Efficiency and Practical Considerations in Duct Design

9. Ducts for most HVAC systems are designed for pressures that range from –750 Pa (–3 inH2O) on the intake side of fans to 2500 Pa (10 inH2O) on the outlet side. However, some large commercial or industrial installations may range from –2500 Pa (–10 inH2O) to 25 kPa (100 inH2O). Structural strength, rigidity, and vibration must be considered.

19.4 Energy Efficiency and Practical Considerations in Duct Design

10. Noise generation in air distribution systems must be considered to ensure that occupants are not annoyed by high noise levels. Special care should be given to fan selection and location and air velocity in ducts and through outlet grilles. Sound insulation, vibration isolators, and mounting techniques should be examined to minimize noise.