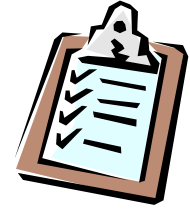


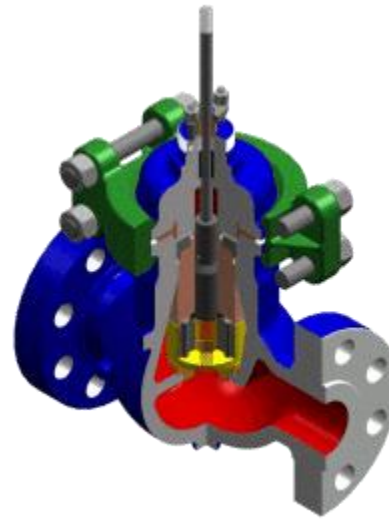
Hardware Components in BAS/BEMS

(Part II – Valves and Dampers)

Contents



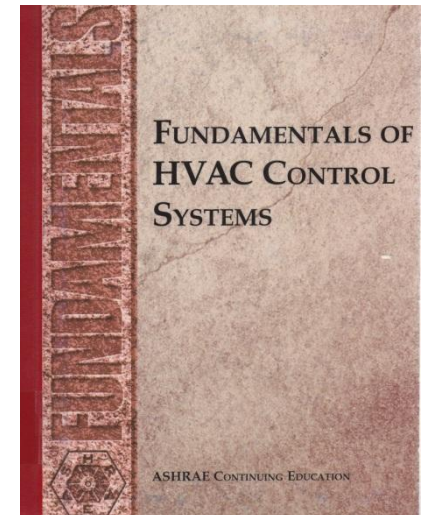
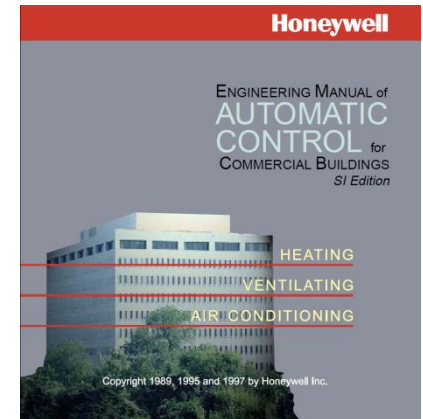
- ▶ Design Principles
 - Control valves
 - Control dampers



References

The details of the material can be found in

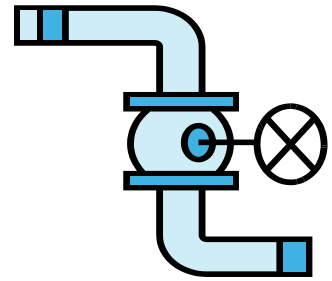
- ▶ Engineering Manual of Automatic Control for Commercial Buildings, pp425–464, Honeywell, 1997
- ▶ Fundamentals of HVAC Control Systems, Ch.3, ASHRAE, 2008



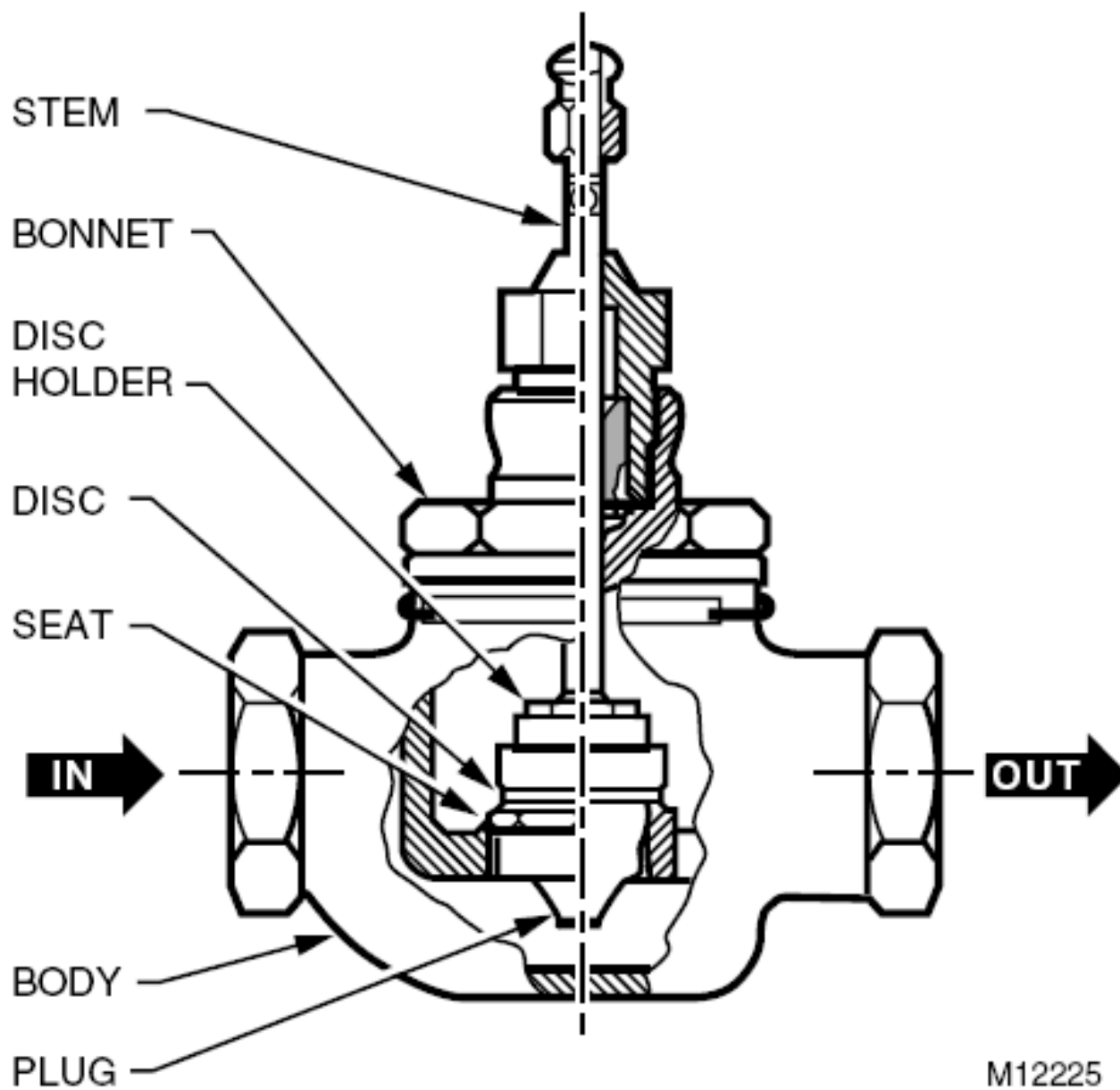
Hardware Components in BAS/BEMS

»» Control Valves

Control Valves



- ▶ Important component of fluid distribution systems
- ▶ Common types:
 - Globe valves (for 2 position & modulating)
 - Ball valves (for shut off and balancing)
 - Butterfly valves (for 2 position)
- ▶ Valve material
 - Bronze, cast iron, steel



Control valve components

Globe Valves

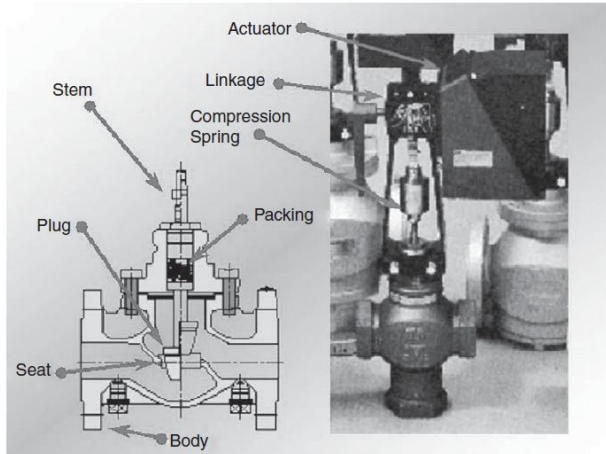


Figure 3-2 Two-way Globe Single-seated Valve (Fluid Flow is Left to Right)

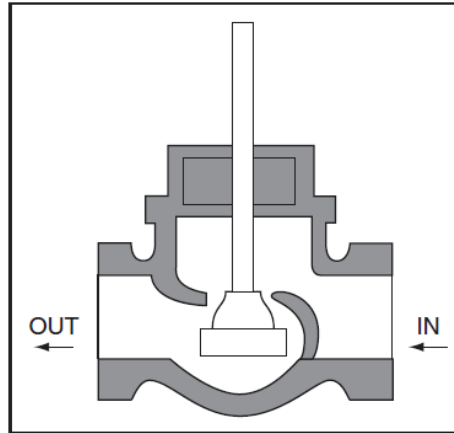


Figure 3-3 Normally Closed Globe Two-way Valve

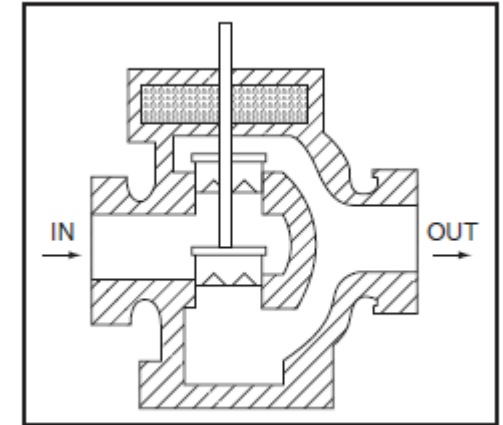
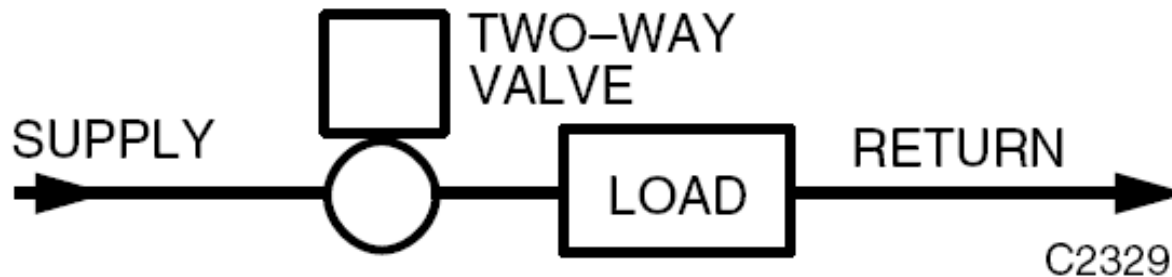


Figure 3-4 Double-seated Two-way Globe Valve

Two-way globe valves



Two-way valve application

[Source: ASHRAE, 2008. *Fundamentals of HVAC Control Systems*]

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Butterfly Valves

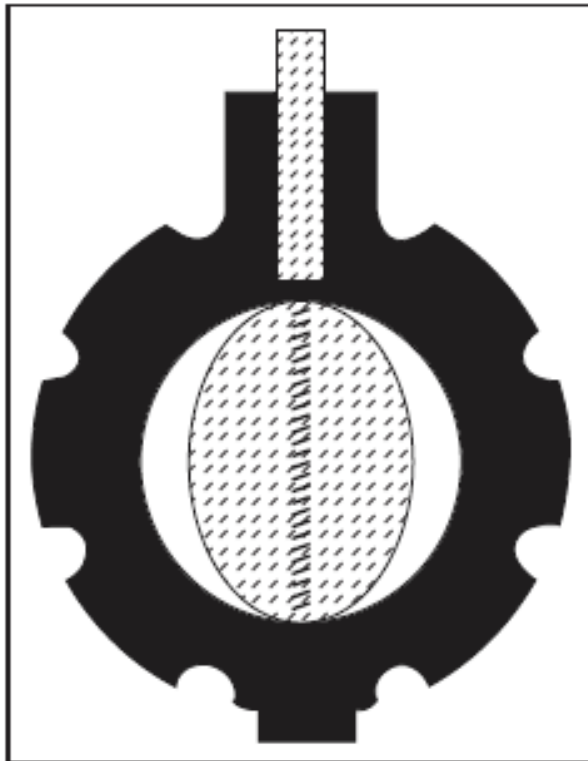
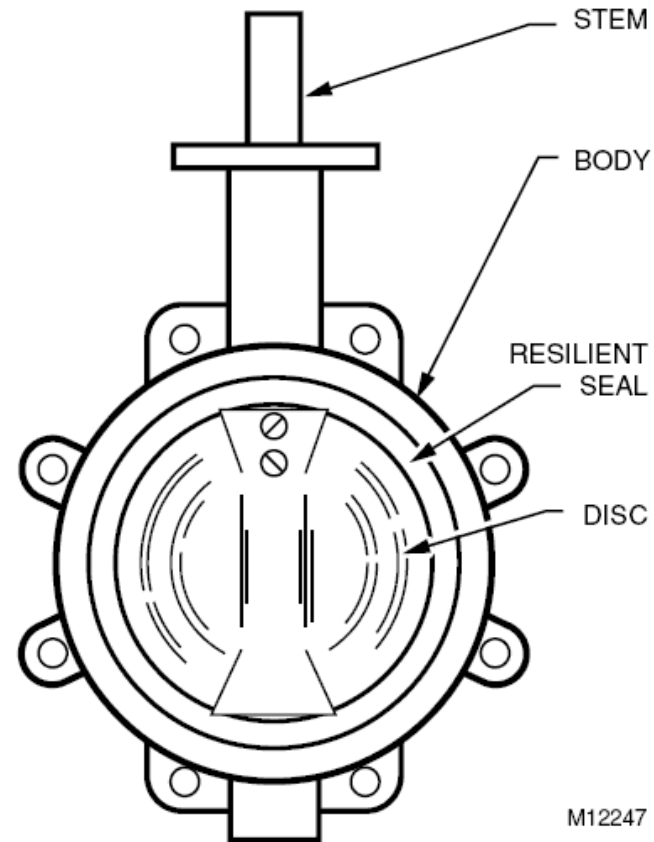


Figure 3-11 Butterfly Valve



[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

[Source: ASHRAE, 2008. *Fundamentals of HVAC Control Systems*]

Ball Valves

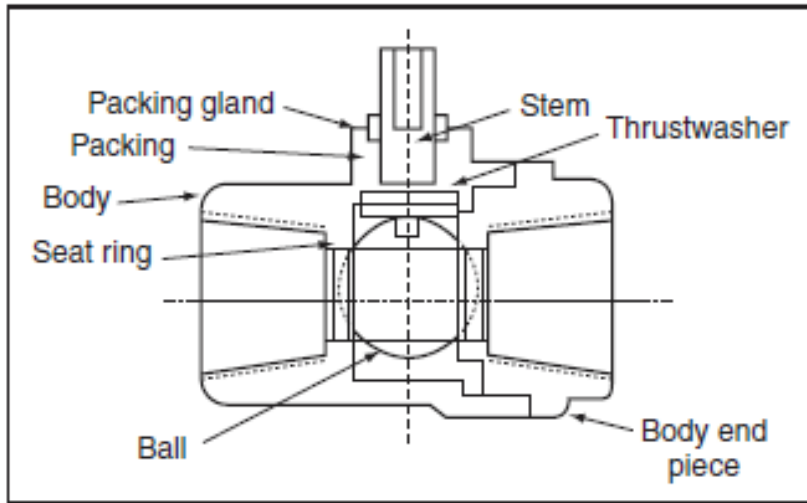


Figure 3-12 Ball Valve Layout

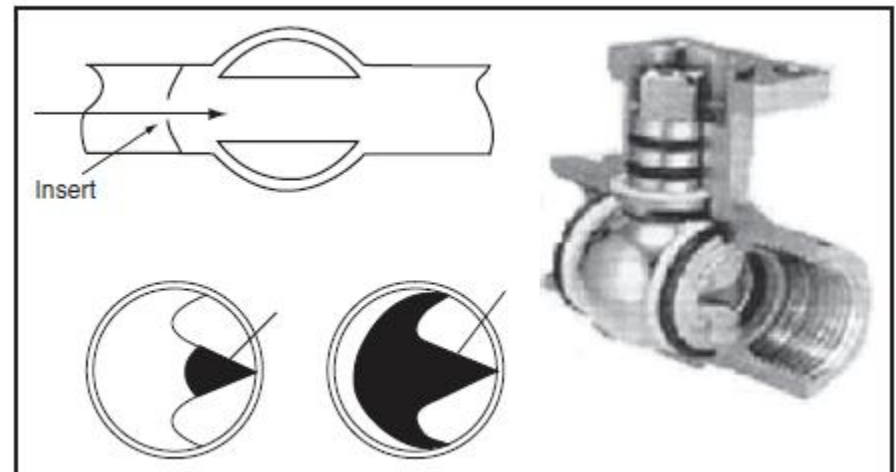


Figure 3-13 Characterized Ball Valve

[Source: ASHRAE, 2008. *Fundamentals of HVAC Control Systems*]

3-Way Valves

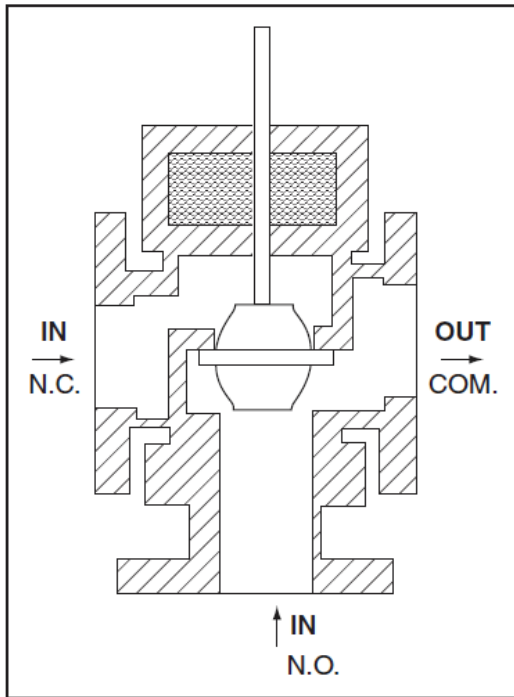


Figure 3-18 Three-way Mixing Valve

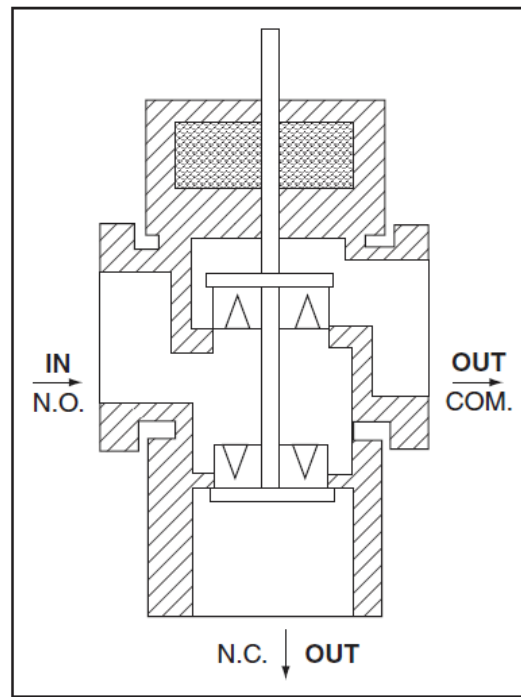
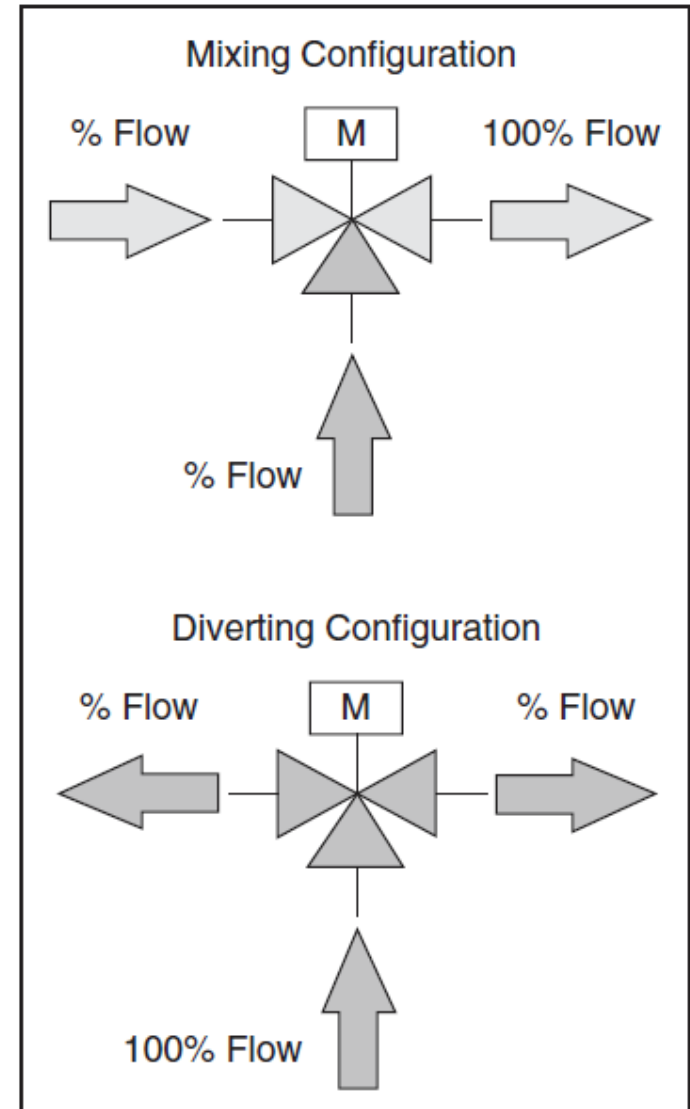
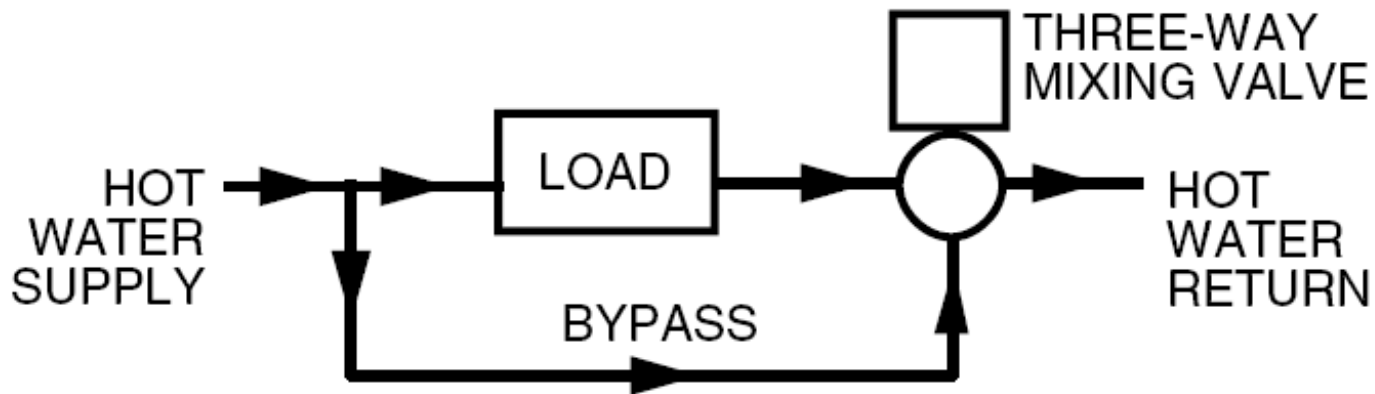


Figure 3-19 Three-way Diverting Valve

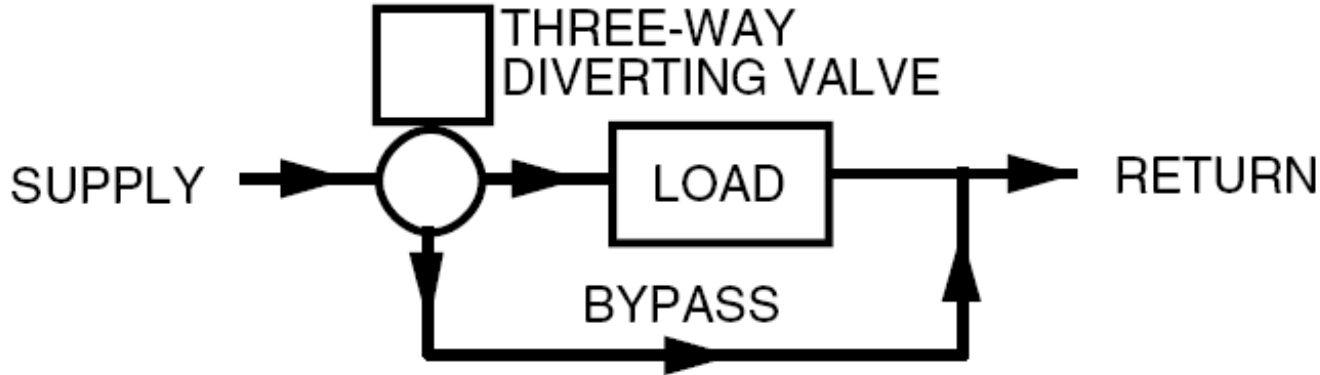


[Source: ASHRAE, 2008. *Fundamentals of HVAC Control Systems*]



A. LOAD BYPASS IN MIXING VALVE APPLICATION

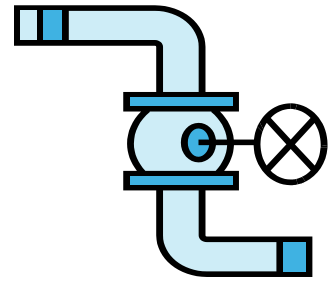
(Less Expensive & More Common)



B. LOAD BYPASS IN DIVERTING VALVE APPLICATION

Three-way valve applications

Control Valves



- ▶ Valve flow characteristics
 - Relationship between the stem travel of a valve, expressed in percent of travel, and the fluid flow through the valve, expressed in percent of full flow
- ▶ Typical flow characteristics
 - Linear
 - Equal percentage
 - Quick opening

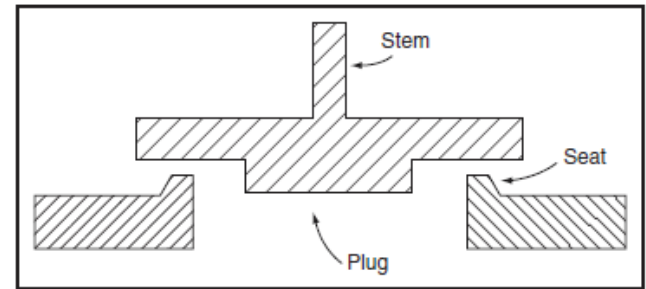
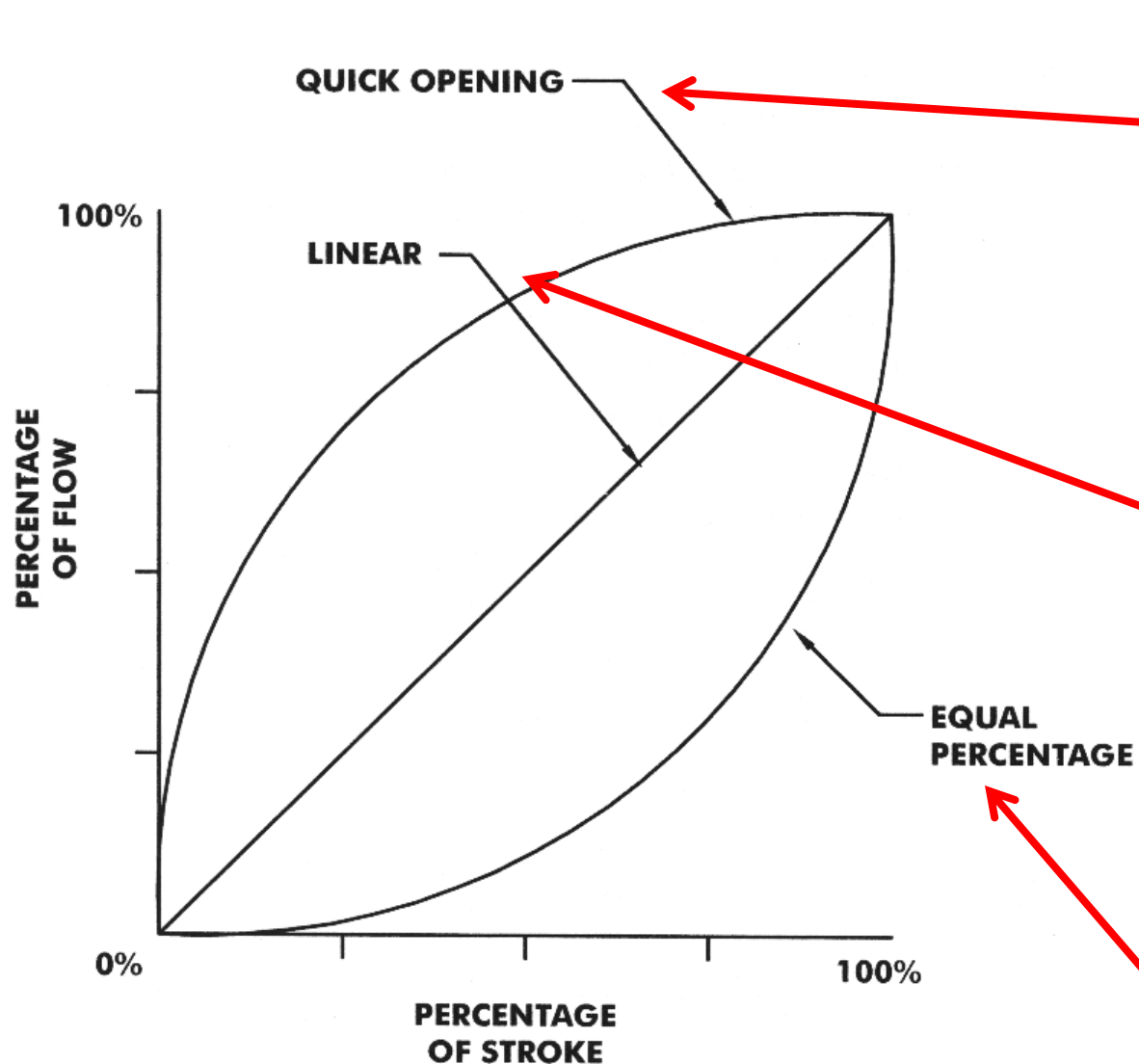


Figure 3-7 Quick-opening (Flat Plate) Valve Plug

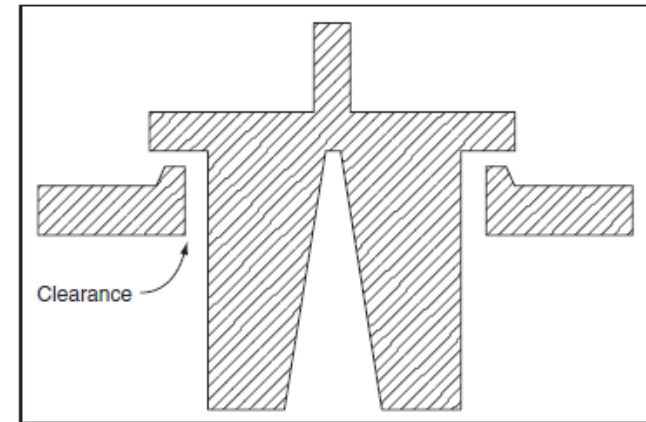


Figure 3-5 Linear (V-Port) Valve Plug

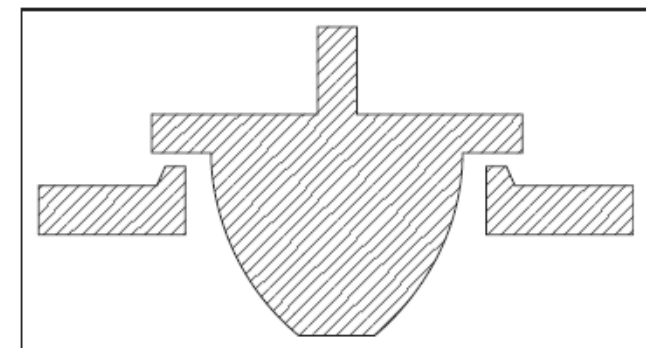
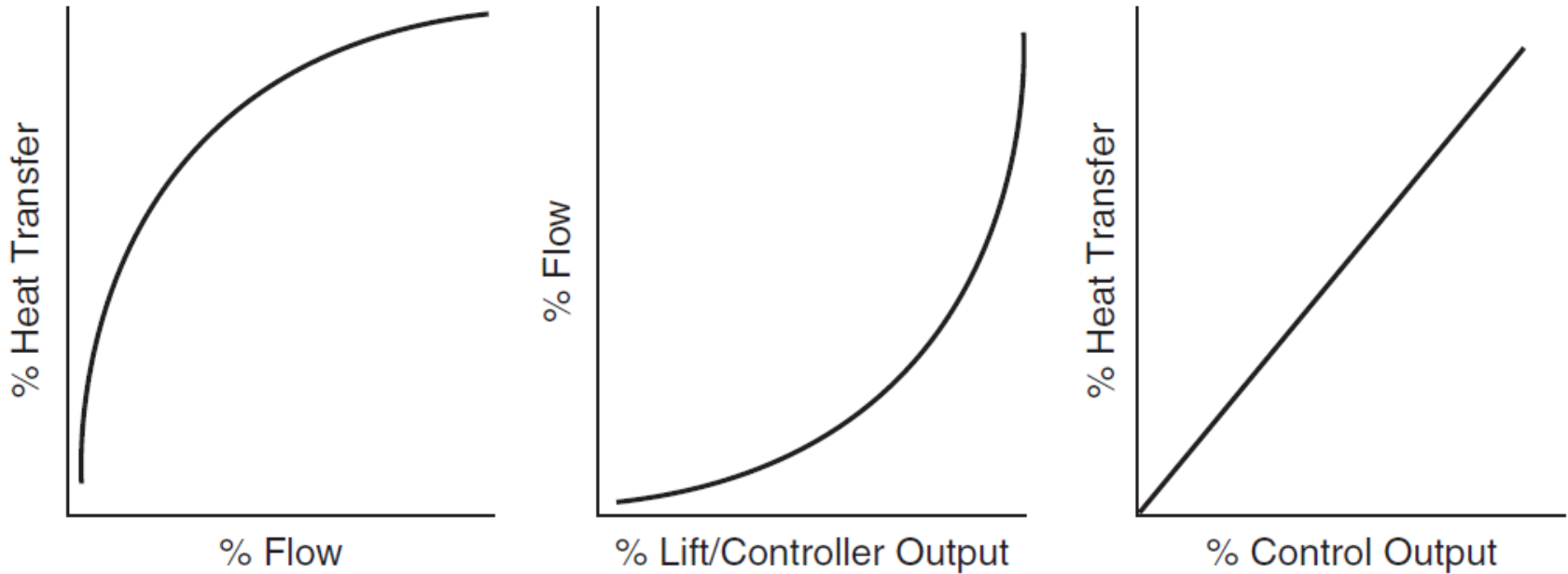


Figure 3-6 Equal Percentage Valve Plug

Flow characteristics of control valves

Combination of coil and control valve characteristics



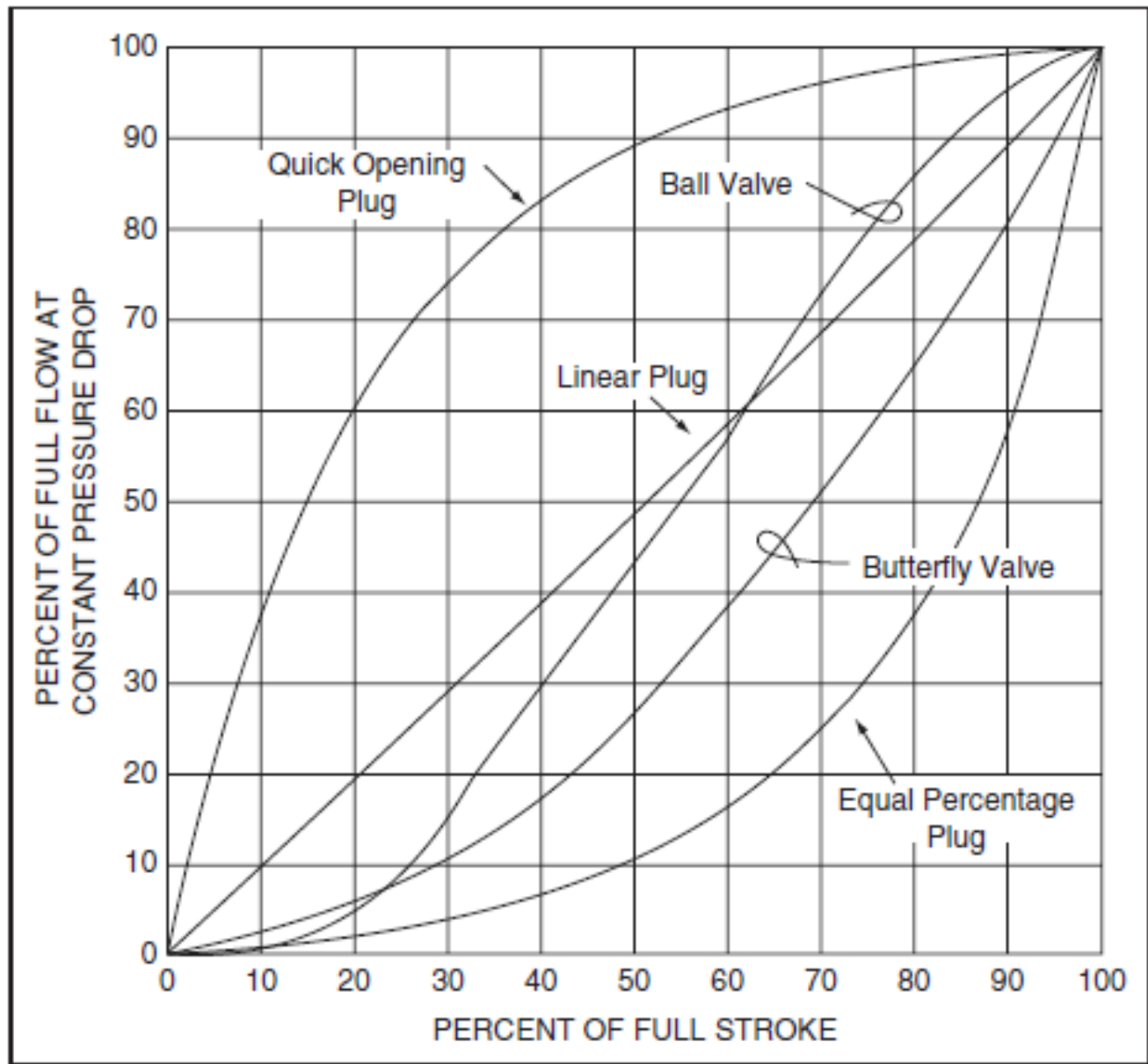


Figure 3-10 Typical Valve Characteristics at Constant Pressure Drop

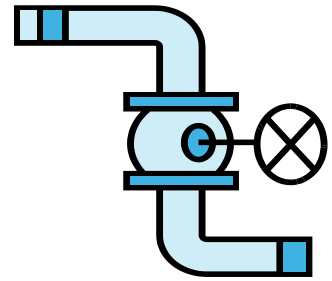
[Source: ASHRAE, 2008. *Fundamentals of HVAC Control Systems*]

Control Flow Characteristics

Valve Type	Flow Characteristic Available	Application
Globe Valve	A. Linear B. Equal percentage C. Quick opening	A. Steam B. Chilled water and hot water coils C. Open – close
Butterfly	Quick opening	Automatic shut-off for boilers, chillers, and cooling towers
Ball Valve	Varies	Small reheat coils. Also chilled water and hot water coils

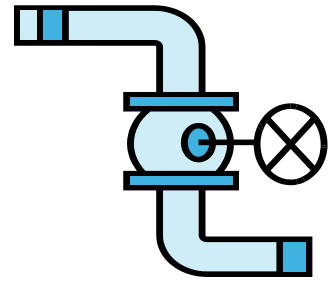
Table 9-1: Flow characteristics and applications of various control valves.

Valve Flow Terms



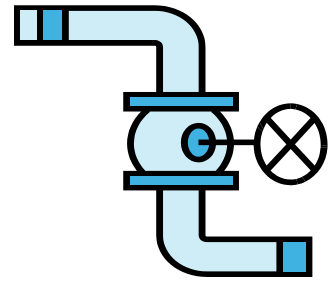
- Rangeability:
 - The ratio of maximum flow to minimum controllable flow
 - Approximate ratios are 50:1 for V-port globe valves and 30:1 for contoured plug valves
 - E.g. valve total flow capacity = 10L/s in fully open, if rangeability is 30:1, then the valve can control flows down to $(10\text{L/s} \times 1/30) = 0.3\text{L/s}$

Valve Flow Terms



- Turndown:
 - The ratio of maximum flow to minimum controllable flow of a valve installed in a system.
 - Turndown is equal to or less than rangeability
 - E.g. consider the same valve –
 - 10L/s fully open, rangeability 30:1, minimum controllable flow = 0.3L/s
 - If the system max. flow = 6.6L/s
 - Turndown = 6.6L/s : 0.3L/s = 22:1

Valve Flow Terms



- Flow coefficient (capacity index): Used to state the flow capacity of a control valve for specified conditions
 - British version A_v
 - North American K_v
 - United States C_v

Flow coefficient:

$$A_V = q \sqrt{\frac{\rho}{\Delta P}} \quad (\text{British Version})$$

q = volume flow (m^3/s)

ρ = fluid density (kg/m^3)

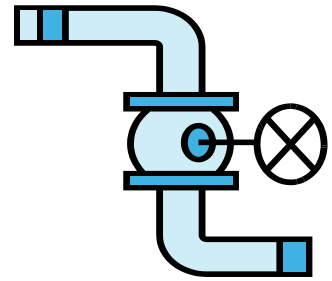
ΔP = static pressure loss across the valve (Pa)

For valve used in water application:

(North American Version)

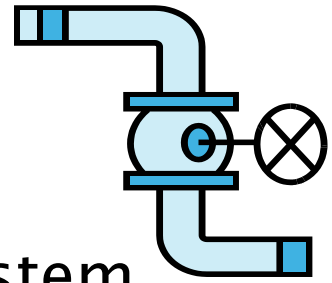
$$K_V = Q \sqrt{\frac{\rho}{\Delta P \cdot 10}} \quad \begin{array}{l} Q = \text{volume flow } (\text{m}^3/\text{h}) \\ \rho = \text{fluid density } (\text{kg}/\text{m}^3) \\ \Delta P = \text{static pressure loss} \\ \text{across the valve } (\text{kPa}) \end{array}$$

Valve Ratings



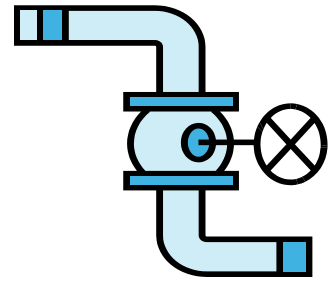
- Flow coefficient – K_v
- Close-off rating:
 - The maximum pressure drop that a valve can withstand without leakage while in the full closed position
 - E.g. a close-off rating 70kPa can result from up/downstream pressure of 270kPa/200kPa
- Maximum pressure and temperature:
 - The maximum pressure and temperature limitations of fluid flow that a valve (all components) can withstand
 - May change according to different pressure temperature combinations.

Valve Selection

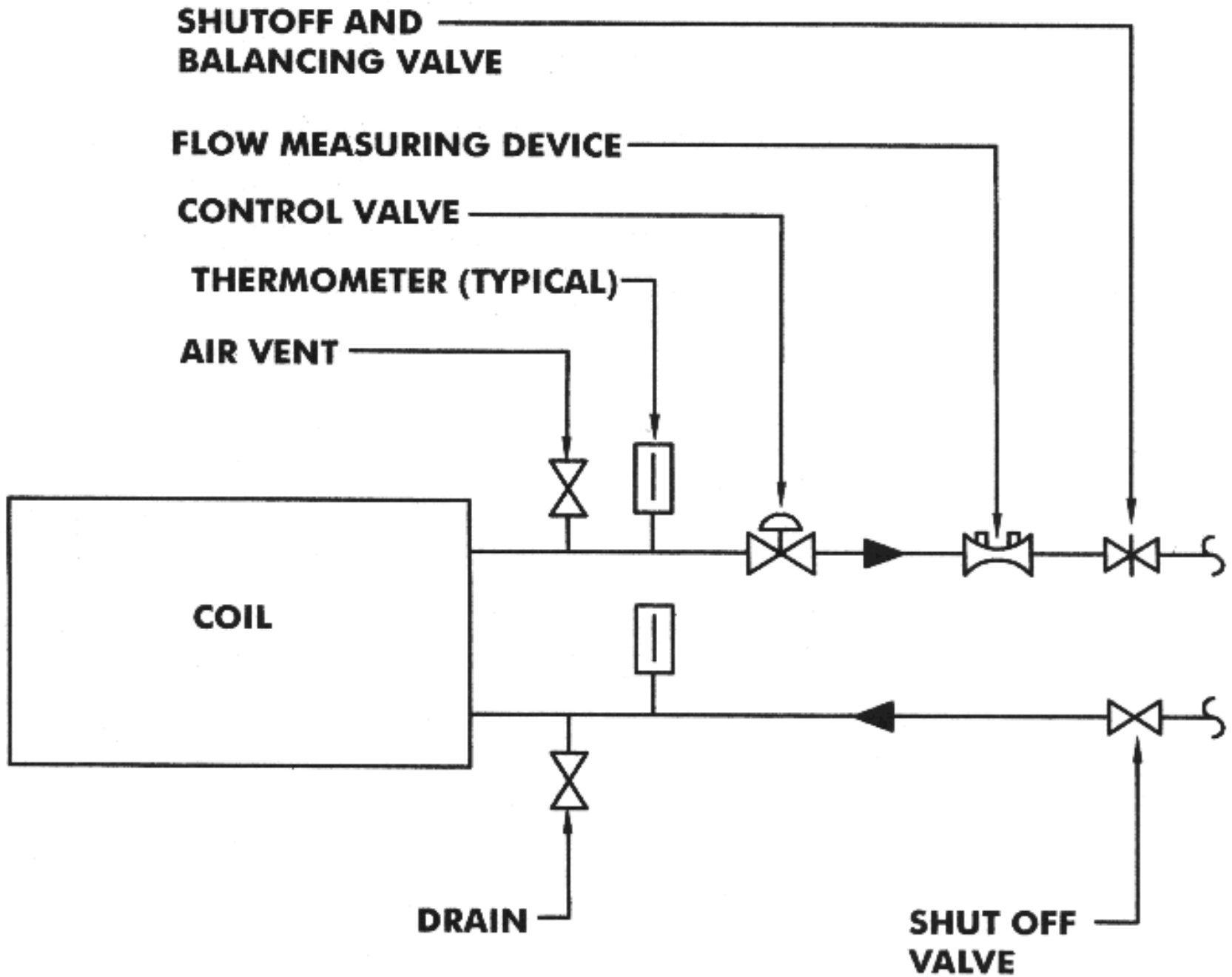


- When matching a valve to the hydronic system, ask yourselves the following questions:
 - What is the piping arrangement and size?
 - Does the application require two-position control or proportional control?
 - Does the application require a normally open or normally closed valve?
 - Should the actuator be direct acting or reverse acting?
 - Is tight shut-off necessary?
 - What differential pressure does the valve have to close against?
 - How much actuator close-off force is required?
 - What type of medium is being controlled?
 - What are the temperature and pressure ranges of the medium?
 - What is the pressure drop across the valve? Is it high enough?

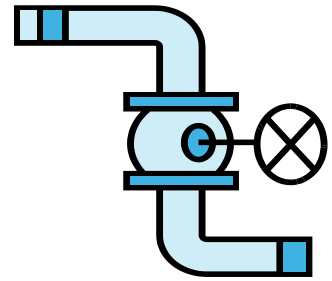
Control Valves



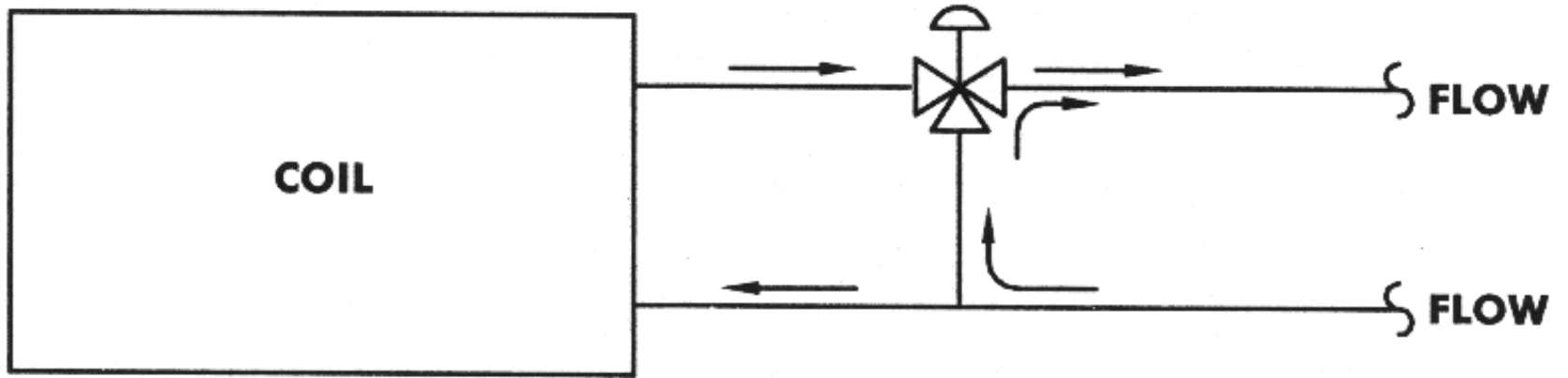
- ▶ Location of control valves
 - At the outlet on the top of cooling/heating coils
 - Avoid coil starvation from water flow (lower pressure)
 - Flow of water from the bottom to the top (avoid air bubble)
 - Flow measuring & balancing device should be placed after the control valve
 - Provide a means of shut-off to allow a proper means for servicing



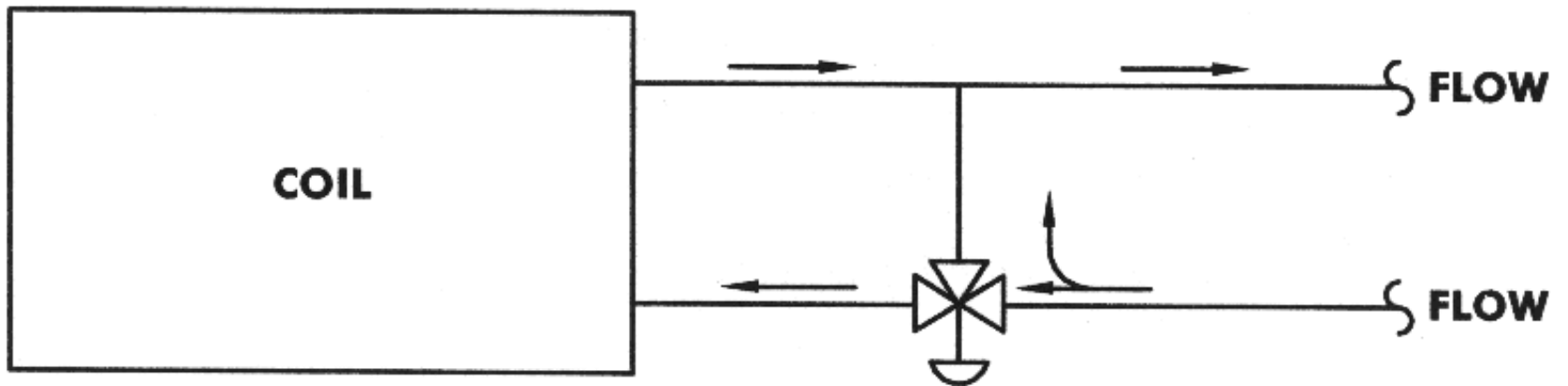
Control Valves



- ▶ Mixing & diverting three-way control valves
 - For HVAC applications, three-way control valves are typical mixing
 - Diverting three-way control valves may be used for industrial applications (more expensive)

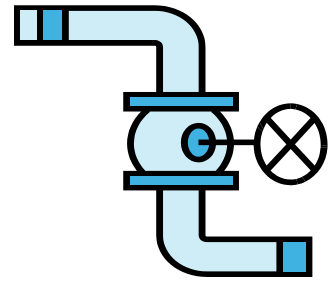


MIXING THREE-WAY CONTROL VALVE

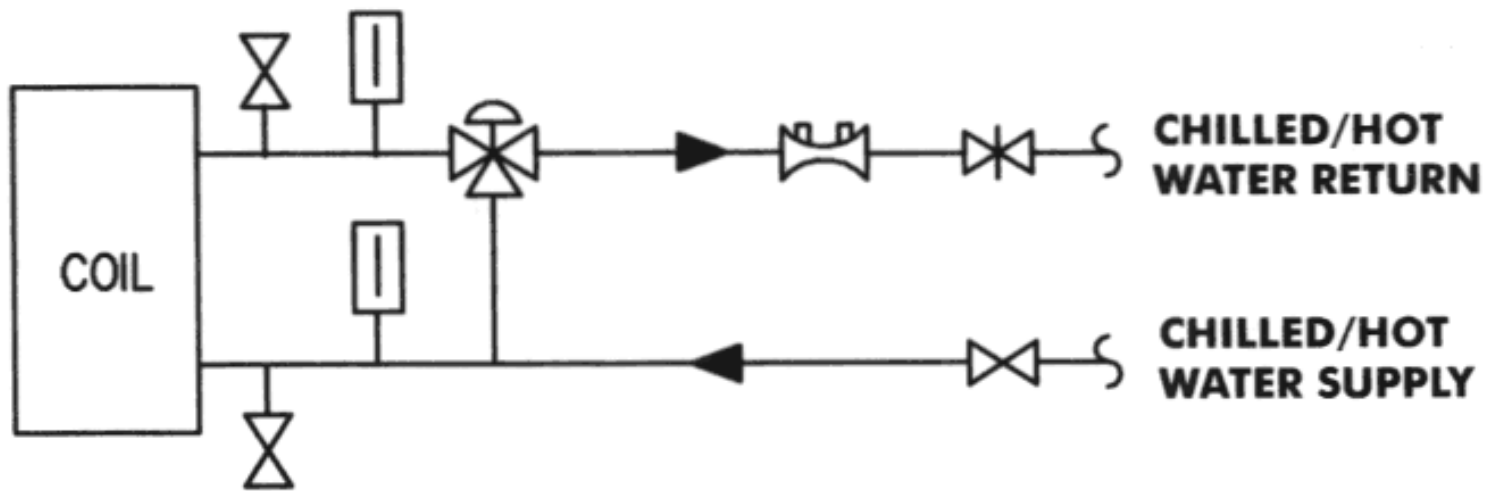


DIVERTING THREE-WAY CONTROL VALVE

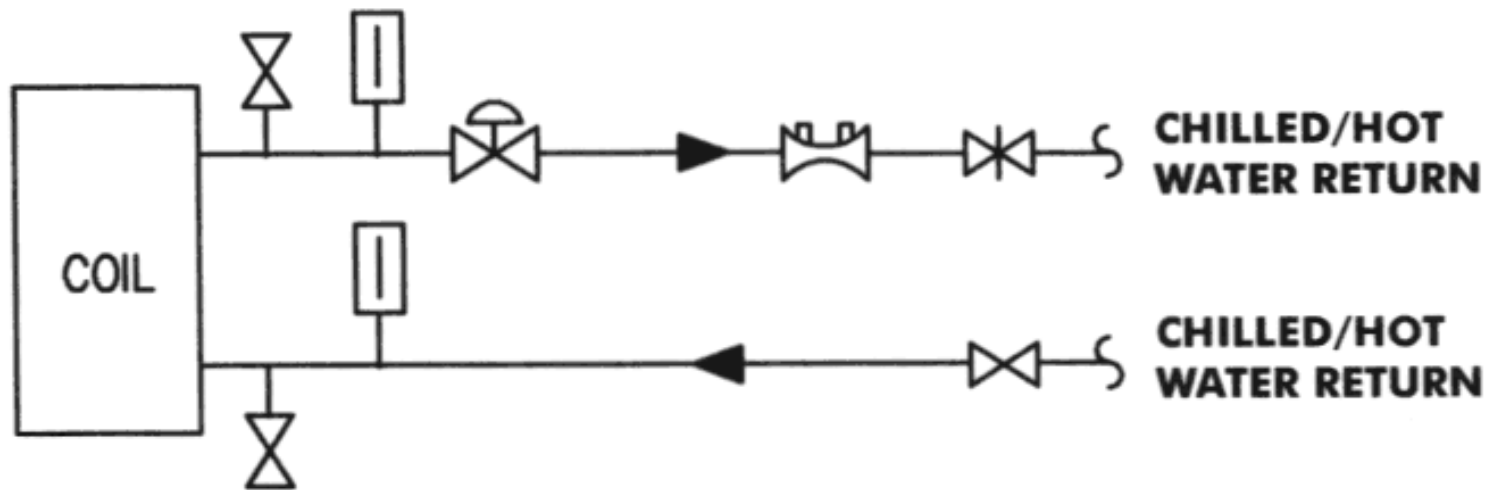
Control Valves



- ▶ Two-way vs. three-way control valves
 - Two-way: for variable flow
 - More sensitive to high differential pressure
 - Harder to close off against line pressure
 - Three-way: for constant flow
 - Actuator does not need to be as powerful

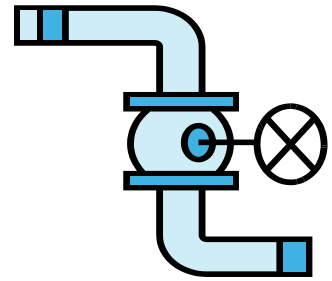


CHILLED/HOT WATER PIPING WITH THREE-WAY CONTROL VALVE



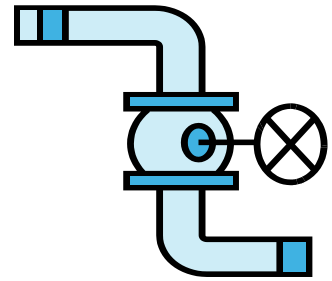
CHILLED/HOT WATER PIPING WITH TWO-WAY CONTROL VALVE

Control Valves



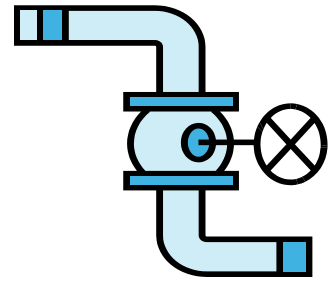
- ▶ Sizing of control valves must know:
 - Medium that the valves control, e.g. water, steam
 - Inlet pressure under max. load demand
 - Maximum allowable differential pressure across valve (close-off pressure)
 - Valve size (when the required capacity is not available, select the next closest & calculate the resulting valve pressure differential to verify acceptable performance)
- ▶ What are the effects of undersized or oversized control valves?

Control Valves



- ▶ How to size control valves
 - Many methods/techniques for sizing modulating valves in HVAC systems
 - Goal: adequate pressure drop across the valve to assure proper modulating w/o **undersizing** it
 - **Undersizing** means insufficient pressure drop by the valve comparable to the coil pressure drop
 - A common guideline will be the pressure drop should be 50–70% of the minimum difference between the supply and return main pressure at design operating conditions

Control Valves



▶ Water valve sizing example:

- A two-way linear valve is needed to control flow of 7°C chilled water to a cooling coil. The coil manufacturer has specified an eight-row coil having a water flow pressure drop of 22 kPa. Further, specifications say that the coil will produce 13°C leaving air with a water flow of 3.32 m³/h. Supply main is maintained at 275 kPa, return is at 200 kPa. Select required capacity index (Kv) of the valve.

Answer:

Use the water valve K_V formula to determine capacity index for Valve V1 as follows:

$$K_V = Q \sqrt{\frac{\rho}{\Delta P \cdot 10}}$$

Where:

Q = Flow of fluid in Cubic meters per hour required is 3.32 m³/h.

ρ = Density of water is 1000.

ΔP = Pressure drop across the valve. The difference between the supply and return is 75 kPa. 50% to 70% x 75 kPa = 37.5 to 52.7 kPa. Use 40 kPa for the correct valve pressure drop. Note that 40 kPa is also greater than the coil pressure drop of 22 kPa.

Answer: (Cont'd)

Substituting:

$$K_v = 3.32 \sqrt{\frac{1000}{40 \cdot 10}} = 5.2$$

Select a linear valve providing close control with a capacity index of 5.4 and meeting the required pressure and temperature ratings.

Hardware Components in BAS/BEMS

»» Control Dampers

Control Dampers



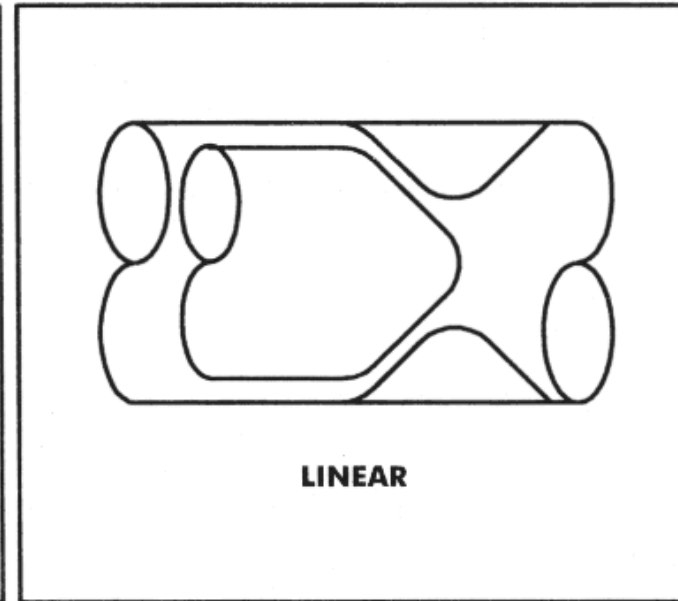
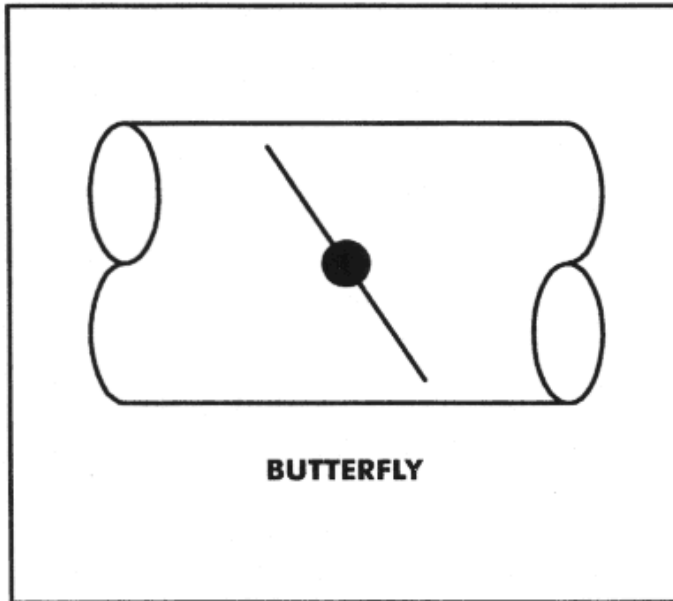
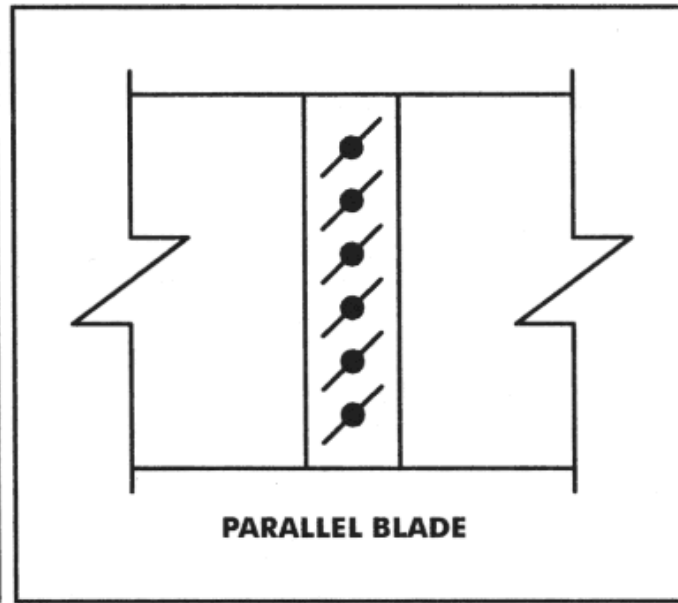
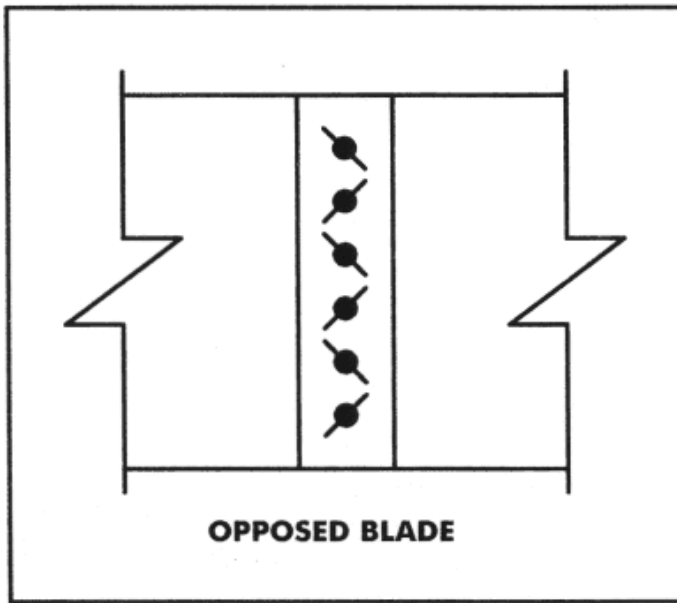
▶ Control dampers

- For controlling air distribution, e.g.
 - Fire damper: A thermally actuated damper arranged to automatically restrict the passage of fire and/or heat at a point where an opening violates the integrity of a fire partition or floor
 - Smoke damper: A damper arranged to control passage of smoke through an opening or a duct
 - Volume control damper (VCD): A device used to regulate the flow of air in an HVAC system

Control Dampers

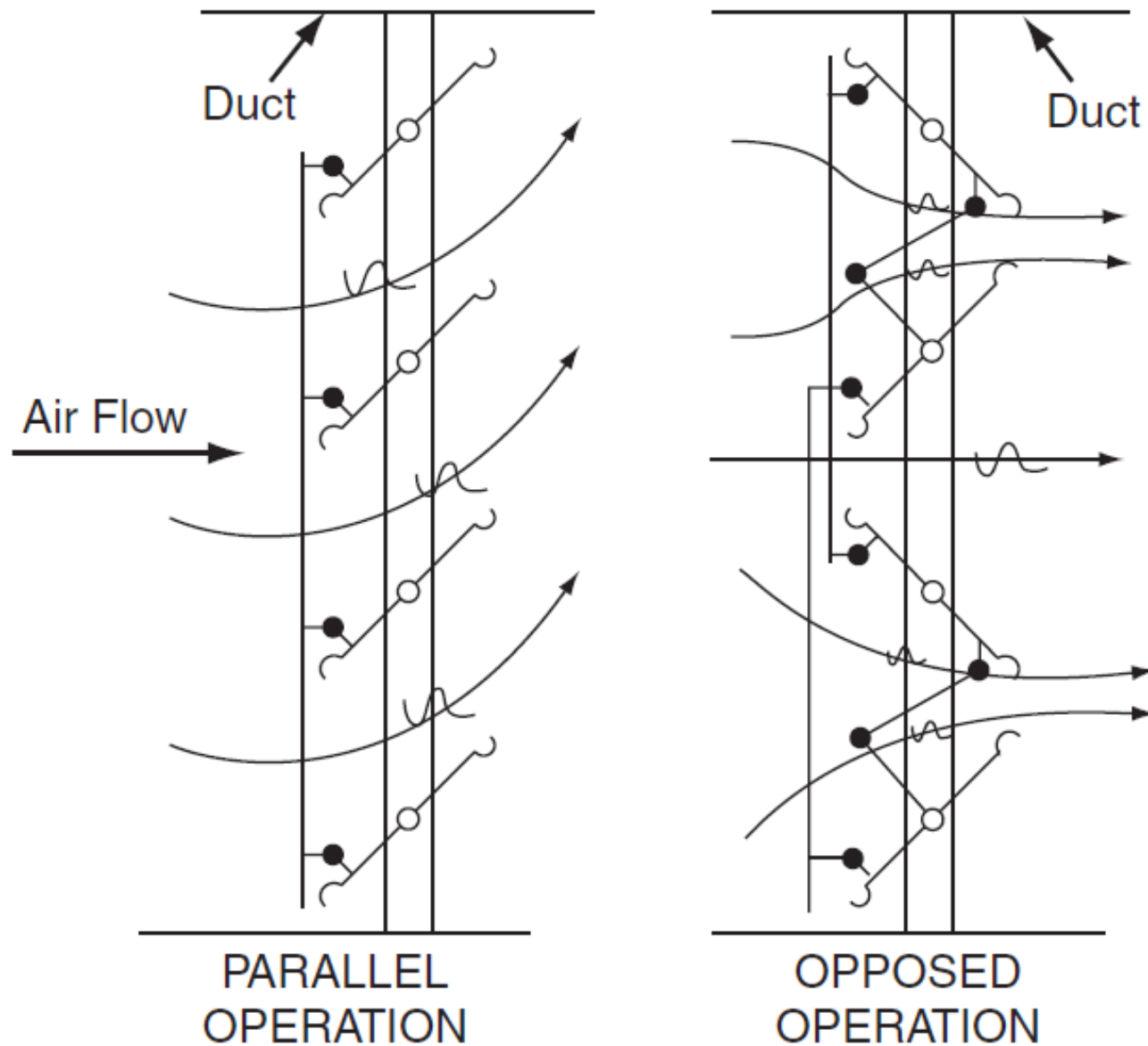


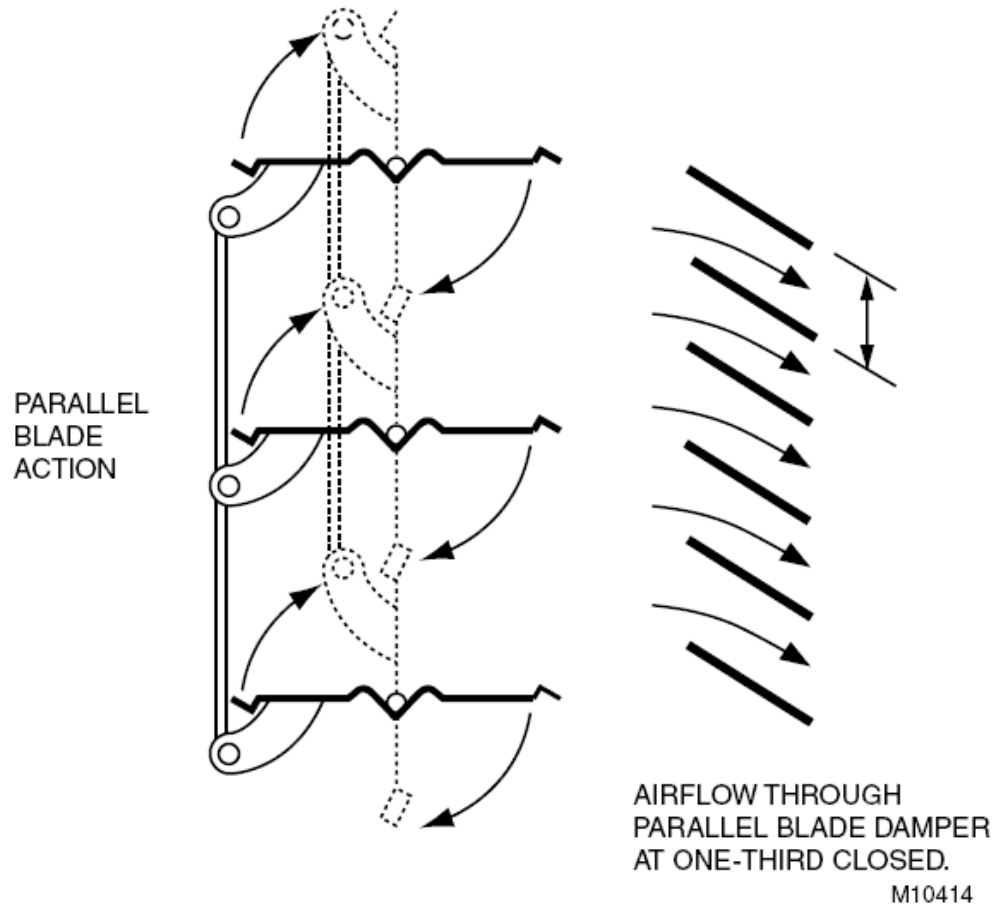
- ▶ Common types:
 - Opposed blade dampers (e.g. in AHU)
 - Parallel blade dampers
 - Butterfly dampers (e.g. in VAV box)
 - Linear air valves (e.g. in fume hood)
 - Specialty dampers



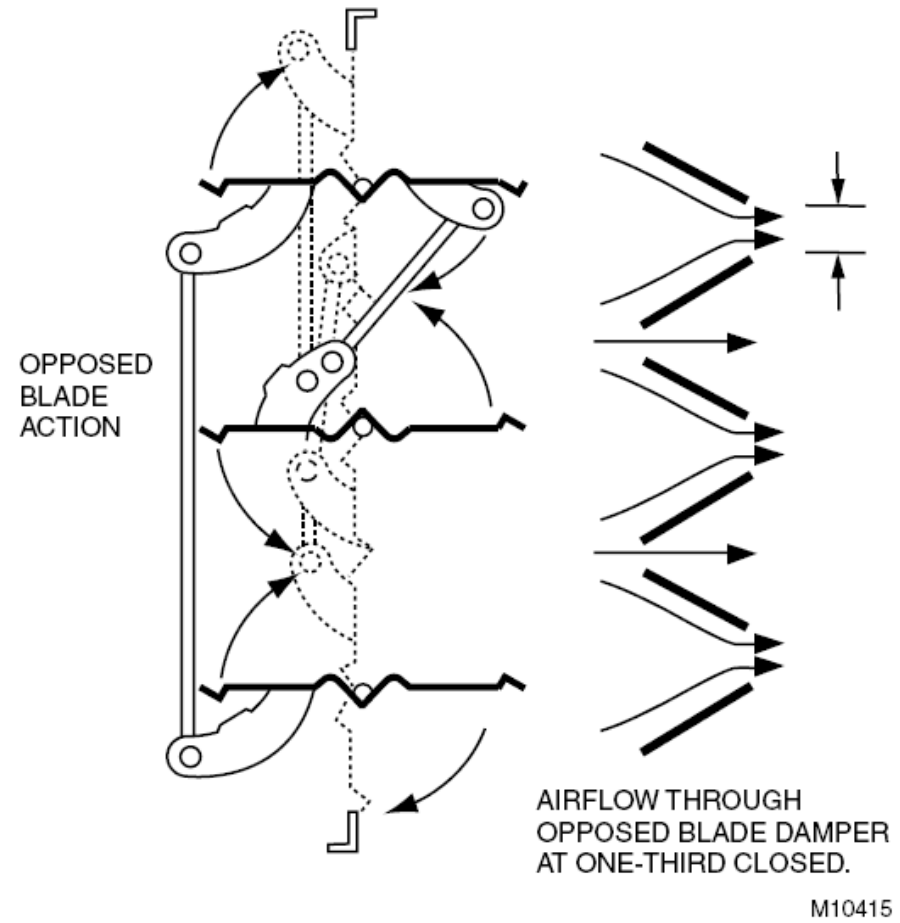
Four types of control dampers

Flow pattern through dampers



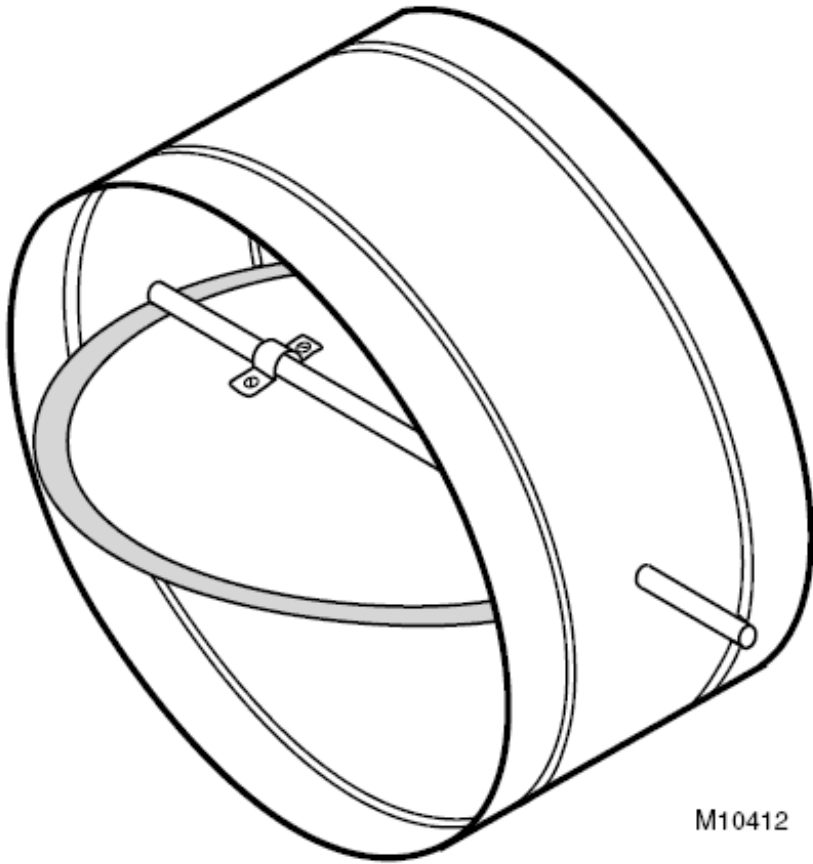


Parallel blade damper



Opposed blade damper

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

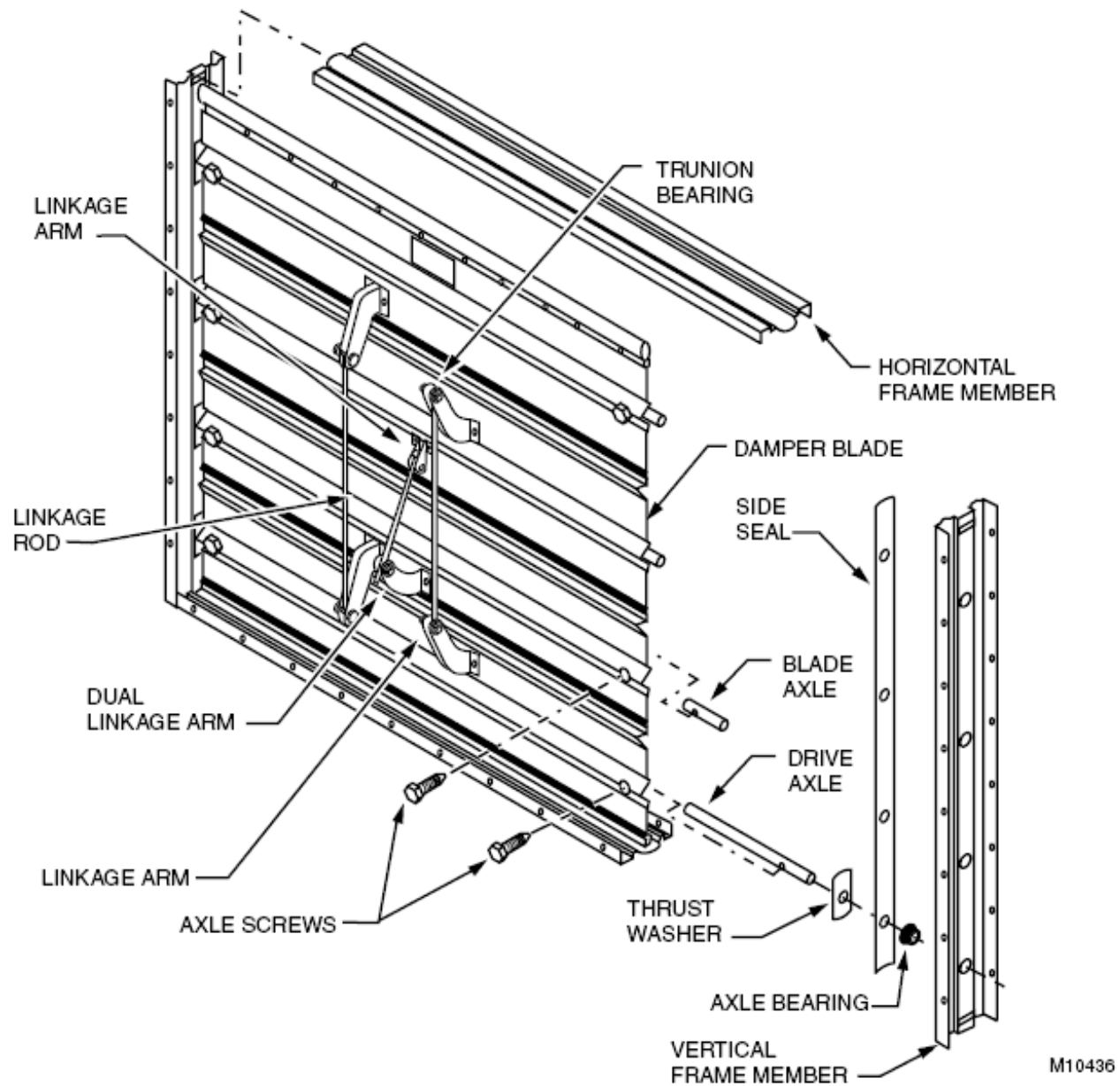


M10412

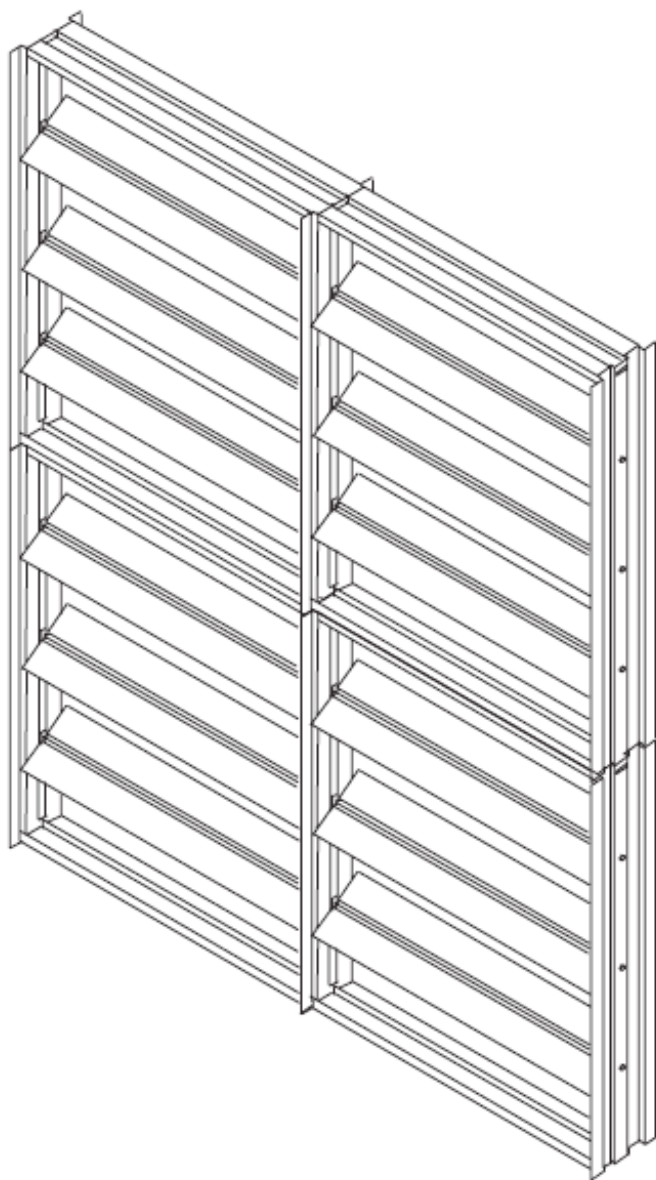
Round damper



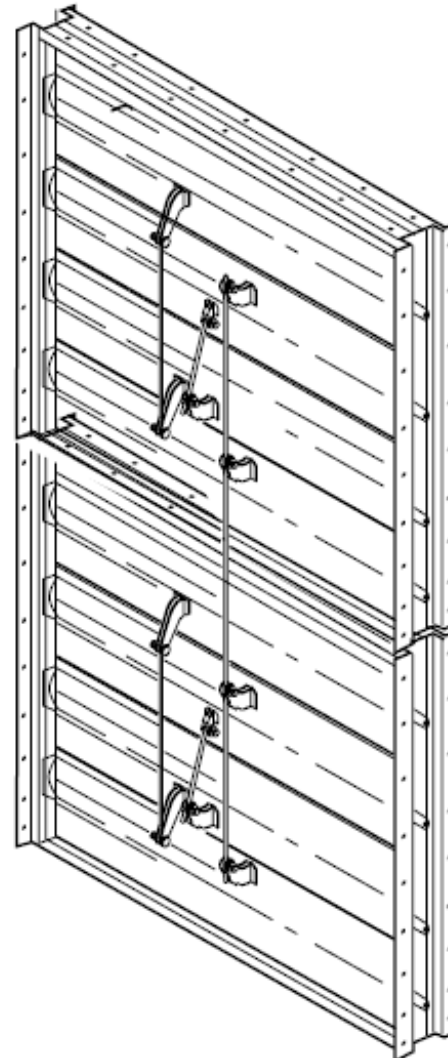
Volume control damper
(opposed blade)



Typical (opposed blade) damper construction



M10417



M10411

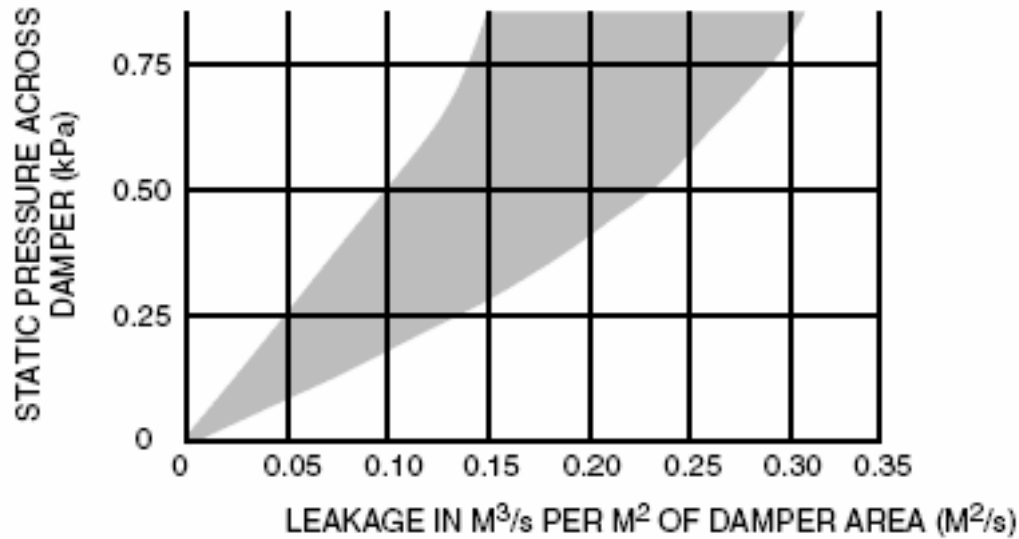
Multiple section damper assembly

Damper Performance



- Leakage ratings
 - For typical dampers, leakage increases more significantly with the number of blades than with the length of the blades
- Torque requirements
 - Operating and close-off torque requirements
 - Closing torque: the torque required to force the blades together sufficiently to achieve minimum possible leakage
 - Dynamic torque: required to overcome the effect of high velocity airflow over the blades

TORQUE APPLIED TO DAMPER = 6 Nm/m^2 OF DAMPER AREA

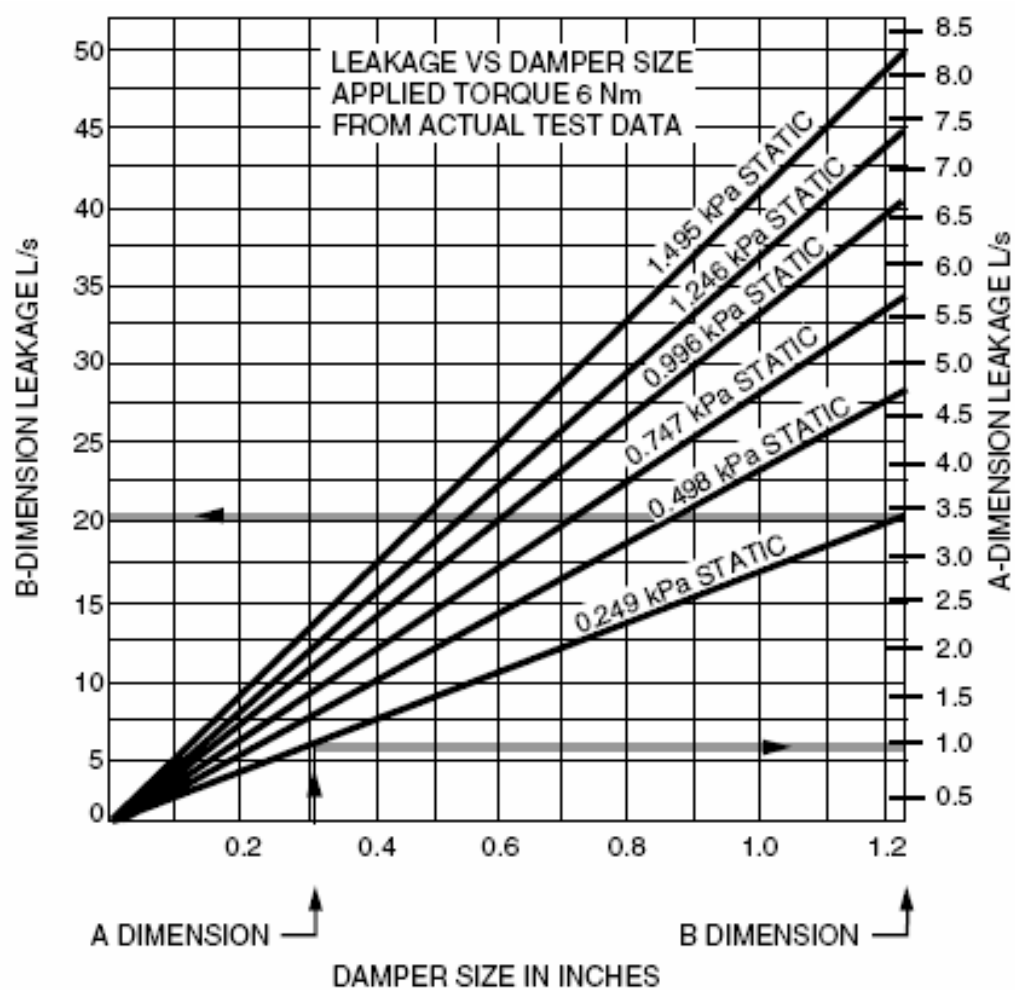


NOTE:

LEAKAGE OF A SPECIFIC DAMPER DEPENDS UPON THE HEIGHT AND WIDTH RELATIONSHIP AS WELL AS THE AREA. THE SHADED AREA SHOWS THE RANGE OF LEAKAGE FOR A GIVEN AREA.

M15302

Fig. 18. Graphic Presentation of Leakage Performance.



TOTAL LEAKAGE =
B-DIMENSION LEAKAGE + A-DIMENSION LEAKAGE
WHERE:
A-DIMENSION = OUTSIDE DIMENSION PARALLEL TO
THE DAMPER BLADES
B-DIMENSION = OUTSIDE DIMENSION PERPENDICULAR
TO THE DAMPER BLADES

C3201

Fig. 19. Low Leakage Dampers.

Damper Performance



- Velocity ratings
 - A higher velocity rating of one damper compared to another indicates the former damper has stiffer blade and linkage design and that the bearings may also be capable of higher loads
- Temperature ratings
 - Maximum temperature the damper will function normally
 - Bearings and seals are constructed of heat resistant materials if high temperature rating.
- Pressure ratings
 - Maximum static pressure differential which may be applied across the assembly when the blades are closed
- UL classification (fire/smoke)
 - UL 555S (Standard for Leakage Rated Dampers for Use in Smoke Control Systems)

Table 2. Maximum Static Pressure Differential

Damper Type	Pressure Differential (kPa)
Standard Damper	0.75
Standard and High Temperature, Low Leakage Damper	1.50
Low Static, Low Leakage Damper	0.50

Table 3. Maximum Static Pressure Differential Capability

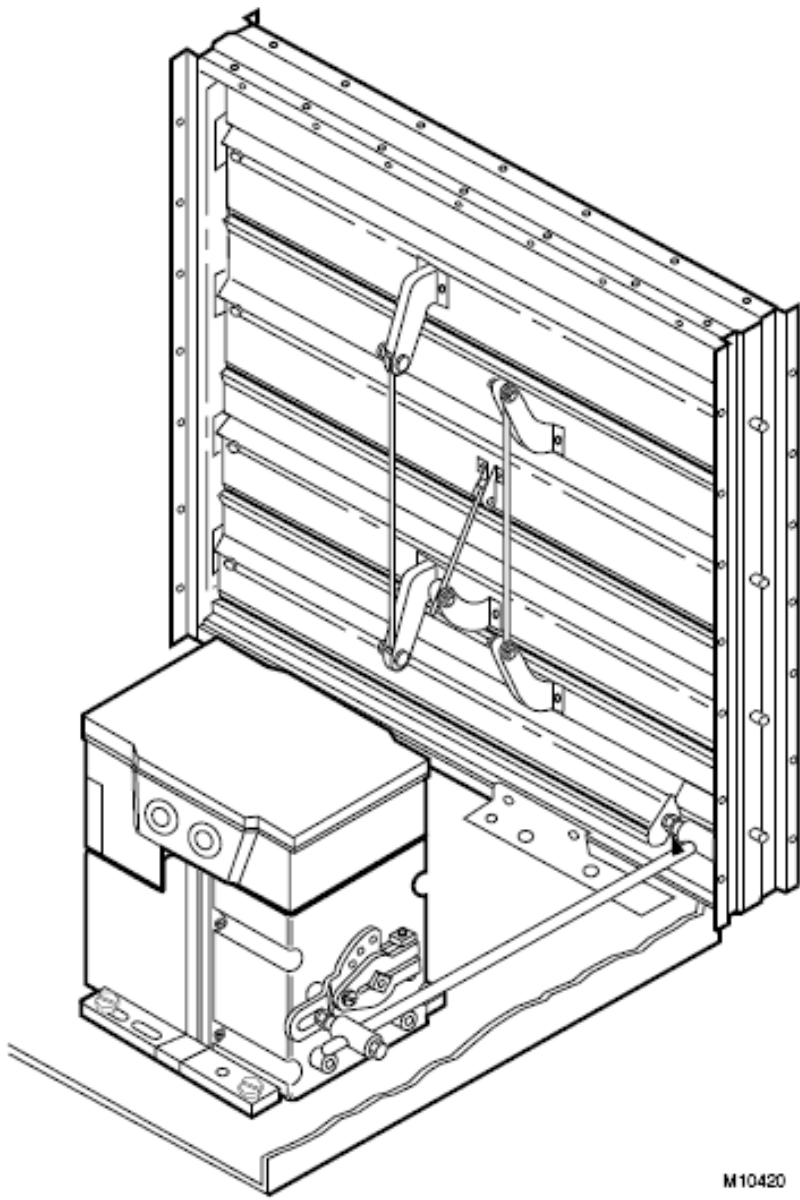
Damper Length (mm)	Max Close-Off Static (kPa)
305	2.0
610	2.0
915	1.5
1220	1.0

Control Dampers

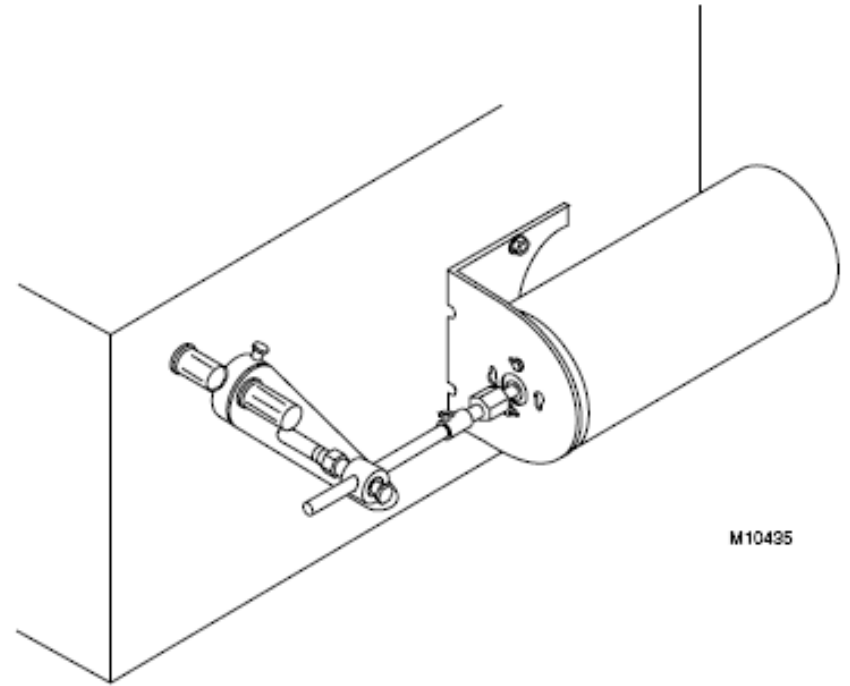


- ▶ Application environment
 - Velocity (higher forces with higher velocity)
 - Static pressure
 - Temperature
 - Corrosion
 - Turbulence

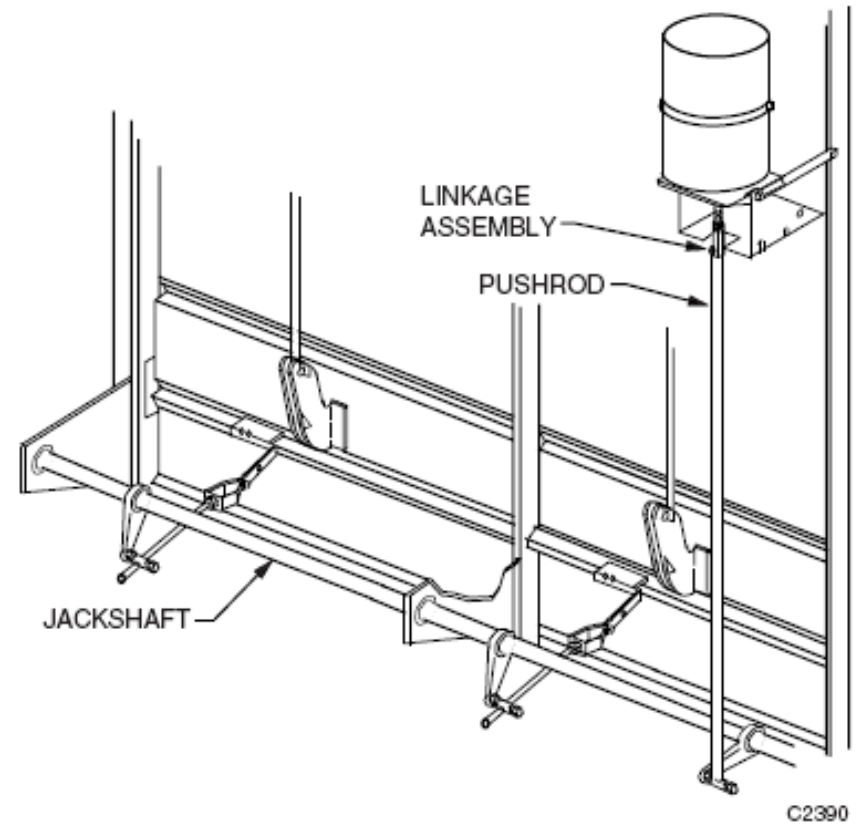
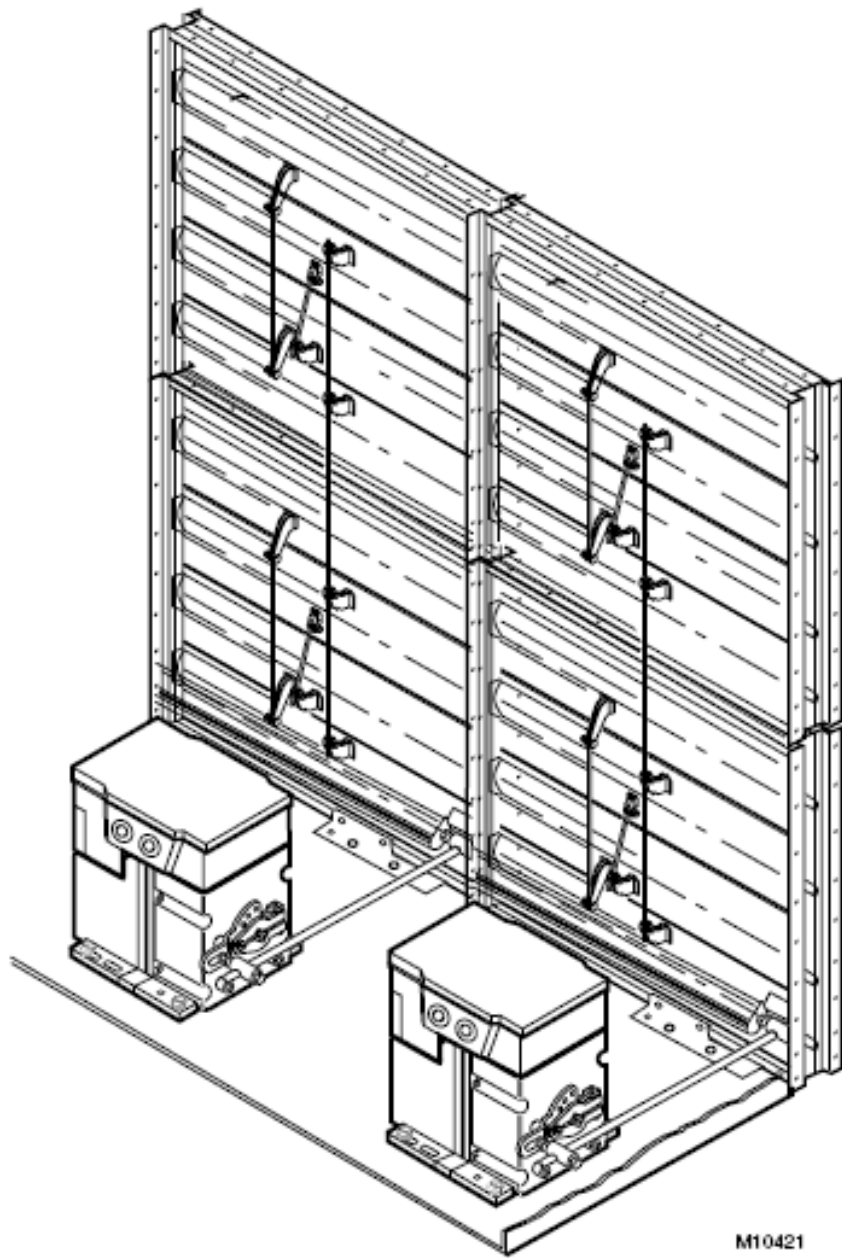
- ▶ Actuators and linkages



Internally mounted electric actuator



Externally mounted
pneumatic actuator



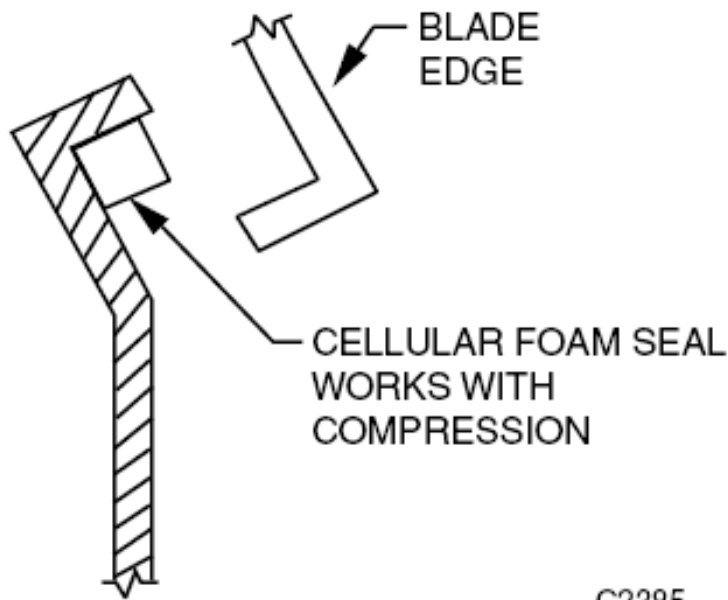
Damper jackshaft application

Control of a multiple section damper

Control Dampers

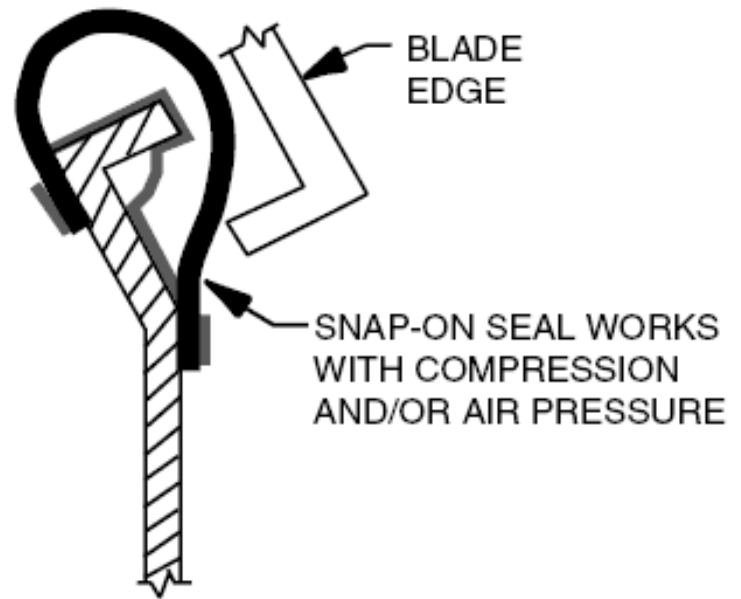


- ▶ Damper leakage
 - All dampers leak!
 - Damper leakage rate at specified pressure drop
 - Low leakage dampers are more expensive, have higher pressure drop & require larger actuators
 - Use them only where tight shut-off is necessary
- ▶ Sizing control damper actuator
 - Equation:
 - Required torque = (Area of damper) x (Rated torque)



C2385

Cellular foam blade edge seal



C2387

Snap-on blade edge seal

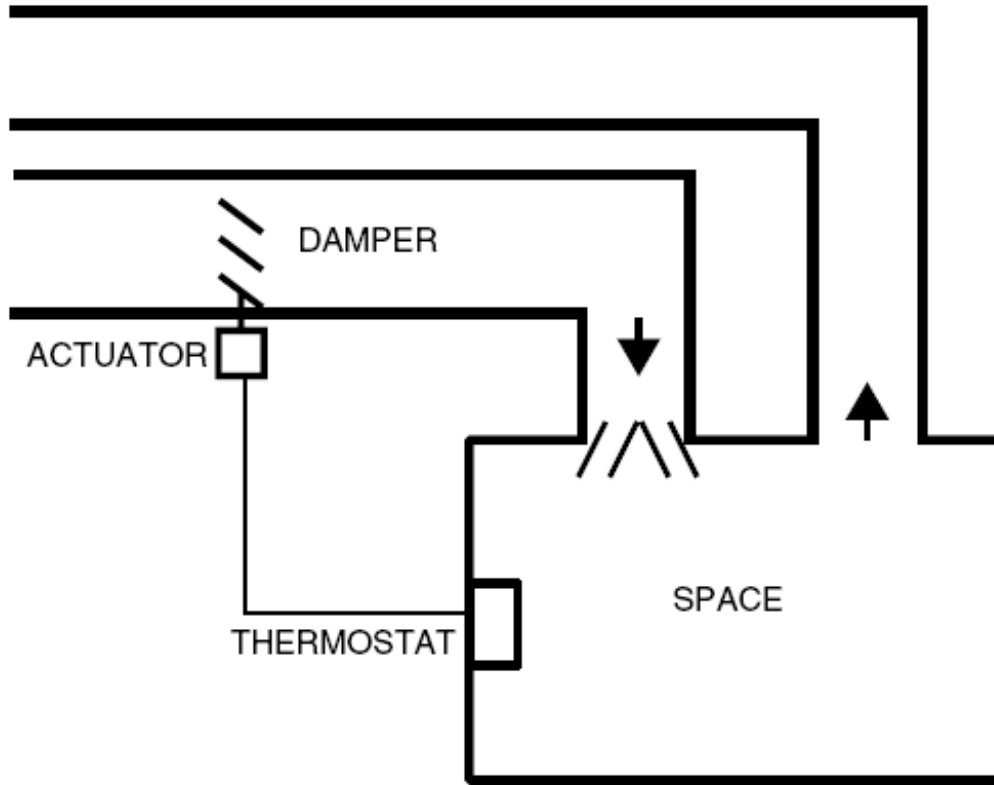
Examples of sealing methods for low-leakage dampers

Damper Sizing

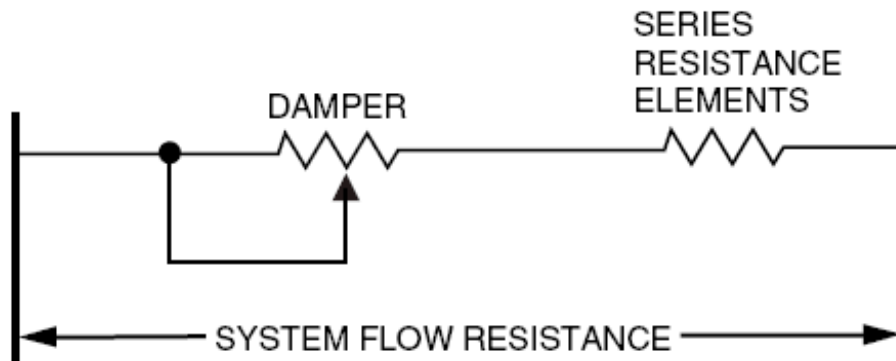


▶ Damper sizing

- Typically chosen based on duct size and convenience of location
- Proper selection and sizing provides the following benefits:
 - Lower installation cost (damper sizes are smaller)
 - Smaller actuators or a fewer number of them are required
 - Reduced energy costs (smaller damper, less overall leakage)
 - Improved control characteristics (rangeability) because the ratio of total damper flow to minimum controllable flow is increased
 - Improved operating characteristics (linearity)



Control loop for a damper system

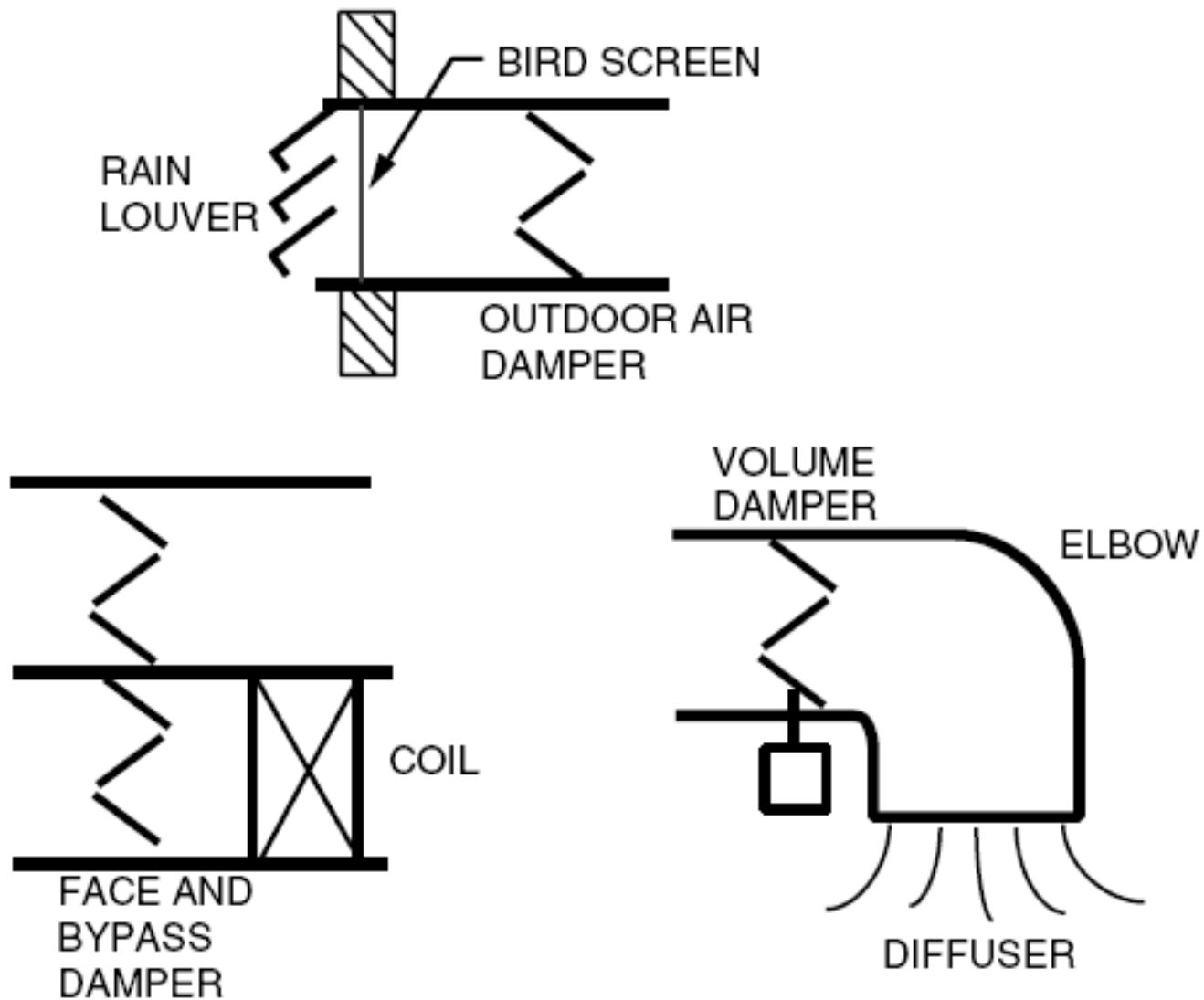


Resistance to airflow in actual system

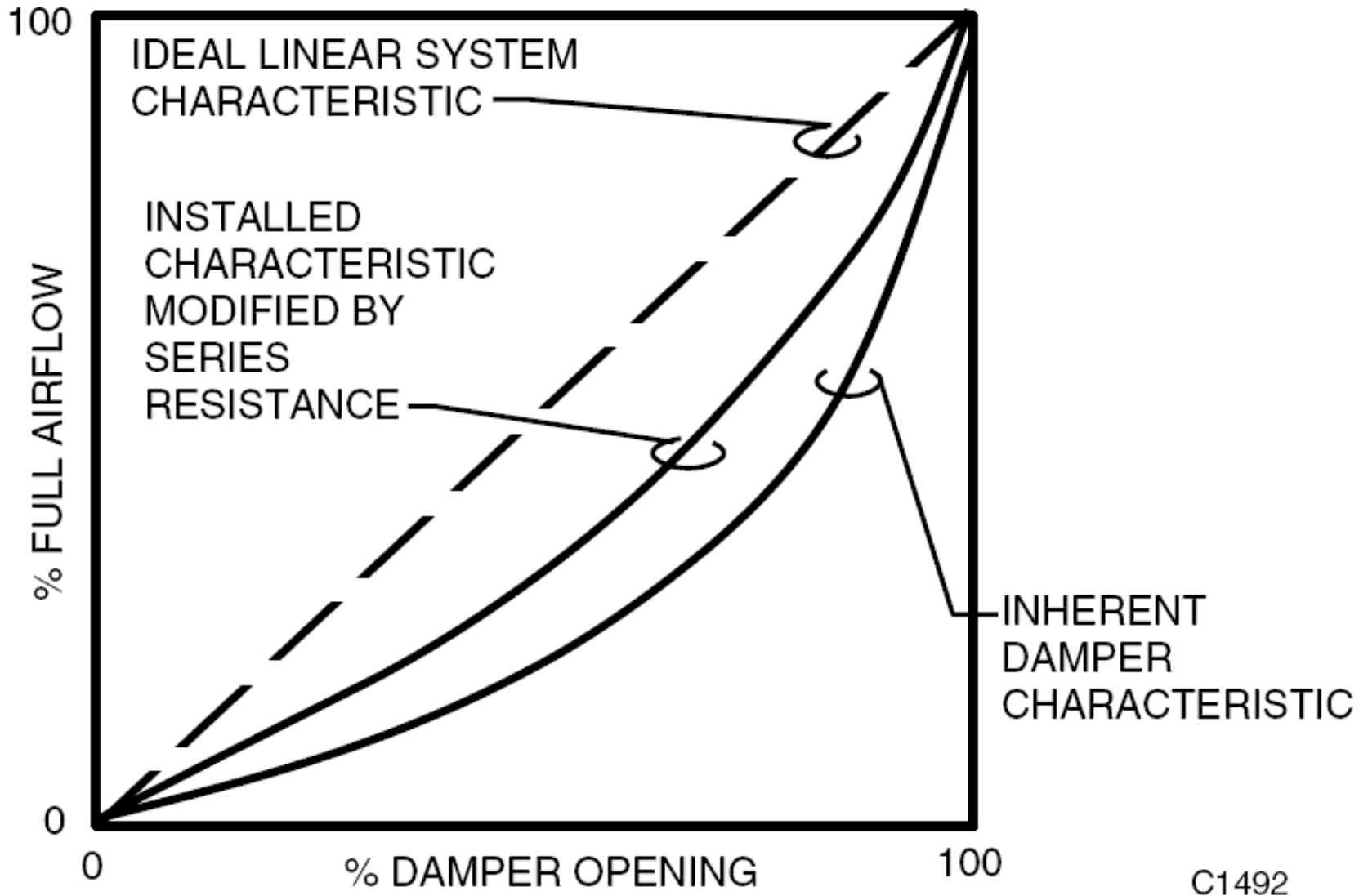
Control Dampers



- ▶ Damper characteristics
 - Inherent characteristics
 - Defined at a constant pressure drop with no series resistance (coils, filters, louvers, diffusers, or other items)
 - Installed characteristics
 - Determined by the ratio of series resistance elements to damper resistance
 - Series resistance elements such as duct resistance, coils, and louvers, cause the pressure drop to vary as the damper changes position



Examples of resistance to airflow



C1492

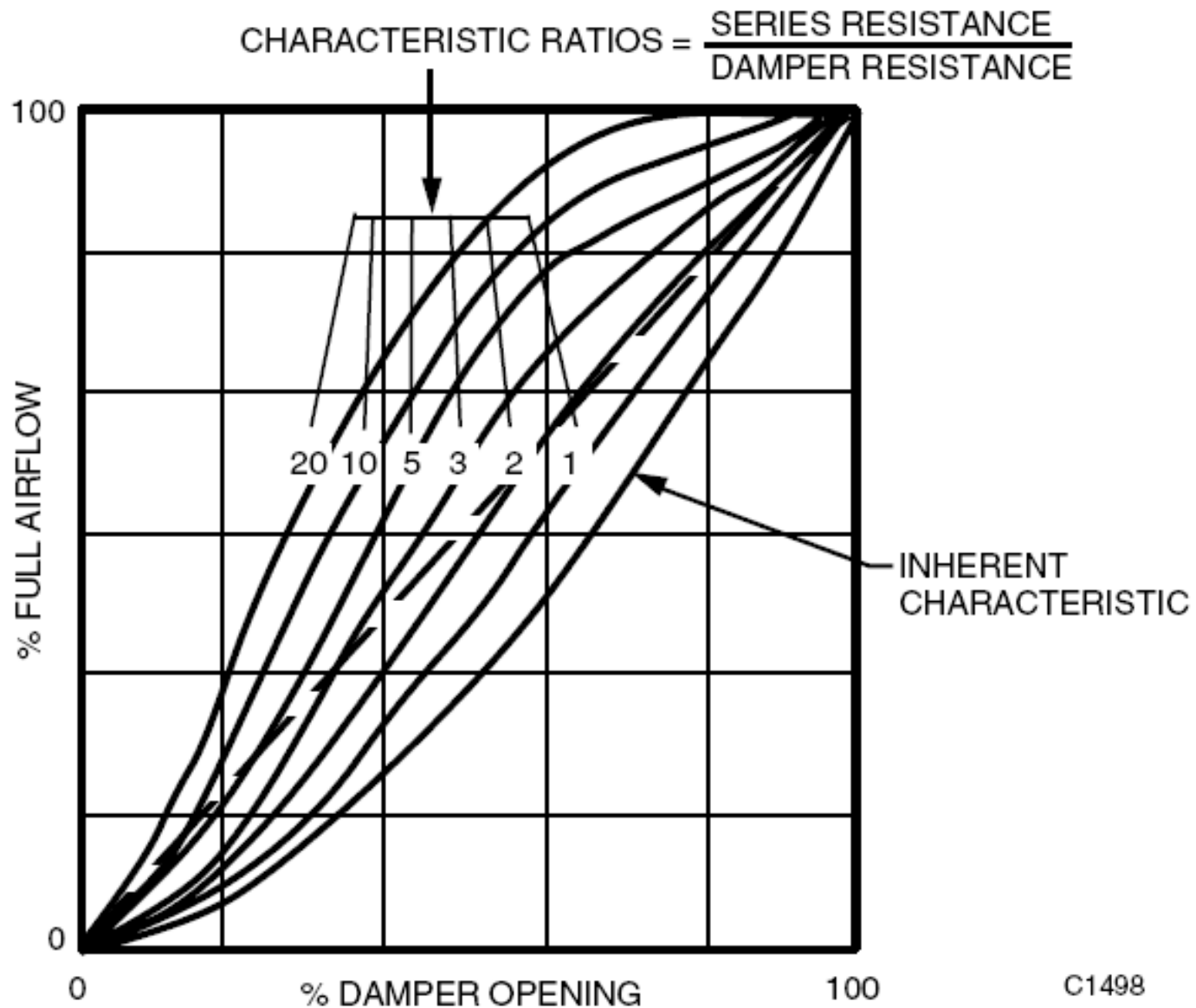
Installed versus inherent airflow characteristics for a damper

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

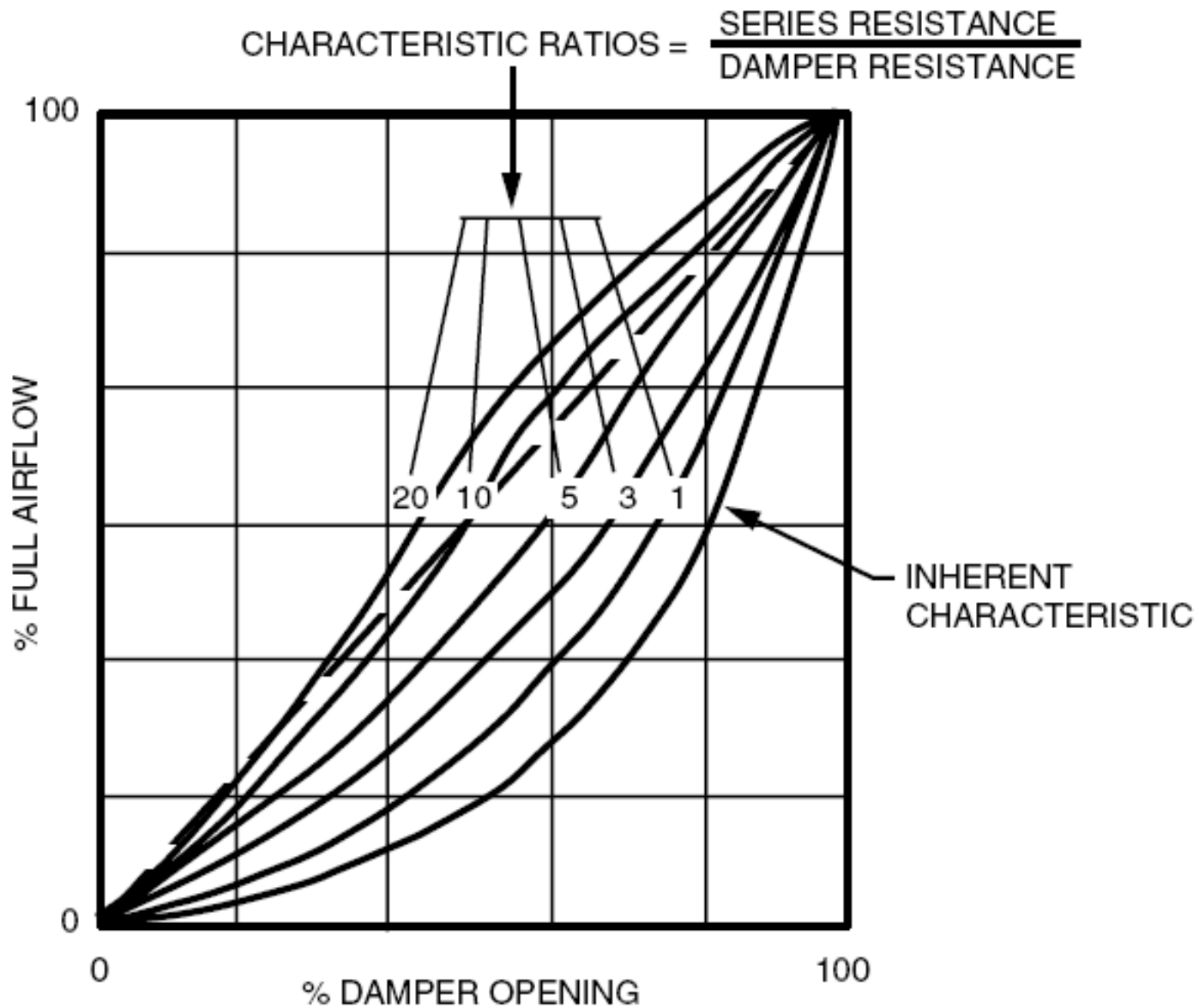
Control Dampers



- ▶ Damper characteristics (cont'd)
 - Characteristic Ratio
 - = series resistance / damper resistance
 - = total resistance / damper resistance - 1
 - Where Total resistance = damper resistance + series resistance
 - To achieve performance closest to the ideal linear flow characteristic, a characteristic ratio of 2.5 for parallel blade dampers and 10 for opposed blade dampers should be used (see previous figures)



Damper system characteristics of parallel blade dampers

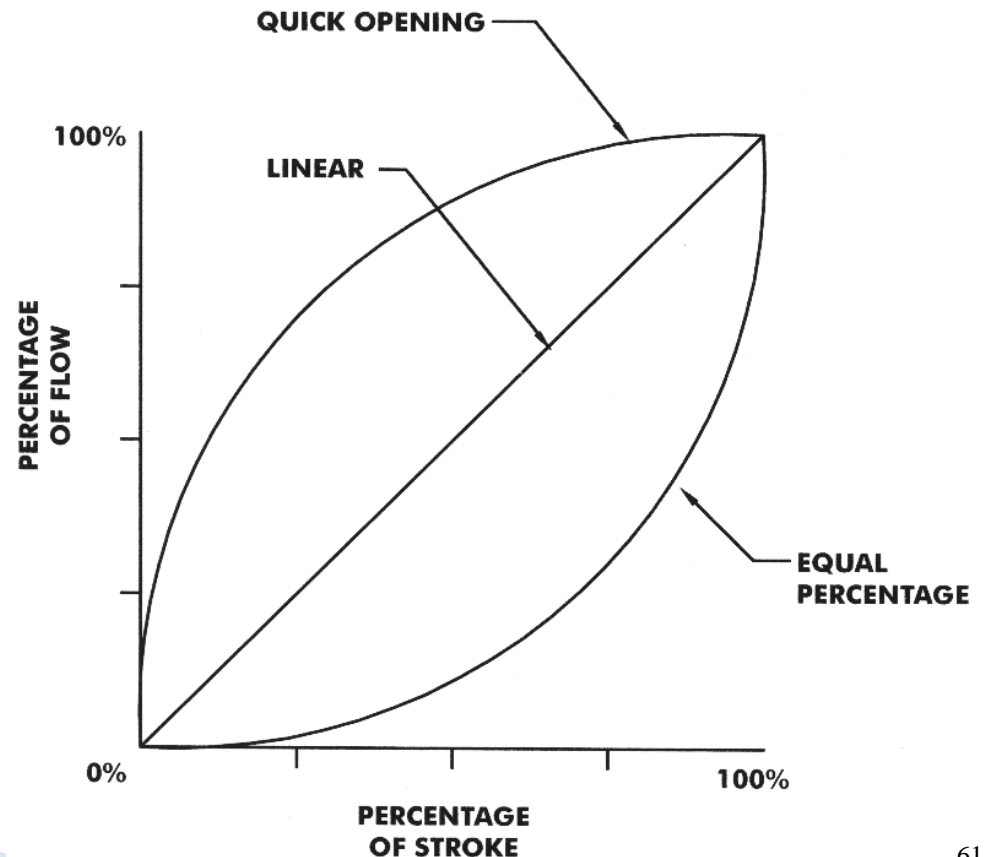


Damper system characteristics of opposed blade dampers

Control Dampers



- ▶ Control damper flow characteristics (similar to control valves)
 - Quick opening
 - Linear
 - Equal percentage

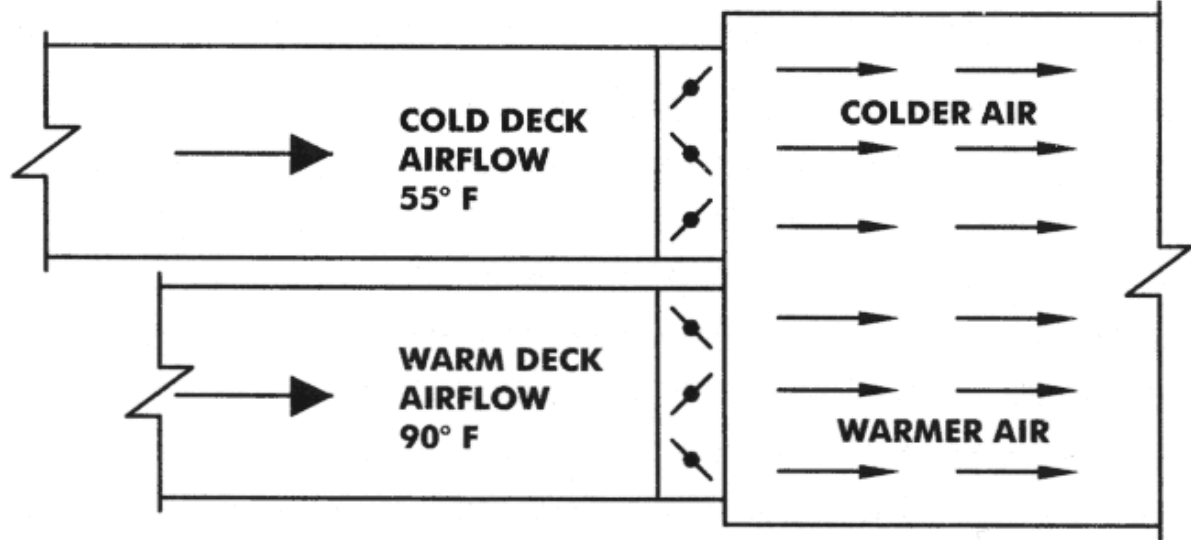


Control Dampers

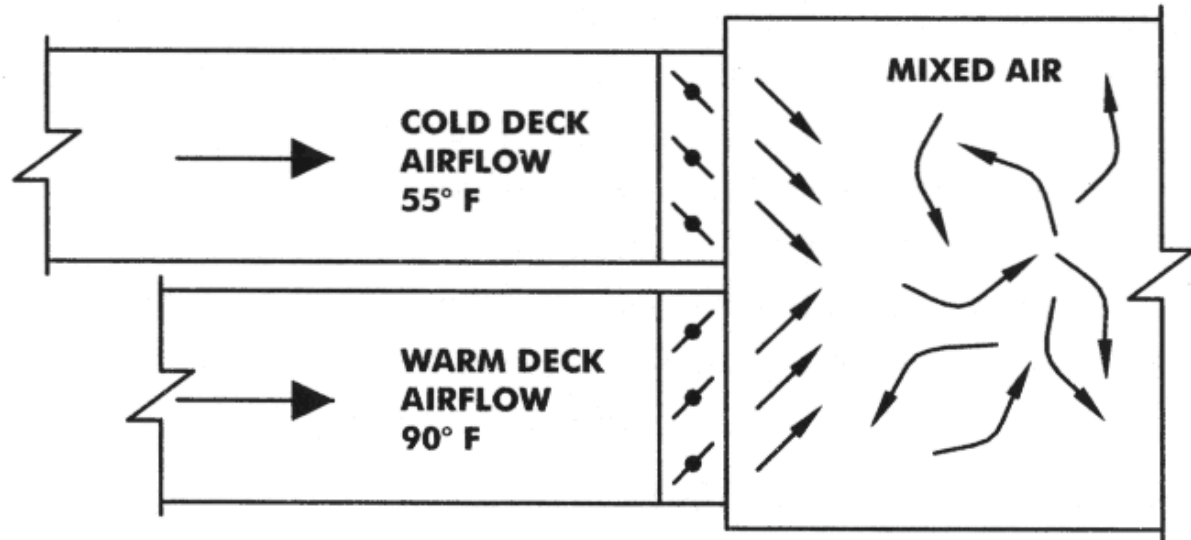


- ▶ Parallel blade damper
 - For two-position applications
 - Good for reducing air turbulence
 - Less expensive, but requires larger actuators

- ▶ Opposed blade damper
 - For volume control & airflow modulation
 - Greater pressure loss (better control)
 - Flow characteristics are more linear



OPPOSED BLADE DAMPERS



PARALLEL BLADE DAMPERS

Control Dampers

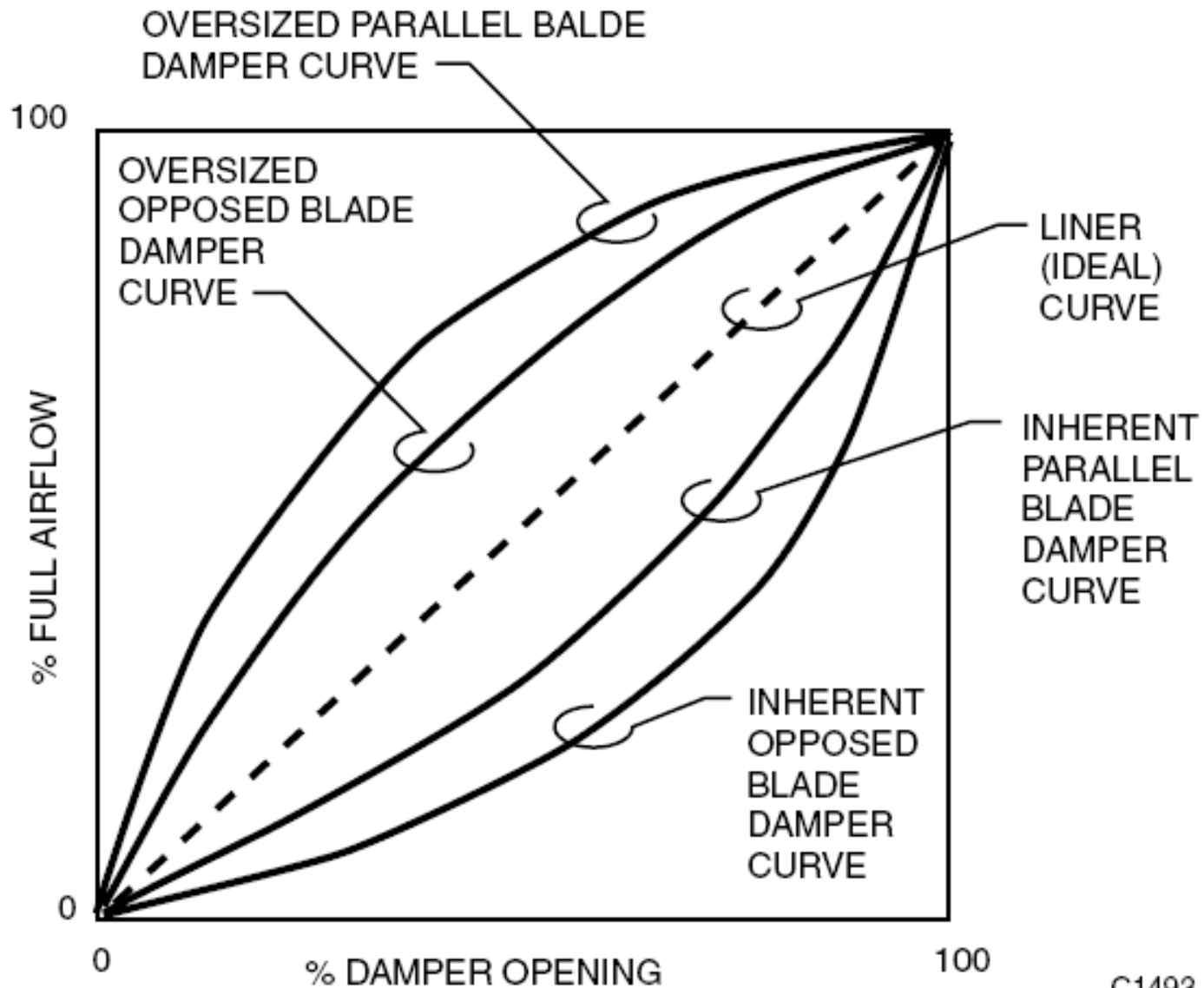


- ▶ Sizing control damper
 - Various methods recommended by manufacturers
 - Similar to control valves
 - The greater the pressure drop, the better the modulation
 - Modulating control dampers are sized for a face velocity of about 5–10 m/s
 - Proper sizing of dampers requires
 - Detailed examination of the entire system
 - A pressure drop evaluation of various components
 - Noise, vibration, & other circumstances

Control Dampers

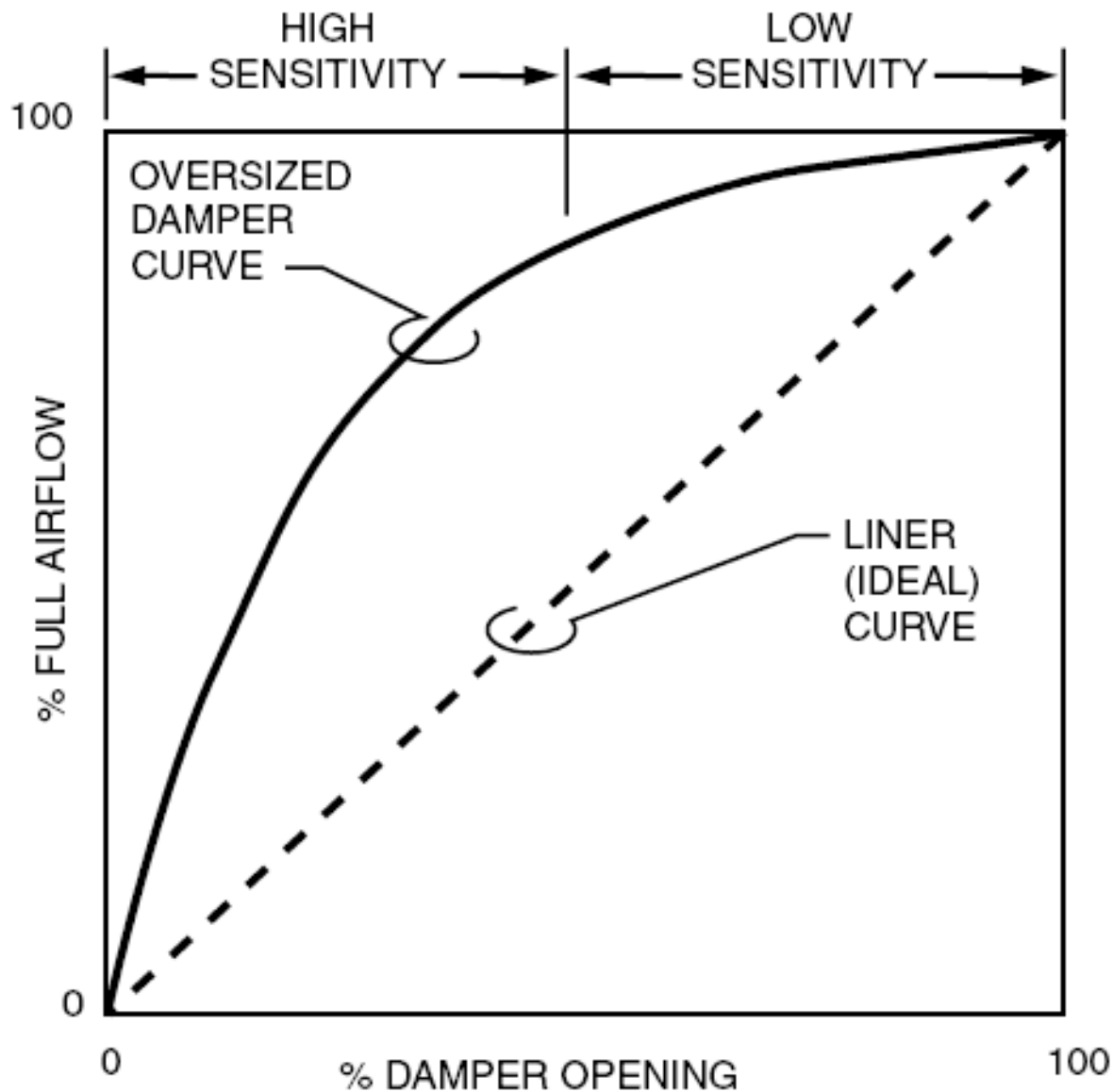


- ▶ Oversized Damper Characteristics
 - An oversized damper is one that has a characteristic ratio higher than 2.5 for parallel blade dampers or 10 for opposed blade dampers
 - As Characteristic Ratio
 - = series resistance / damper resistance
 - Higher characteristic ratios mean the series resistance dominates!



Comparison of oversized parallel versus oversized opposed blade dampers

C1493



Effects of oversized damper on system sensitivity

Damper Sizing

Table 4. Damper Sizing Procedure.

Step	Procedure
1	<p>Calculate the approach velocity:</p> $\text{Approach velocity (m/s)} = \frac{\text{Airflow (L/s)}}{\text{Duct Area (m}^2\text{)}} \times \frac{1 \text{ m}^3}{1000\text{L}}$
2	<p>Using the approach velocity from Step 1, calculate a correction factor:</p> $\text{Correction factor} = \frac{25.8}{[\text{Approach velocity (m/s)}]^2}$
3	<p>Calculate the pressure drop at 5.08 m/s:</p> <p>Pressure drop at 5.08 m/s = Pressure drop at approach velocity x correction factor (Step 2)</p>
4	<p>Calculate free area ratio^a:</p> <p>For pressure drops (Step 3) ≥ 57.1 Pa: Ratio = [1 + (0.0859 x pressure drop)]^{-0.3903}</p> <p>For pressure drops (Step 3) < 57.1 Pa: Ratio = [1 + (0.3214 x pressure drop)]^{-0.2340}</p>
5	<p>Calculate damper area (m²):</p> <p>For parallel blade dampers: Damper area (m²) = (Duct area (m²) x ratio, x 1.2897)^{0.9085}</p> <p>For opposed blade dampers: Damper area (m²) = (Duct area (m²) x ratio, x 1.4062)^{0.9217}</p>

^a The free area of a damper is the open portion of the damper through which air flows. The free area ratio is the open area in a damper divided by the total duct area.

Worked Example

A 1.485m² duct with an airflow of 9.44m³/s and a pressure drop of 14.9Pa across a parallel blade damper. Determine the size of the damper.

Table 5. Damper Sizing Example.

Step	Example
1	Approach velocity (m/s) = $\frac{9440 \text{ L/s}}{1.485 \text{ m}^2} \times \frac{1\text{m}^3}{1000\text{L}} = 6.35 \text{ m/s}$
2	Correction factor = $\frac{25.8}{16.35} = 0.64$
3	Pressure drop at 5 m/s = 14.9 Pa x 0.64 = 9.43 Pa
4	Free area ratio = $[1 + (0.3214 \times 9.43)]^{-0.2340}$ = $3.03^{-0.2340}$ = 0.772
5	Damper area (parallel blades) = $(1.485 \text{ m}^2 \times 0.772 \times 1.2897)^{0.9085}$ = $1.3828^{0.9085}$ = 1.342 m ²

Table 6. Damper Pressure Drop Calculation Procedures

Step	Procedure
1	a. Determine the number of sections required. The area of the damper must not exceed the maximum size for a single section. If the damper area exceeds the single section area: b. Divide the area of the damper, the area of the duct, and the airflow by the number of damper sections. c. Use the values from Step b in the following Steps.
2	Calculate the free area ratio ^a : For parallel blade dampers, the free area ratio is found: $\text{Ratio} = (0.0798 \times \text{damper area m}^2)^{0.1007} \times \frac{\text{Damper area (m}^2\text{)}}{\text{Duct area (m}^2\text{)}}$ For opposed blade dampers, the free area ratio is found: $\text{Ratio} = (0.0180 \times \text{damper area m}^2)^{0.0849} \times \frac{\text{Damper area (m}^2\text{)}}{\text{Duct area (m}^2\text{)}}$
3	Using the ratio from Step 1, calculate the pressure drop at 5.08 m/s. For ratios ≤ 0.5 : $\text{Pressure drop (Pa)} = -11.64 \times (1 - \text{ratio})^{-2.562}$ For ratios > 0.5 : $\text{Pressure drop (Pa)} = -3.114 \times (1 - \text{ratio})^{-4.274}$
4	Calculate the approach velocity: $\text{Approach velocity (m}^3\text{/s)} = \frac{\text{Airflow (m}^3\text{/s)}}{\text{Duct Area (m}^2\text{)}}$
5	Using the approach velocity from Step 3, calculate a correction factor: $\text{Correction factor} = \frac{25.8}{[\text{Approach velocity (m/s)}]^2}$
6	Calculate the pressure drop across the damper: $\text{Pressure drop (Pa)} = \frac{\text{Pressure drop (Pa) at 5.08 m/s (Step 2)}}{\text{Correction factor (Step 4)}}$

^a The free area of a damper is the open portion of the damper through which air flows. The free area ratio is the open area in a damper divided by the total duct area.

Worked Example

A 1.50m² parallel blade damper in a 1.69m² duct with an airflow 9.45m³/s. Determine the pressure drop across the damper.

Table 7. Pressure Drop Calculation Example.

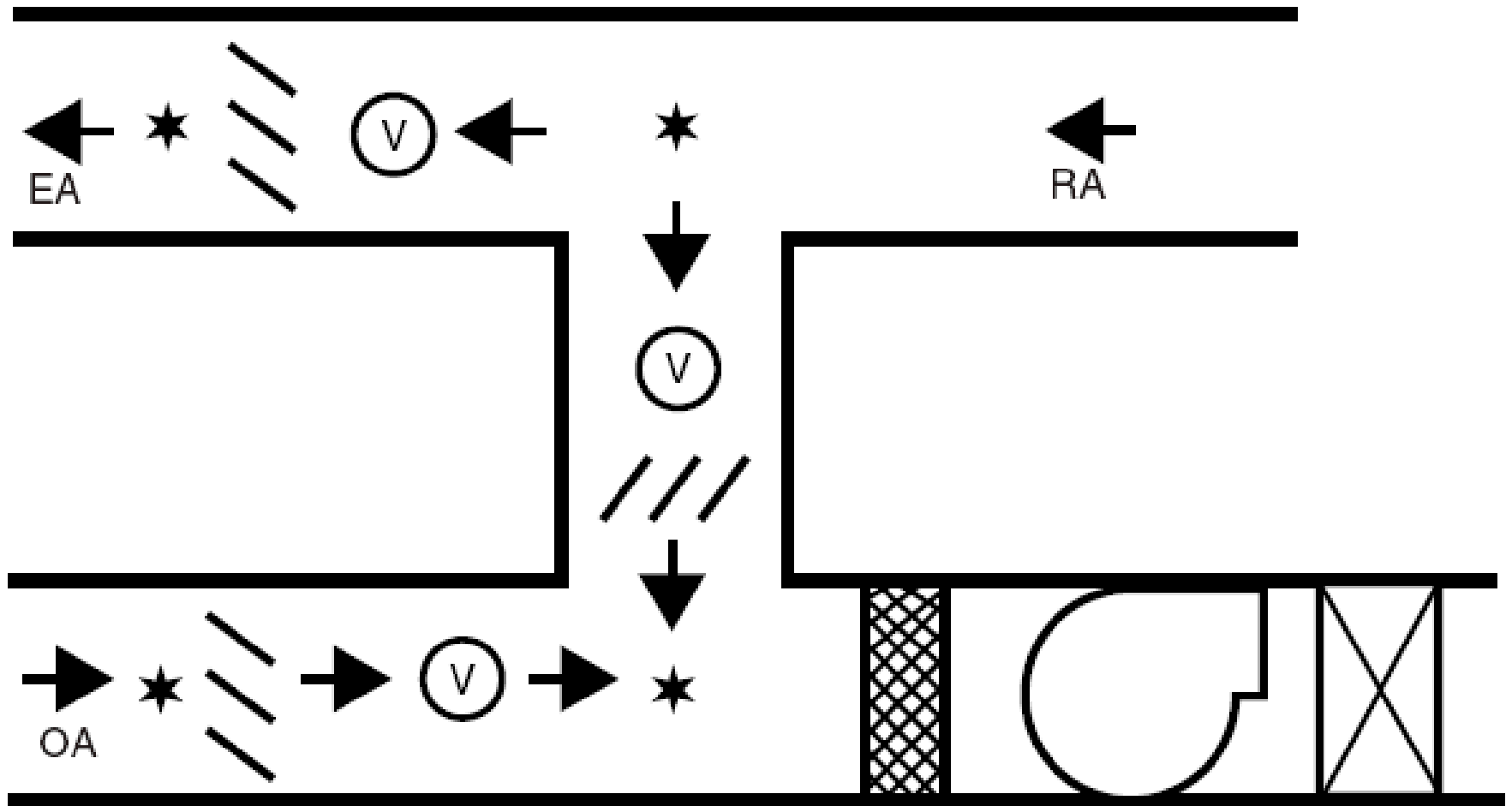
Step	Example
1	Not applicable
2	$\begin{aligned} \text{Free area ratio (parallel blades)} &= (0.0798 \times 1.50 \text{ m}^2)^{0.1007} \times \frac{1.50 \text{ m}^2}{1.69 \text{ m}^2} \\ &= 0.8075 \times 0.8876 \\ &= 0.717 \end{aligned}$
3	$\begin{aligned} \text{Pressure drop at 15.08 m/s} &= -3.114 \times (1 - 0.717^{-4.274}) \\ &= -3.114 \times -3.1449 \\ &= 9.783 \text{ Pa} \end{aligned}$
4	$\begin{aligned} \text{Approach velocity} &= \frac{9.45 \text{ m}^3/\text{s}}{1.69 \text{ m}^2} \\ &= 5.59 \text{ m/s} \end{aligned}$
5	$\begin{aligned} \text{Correction factor} &= \frac{25.8}{5.59^2} \\ &= 0.826 \end{aligned}$
6	$\begin{aligned} \text{Pressure drop across damper} &= \frac{9.783 \text{ Pa}}{0.826} \\ &= 11.86 \text{ Pa} \end{aligned}$

Had the duct size been 1.50 m², the same size as the damper, the pressure drop would have been lower (7.25 Pa).

Damper Applications

Table 8. Damper Applications.

Control Application	Damper Type
Return Air	Parallel
Outdoor Air or Exhaust Air (with Weather Louver or Bird Screen) (without Weather Louver or Bird Screen)	Opposed Parallel
Coil Face	Opposed
Bypass (with Perforated Baffle) (without Perforated Baffle)	Opposed Parallel
Two-Position (all applications)	Parallel

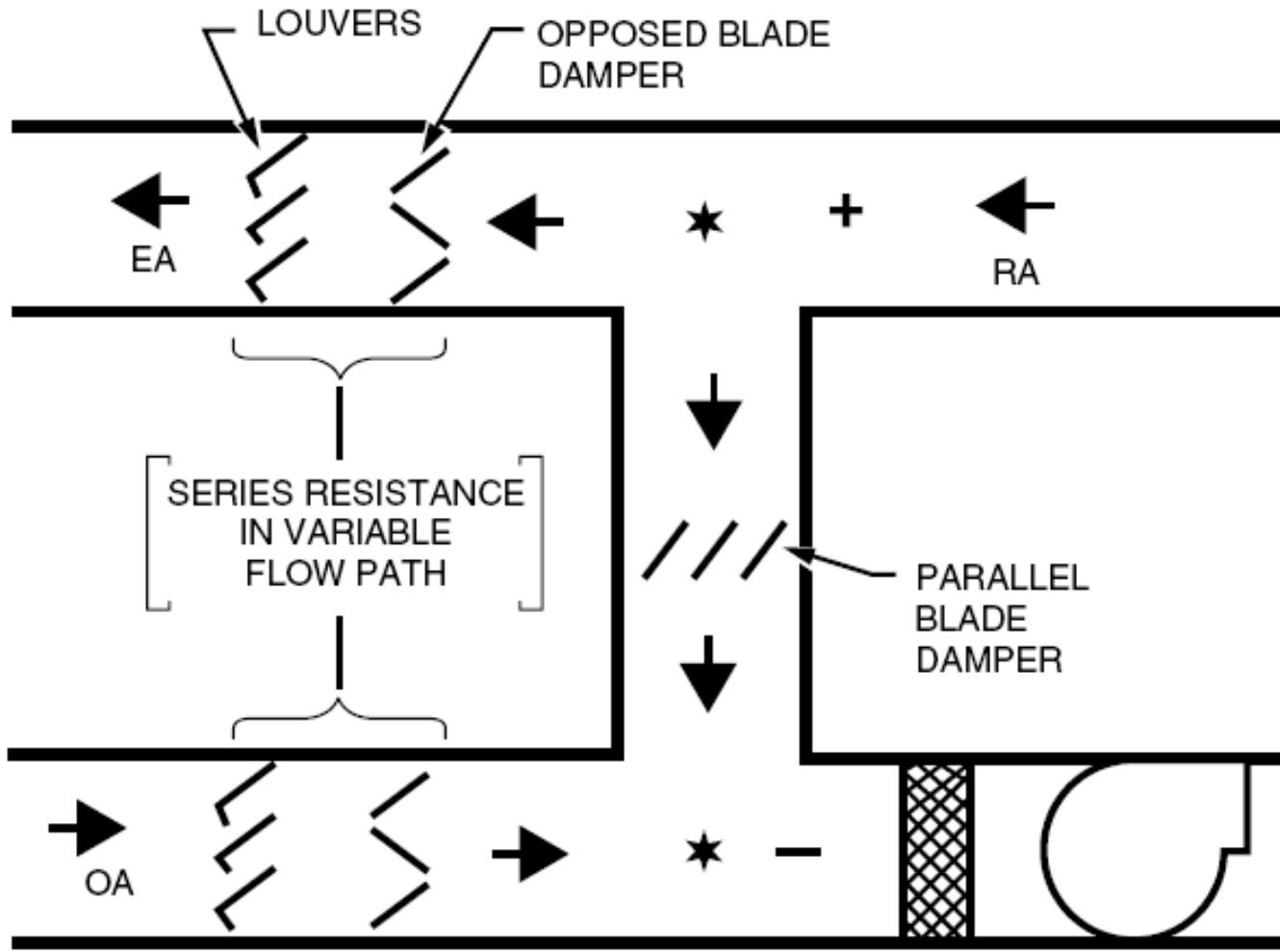


★ POINTS OF CONSTANT PRESSURE

(V) PATHS OF VARIABLE FLOW

C2393

Mixed air control system (parallel blade dampers)



- ★ POINTS OF CONSTANT PRESSURE
- + HIGH PRESSURE
- LOW PRESSURE

C2394

Mixed air system with louvers