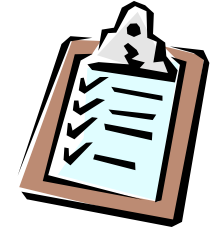# Hardware Components (II)

Dr. Sam C M Hui

Department of Mechanical Engineering
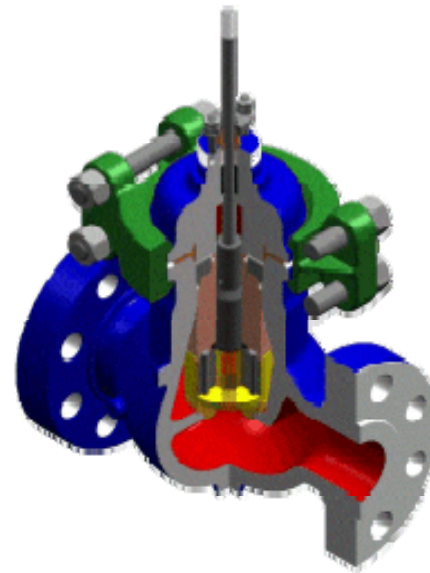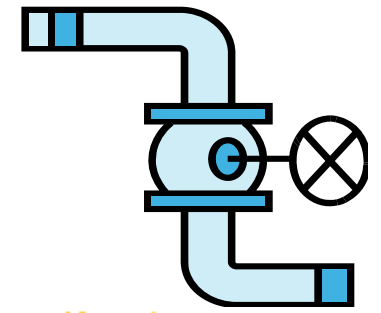The University of Hong Kong
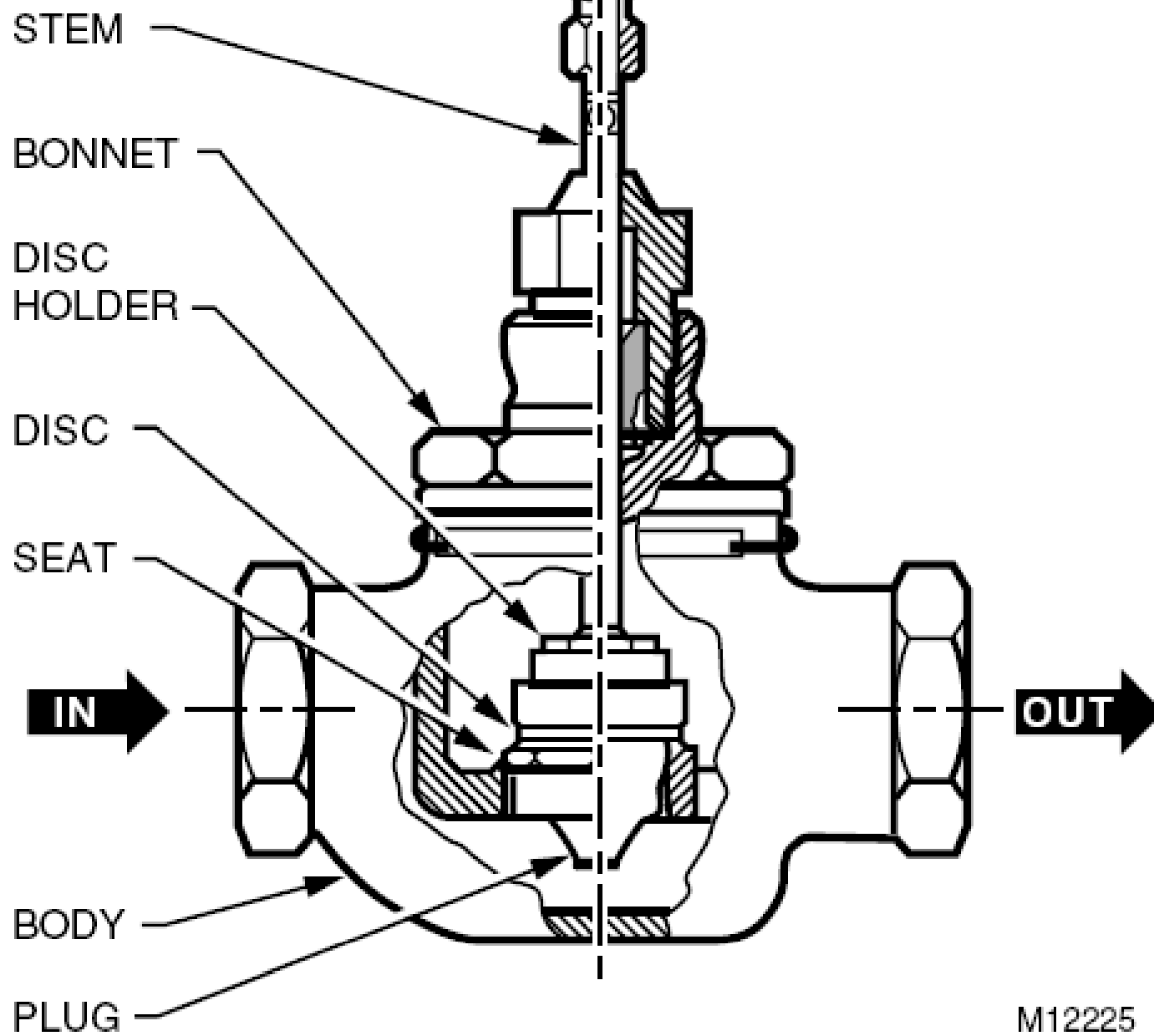E-mail: cmhui@hku.hk

Feb 2010

Contents

- Design Principles

  - Control valves

  - Control dampers

Control Valves

- Important component of fluid distribution systems

- Common types:
  - Globe valves (for modulating)
  - Ball valves (less expensive)
  - Butterfly valves (for isolation)

- Valve material
  - Bronze, cast iron, steel

STEM

BONNET

DISC
HOLDER

DISC

SEAT

IN

OUT

BODY

PLUG

M12225

Control valve components

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]
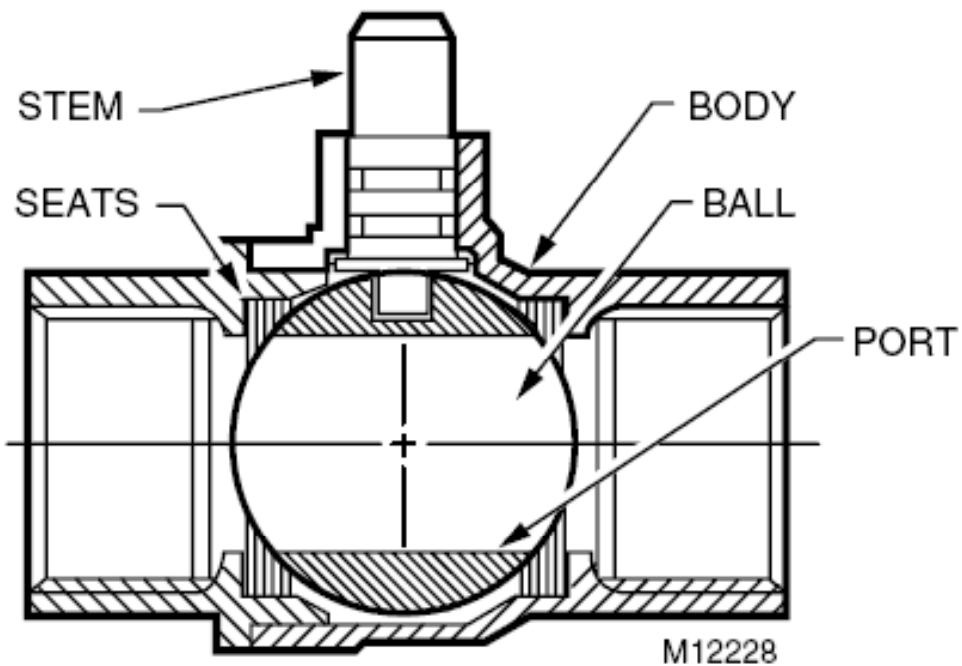
Ball valve
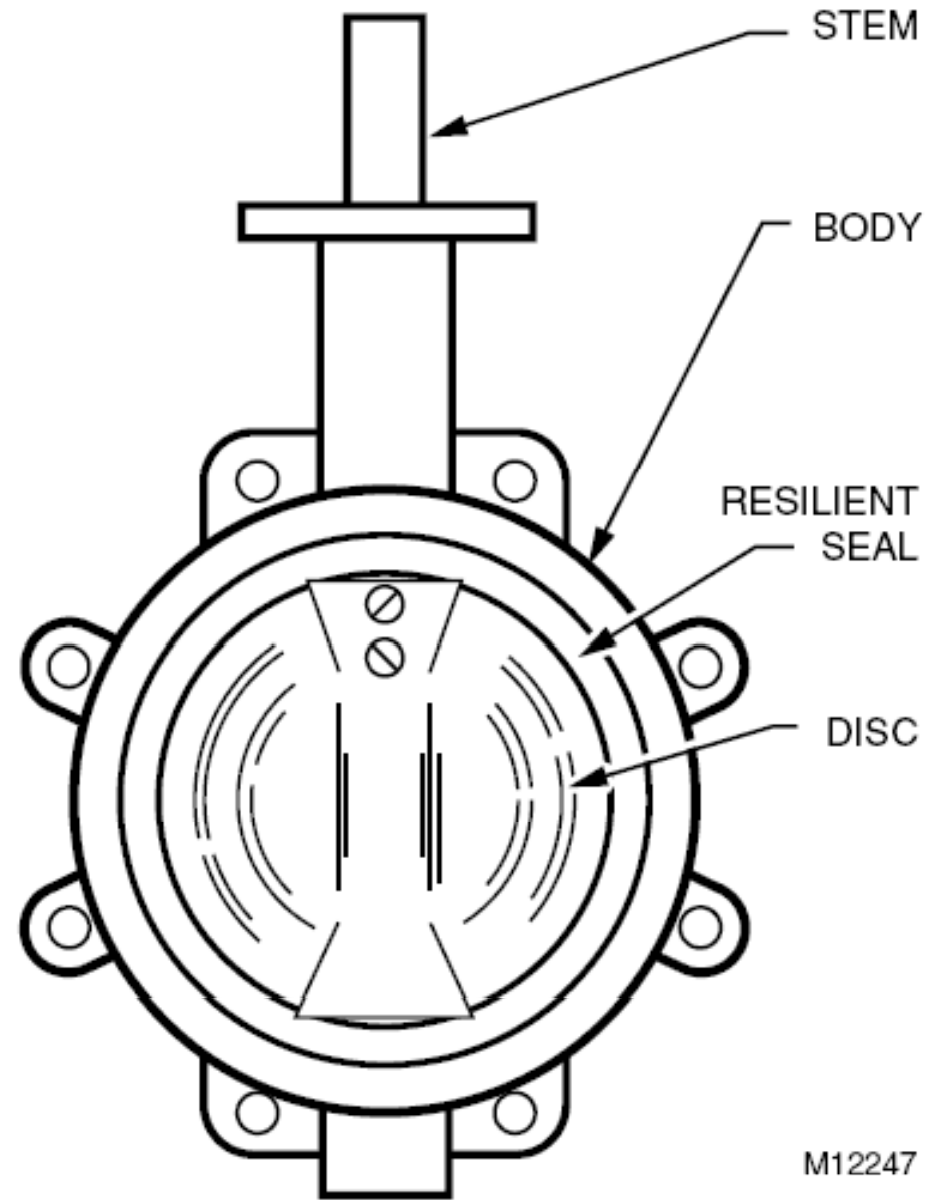
Butterfly valve
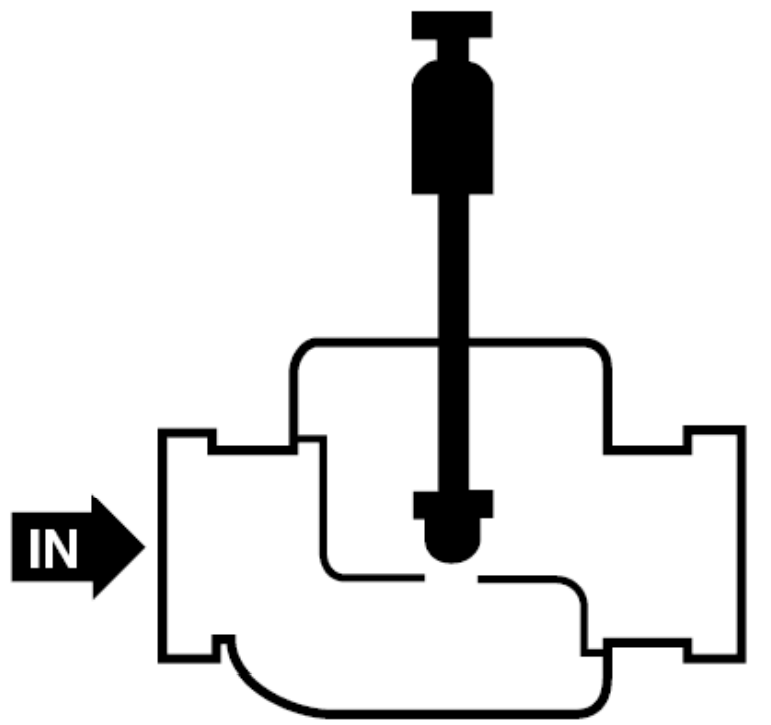
PUSH-DOWN-TO-CLOSE
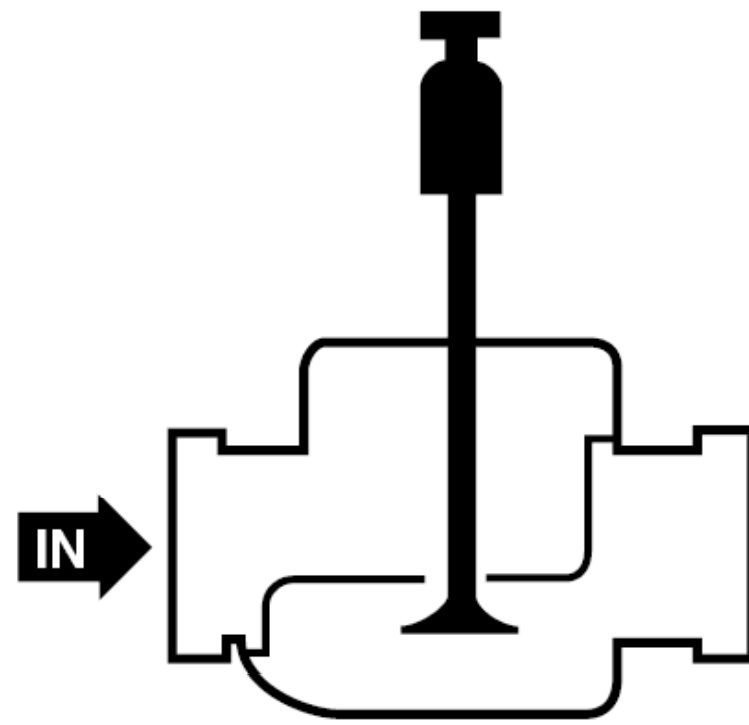
PUSH-DOWN-TO-OPEN

C2328

Two-way globe valves

SUPPLY

TWO–WAY VALVE

LOAD

RETURN
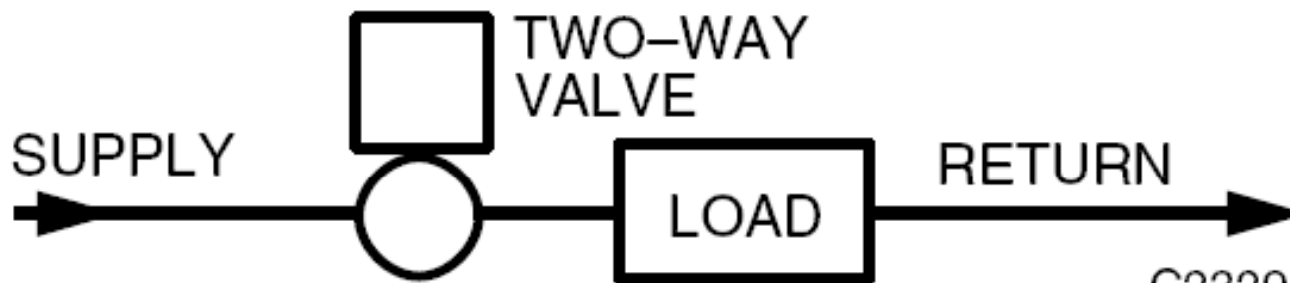
C2329

Two-way valve application

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

MIXING VALVE

DIVERTING VALVE

IN → → OUT
↑ IN

IN → → OUT
OUT ↓
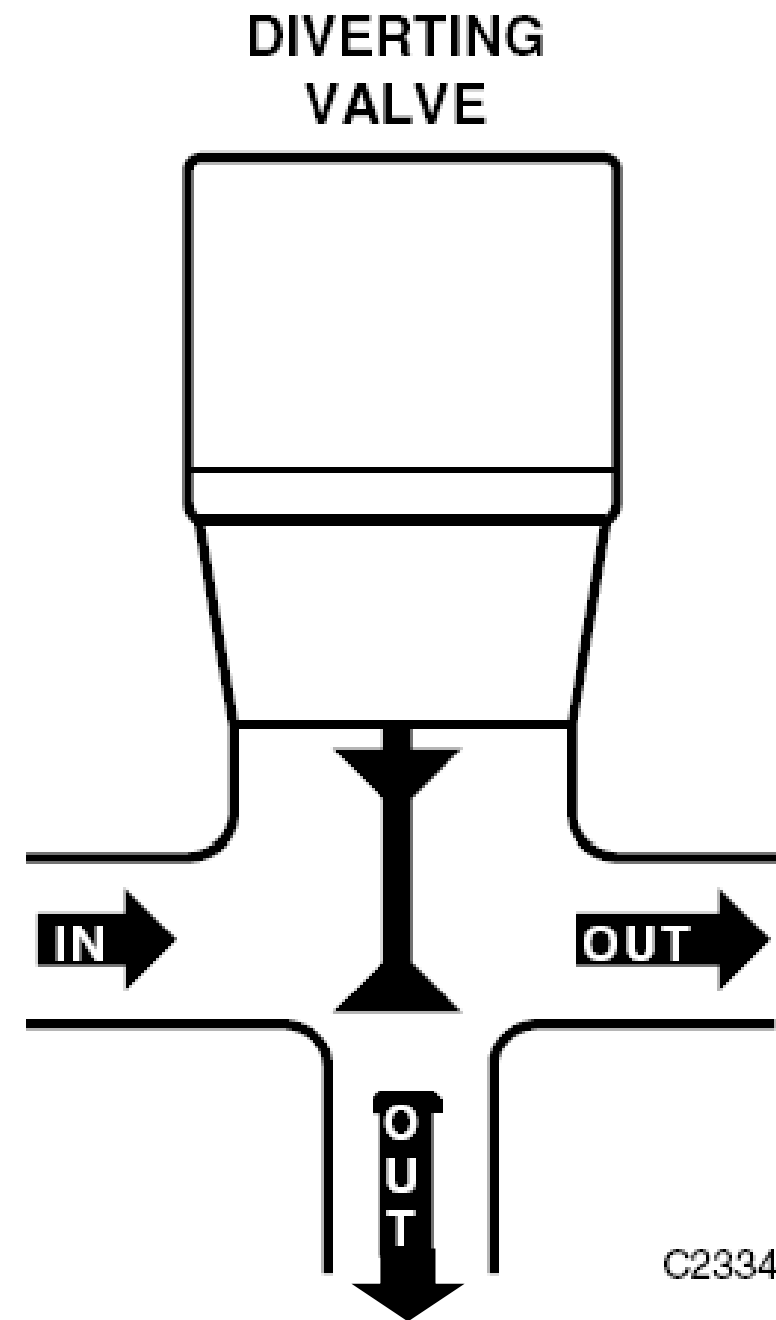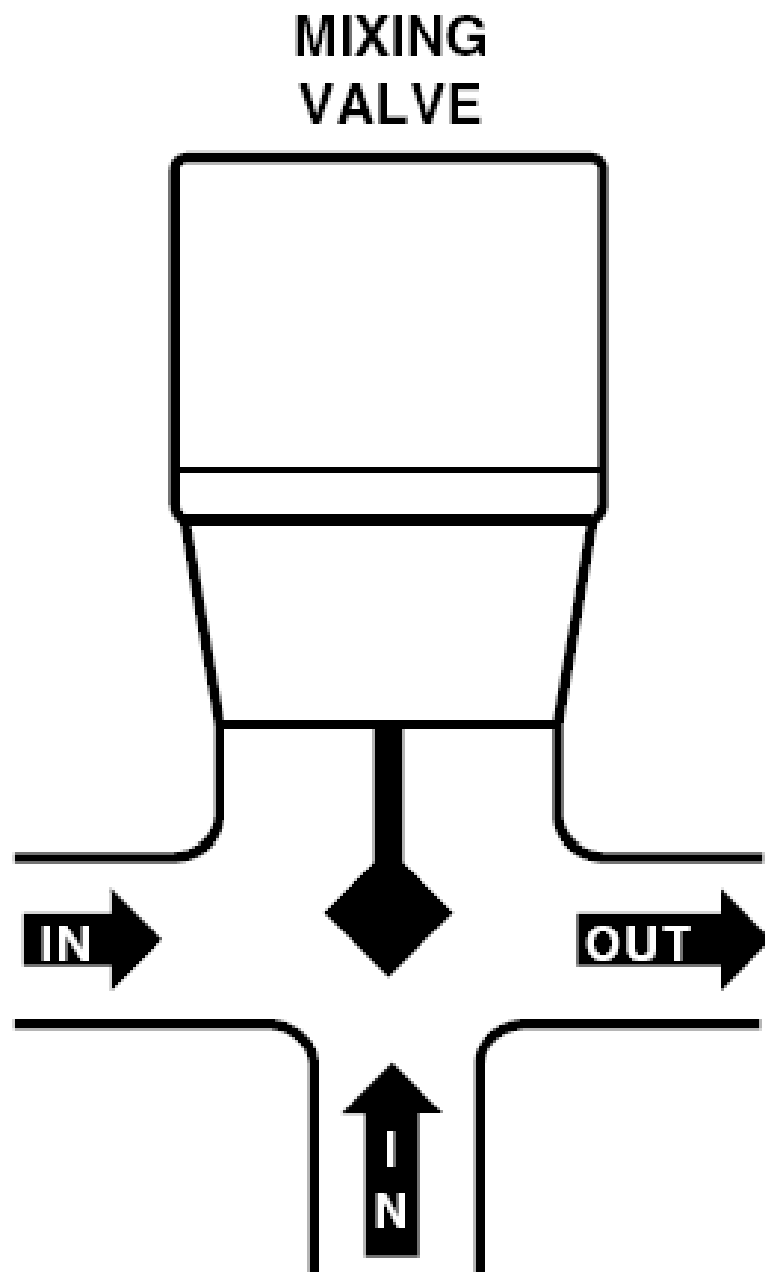
C2334

Three-way valves

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]
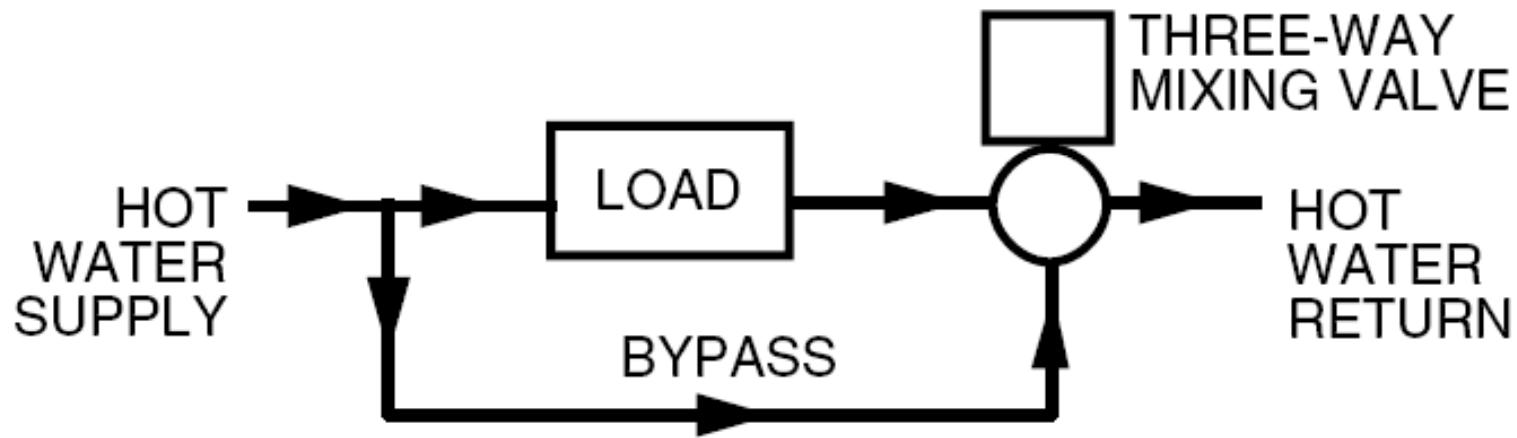
A. LOAD BYPASS IN MIXING VALVE APPLICATION
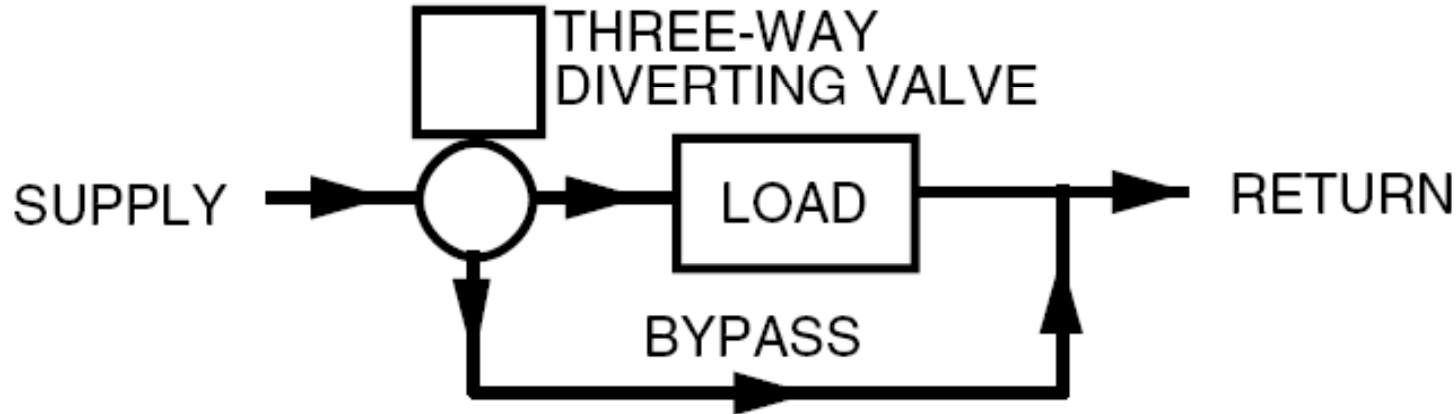
B. LOAD BYPASS IN DIVERTING VALVE APPLICATION

Three-way valve applications
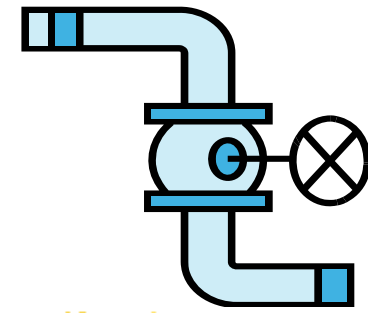
Control Valves

- 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
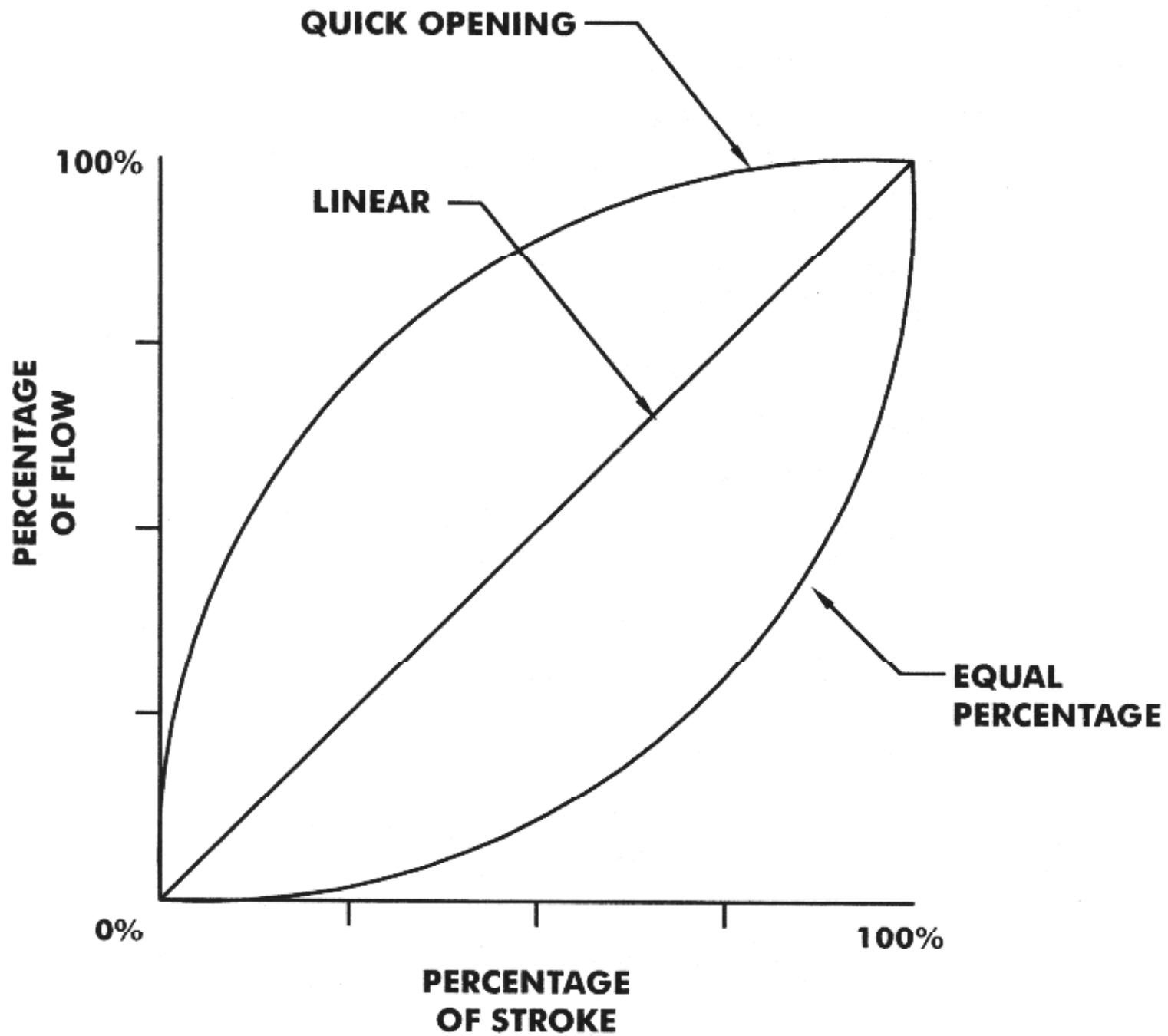
Flow characteristics of control valves
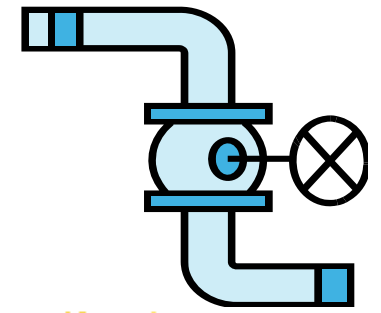
Combination of coil and control valve characteristics

[Source: Montgomery, R. and McDowall, R., 2008. *Fundamentals of HVAC Control Systems*]
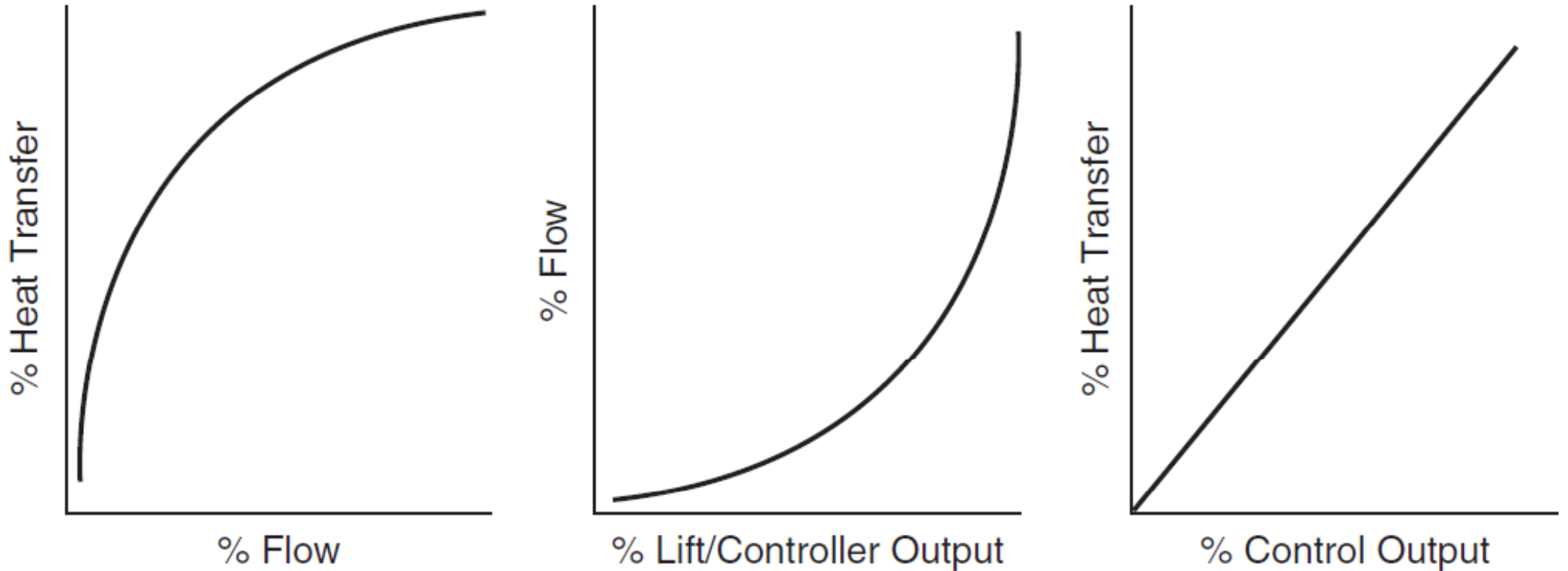
Control Flow Characteristics

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.

Control Valves

- Valve flow terms
    - <u>Rangeability</u>: The ratio of maximum flow to minimum controllable flow

    - <u>Turndown</u>: The ratio of maximum flow to minimum controllable flow of a valve installed in a system. Turndown <= rangeability

    - <u>Flow coefficient</u> (capacity index): Used to state the flow capacity of a control valve for specified conditions

Flow coefficient:

$$A_V = q\sqrt{\dfrac{\rho}{\Delta P}}$$

q = volume flow (m³/s)
ρ = fluid density (kg/m³)
ΔP = static pressure loss across the valve (Pa)

For different units and locations, C_V and K_V are used.
For valve used in water application:

$$K_V = Q\sqrt{\dfrac{\rho}{\Delta P \cdot 10}} \qquad Q = \text{volume flow (m}^3\text{/h)}$$

Control Valves
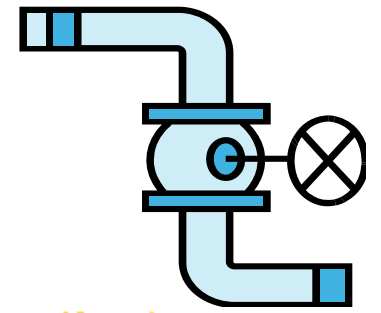
- Valve ratings
  - Flow coefficient
  - Close-off rating:
    - The maximum pressure drop that a valve can withstand without leakage while in the full closed position
  - Pressure drop:
    - The difference in upstream and downstream pressures of the fluid flowing through the valve
  - Maximum pressure and temperature:
    - The maximum pressure and temperature limitations of fluid flow that a valve can withstand

Control Valves
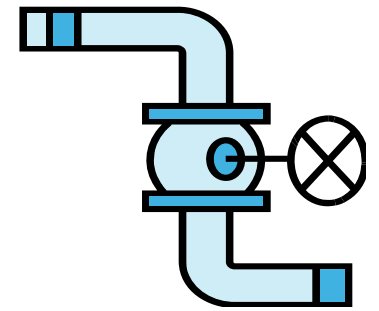
- Valve selection
  - Match a valve to the control and hydronic system physical requirements
    - What is the piping arrangement and size?
    - Does the application require two-position control or proportional control?
    - Does the application require a normally open or normally closed valve?
    - 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
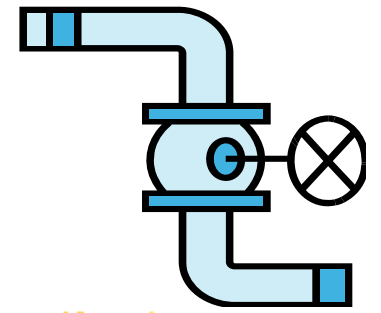
- Location of control valves
  - At the outlet on the top of cooling/heating coils
    - Avoid coil starvation from water flow (lower pressure)
    - Flow of water from the bottom to the top (avoid air bubble)
  - Flow measuring & balancing device should be placed after the control valve
  - Provide a means of shut-off to allow a proper means for servicing

SHUTOFF AND BALANCING VALVE

FLOW MEASURING DEVICE

CONTROL VALVE

THERMOMETER (TYPICAL)

AIR VENT

COIL

DRAIN

SHUT OFF VALVE

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]
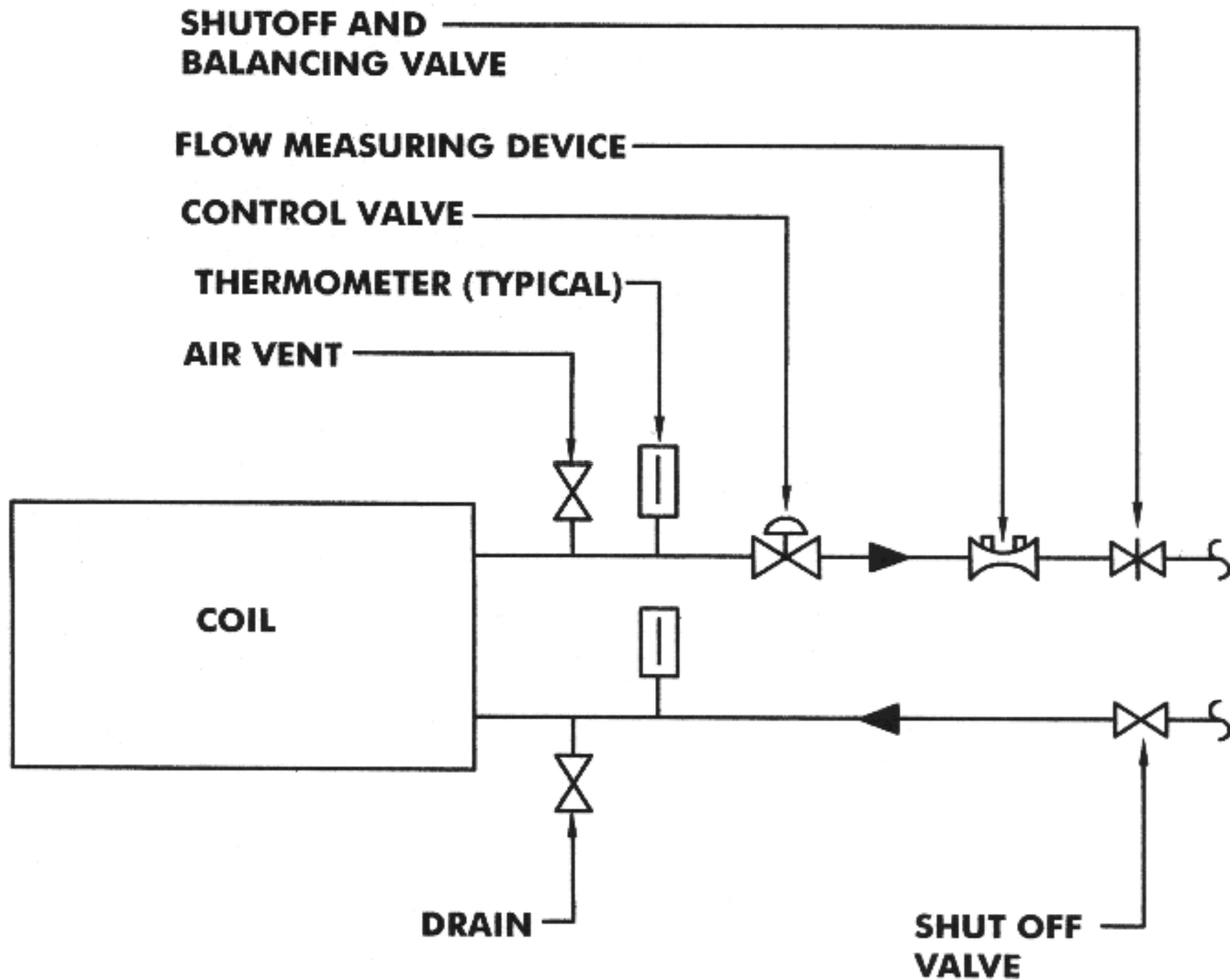
Control Valves

- 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)
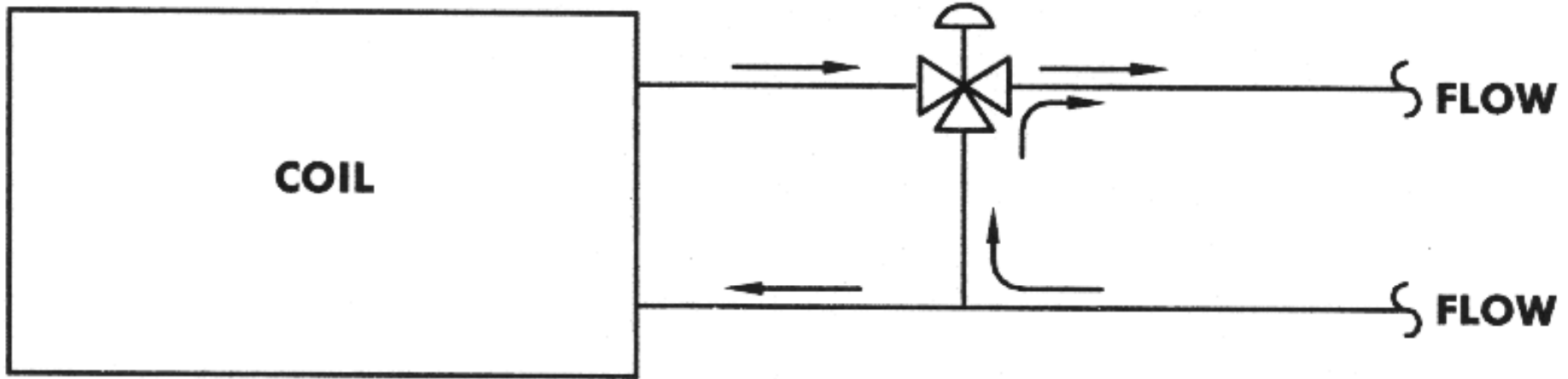
MIXING THREE-WAY CONTROL VALVE
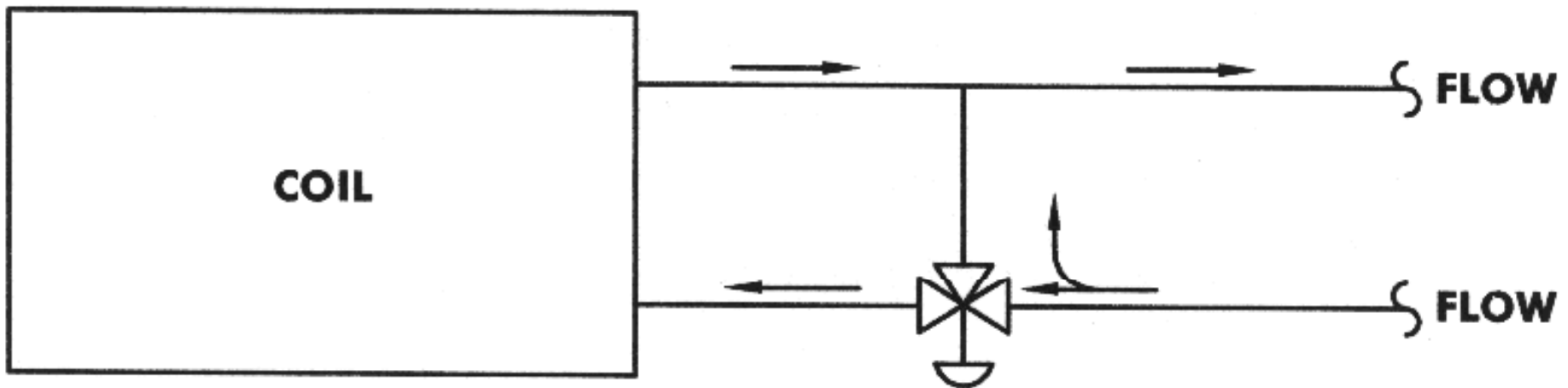
DIVERTING THREE-WAY CONTROL VALVE

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
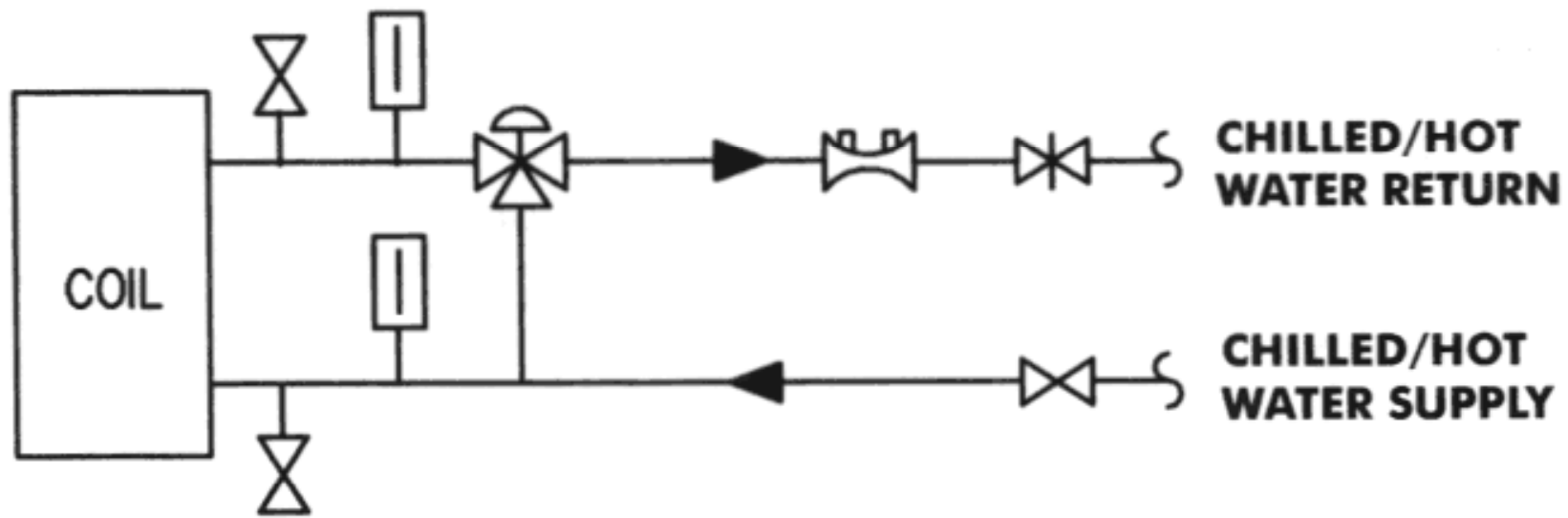
CHILLED/HOT WATER PIPING WITH THREE-WAY CONTROL VALVE
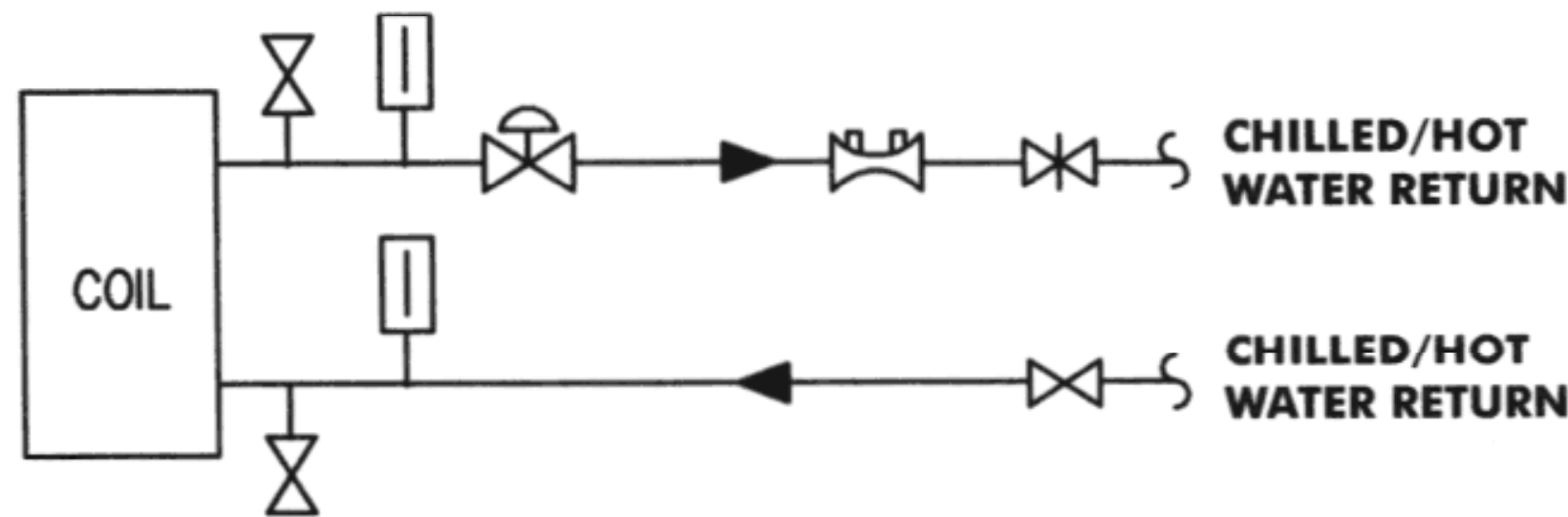
CHILLED/HOT WATER PIPING WITH TWO-WAY CONTROL VALVE
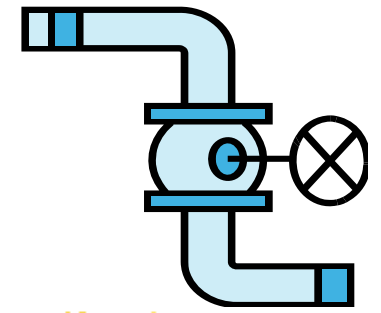
Control Valves

- 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?
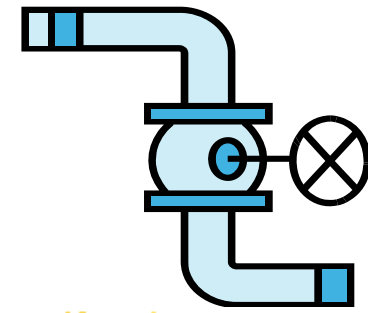
Control Valves

- How to size control valves
  - Valve equation: Pressure drop = (Flow / Cv) ^{2}
  - Cv = flow coefficient of control valve
    - Tested & published by manufacturer at fully open
  - 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
  - Often it is more than an art than science!

Control Valves
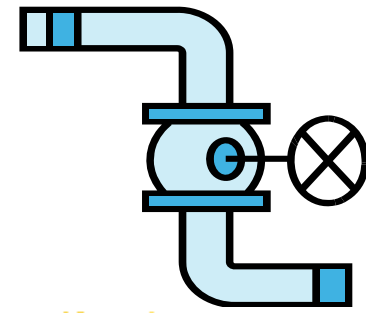
- <u>Water valve sizing example</u>:

  - 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 m^3/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.

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

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.

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
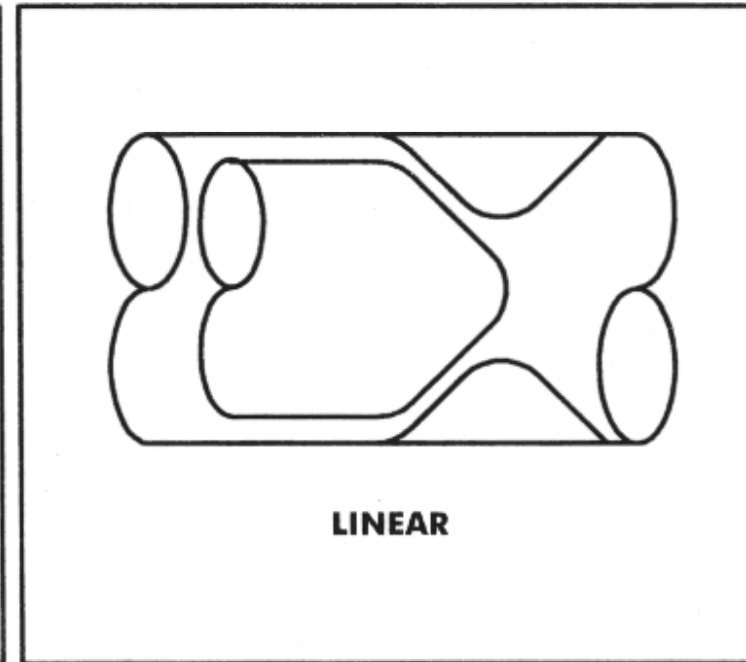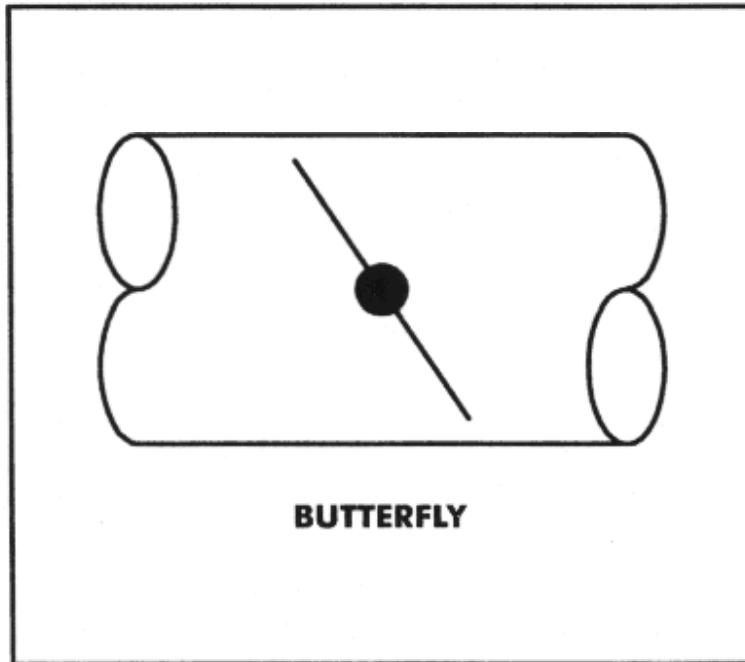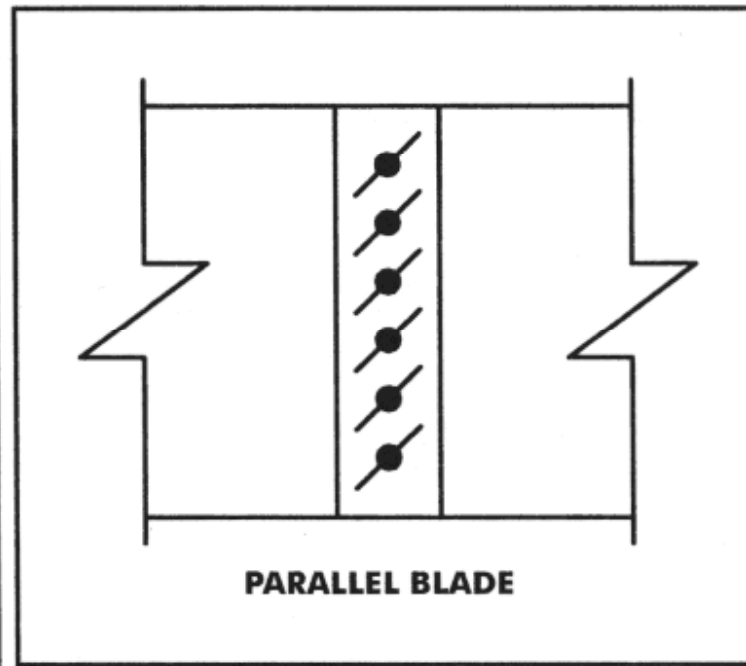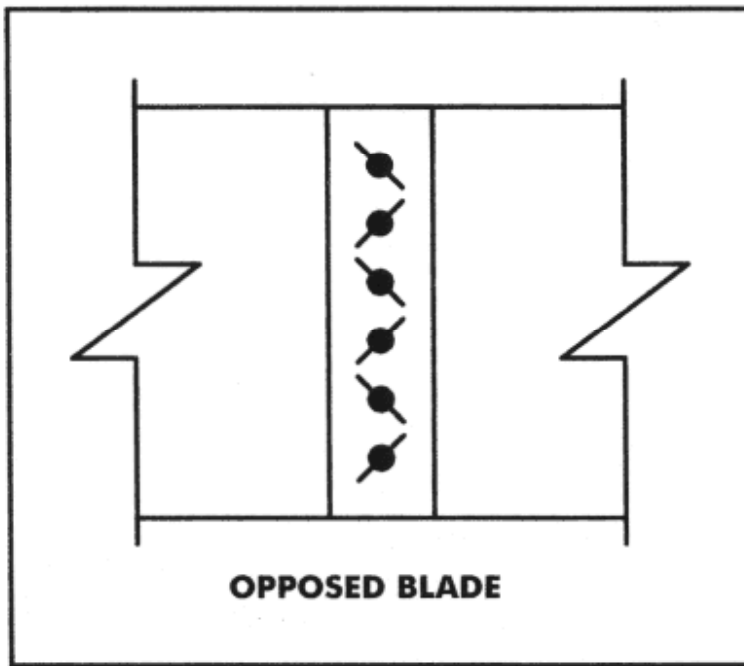
Four types of control dampers

Flow pattern through dampers

Duct

Air Flow

Duct

PARALLEL
OPERATION
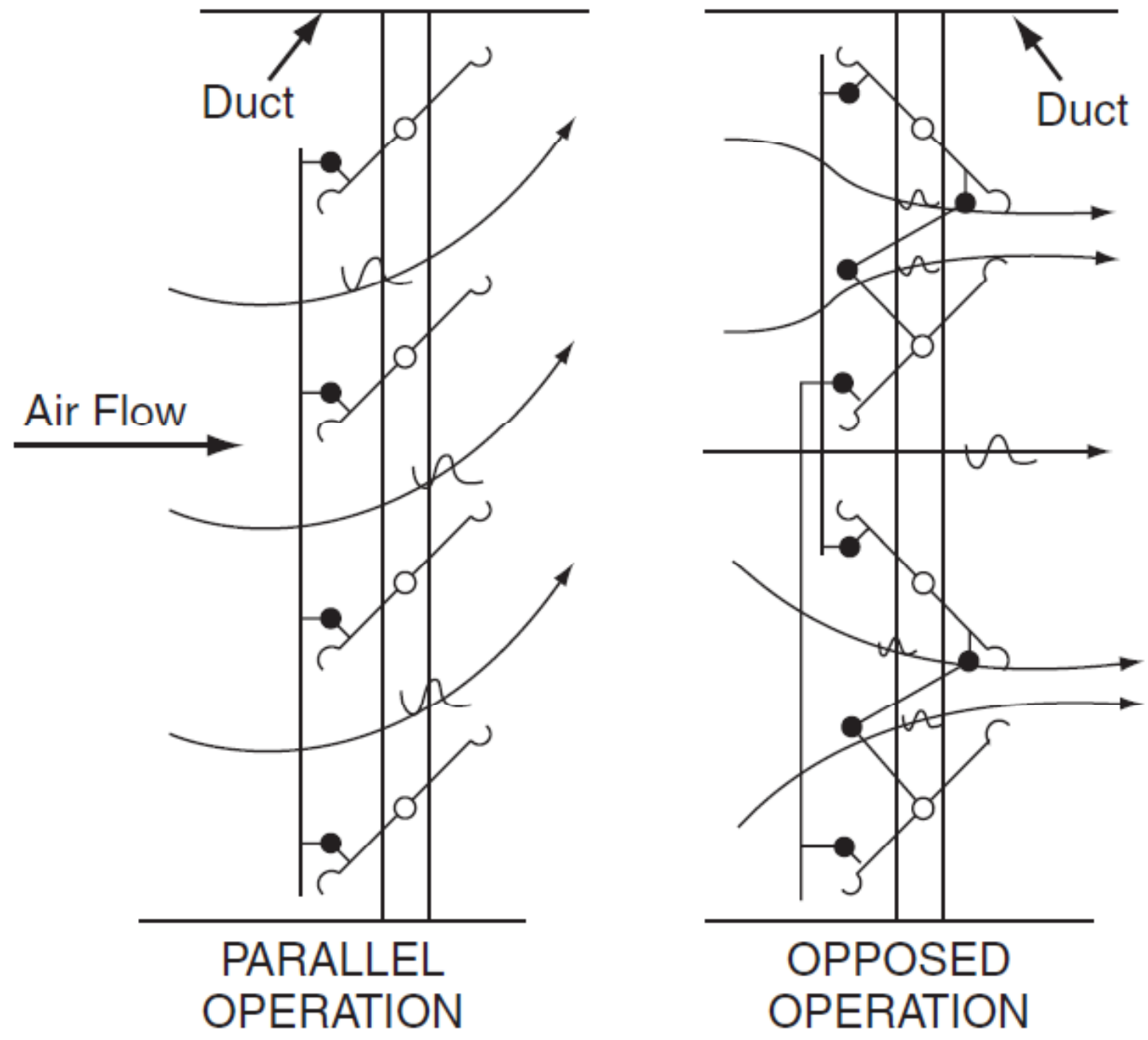
OPPOSED
OPERATION

[Source: Montgomery, R. and McDowall, R., 2008. *Fundamentals of HVAC Control Systems*]

PARALLEL BLADE ACTION
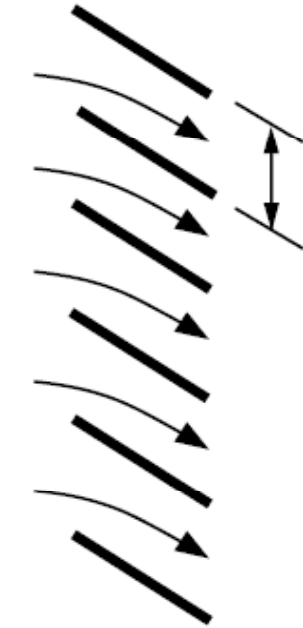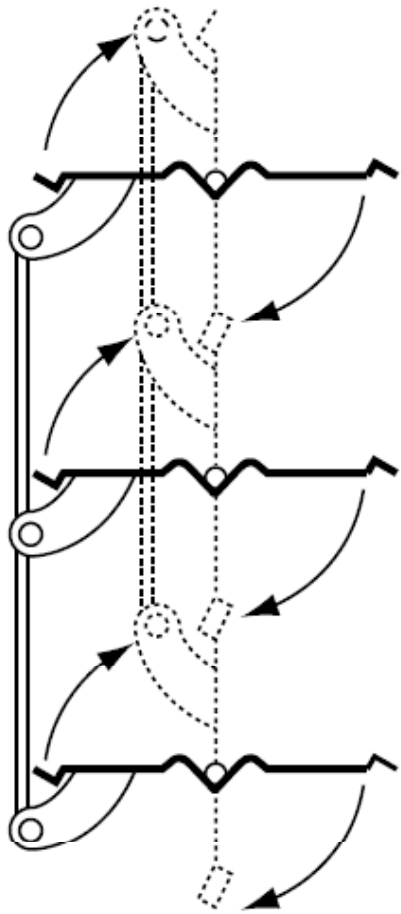
AIRFLOW THROUGH PARALLEL BLADE DAMPER AT ONE-THIRD CLOSED.

M10414

OPPOSED BLADE ACTION
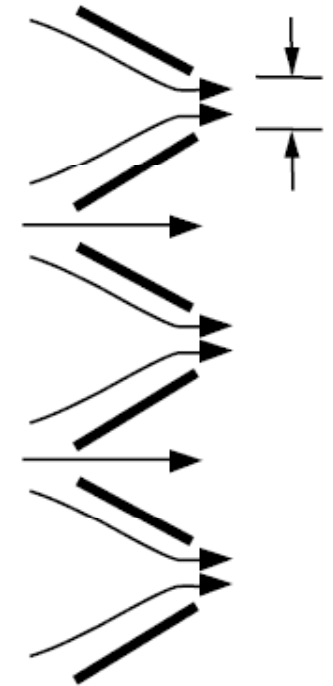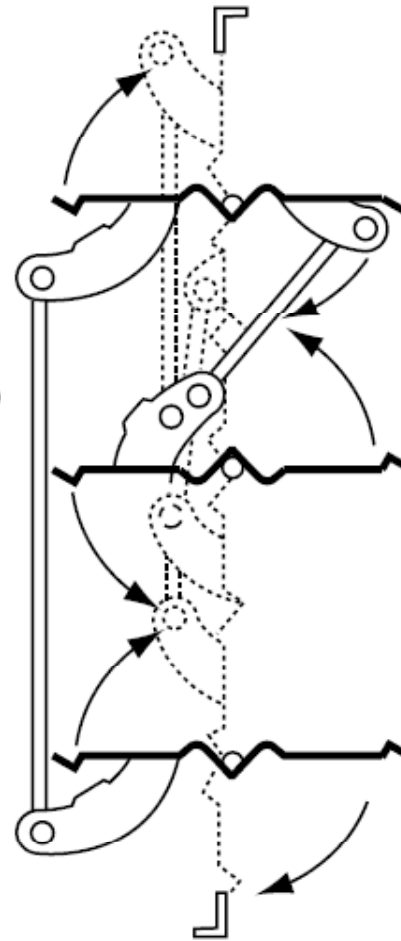
AIRFLOW THROUGH OPPOSED BLADE DAMPER AT ONE-THIRD CLOSED.

M10415

Parallel blade damper

Opposed blade damper

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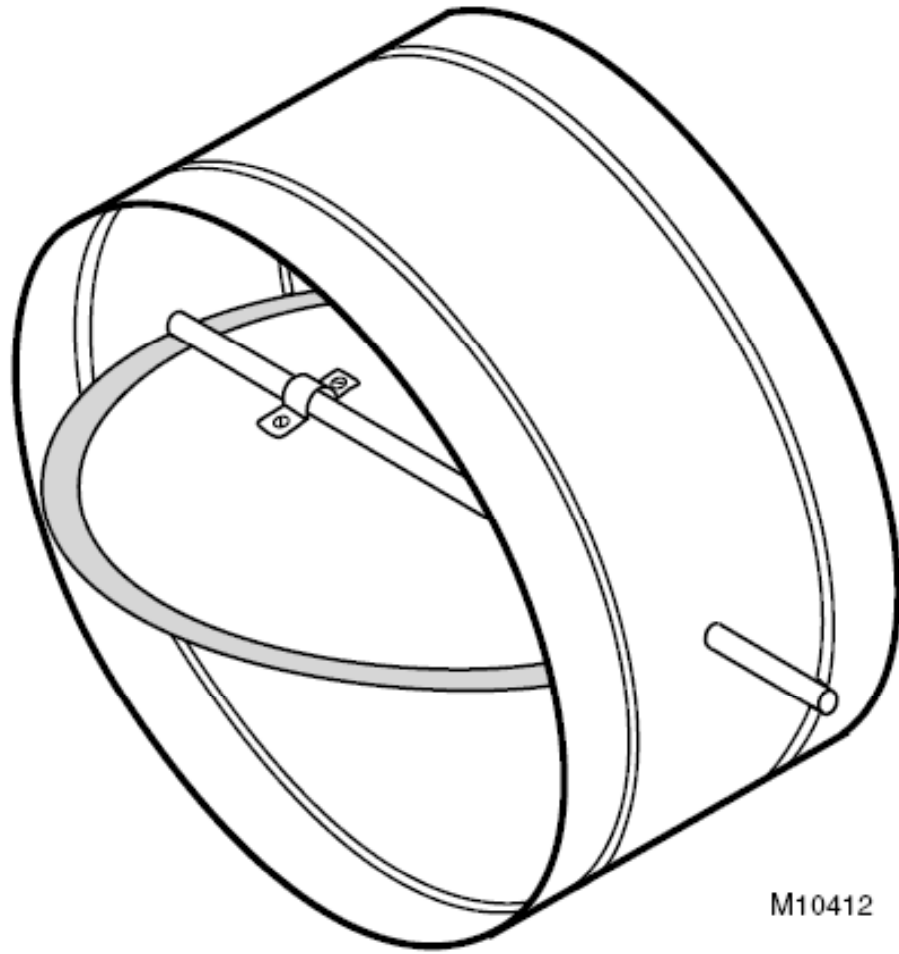
Round damper

Volume control damper
(opposed blade)
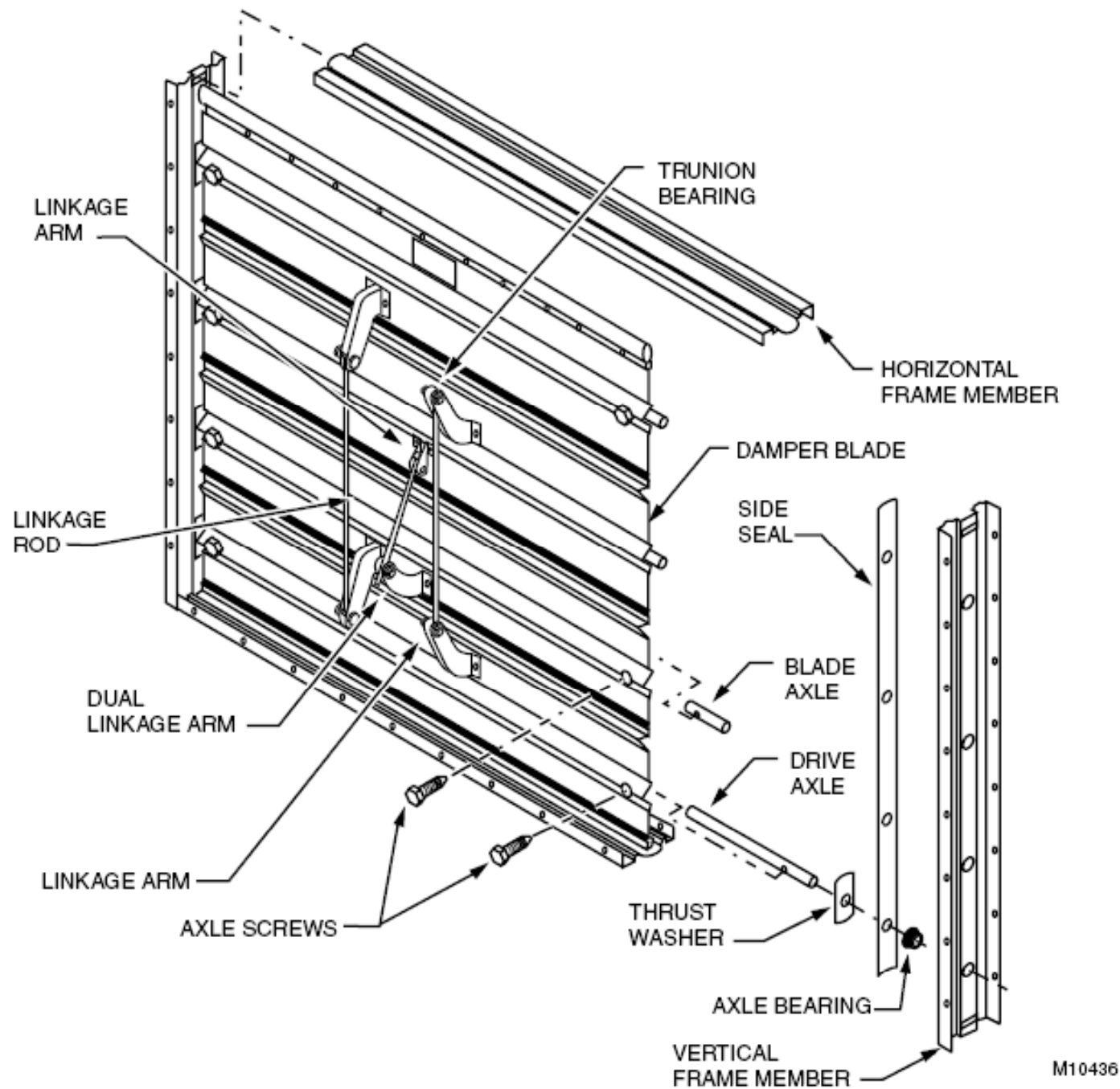
Typical (opposed blade) damper construction

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]
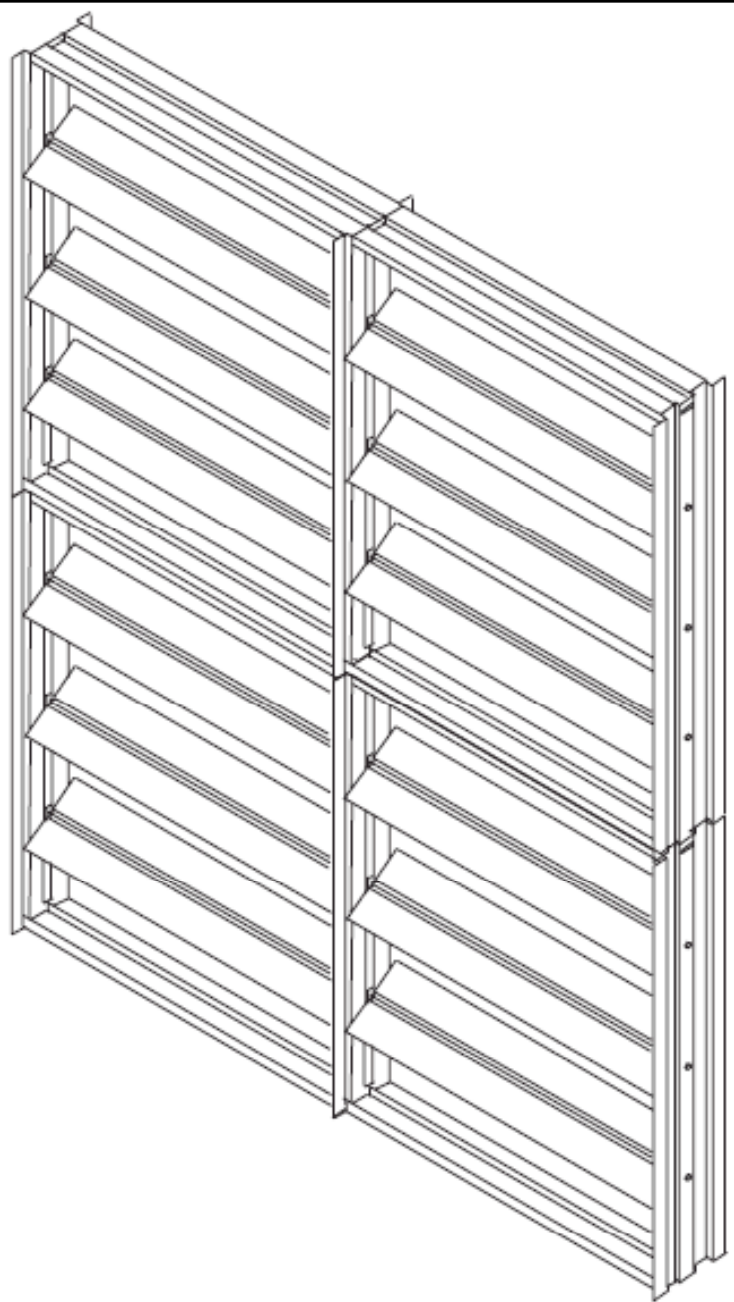
M10417
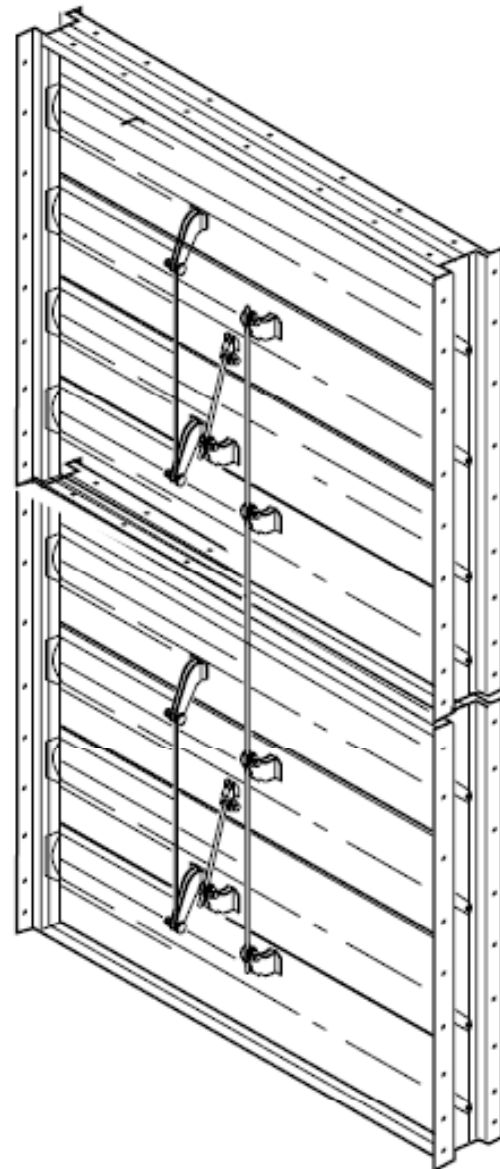
M10411

Multiple section damper assembly

Control Dampers

- Performance data
  - 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/m² OF DAMPER AREA
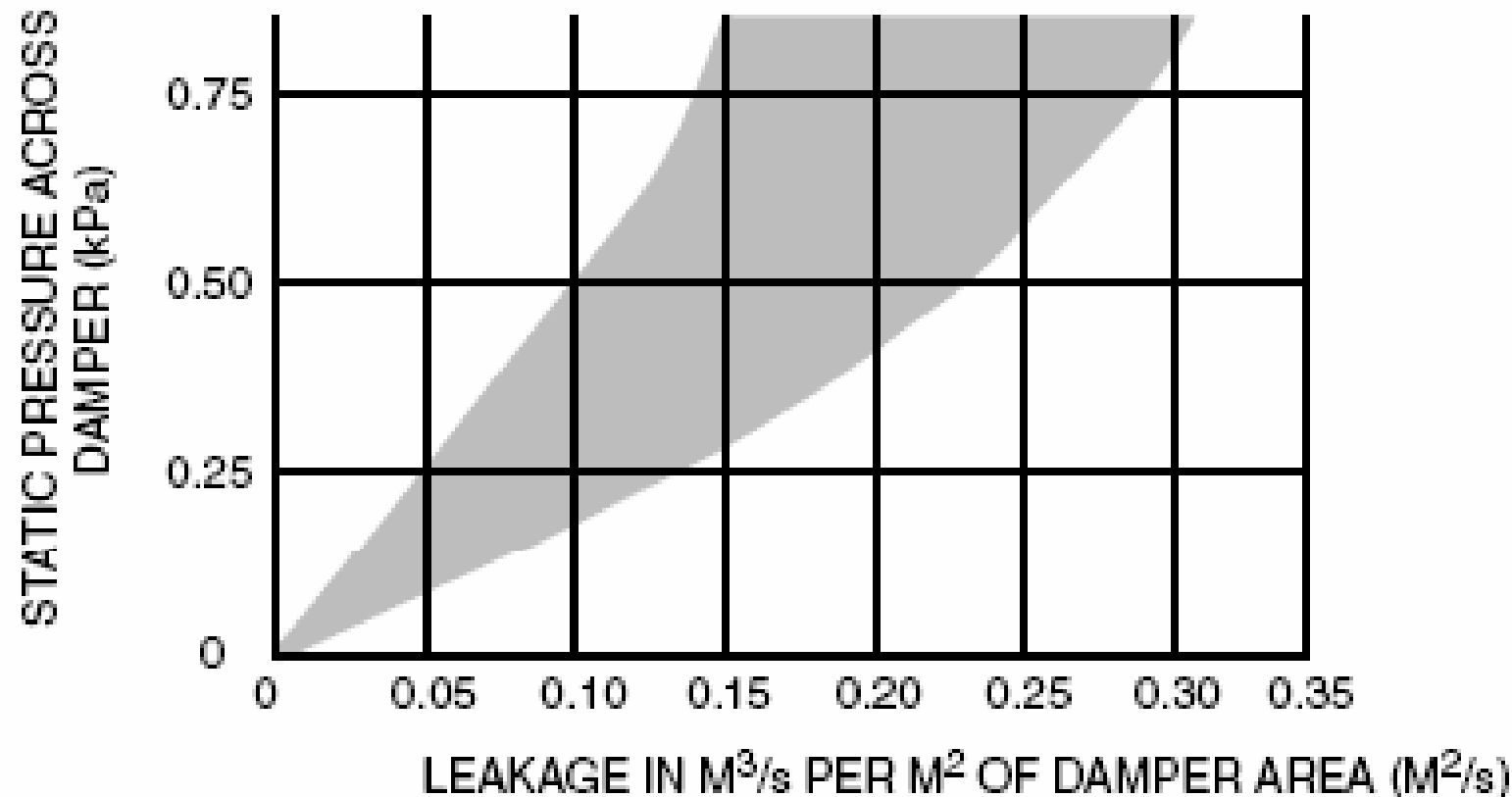
NOTE:

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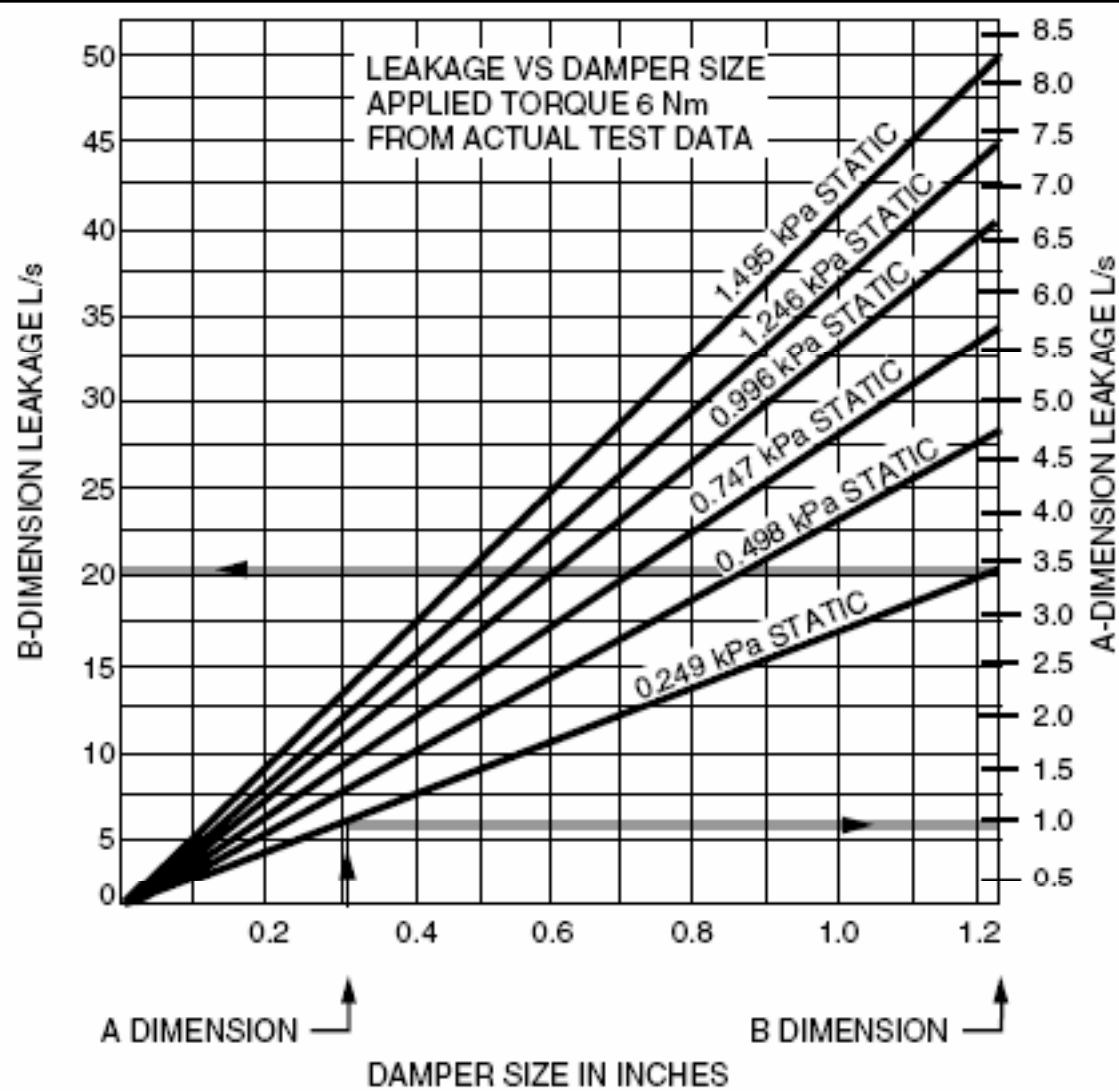
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Fig. 19. Low Leakage Dampers.

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

Control Dampers

- Performance data (cont'd)
    - 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
    - Pressure ratings
    - 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

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

Control Dampers

- Application environment
  - Velocity (higher forces with higher velocity)
  - Static pressure
  - Temperature
  - Corrosion
  - Turbulence
 - Nuclear/Seismic applications
- Actuators and linkages

Externally mounted
pneumatic actuator

Internally mounted electric actuator

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

LINKAGE ASSEMBLY

PUSHROD

JACKSHAFT

C2390

M10421
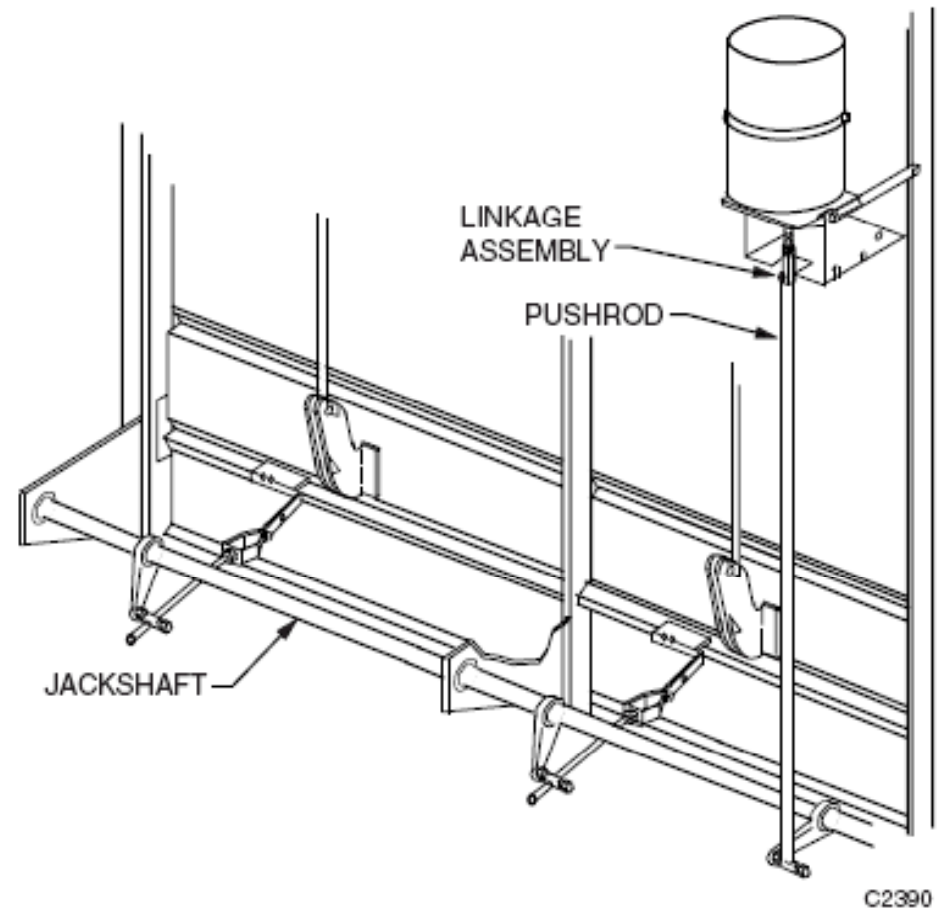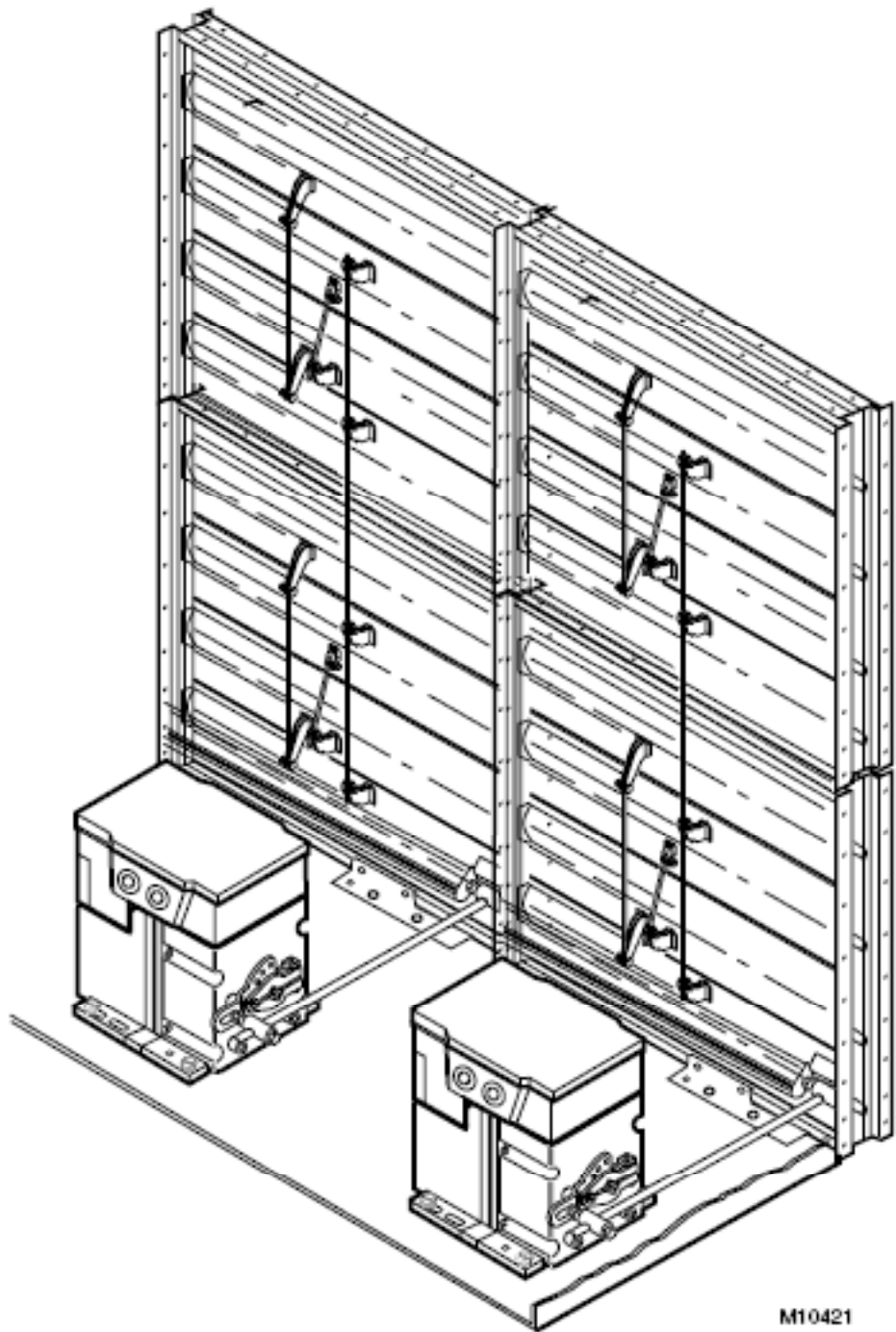
Damper jackshaft application

Control of a multiple section damper

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

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)
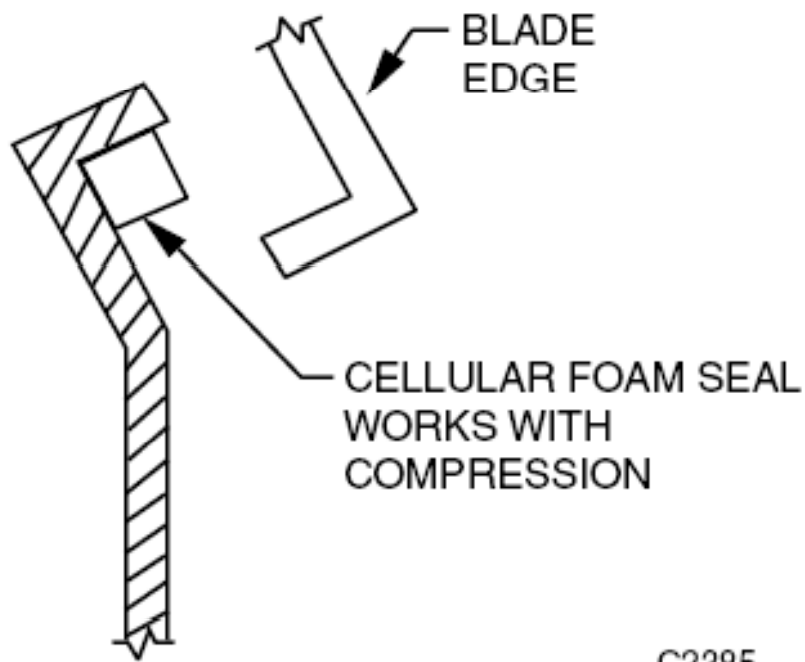
Cellular foam blade edge seal   Snap-on blade edge seal
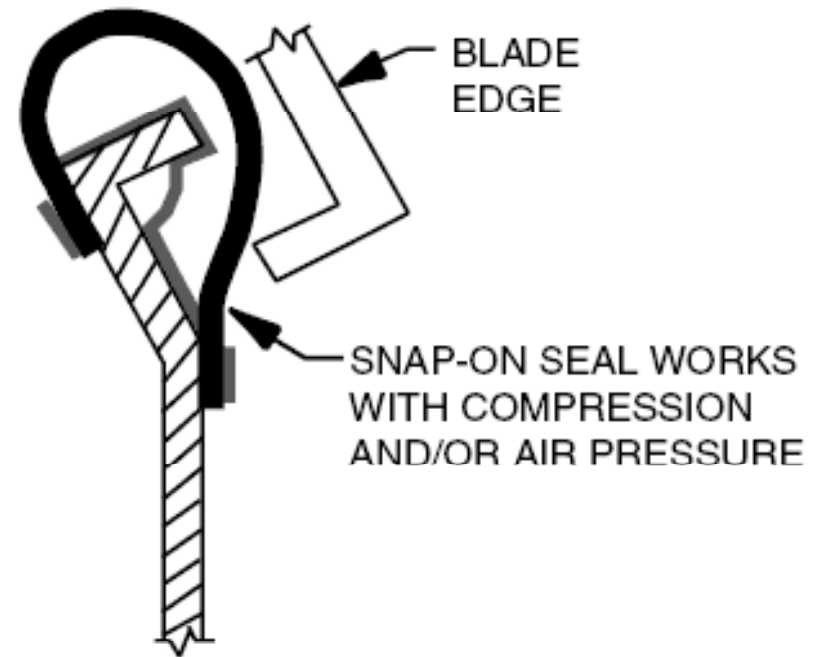
Examples of sealing methods for low-leakage dampers

Control Dampers

- 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)

DAMPER

ACTUATOR

THERMOSTAT

SPACE
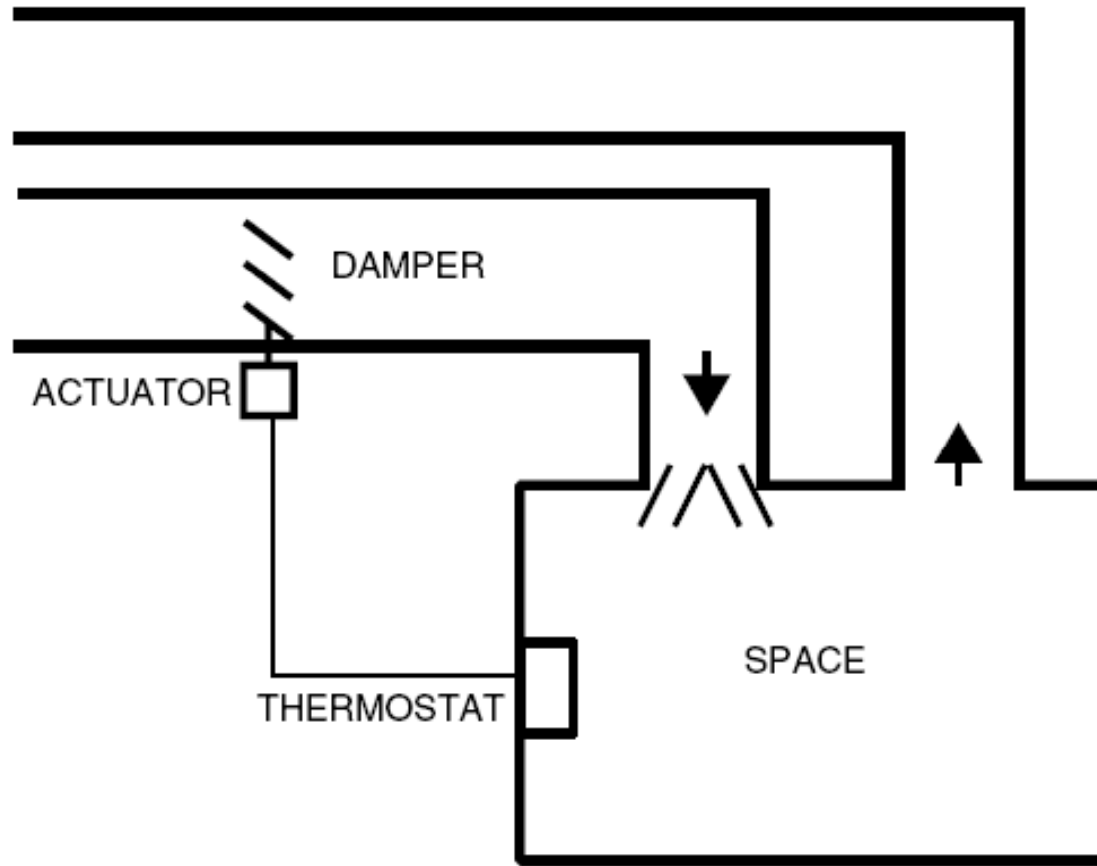
Control loop for
a damper system

DAMPER

SERIES
RESISTANCE
ELEMENTS

SYSTEM FLOW RESISTANCE
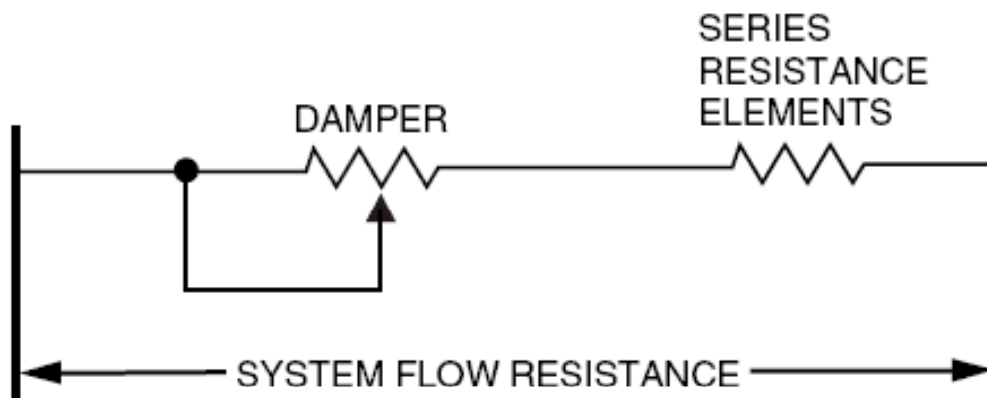
Resistance to airflow
in actual system

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

Control Dampers

- Damper characteristics
  - <u>Inherent</u> characteristics
    - Defined at a constant pressure drop with no series resistance (coils, filters, louvers, diffusers, or other items)
  - <u>Installed</u> 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
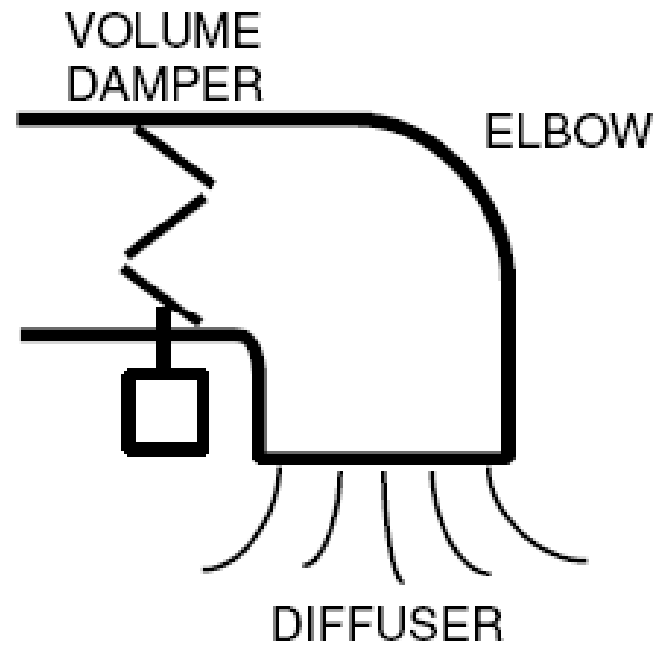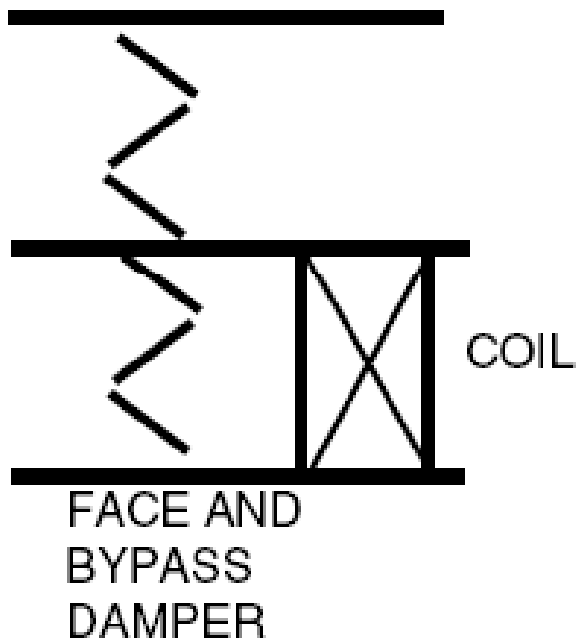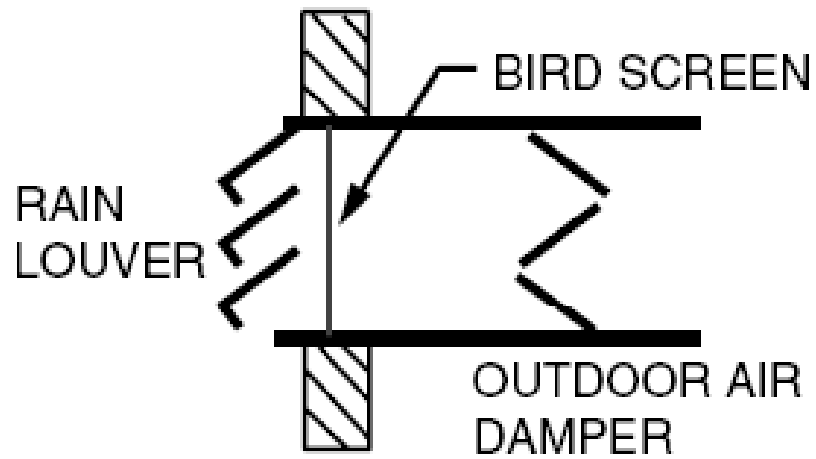
Examples of resistance to airflow
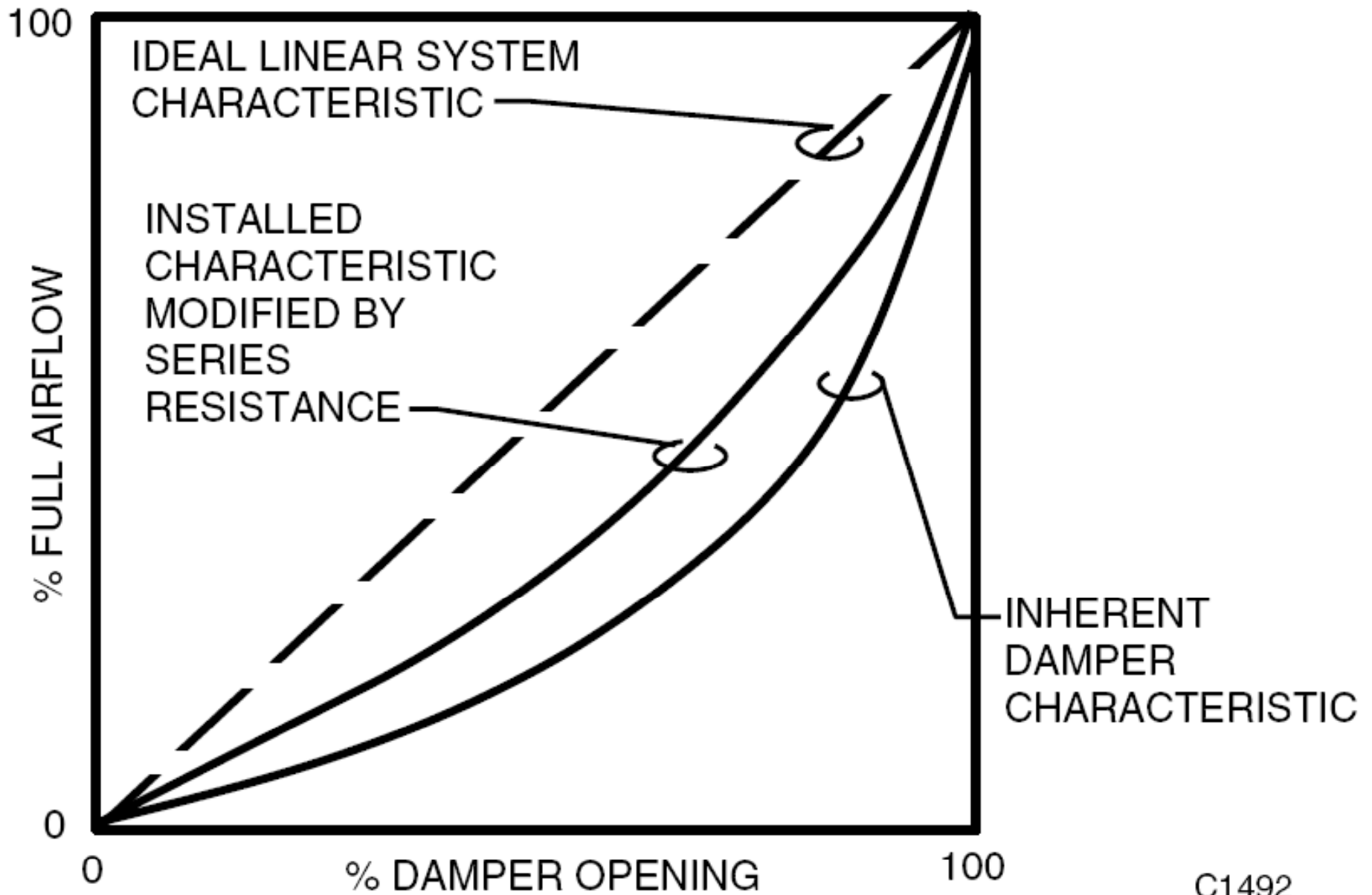
Installed versus inherent airflow characteristics for a damper
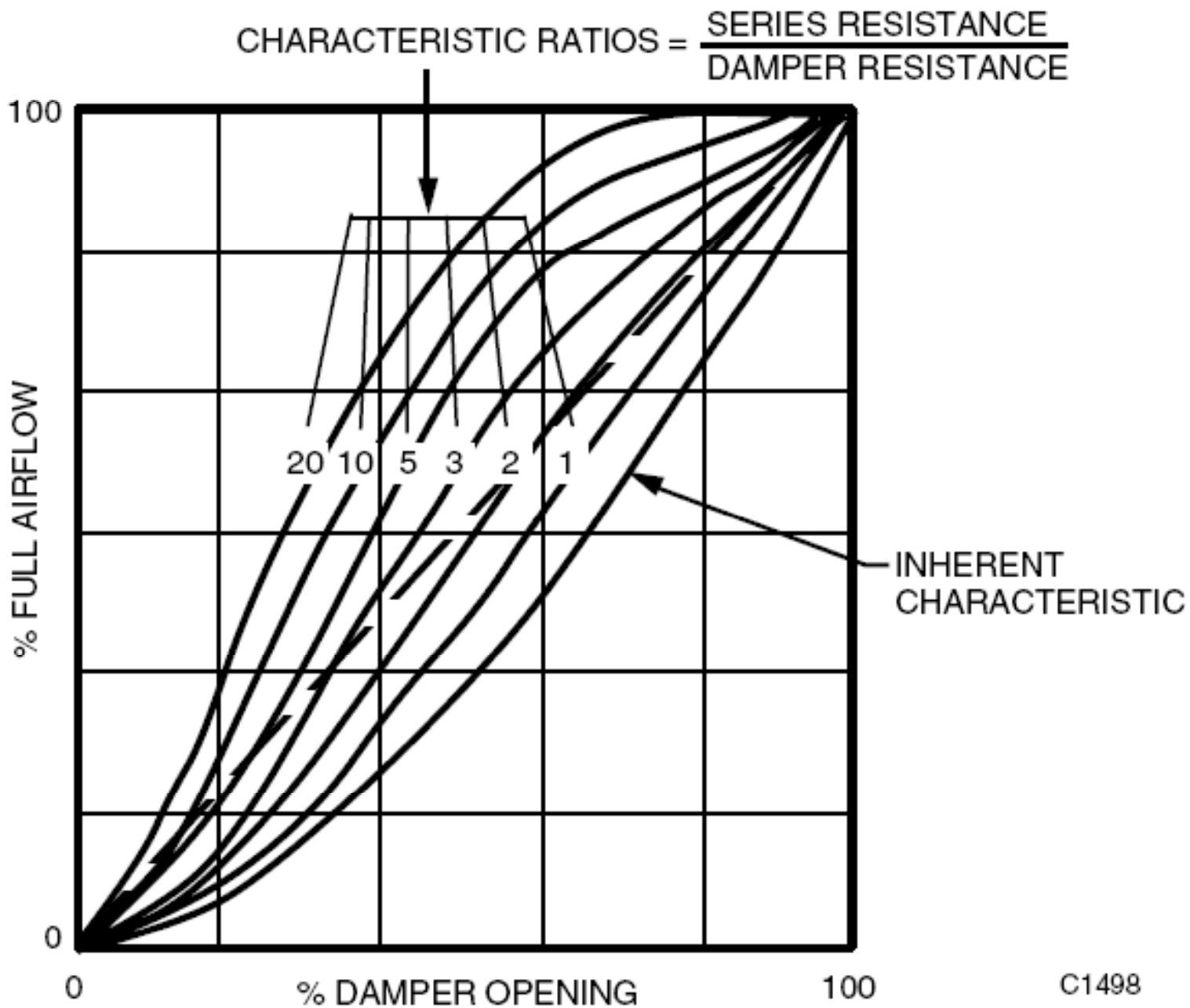
Damper system characteristics of parallel blade dampers
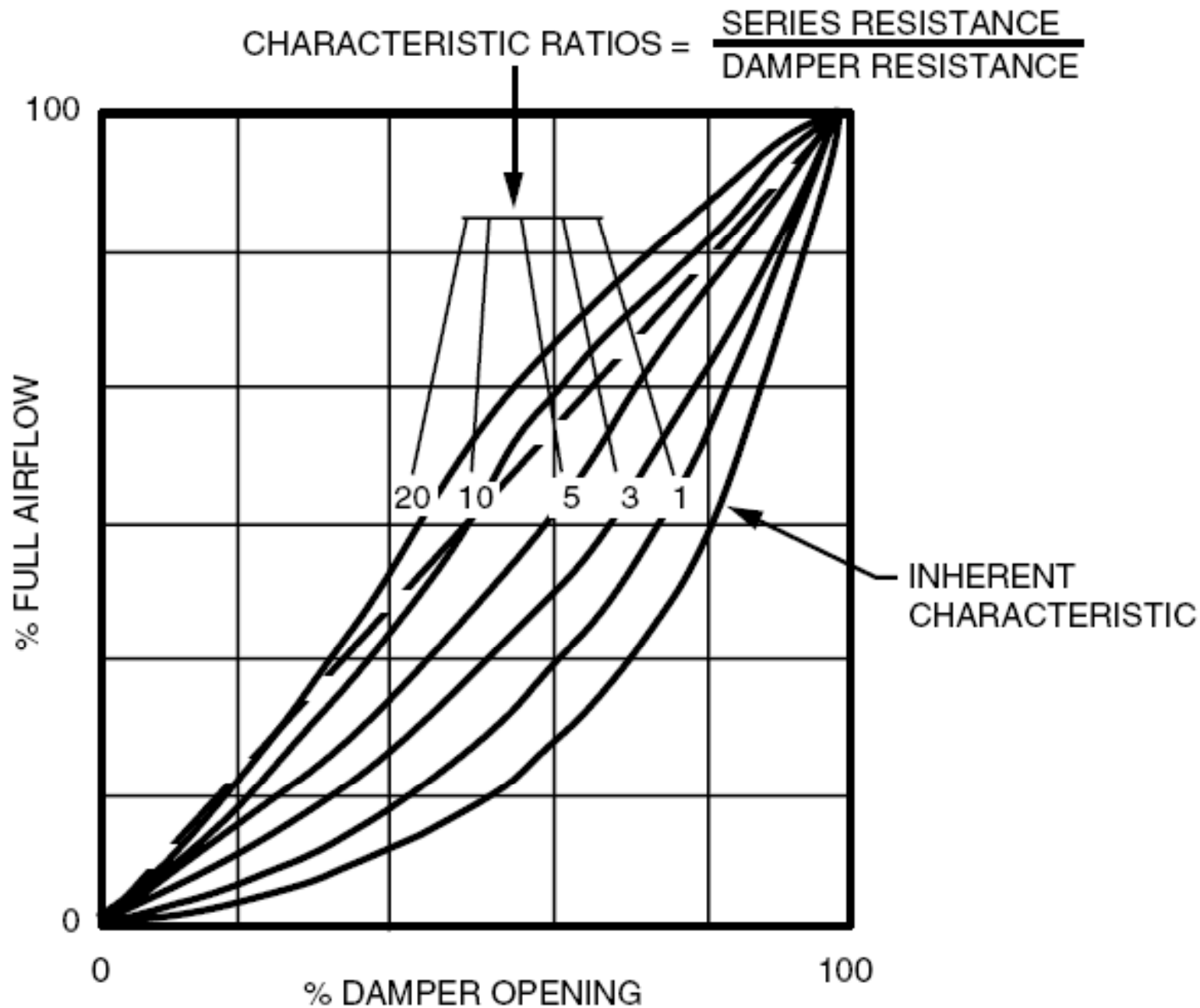
Damper system characteristics of opposed blade dampers

Control Dampers

- Damper characteristics (cont'd)
  - 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)
    - Total resistance = damper resistance + series resistance
    - Characteristic ratio
      - = series resistance /damper resistance
      - = total resistance/damper resistance – 1

Control Dampers

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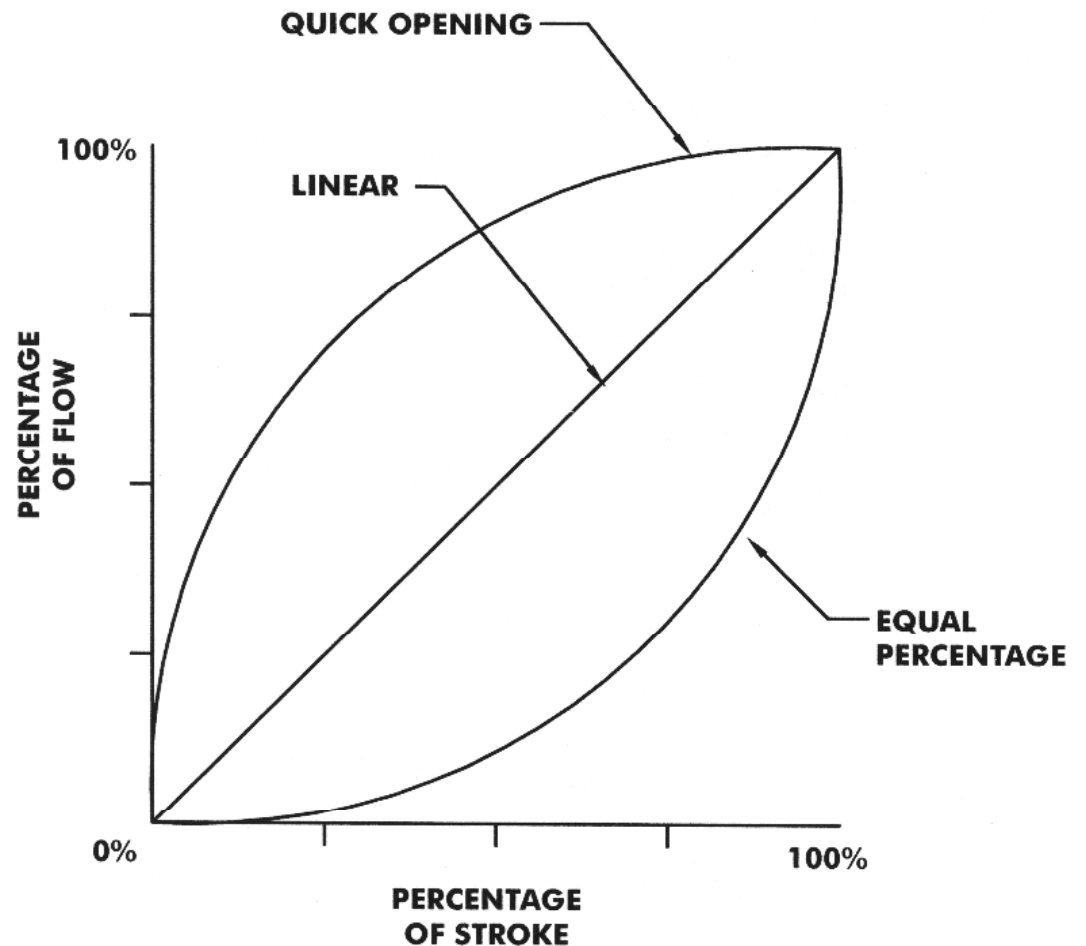
Control Dampers

- 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
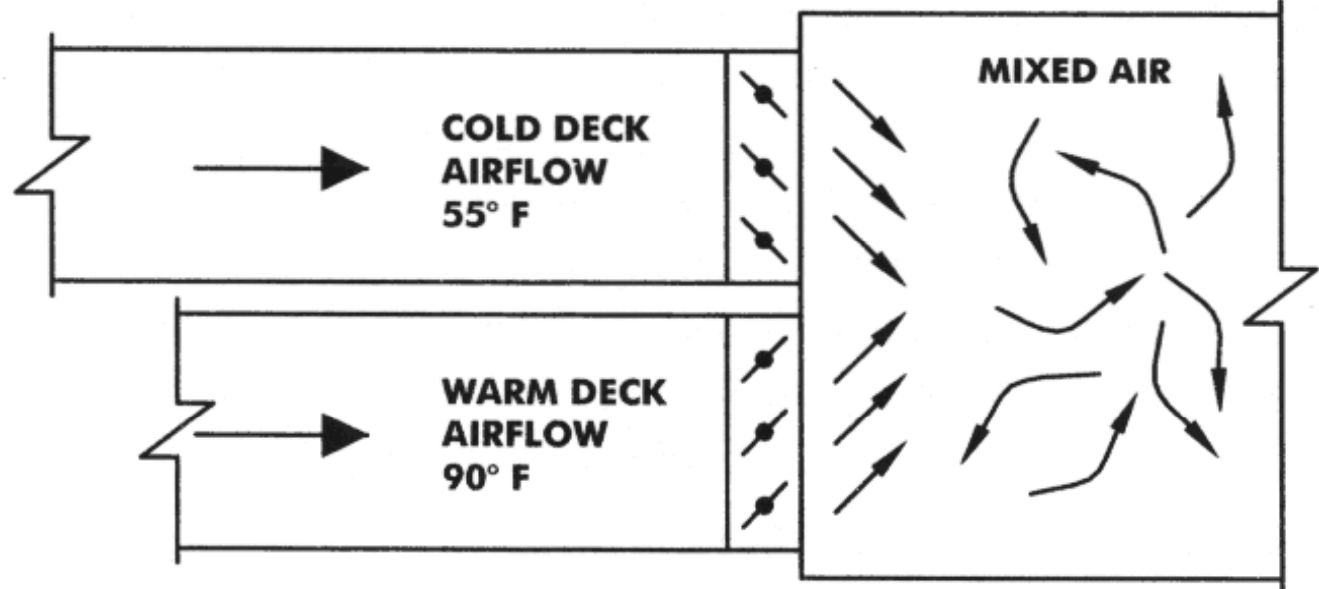
COLD DECK AIRFLOW 55° F

WARM DECK AIRFLOW 90° F

COLDER AIR

WARMER AIR

PARALLEL BLADE DAMPERS

COLD DECK AIRFLOW 55° F

WARM DECK AIRFLOW 90° F

MIXED AIR

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

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
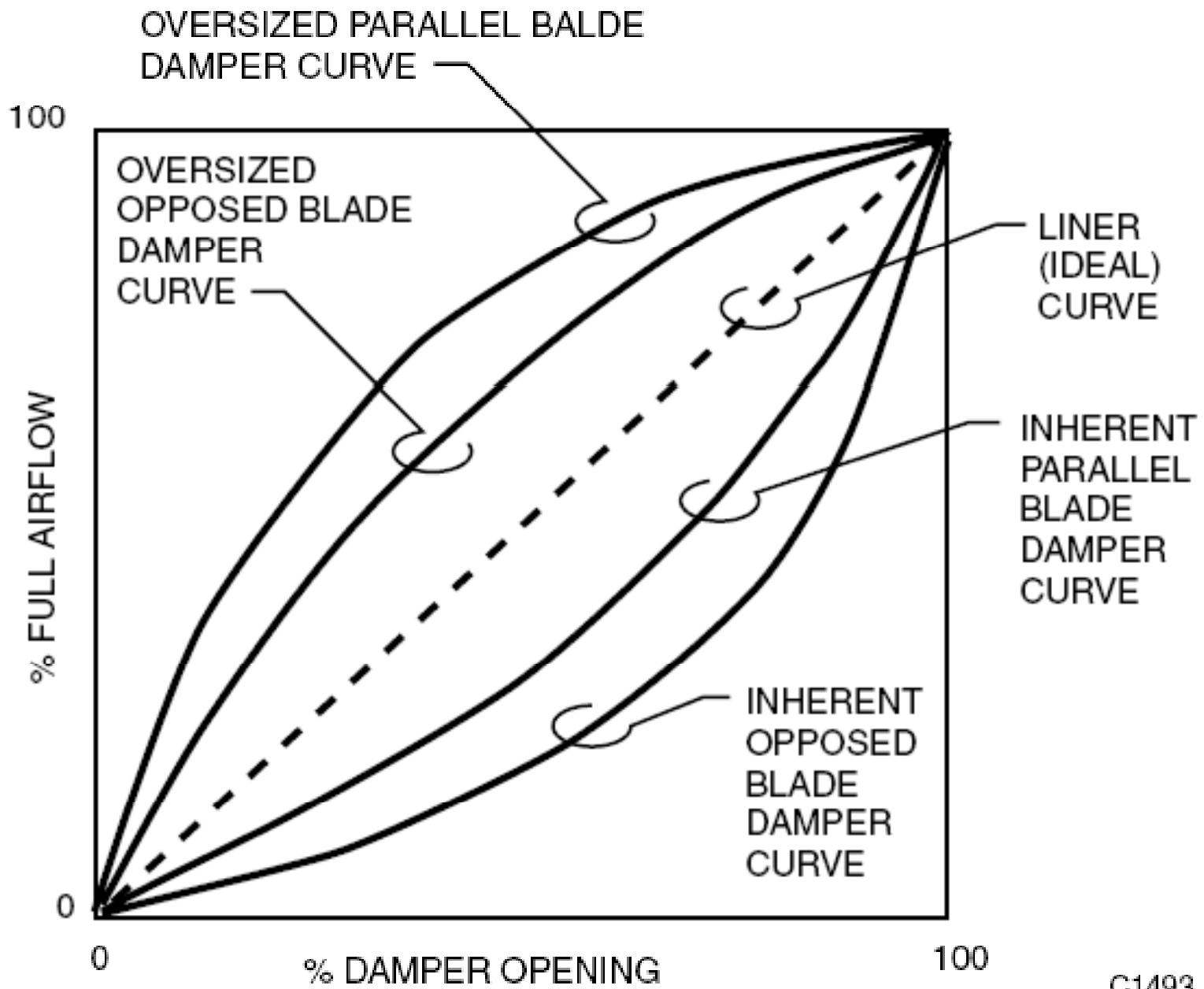
Comparison of oversized parallel versus
oversized opposed blade dampers
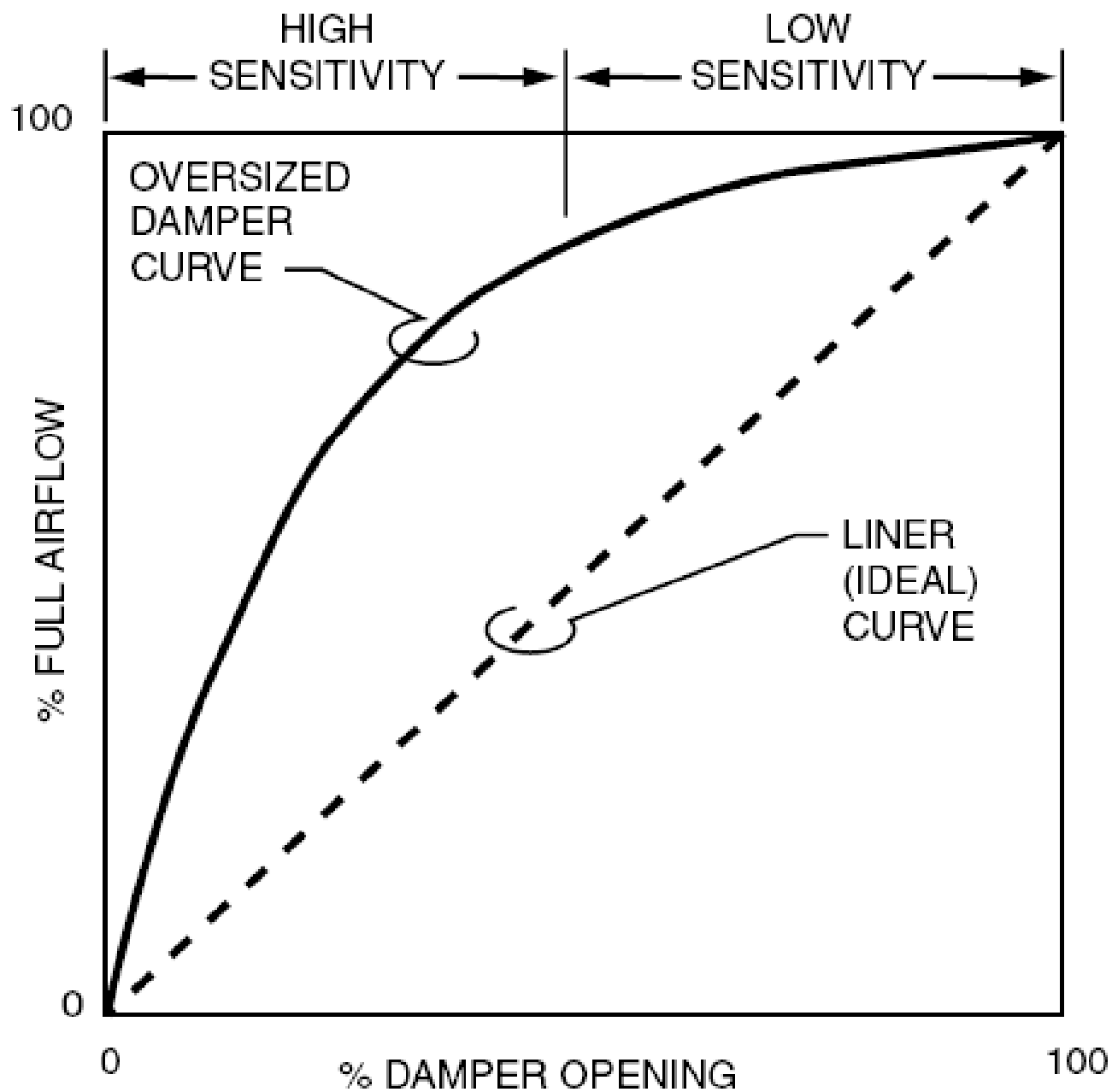
Effects of oversized damper on system sensitivity

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

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

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

EA

RA

OA
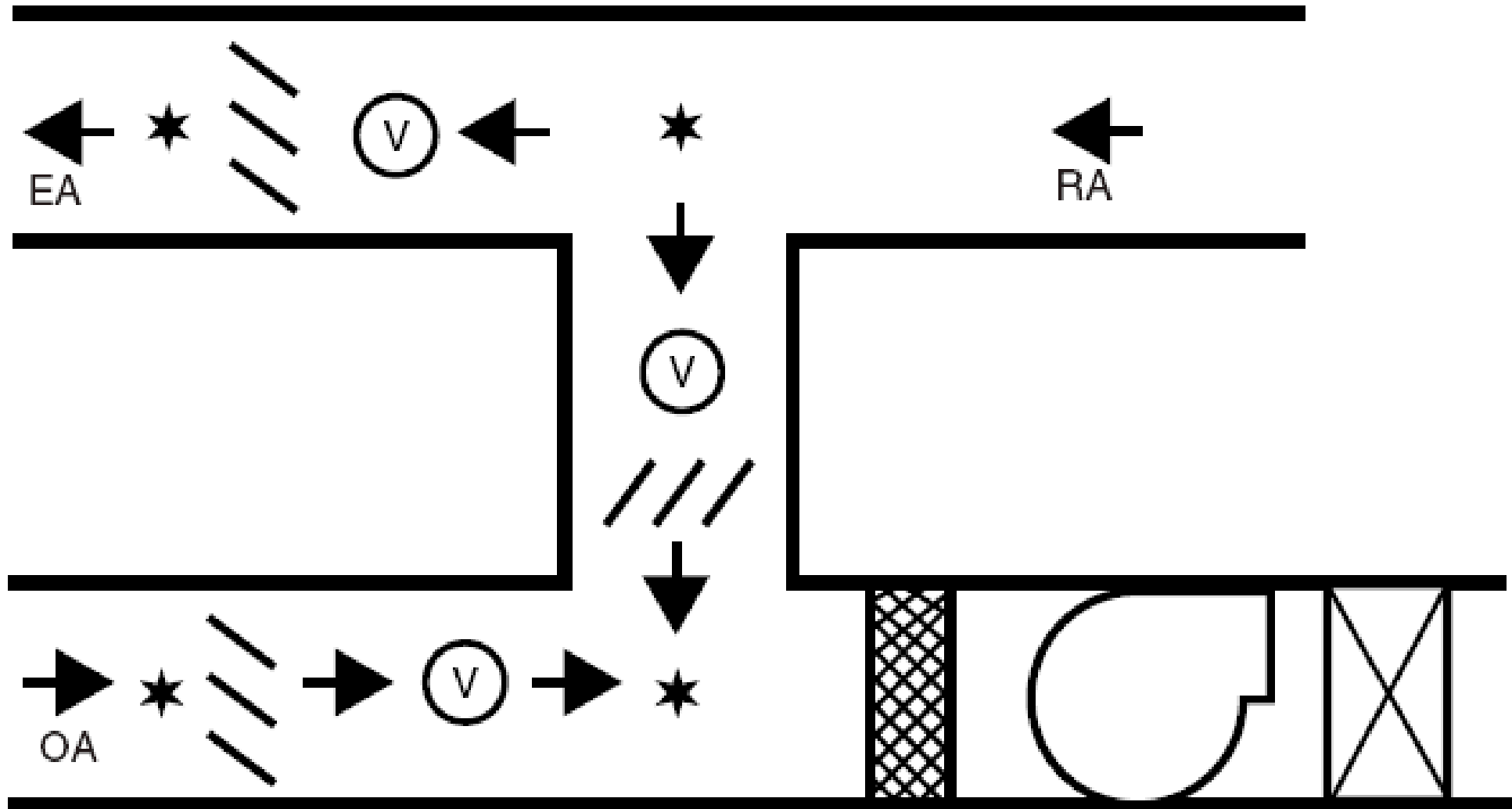
✱ POINTS OF CONSTANT PRESSURE

Ⓥ PATHS OF VARIABLE FLOW

C2393

Mixed air control system (parallel blade dampers)

Mixed air system with louvers

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

Table 4. Damper Sizing Procedure.

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

[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.

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

Table 5. Damper Sizing Example.

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

What will happen if the damper is oversized?

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

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: $$\text{Ratio} = (0.0798 \times \text{damper area m}^2)^{0.1007} \times \frac{\text{Damper area (m}^2)}{\text{Duct area (m}^2)}$$ For opposed blade dampers, the free area ratio is found: $$\text{Ratio} = (0.0180 \times \text{damper area m}^2)^{0.0849} \times \frac{\text{Damper area (m}^2)}{\text{Duct area (m}^2)}$$
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: $$\text{Approach velocity (m}^3\text{/s)} = \frac{\text{Airflow (m}^3\text{/s)}}{\text{Duct Area (m}^2)}$$
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.

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

Table 7. Pressure Drop Calculation Example.

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

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