Hardware Components

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- Control valves
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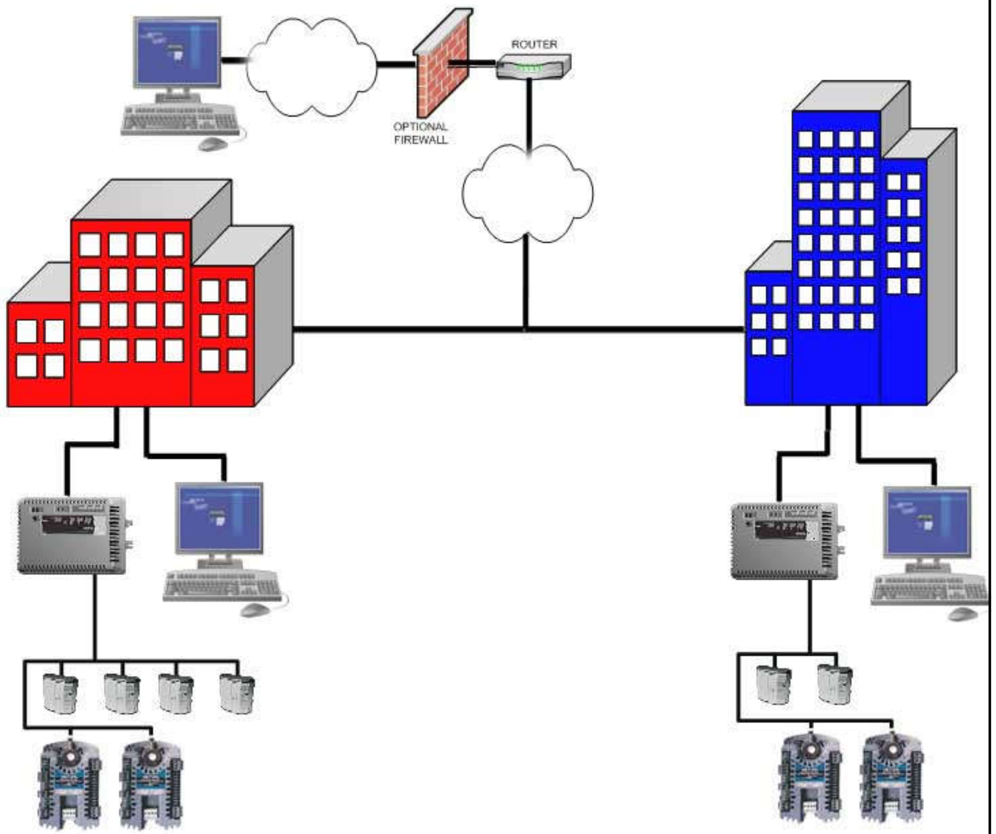
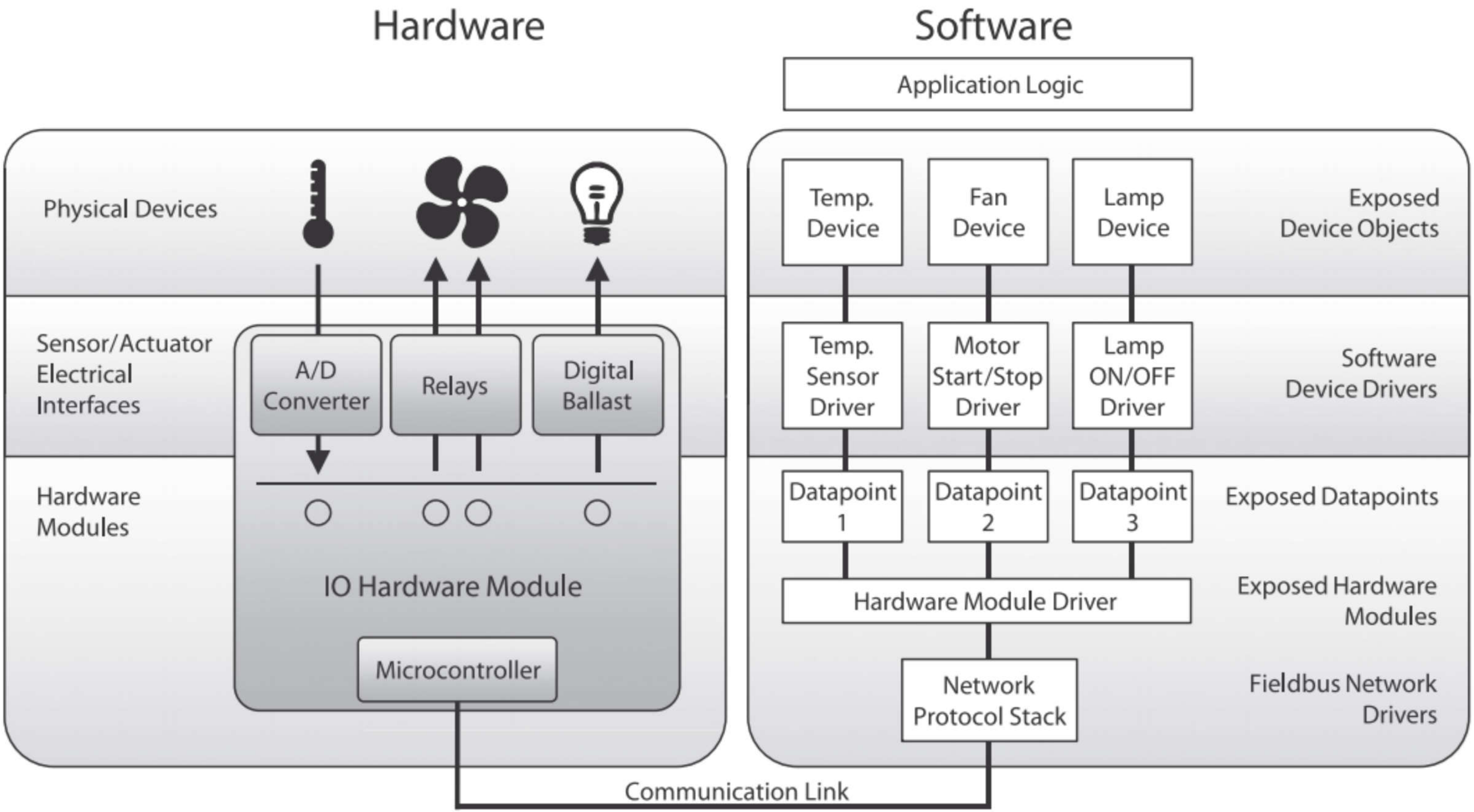
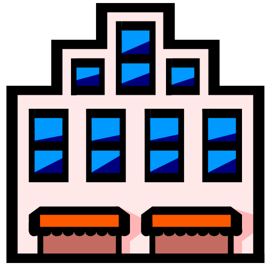


Building automation system hardware and software stack

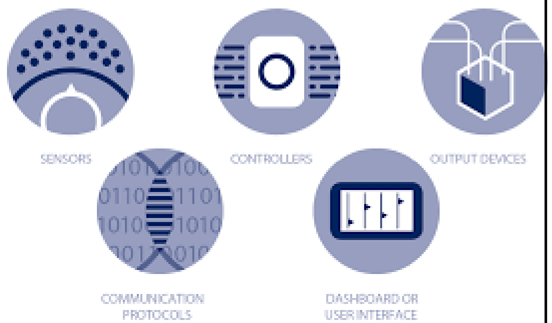


(Source: Domingues P., Carreira P., Vieira R. & Kastner W., 2016. Building automation systems: Concepts and technology review, *Computer Standards and Interfaces*, 45: 1-12. http://dx.doi.org/10.1016/j.csi.2015.11.005)

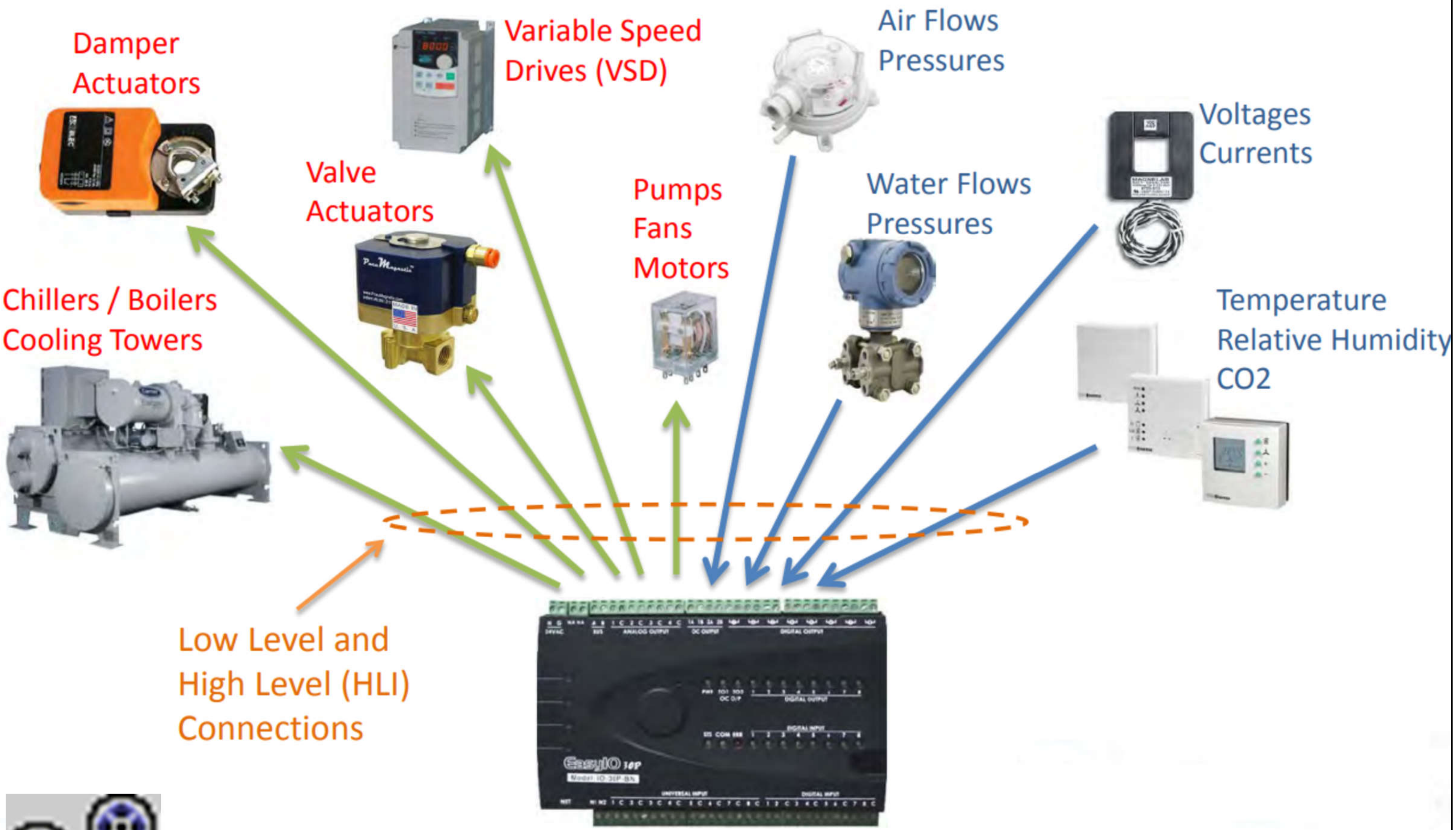
System components



- Typical components of BAS:
  - Sensors (e.g. temperature, humidity, lighting level)
  - Controllers (the “brain” of BAS)
  - Output devices (e.g. actuators & relays, to carry out commands from controllers)
  - Communication protocols (specific language understood by the system components to modify settings or execute commands)
  - Terminal interface (e.g. user interface, workstations)



Typical BAS system components – field devices



Video: Building Automation Systems (BAS) Operations (2:06)
https://youtu.be/ByrysZAwoPI

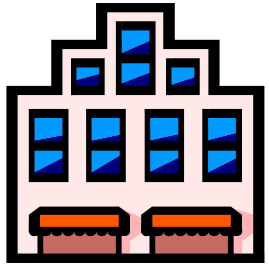
(Source: Andrew Smith, Leader Building Technologies – A.G. Coombs)

System components

- 1. Sensing elements
  - Temperature
  - Humidity/moisture
  - Pressure
  - Flow
  - Proof of operation (e.g. for safety interlock)

- Design factors: accuracy, reliability, repeatability, precision

System components



- 1. (a) Temperature sensing elements can be
  - Bimetal strip
  - A rod-and-tube element
  - A sealed bellows
  - A sealed bellows attached to a capillary or bulb
  - A resistive wire
  - A thermistor or resistance temp. device (RTD)
    - Rapid response to temperature

Temperature sensing elements

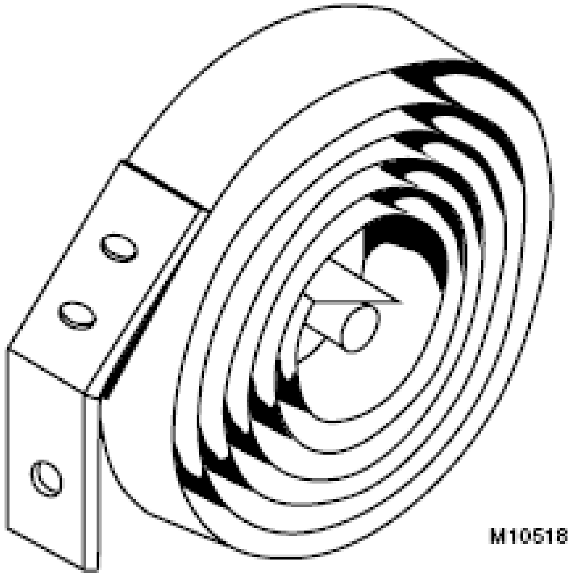


Fig. 49. Coiled Bimetal Element.

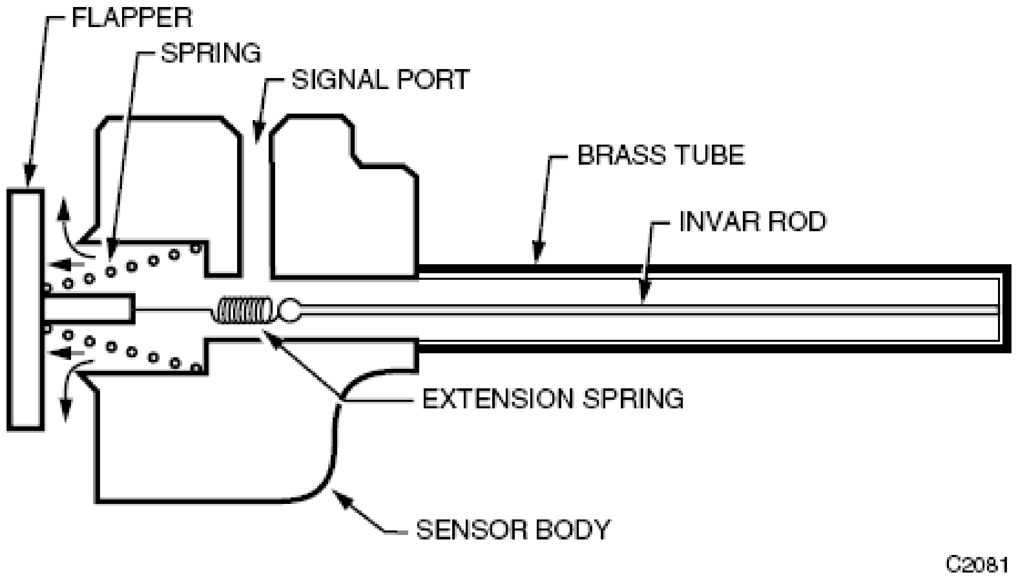


Fig. 50. Rod-and-Tube Element.

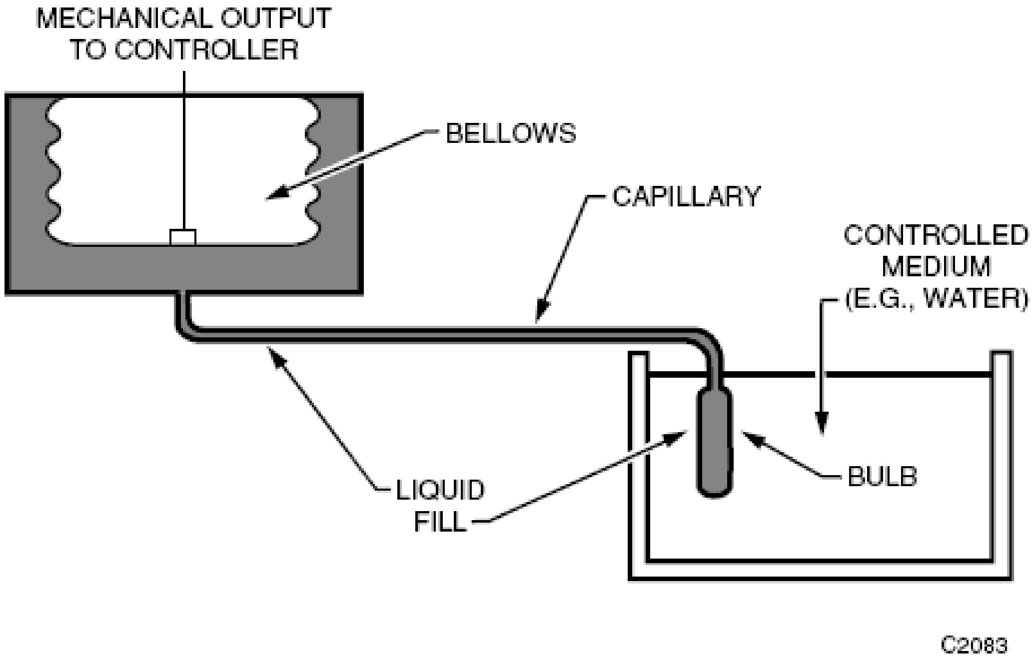


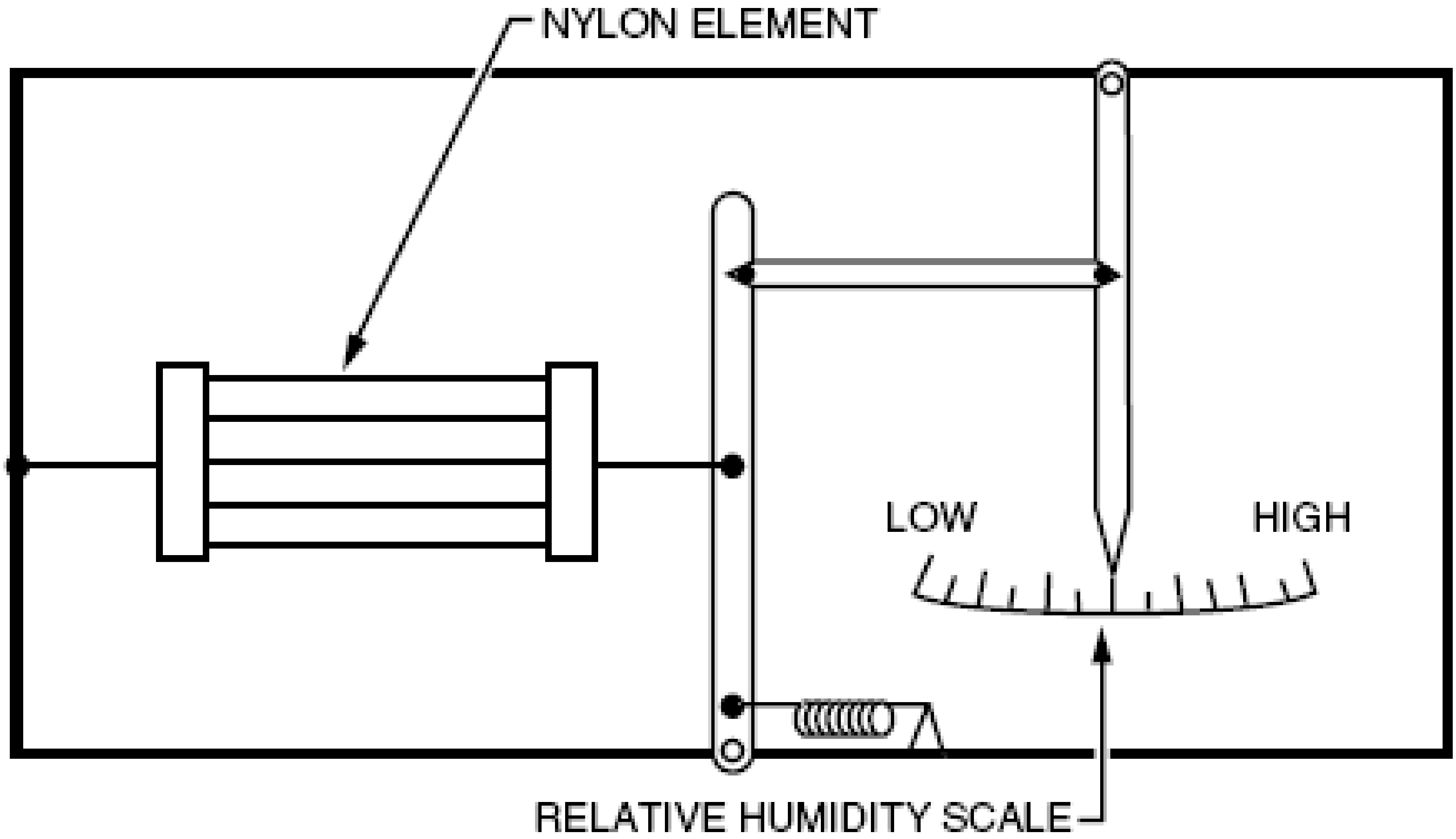
Fig. 51. Typical Remote-Bulb Element.

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

System components

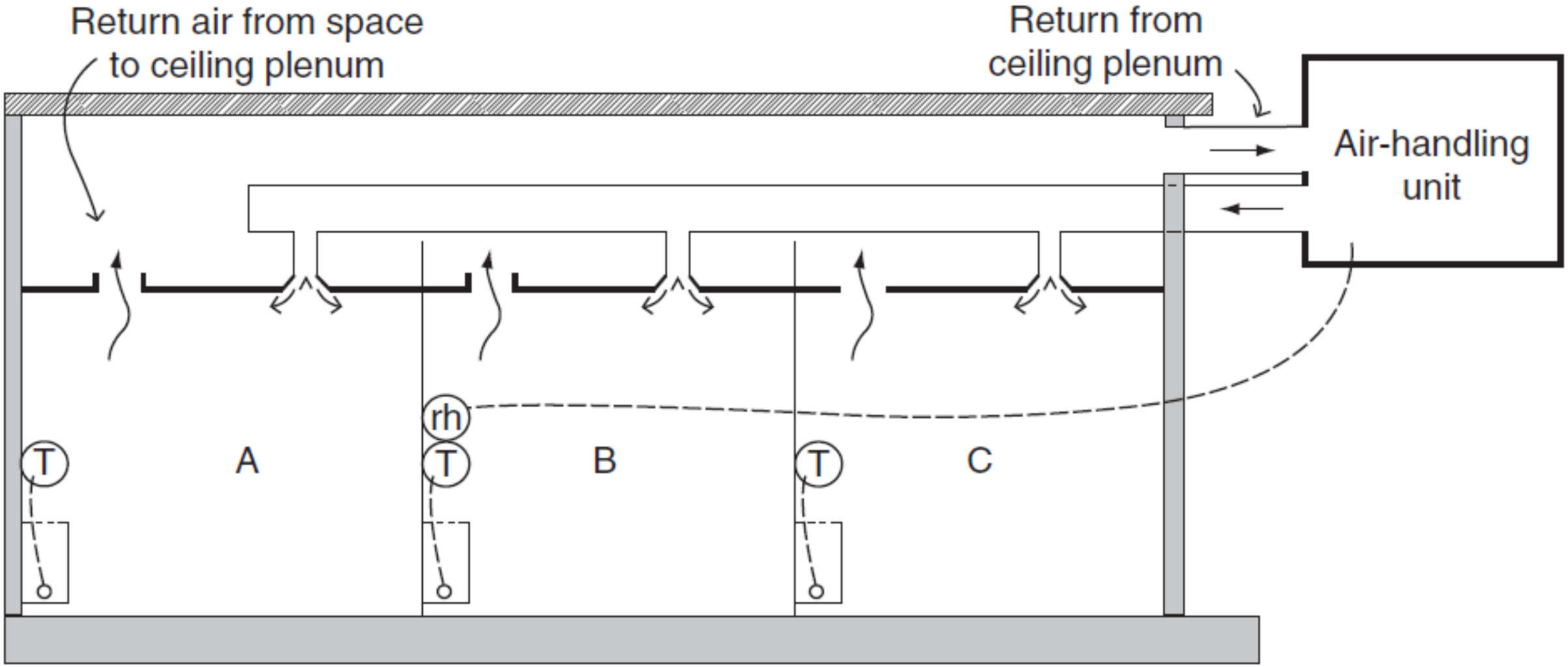
- 1. (b) Moisture sensing elements
  - Mechanical – expand and contract as the moisture level change (“hygroscopic”), e.g. nylon
  - Electronic – change in either the resistance or capacitance of the element
    - Can be affected by temperature changes
    - Temperature compensation may be needed
  - A dew point sensor senses dew point directly or detects condensation on a cooled surface

Typical nylon humidity sensing element



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

Will the position of temp/RH sensors affect the control?

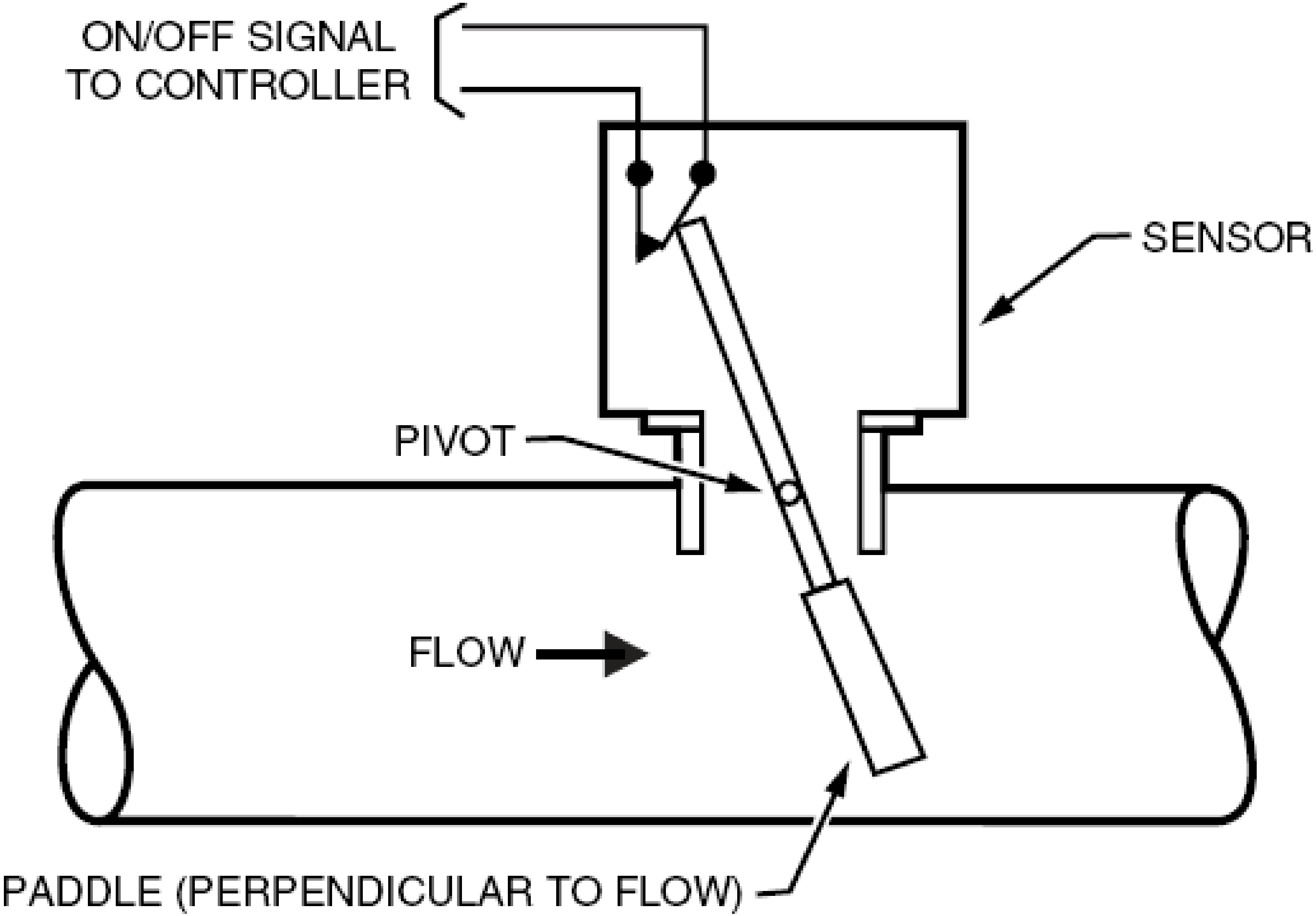


[Source: Montgomery, R. and McDowall, R., 2008. *Fundamentals of HVAC Control Systems*]

System components

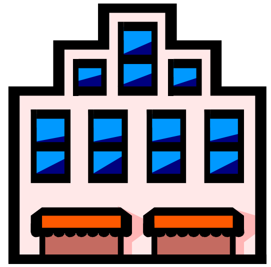
- 1. (c) Flow sensors
  - Sense the rate of liquid and gas flow
    - Flow is difficult to sense accurately under all conditions
  - Selecting the best flow-sensing technique for an application requires considering many aspects
    - Level of accuracy required
    - The medium being measured
    - The degree of variation in the measured flow
  - Flow meters: differential pressure, magnetic, turbine, ultrasonic, vortex shedding & fluidic

Paddle flow sensor



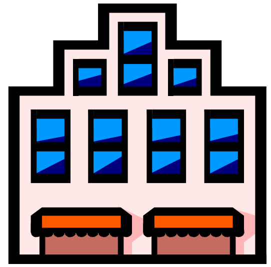
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

System components



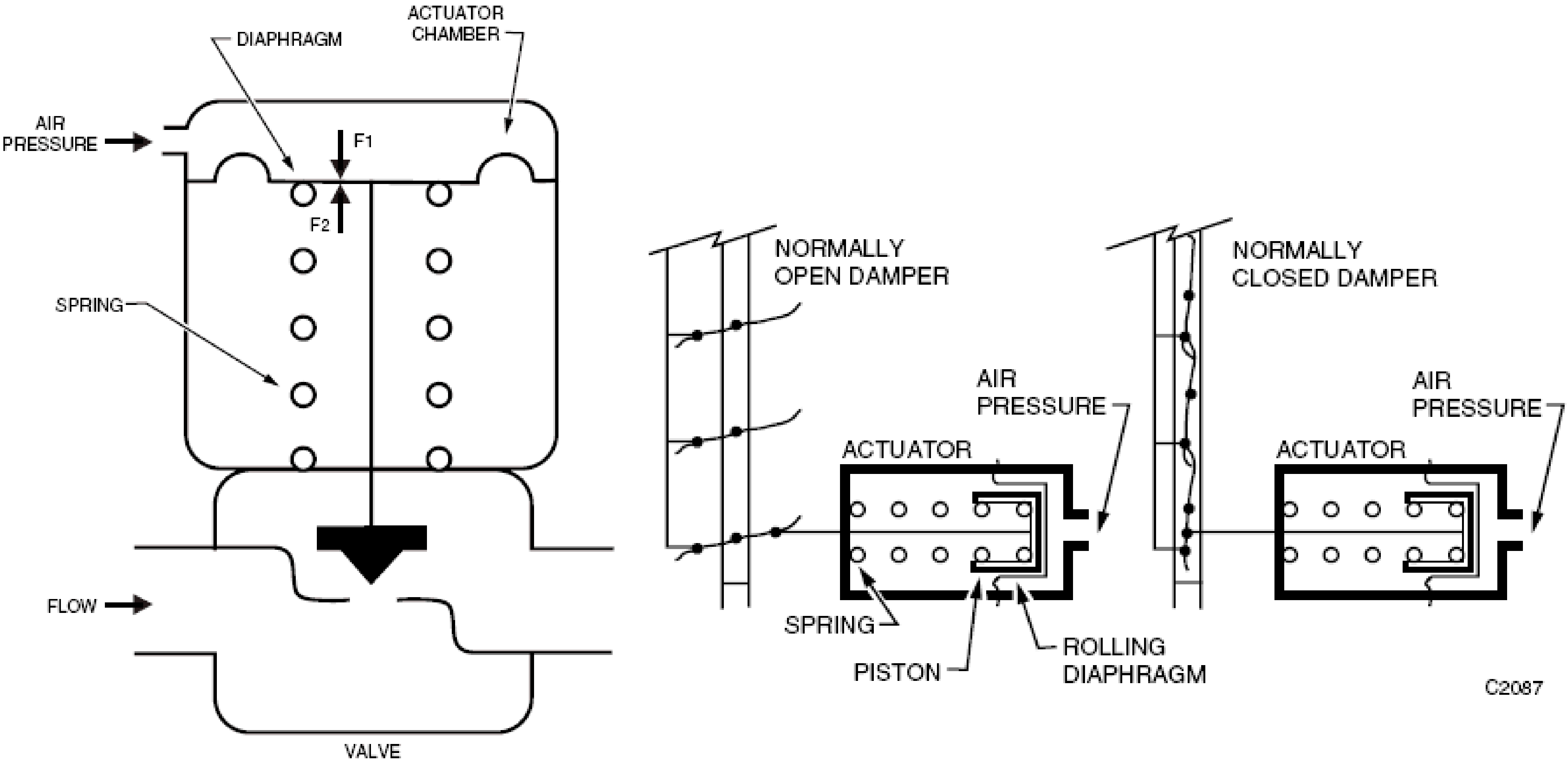
- 2. Transducers
  - Convert (change) sensor inputs and controller outputs from one analogue form to another, more usable, analogue form, e.g. pressure-to-voltage
- 3. Controllers
  - Receive inputs from sensors
  - Compares the input signal with the setpoint
  - Generates an output signal to operate a controlled device

System components



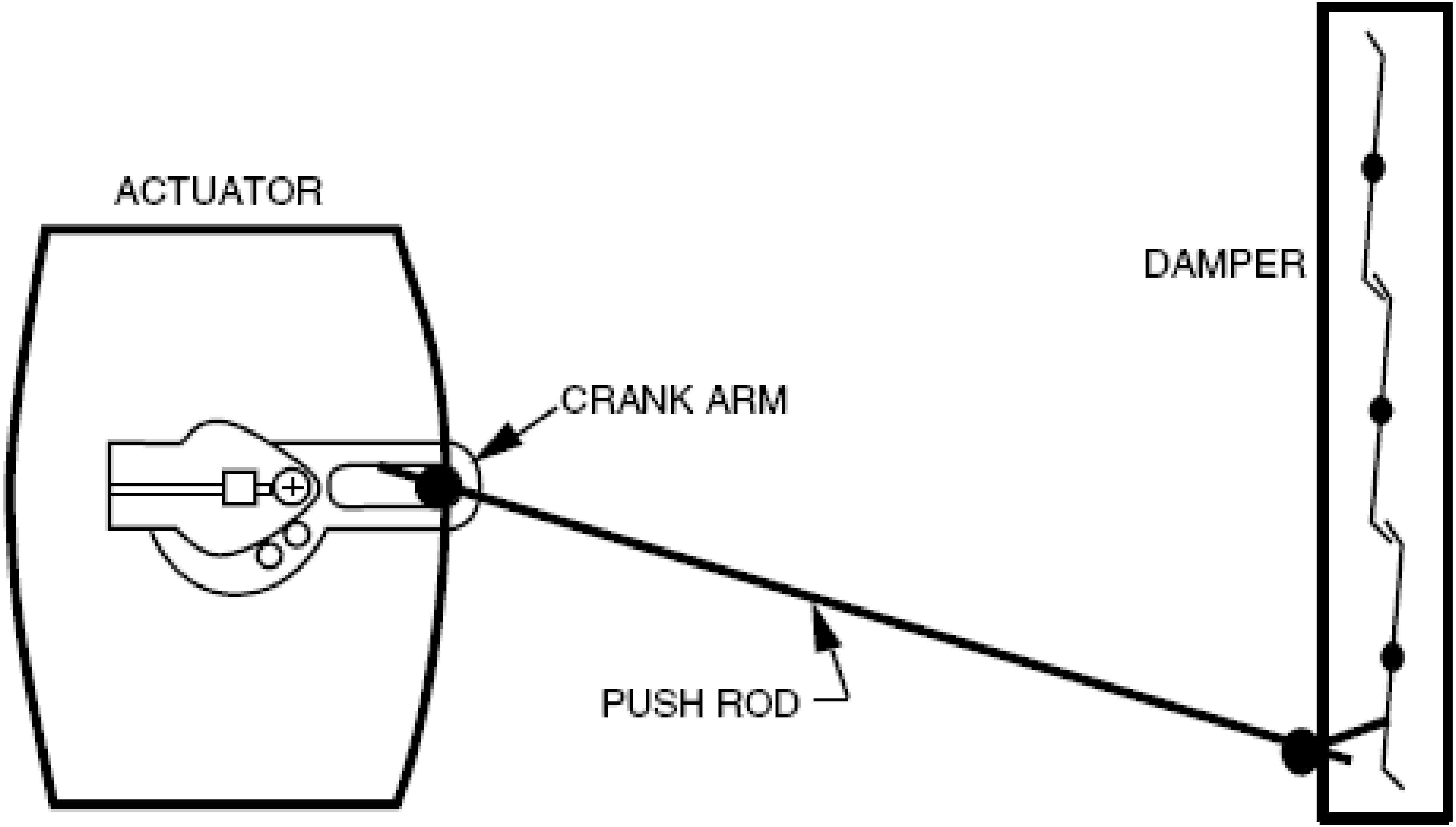
- 4. Actuators
  - A device that converts electric or pneumatic energy into a rotary or linear action, e.g. for valves and dampers (can be pneumatic or electrical controlled)
- 5. Auxiliary element
  - Transducers to convert signals from one type to another (e.g. from pneumatic to electric)
  - Relays and switches to manipulate signals, electric power and compressed air supplies to power the control system
  - Indicating devices to facilitate monitoring of control system activity

Typical pneumatic valve actuator



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

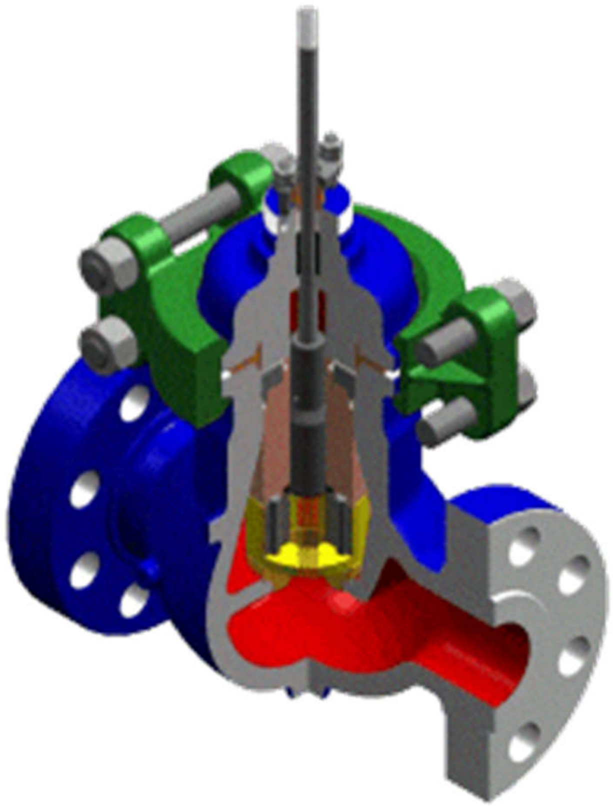
Typical electric damper actuator



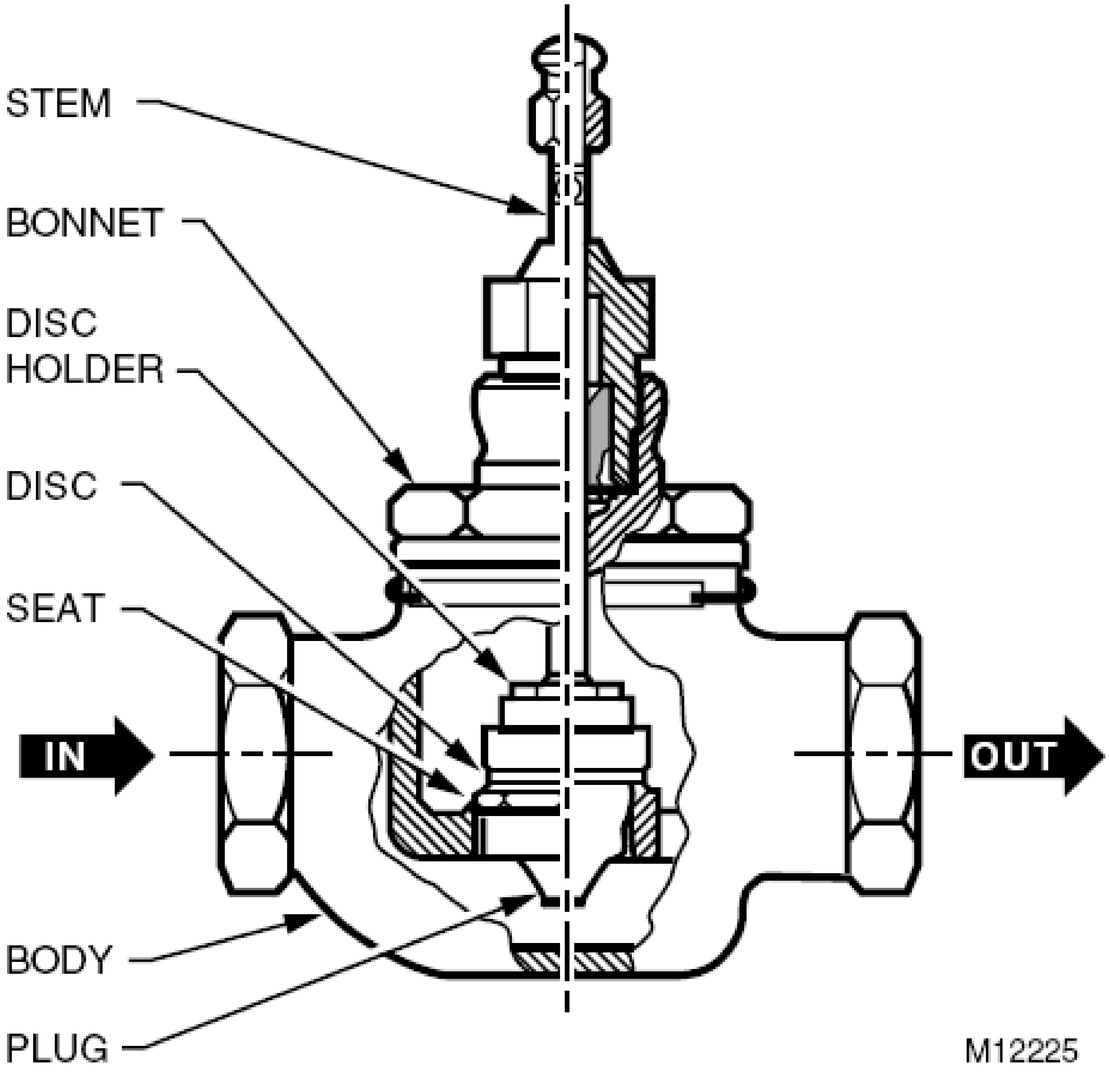
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

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

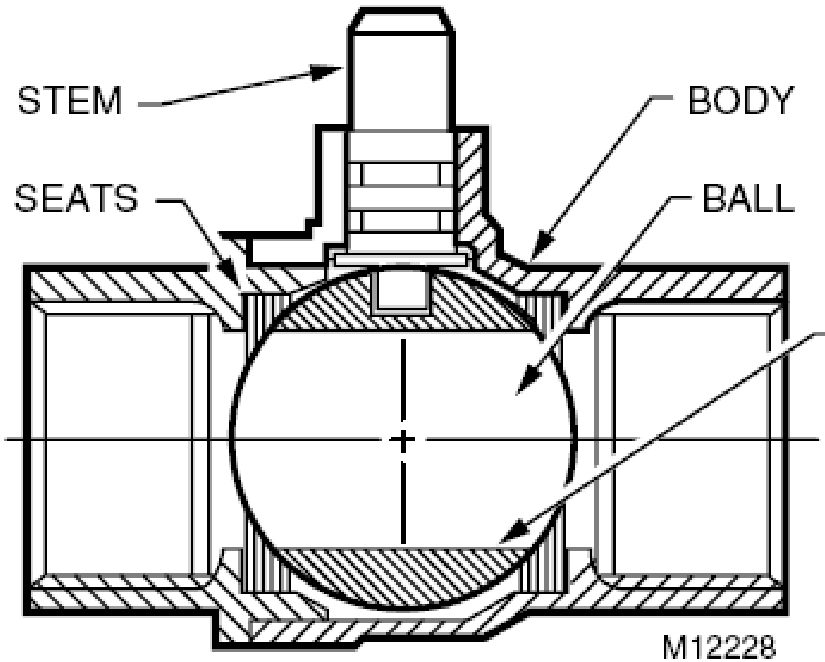


Control valve components

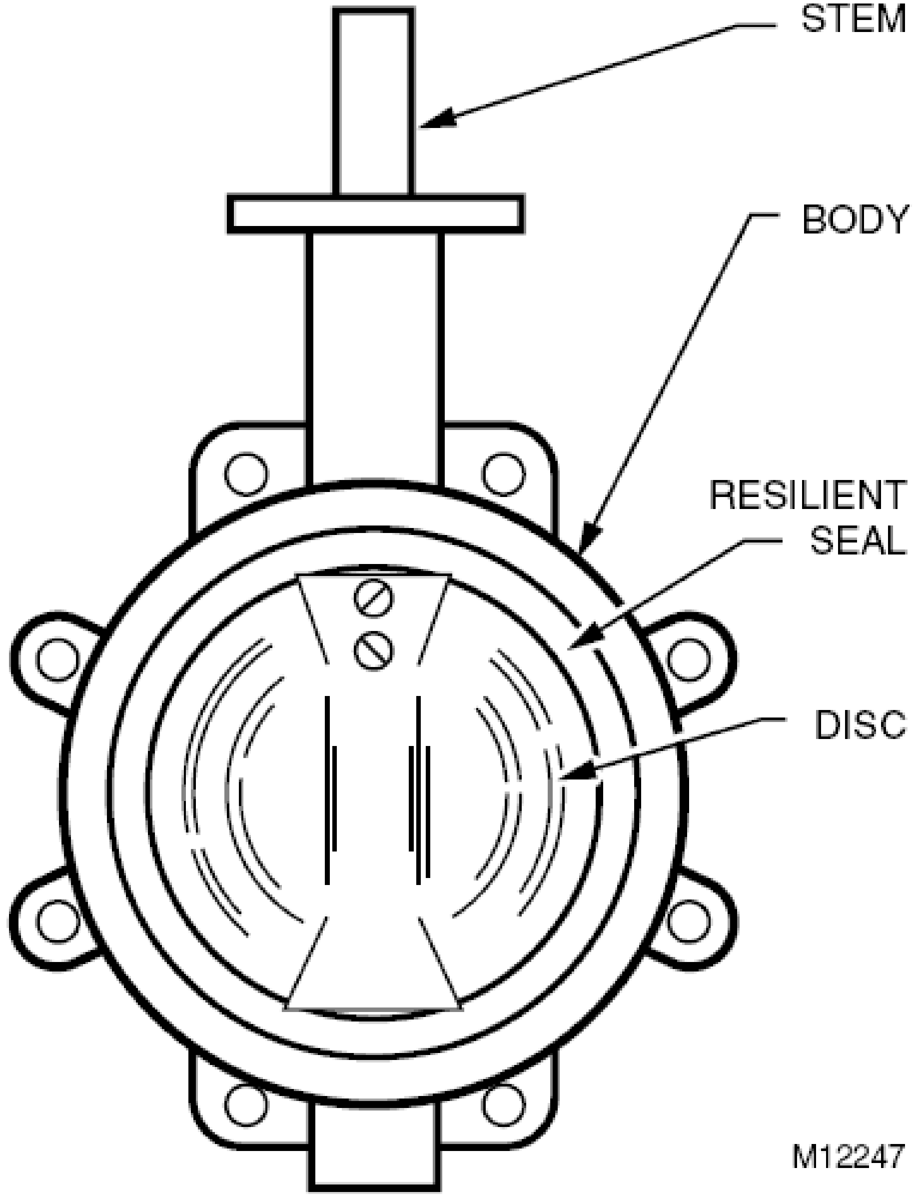


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Examples of ball valve and butterfly valve



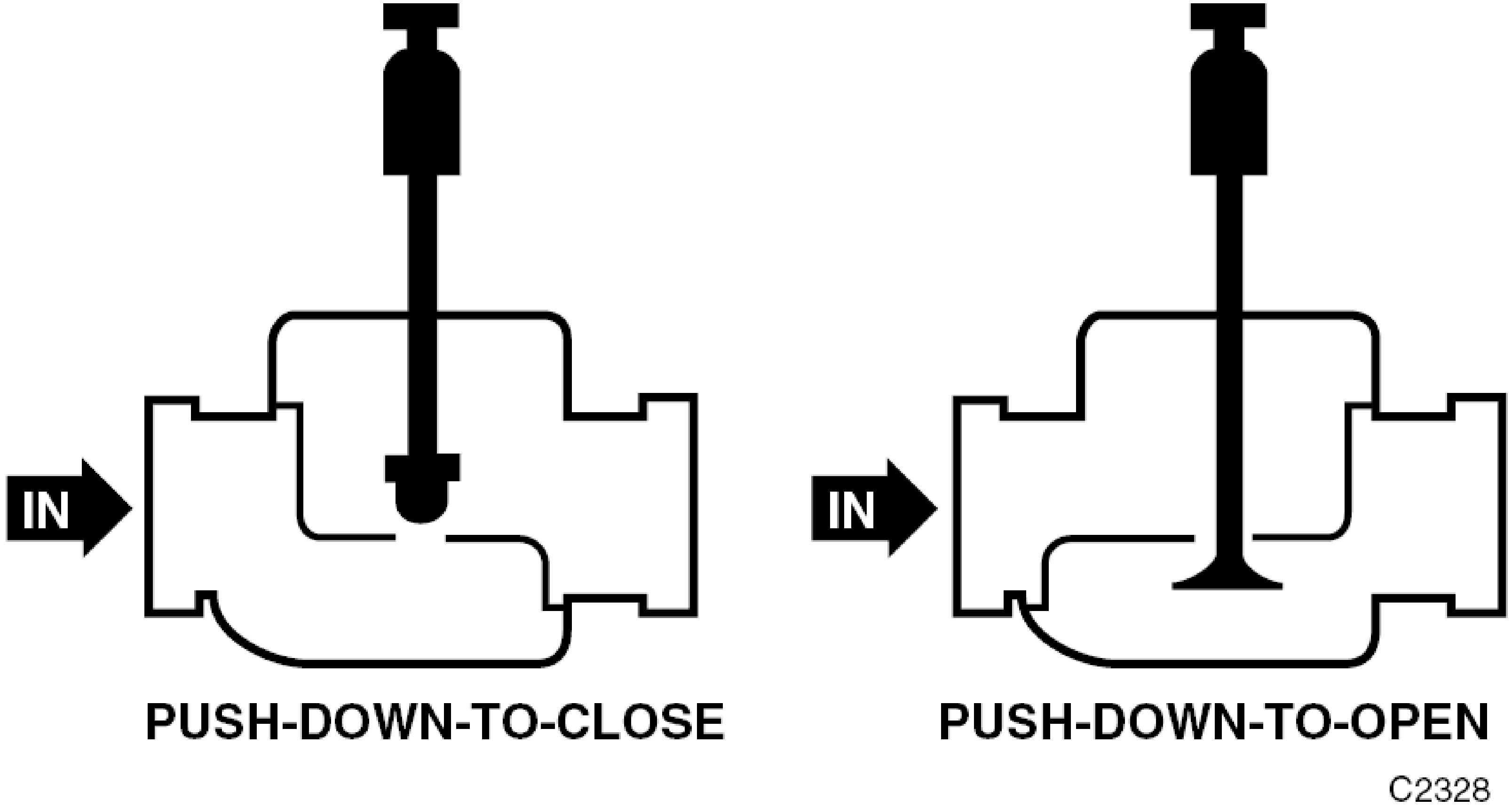
Ball valve



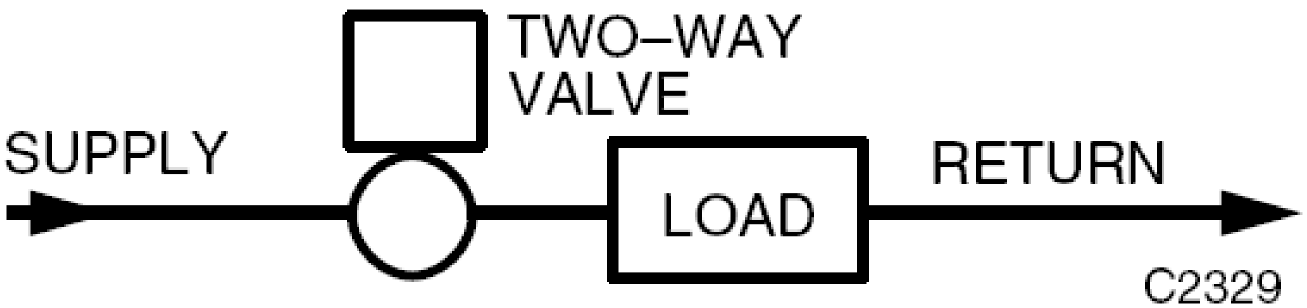
Butterfly valve

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

Two-way valve application

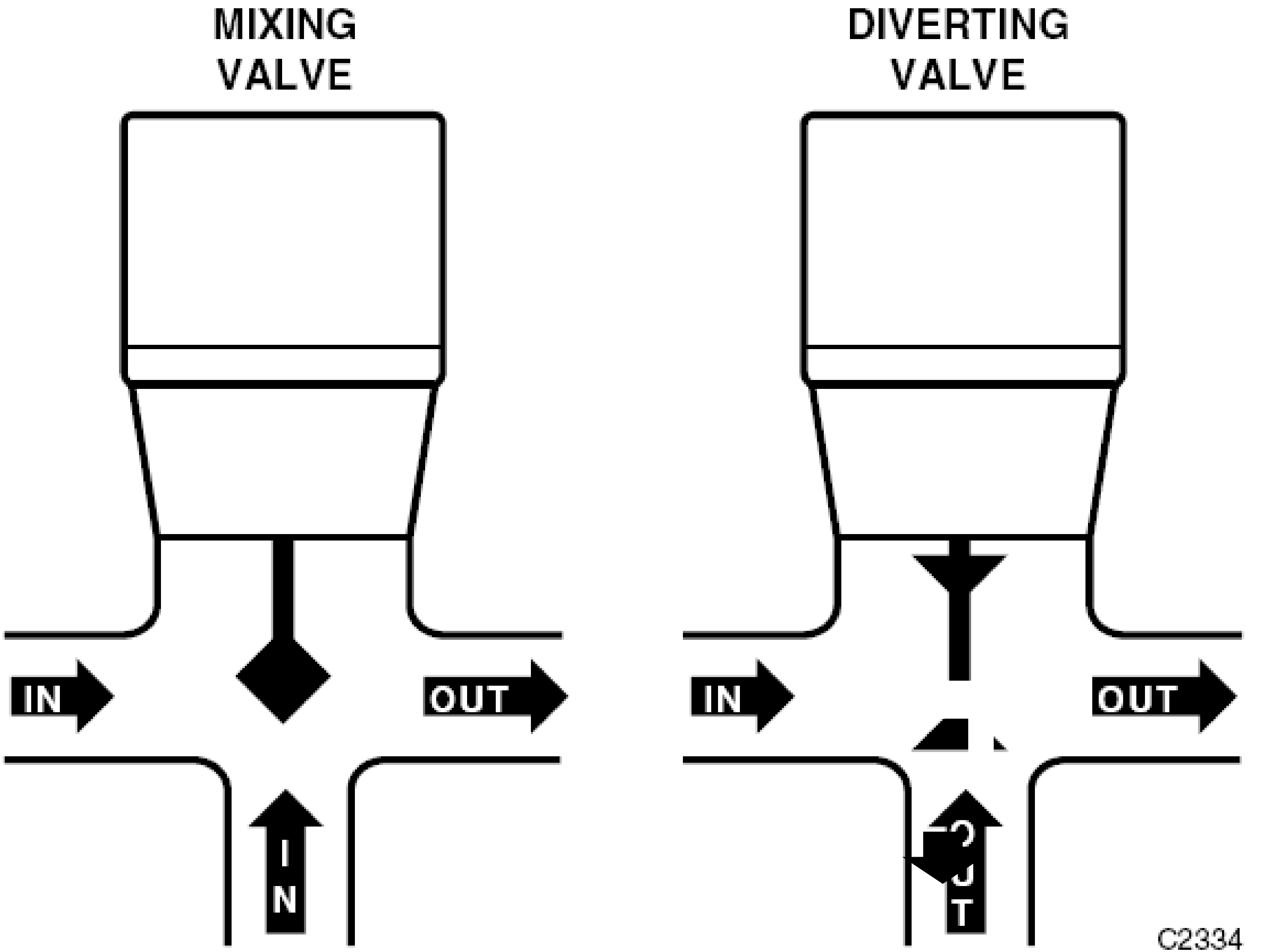


Two-way globe valves



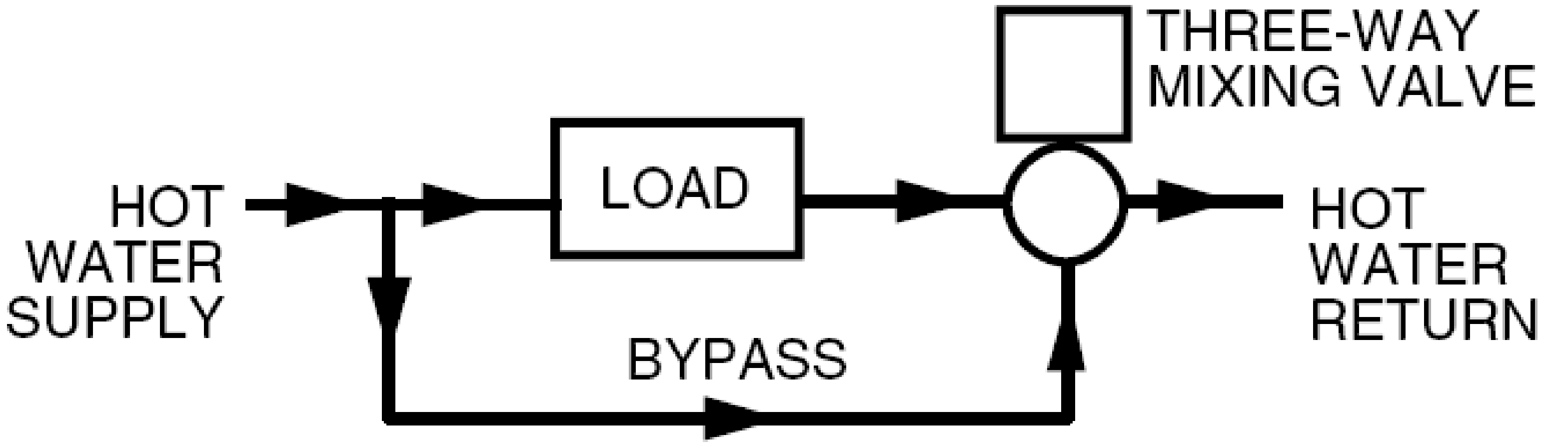
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Examples of three-way valves (mixing and diverting valves)

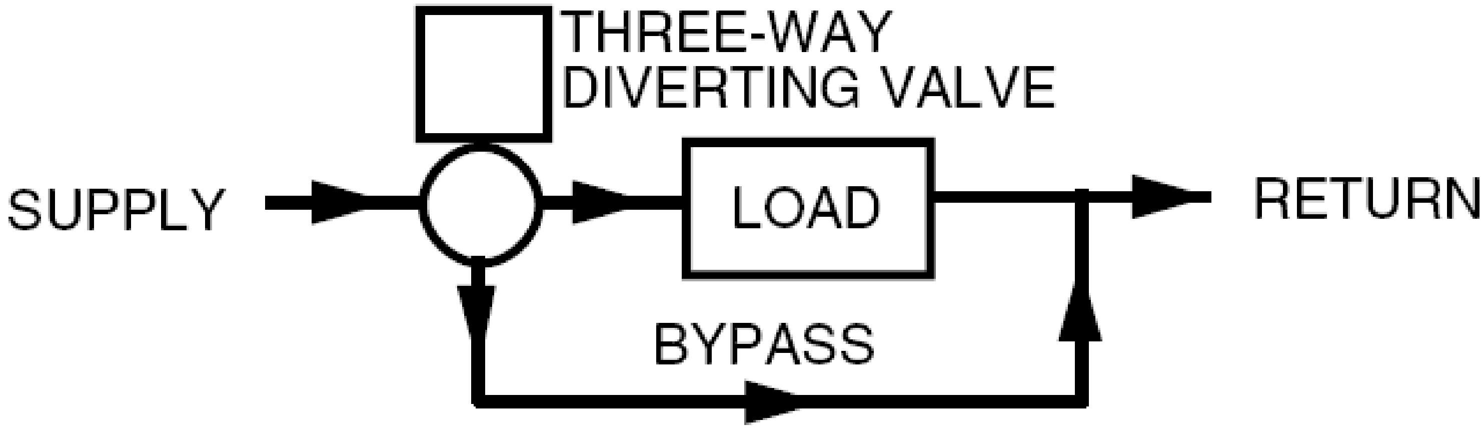


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Three-way valve applications



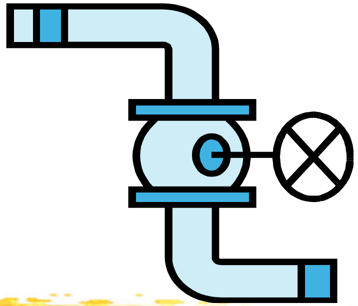
A. LOAD BYPASS IN MIXING VALVE APPLICATION



B. LOAD BYPASS IN DIVERTING VALVE APPLICATION

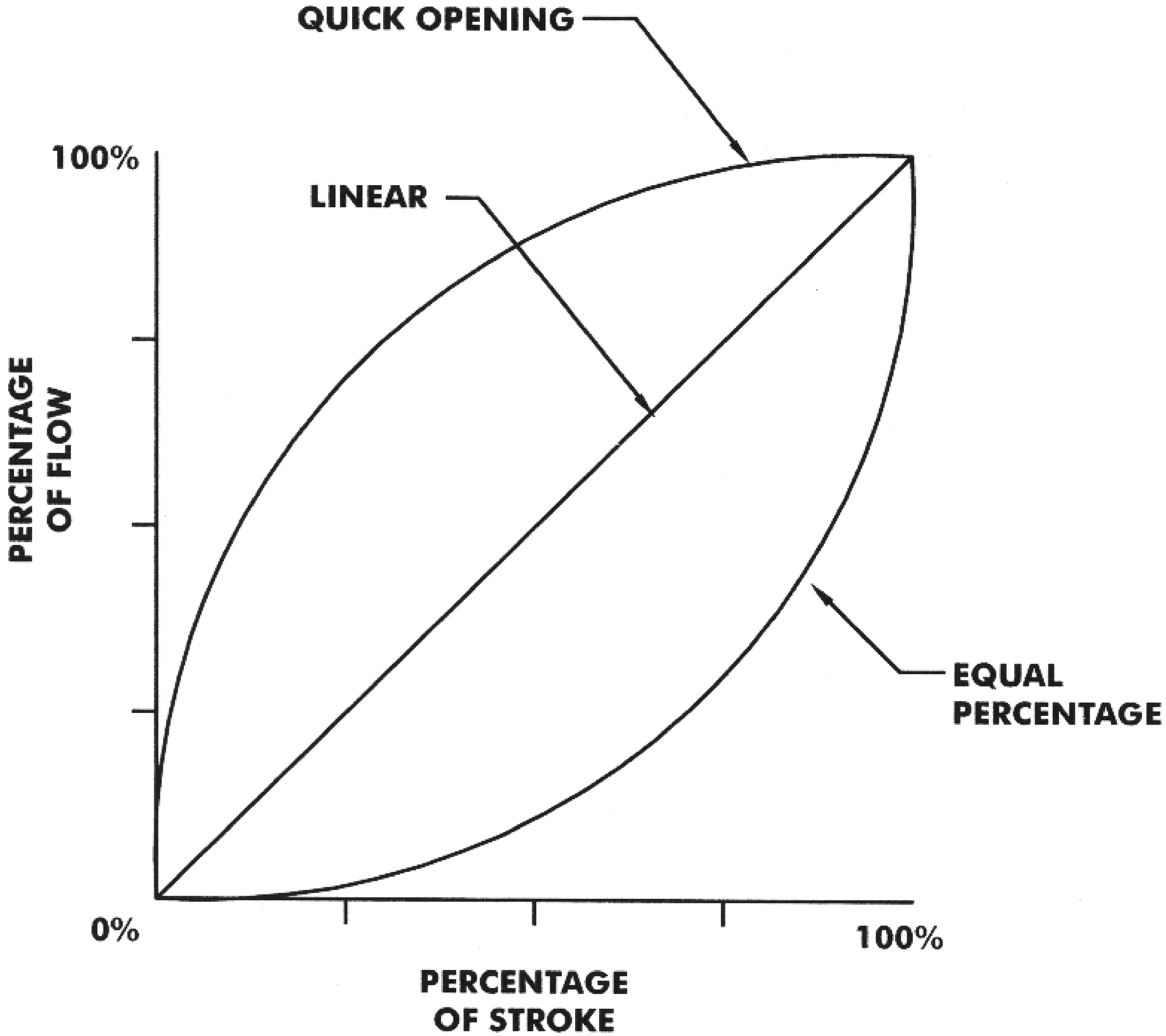
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

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



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

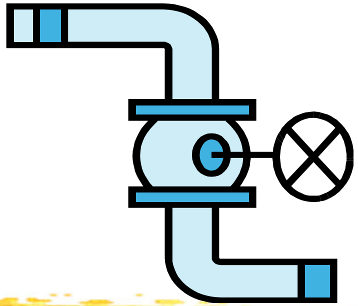
Flow characteristics and applications of various control valves

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.

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

Control valves



- Valve flow terms
  - Rangeability: The ratio of maximum flow to minimum controllable flow
  - Turndown: The ratio of maximum flow to minimum controllable flow of a valve installed in a system. Turndown <= rangeability
  - Flow coefficient (capacity index): Used to state the flow capacity of a control valve for specified conditions

Flow coefficient:

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

q = volume flow (m^3/s)
ρ= fluid density (kg/m^3)
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:

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

Q = volume flow (m^3/h)

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

Selecting 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

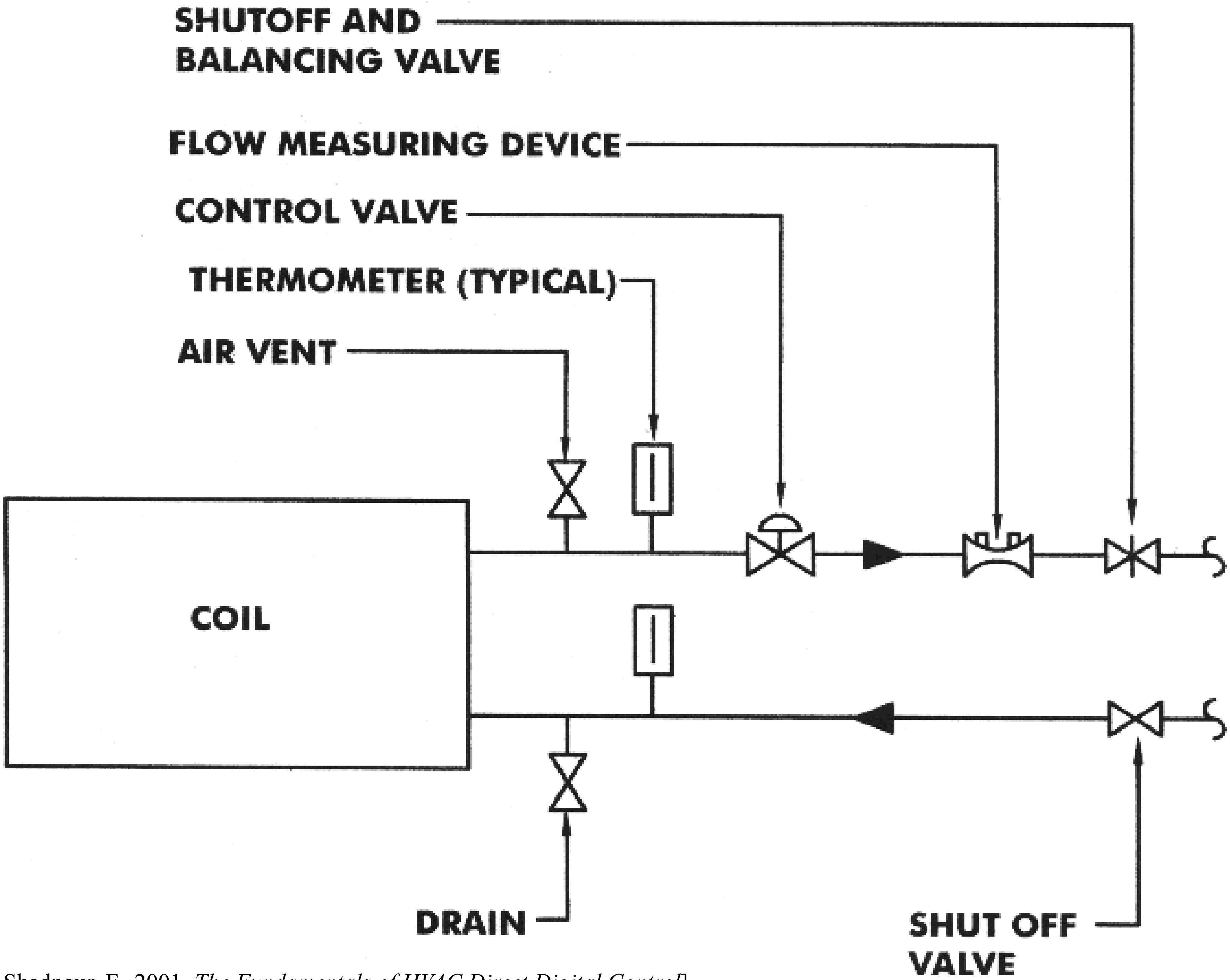
Selecting control valves

- 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?

Selecting 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

Example of control valve location and configuration

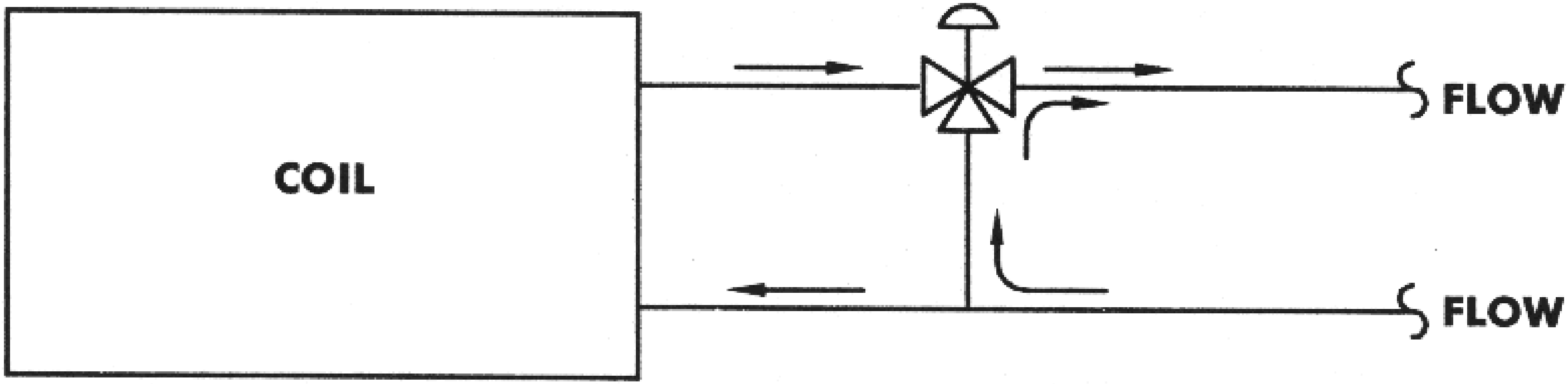


[Source: Shadpour, F., 2001. *The Fundamentals of HVAC Direct Digital Control*]

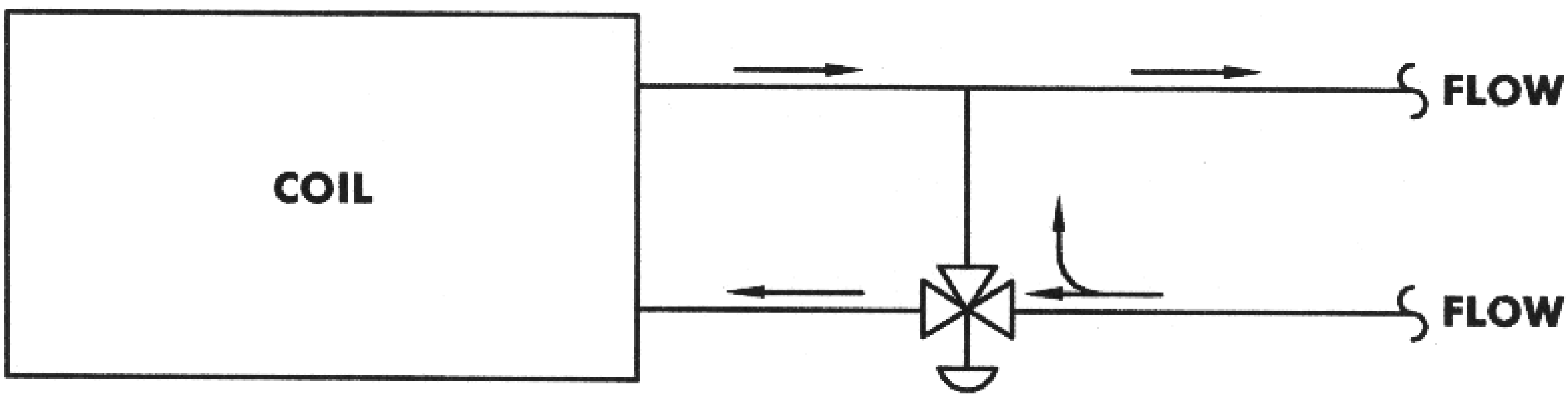
Selecting control valves

- 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)
- 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

Examples of mixing and diverting three-way control valves



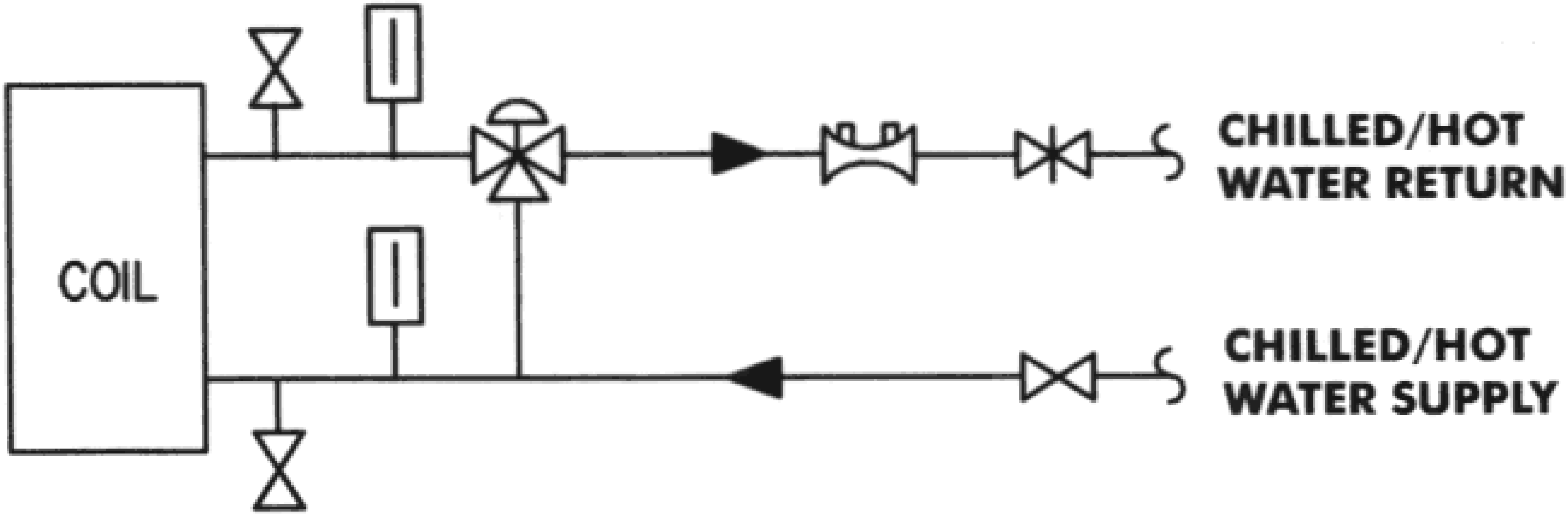
MIXING THREE-WAY CONTROL VALVE



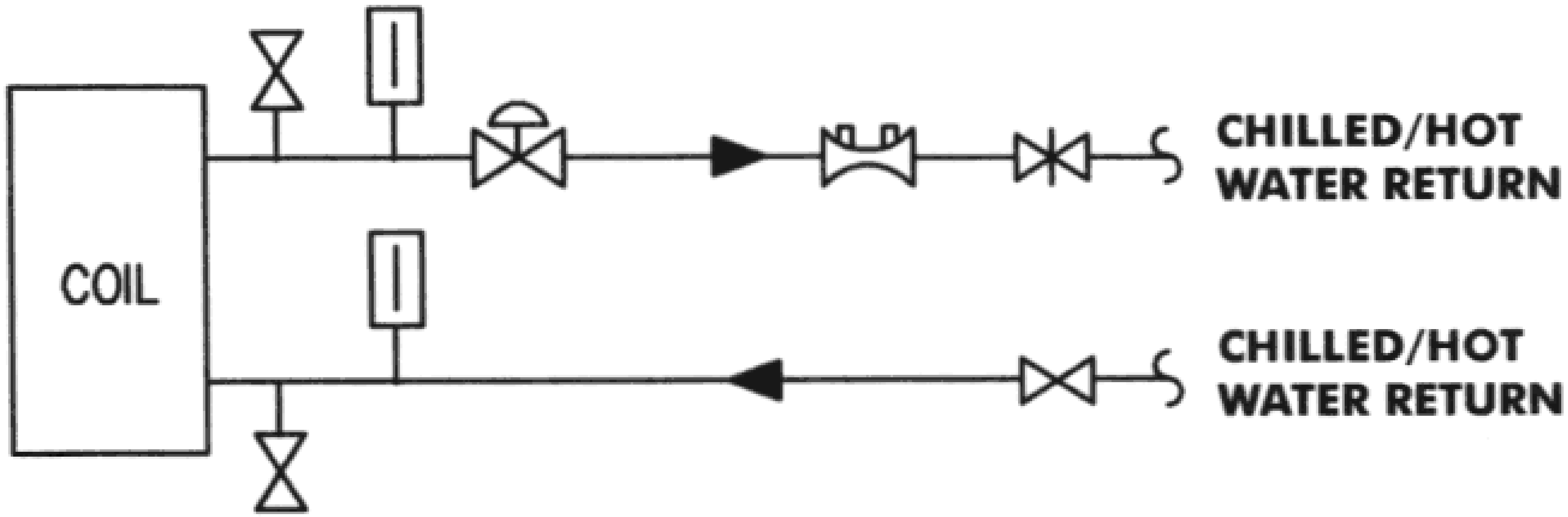
DIVERTING THREE-WAY CONTROL VALVE

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

Three-way and two-way control valves for chilled/hot water piping



CHILLED/HOT WATER PIPING WITH THREE-WAY CONTROL VALVE



CHILLED/HOT WATER PIPING WITH TWO-WAY CONTROL VALVE

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

Selecting control valves

- Selecting/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?

Selecting control valves

- How to size control valves
  - Valve equation: Pressure drop = $(\text{Flow} / \text{Cv})^2$
    - 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!

Selecting 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 m^3/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:

$$K_V = 3.32\sqrt{\frac{1000}{40 \bullet 10}} = 5.2$$

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

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

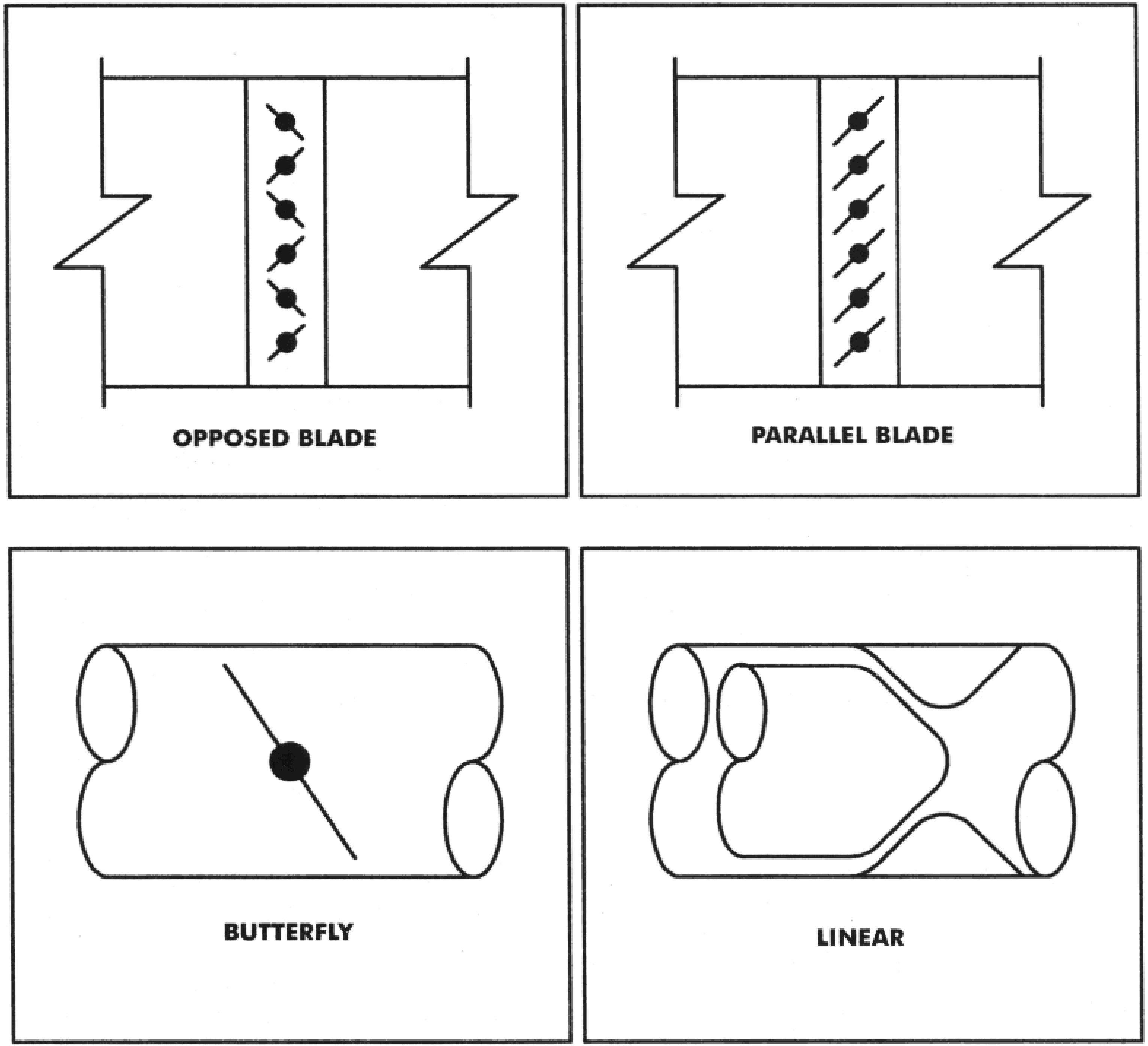
Control dampers

- 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

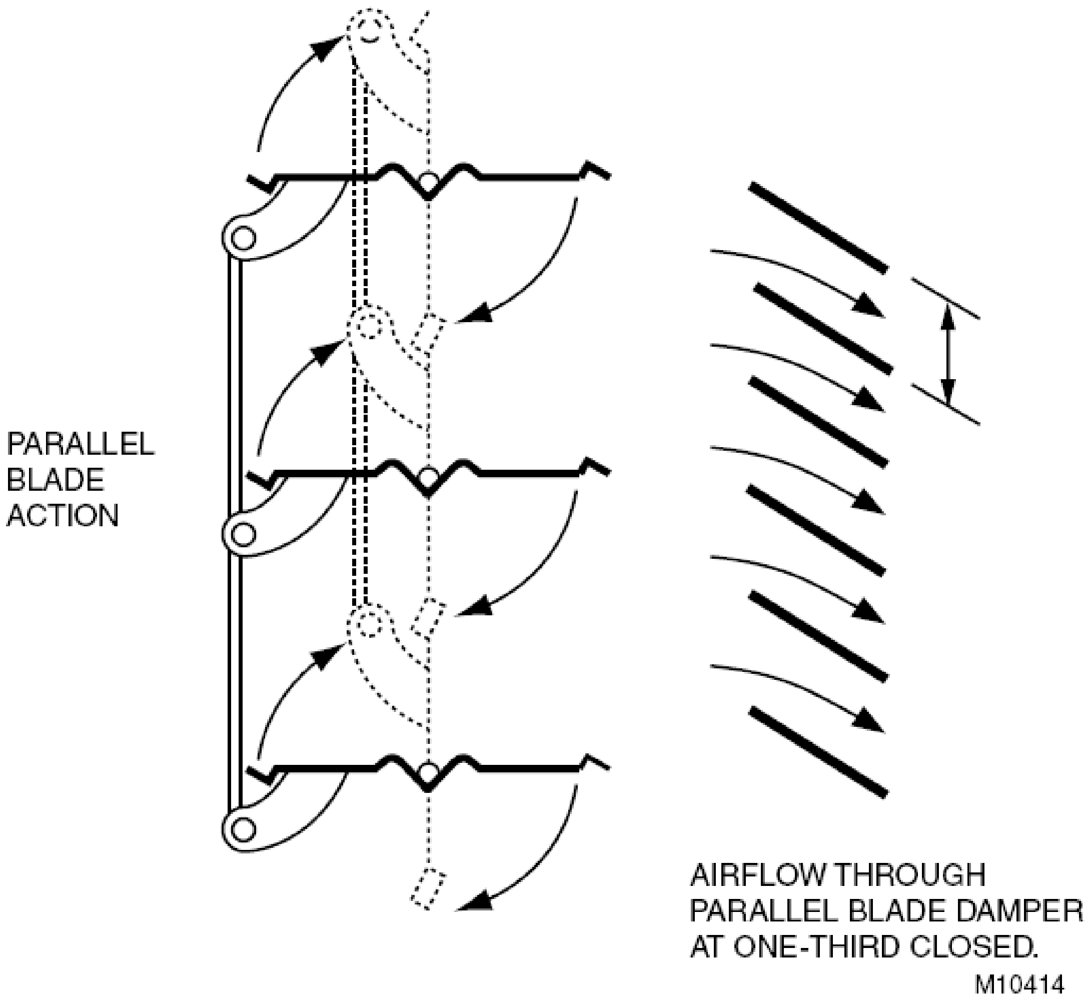
- Common types of control dampers:
  - Opposed blade dampers (e.g. in AHU)
  - Parallel blade dampers
  - Butterfly dampers (e.g. in VAV box)
  - Linear air valves (e.g. in fume hood)
  - Specialty dampers

Four types of control dampers

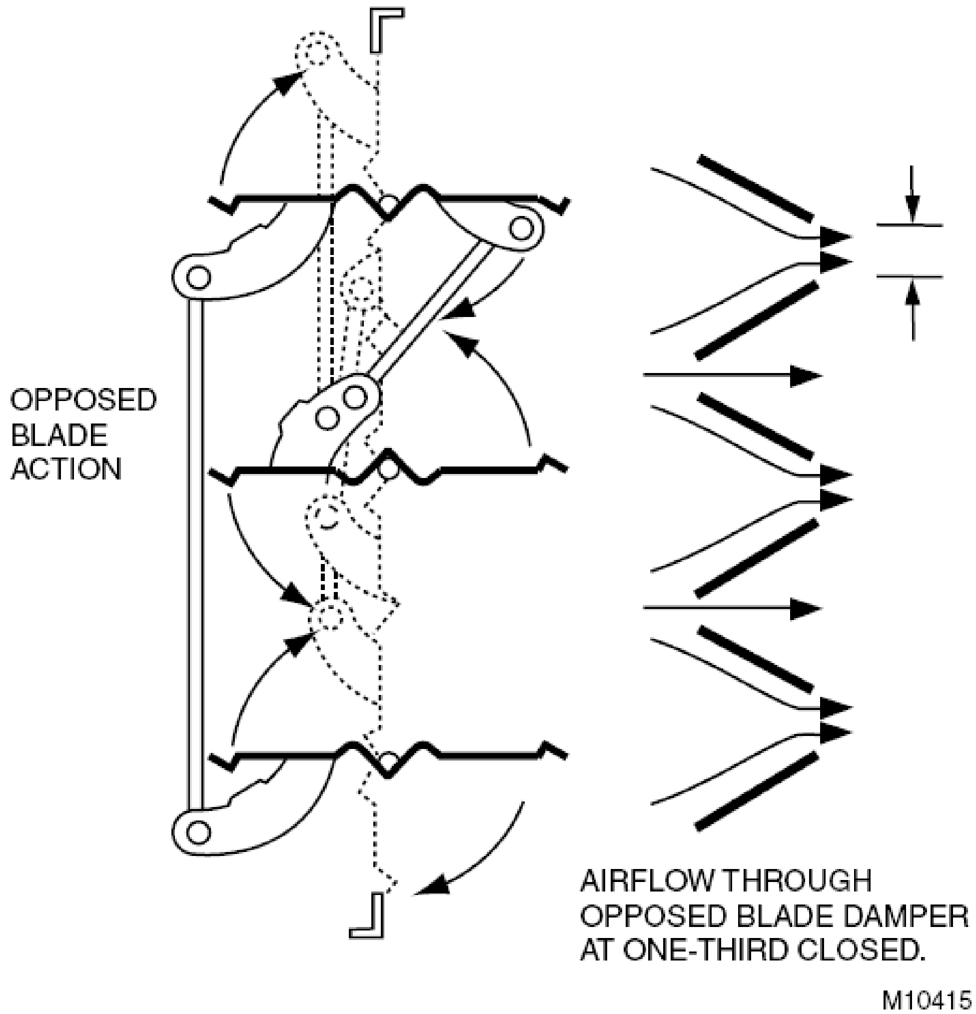


[Source: Shadpour, F., 2001. *The Fundamentals of HVAC Direct Digital Control*]

Parallel blade and opposed blade dampers



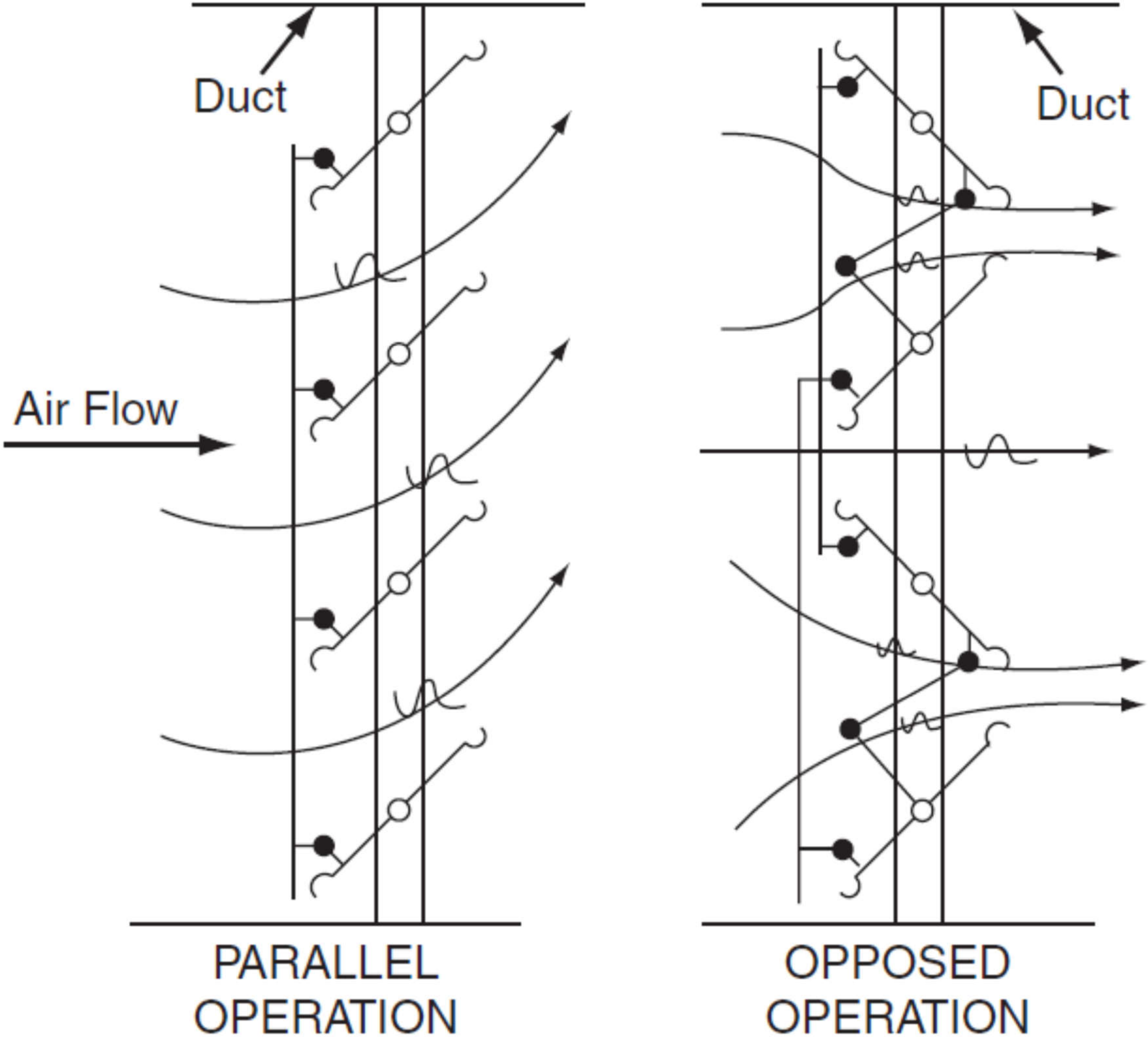
Parallel blade damper



Opposed blade damper

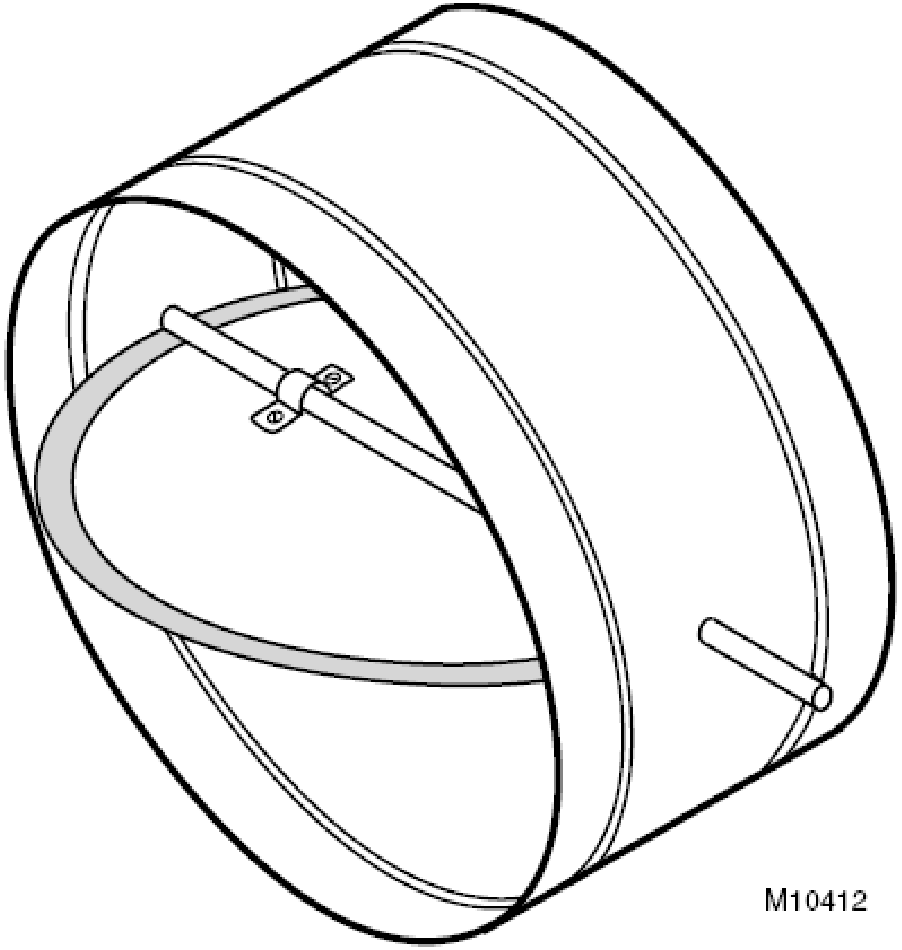
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Air flow pattern through dampers



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

Round damper and volume control damper

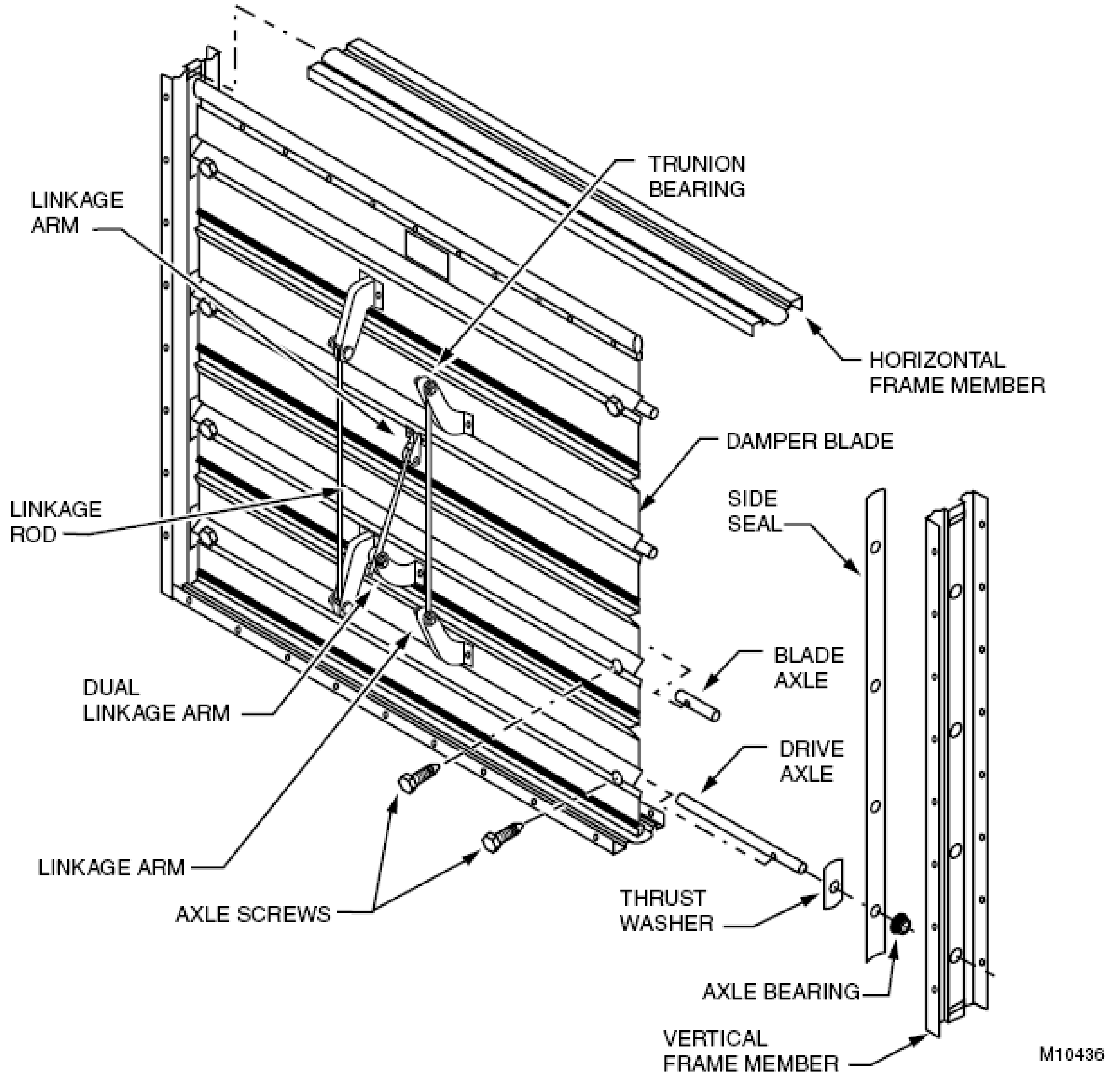


Round damper

Volume control damper (opposed blade)

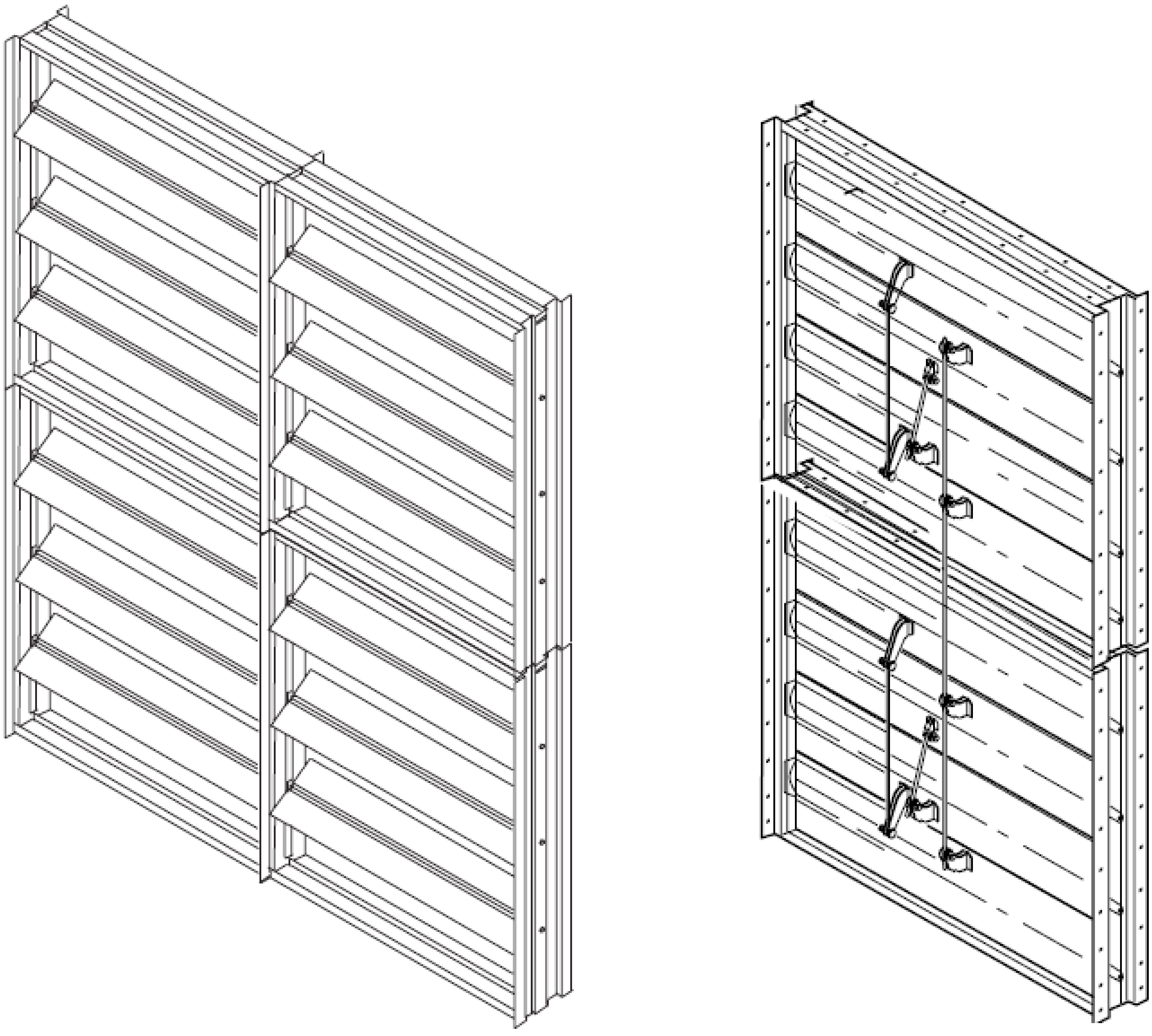
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Typical (opposed blade) damper construction



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

Multiple section damper assembly

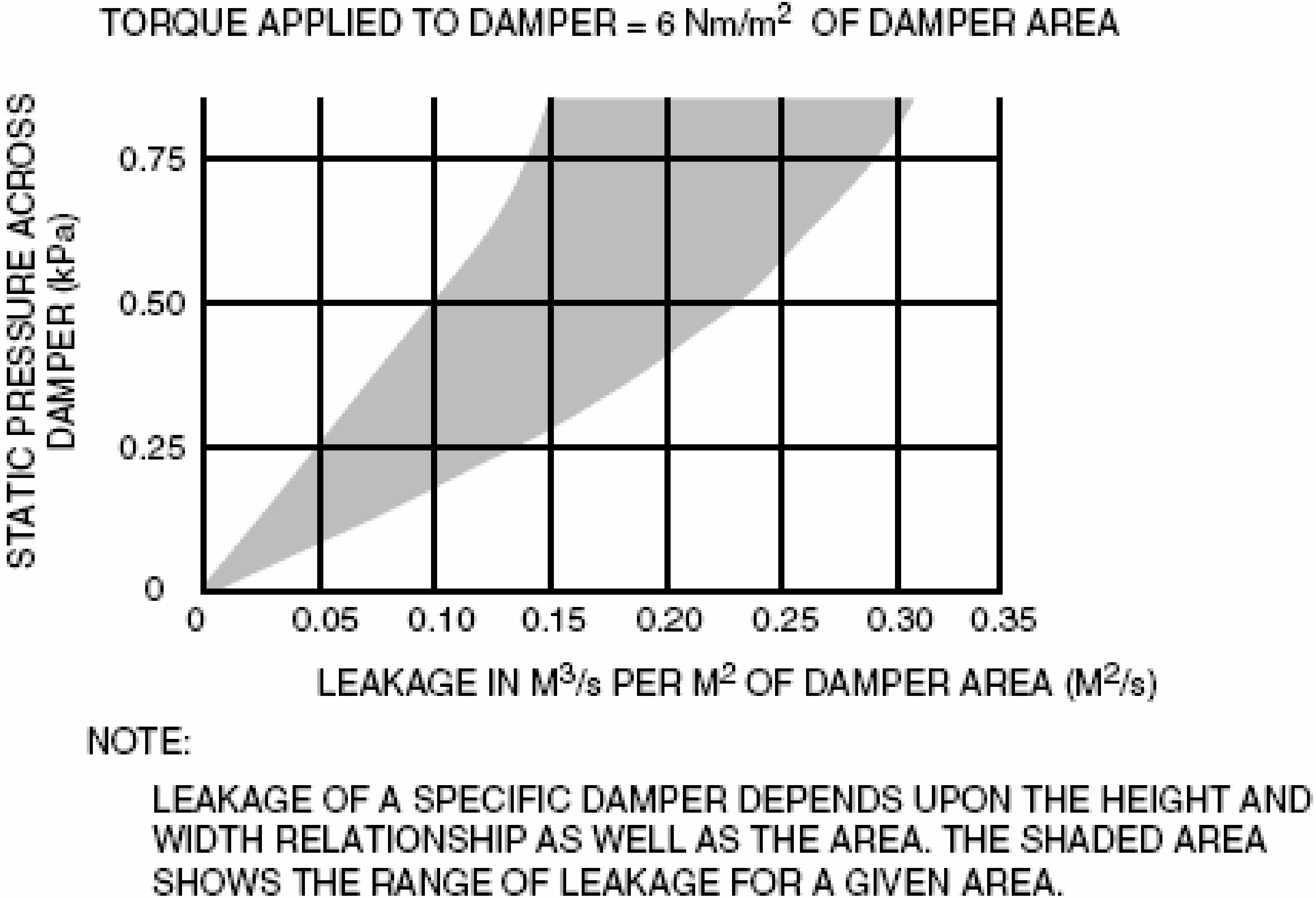


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Control dampers

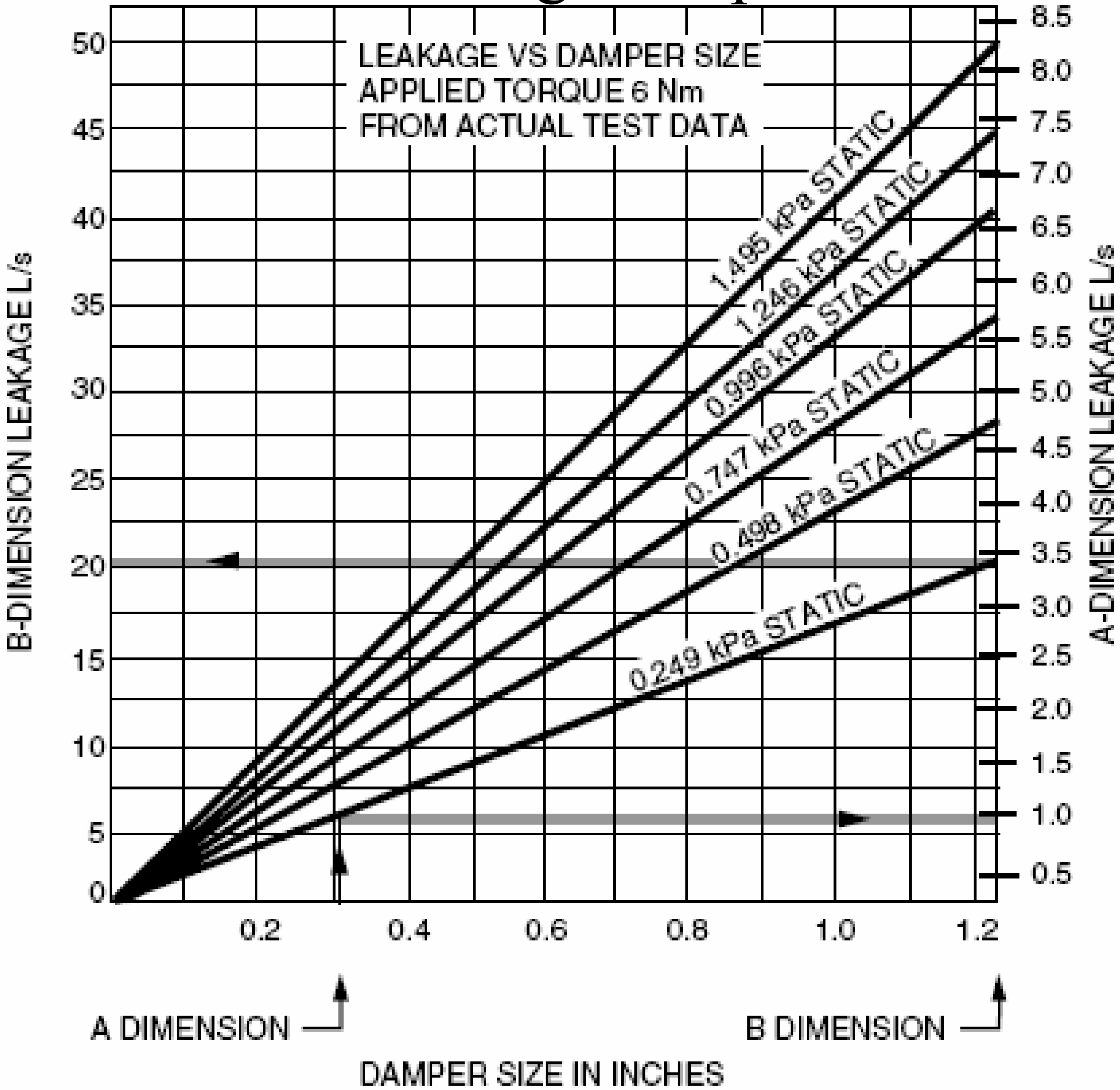
- Performance data
  - Leakage ratings
    - For typical dampers, leakage increases more significantly with the number of blades than with the length of the blades
  - Torque requirements
    - Operating and close-off torque requirements
      - Closing torque: the torque required to force the blades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

Graphic presentation of leakage performance of damper



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

Low leakage dampers



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

[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

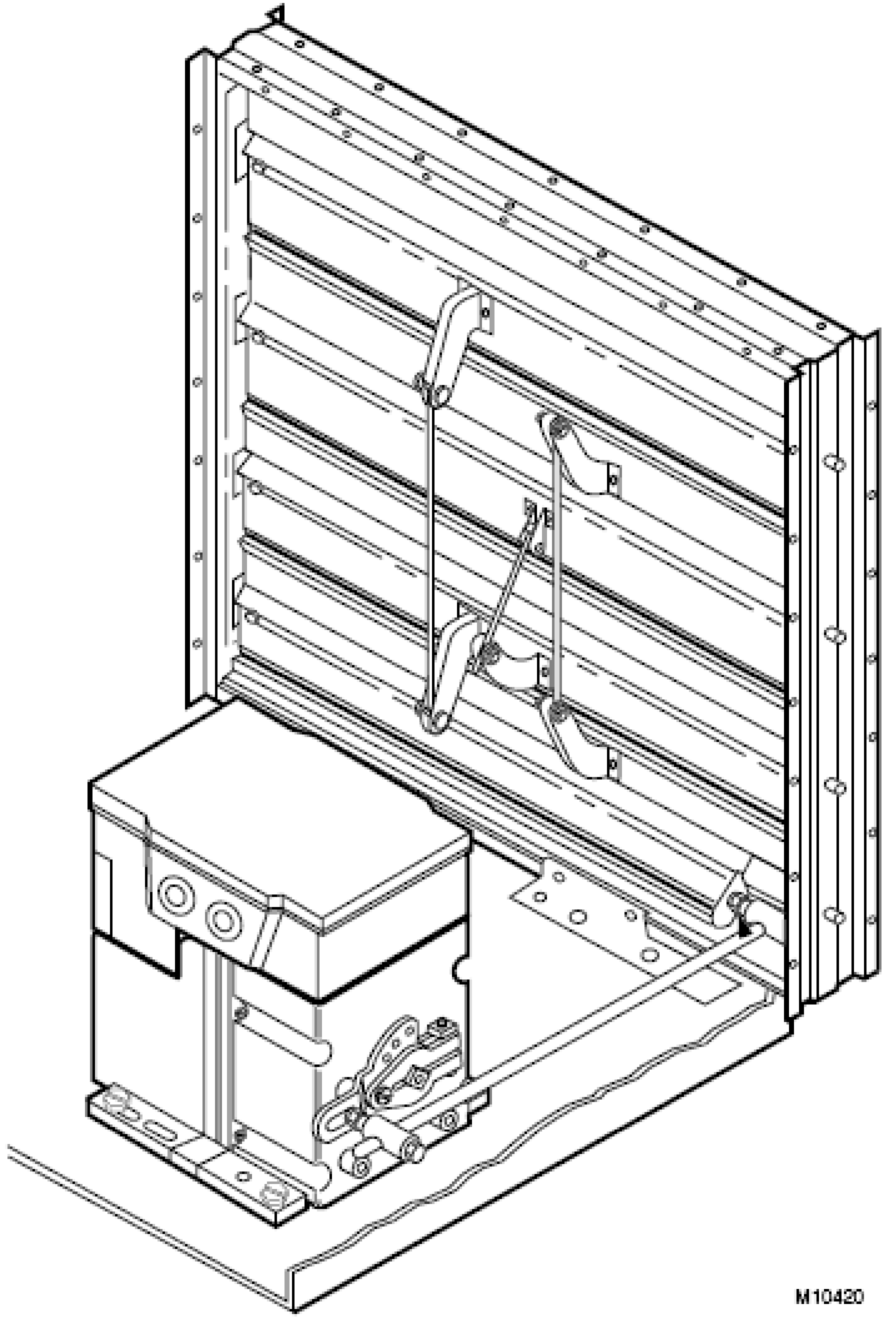
Damper Length (mm)	Max Close-Off Static (kPa)
305	2.0
610	2.0
915	1.5
1220	1.0

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

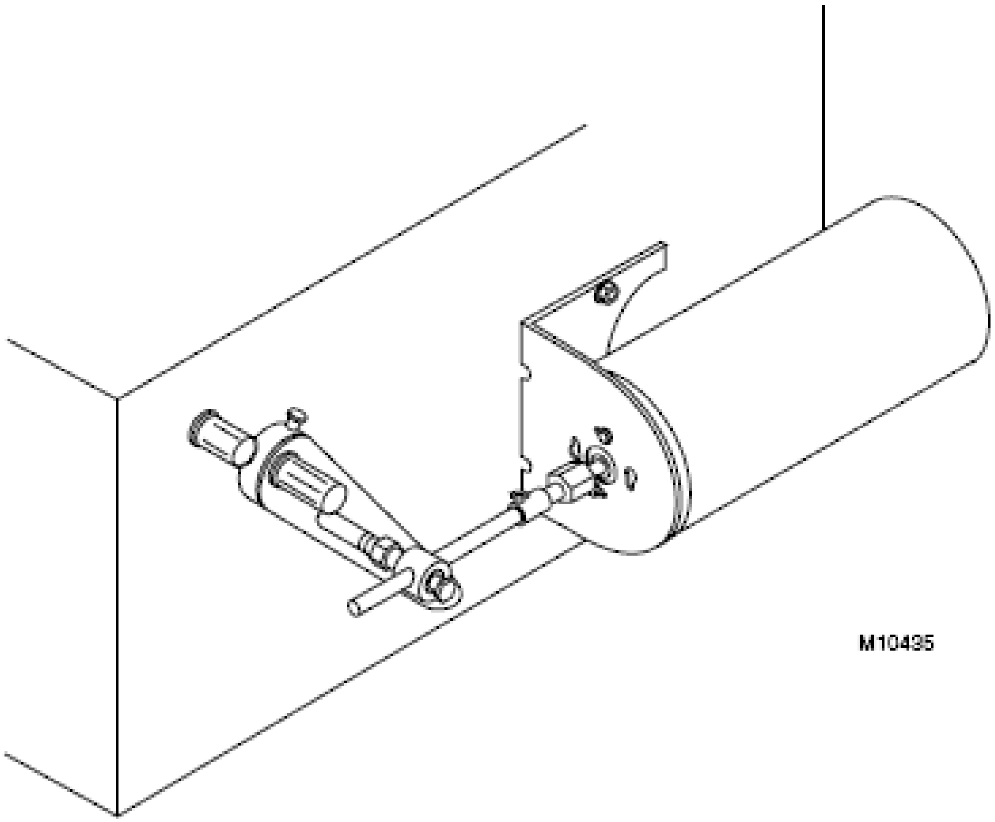
Control dampers

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

Examples of electric and pneumatic actuators for dampers



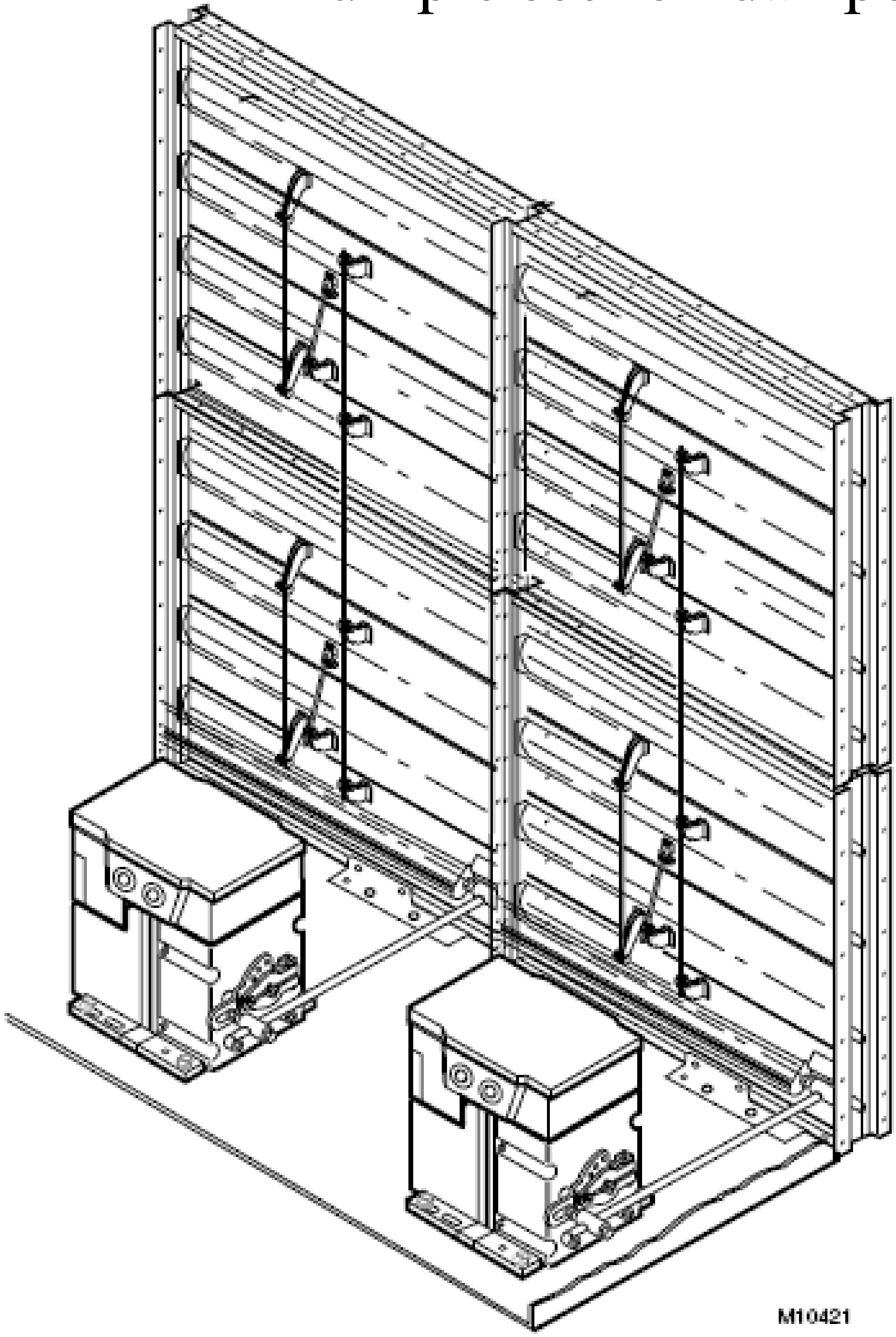
Internally mounted electric actuator



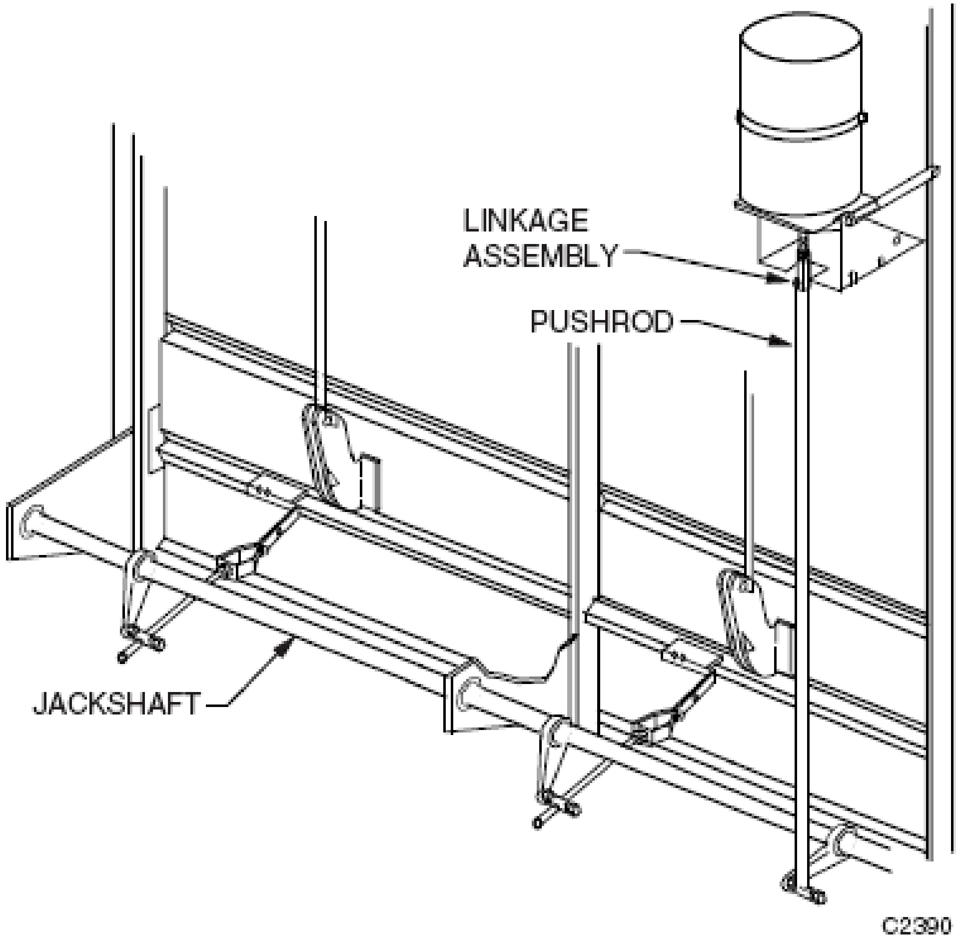
Externally mounted pneumatic actuator

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

Multiple section damper and jackshaft application



Control of a multiple section damper



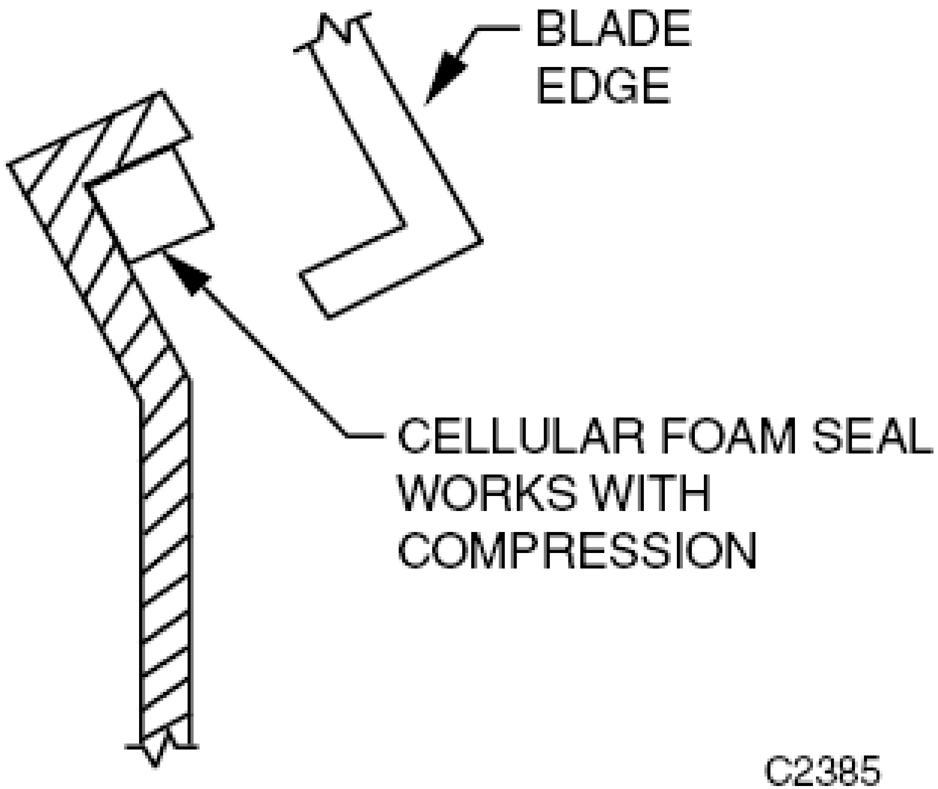
Damper jackshaft application

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

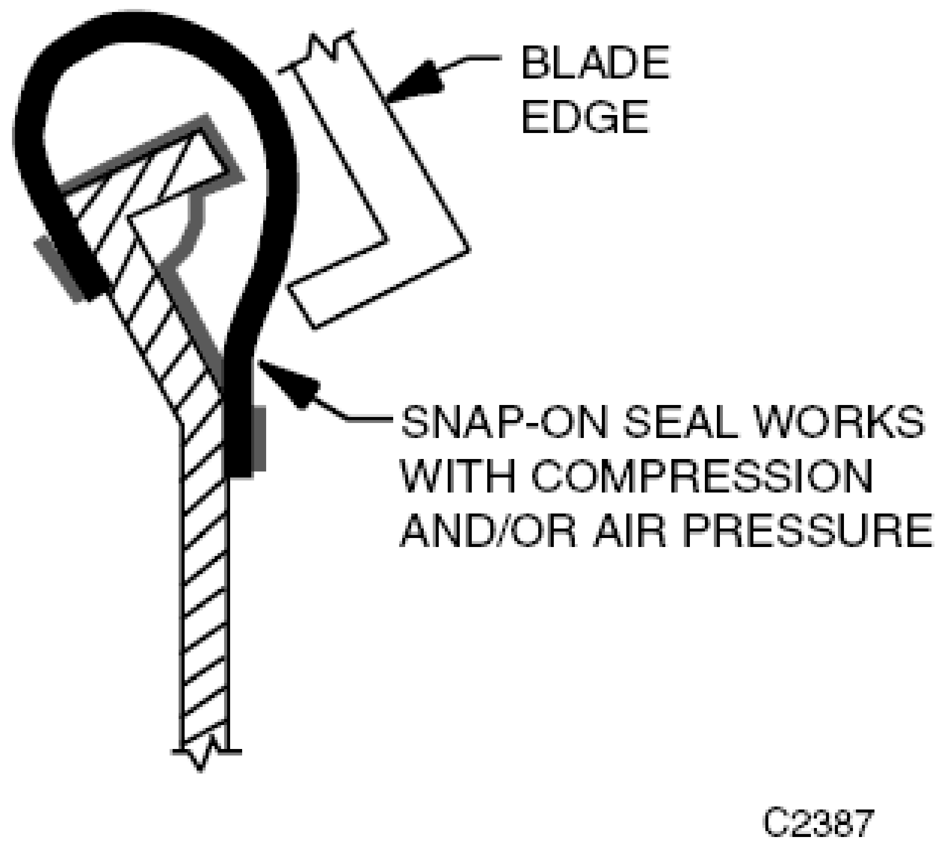
Control dampers

- 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)

Examples of sealing methods for low-leakage dampers



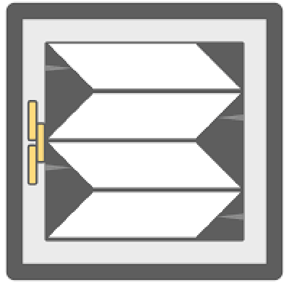
Cellular foam blade edge seal



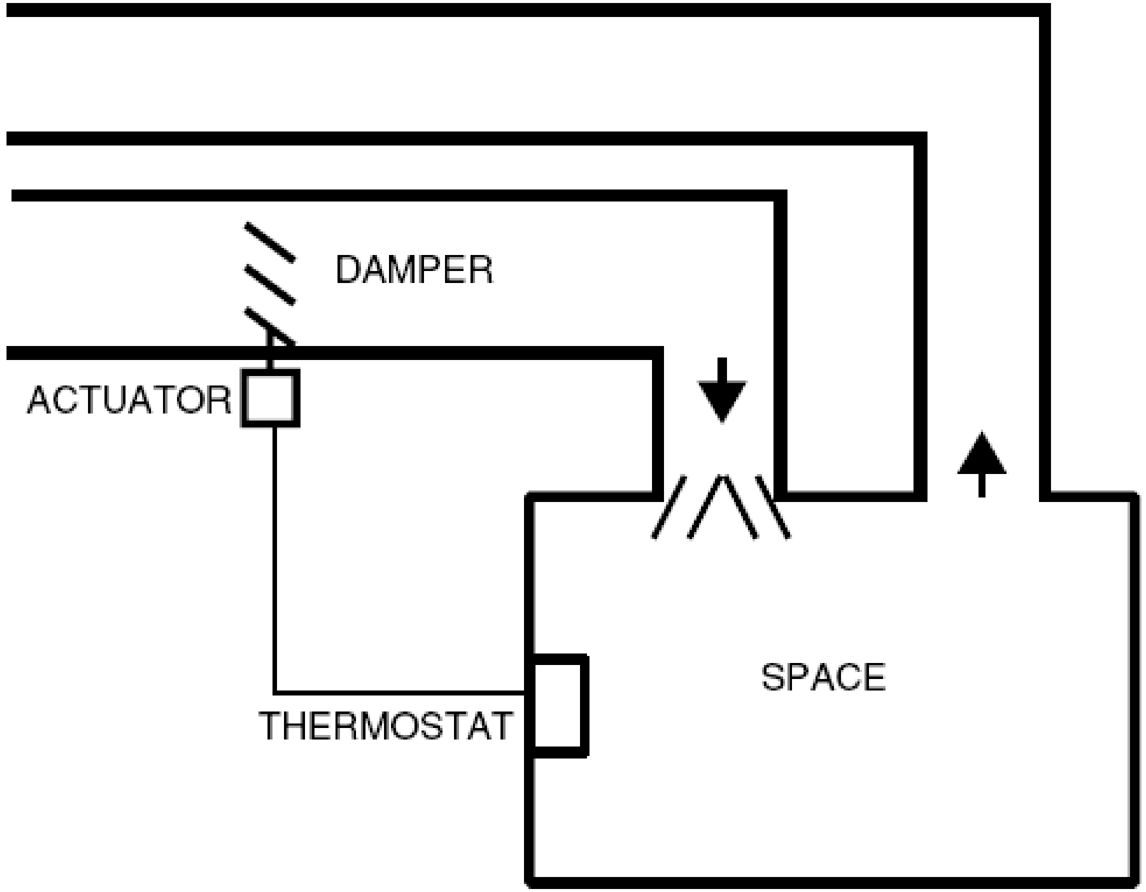
Snap-on blade edge seal

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

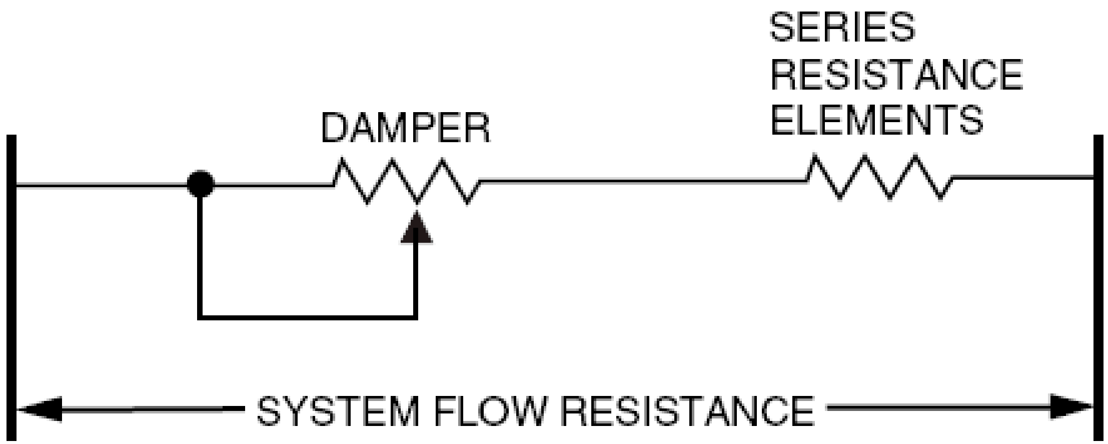
Damper sizing



- Typically chosen based on duct size and convenience of location
- Proper selection and sizing provides 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)



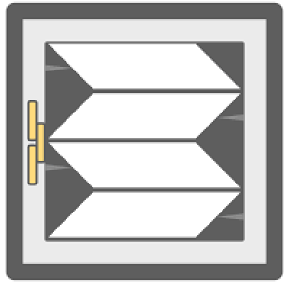
Control loop for a damper system



Resistance to airflow in actual system

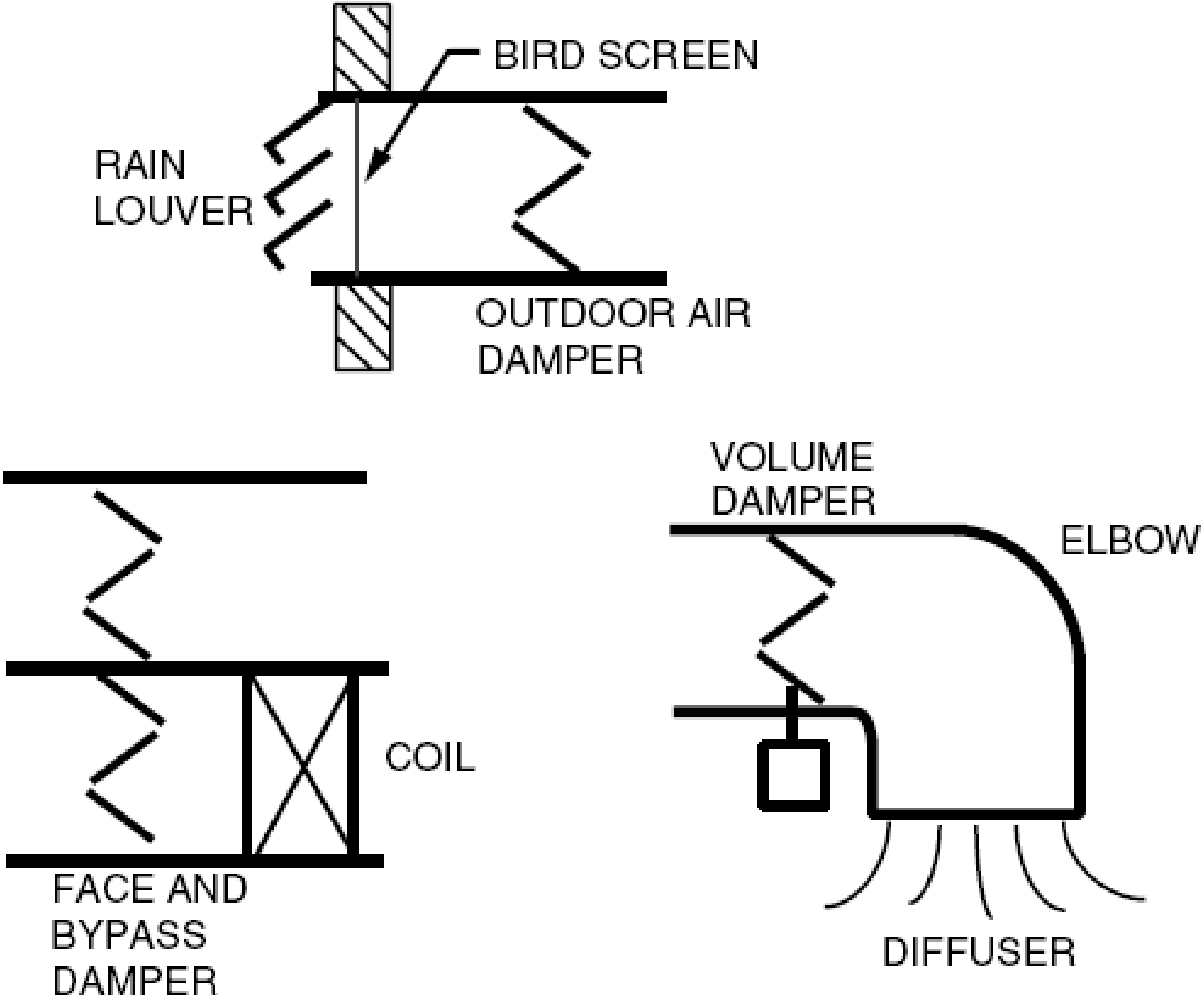
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Damper sizing



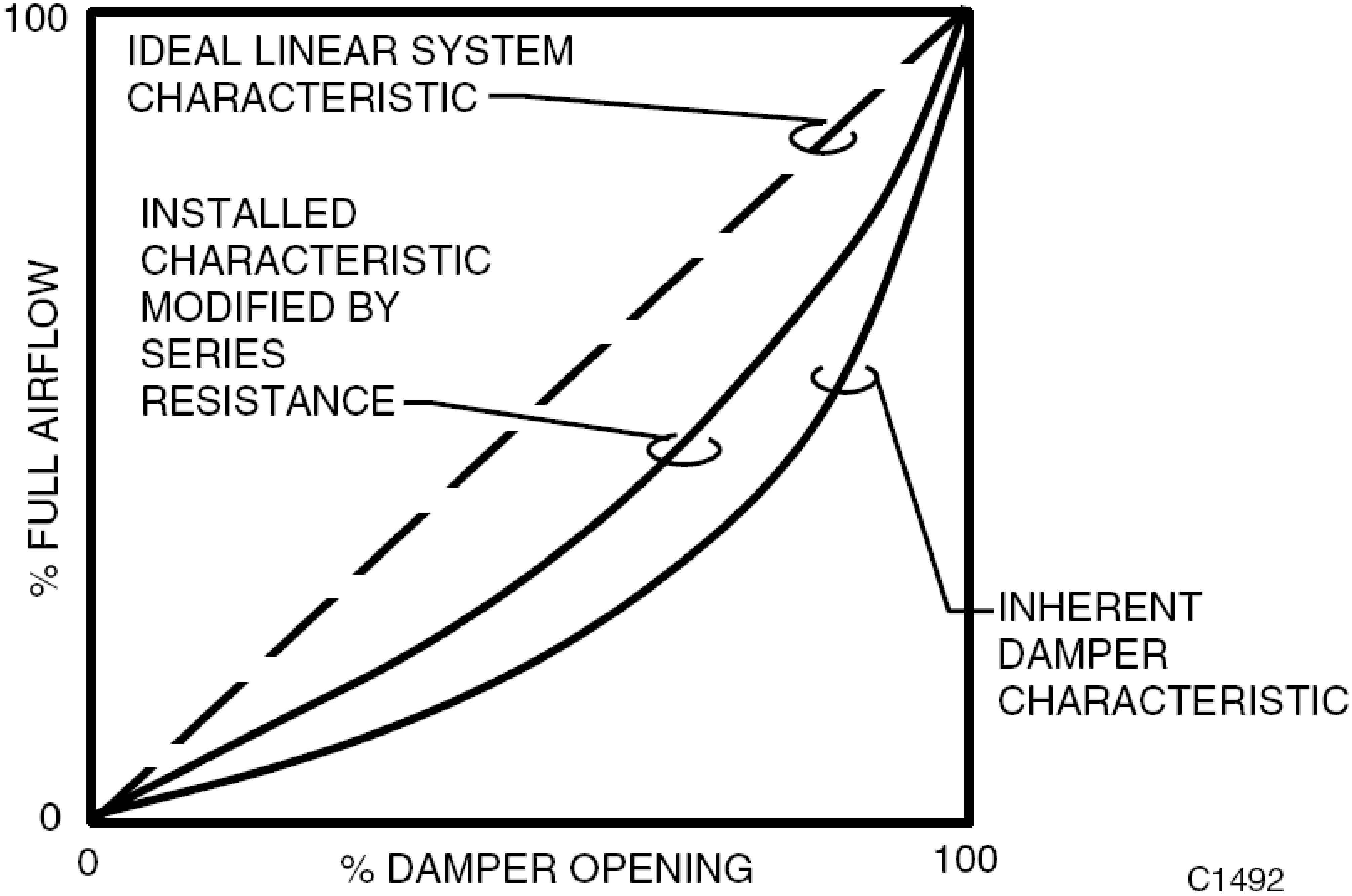
- Damper characteristics
  - Inherent characteristics
    - Defined at a constant pressure drop with no series resistance (coils, filters, louvers, diffusers, or other items)
  - Installed characteristics
    - Determined by the ratio of series resistance elements to damper resistance
    - Series resistance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

Examples of resistance to airflow



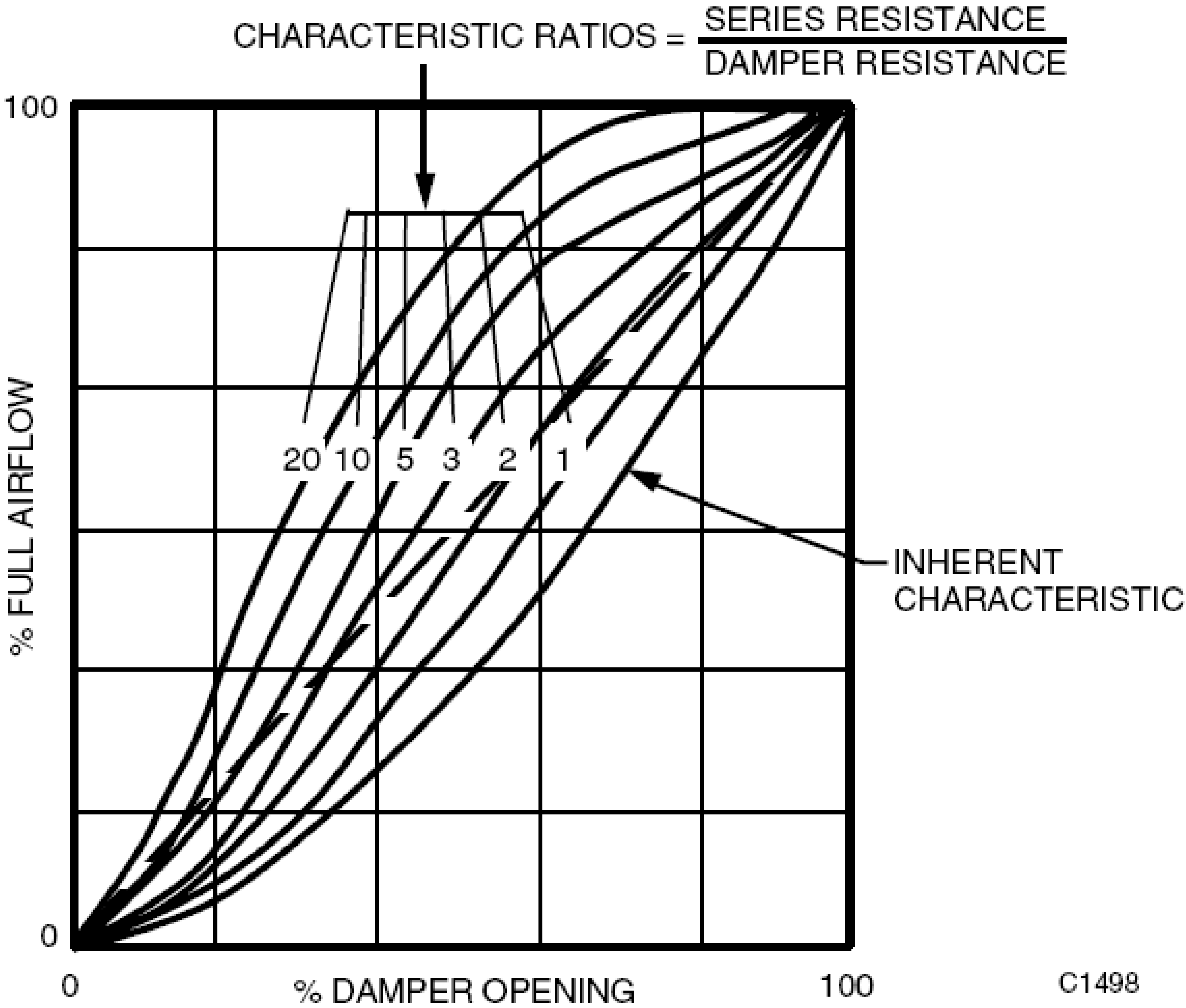
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Installed versus inherent airflow characteristics for a damper



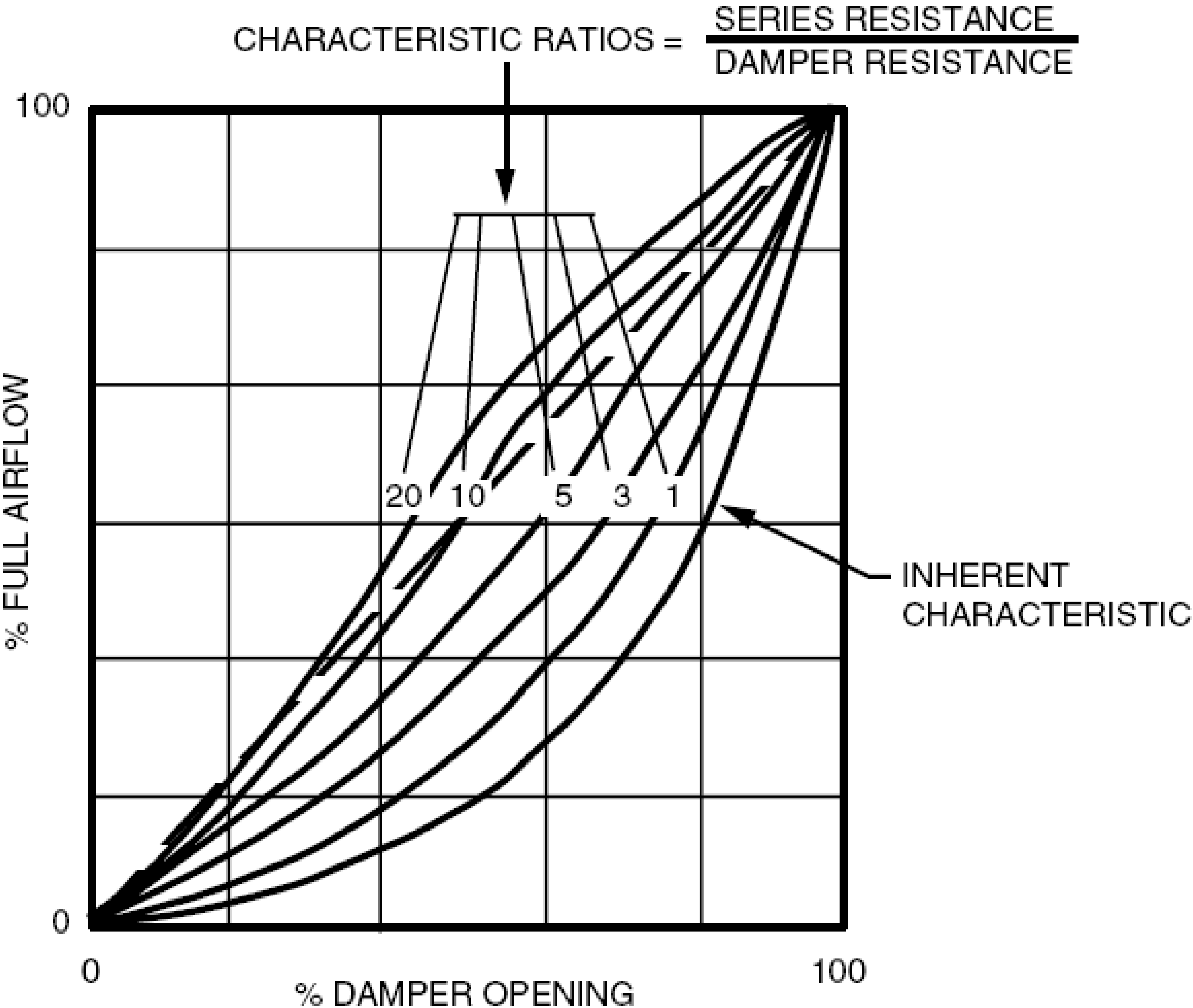
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Damper system characteristics of parallel blade dampers



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

Damper system characteristics of opposed blade dampers



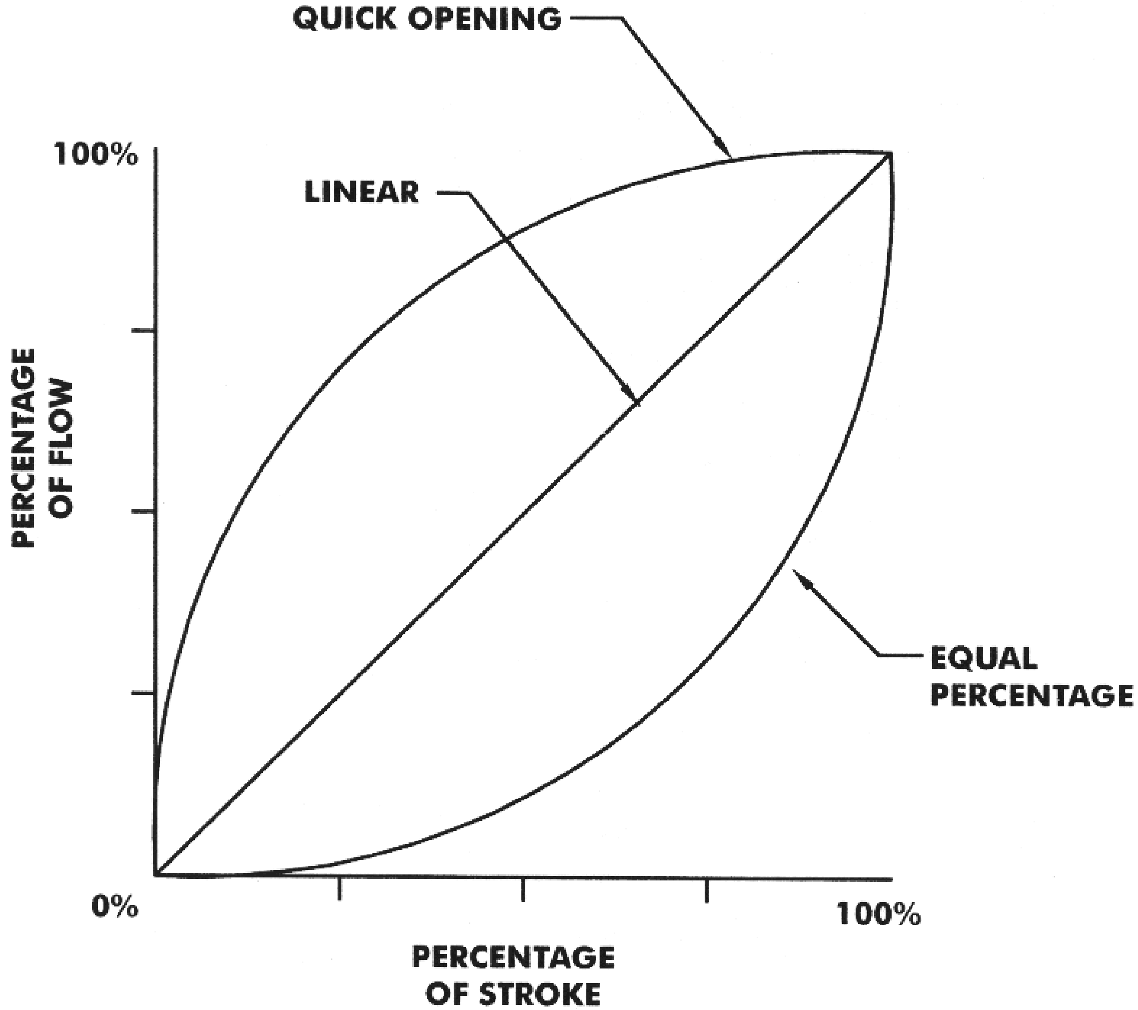
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Damper sizing

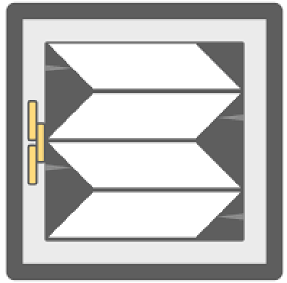
- Damper characteristics (cont'd)
  - To achieve performance closest to the ideal linear flow characteristic, a characteristic ratio of 2.5 for parallel blade dampers and 10 for opposed blade dampers should be used (see previous figures)
    - Total resistance = damper resistance + series resistance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

Damper sizing

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

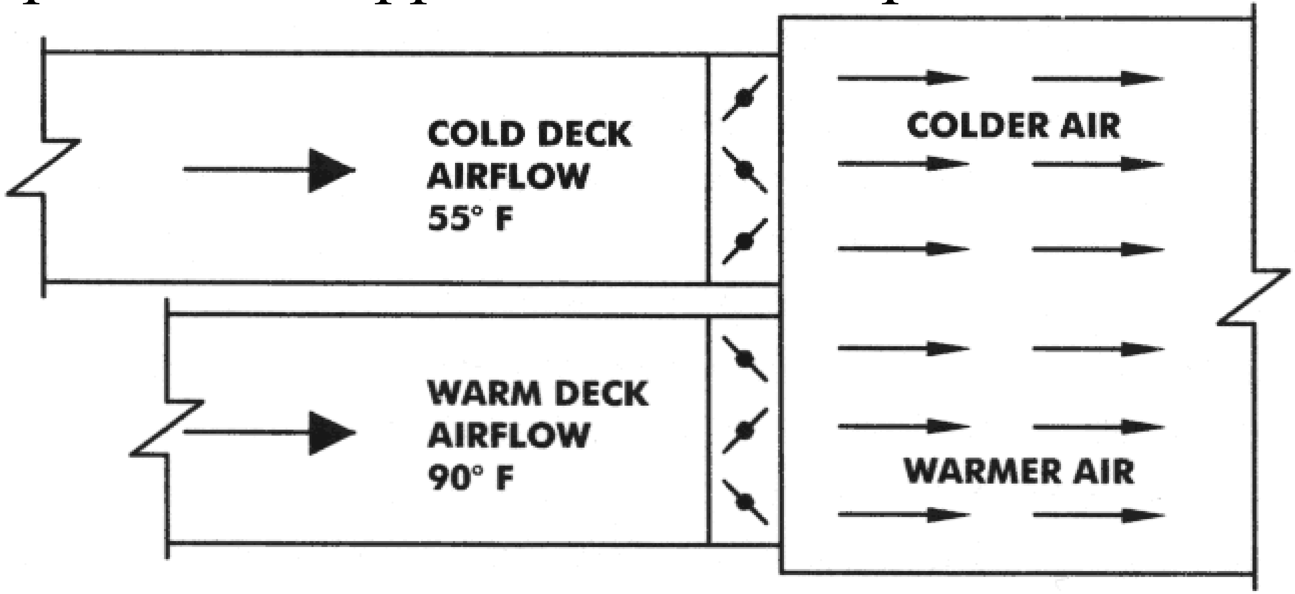


Damper sizing

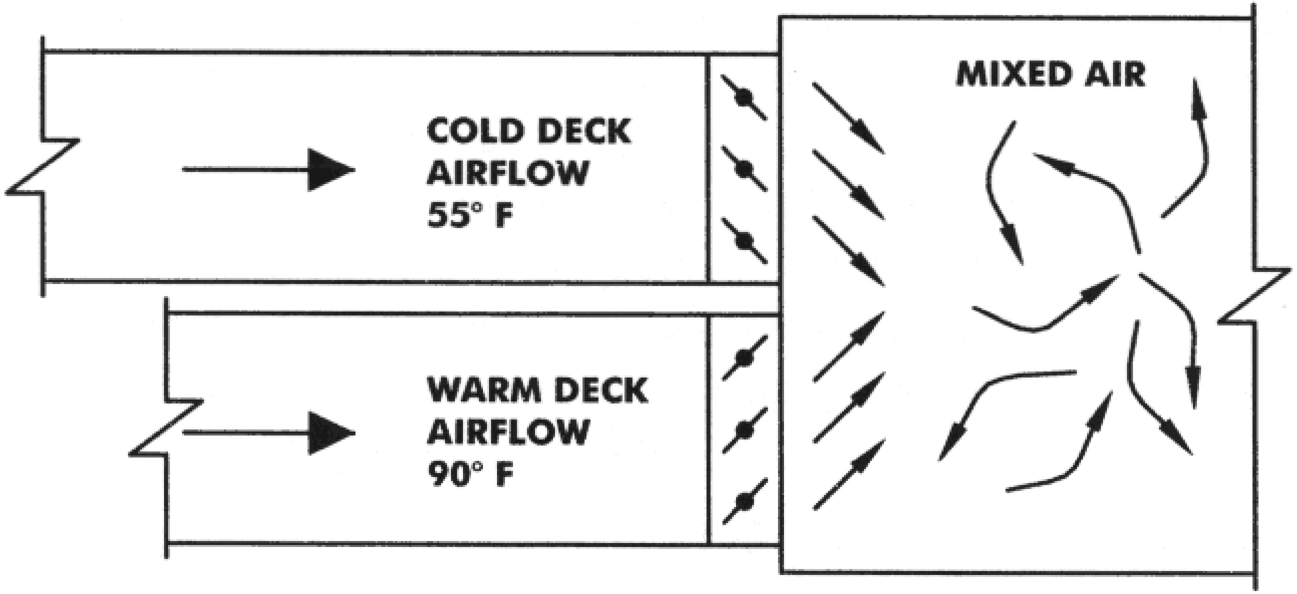


- Parallel blade damper
  - For two-position applications
  - Good for reducing air turbulence
  - Less expensive, but requires larger actuators
- Opposed blade damper
  - For volume control & airflow modulation
  - Greater pressure loss (better control)
  - Flow characteristics are more linear

Air flow patterns of opposed blade and parallel blade dampers



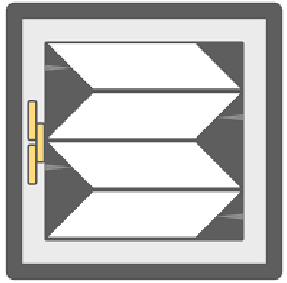
OPPOSED BLADE DAMPERS



PARALLEL BLADE DAMPERS

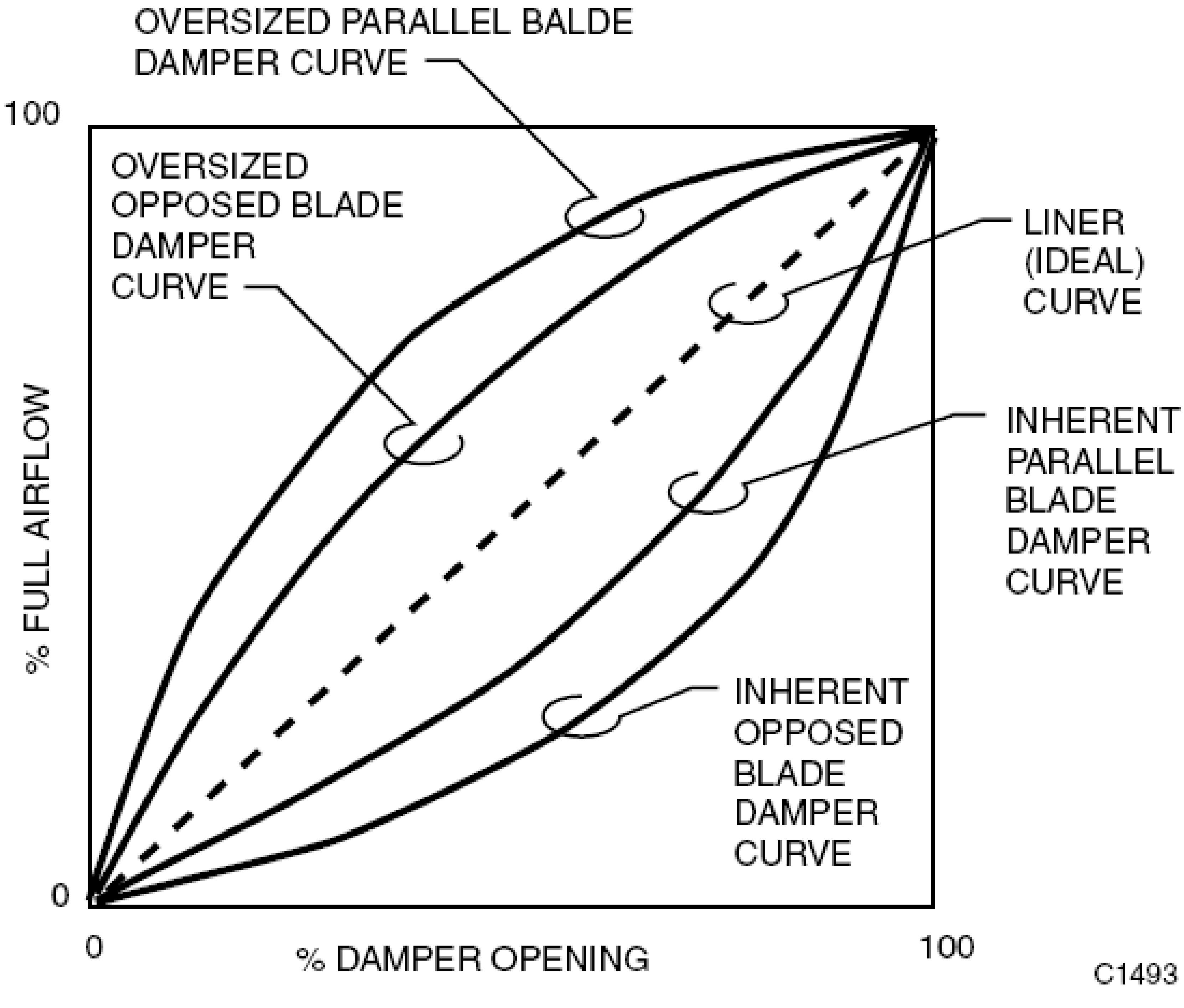
[Source: Shadpour, F., 2001. *The Fundamentals of HVAC Direct Digital Control*]

Damper sizing



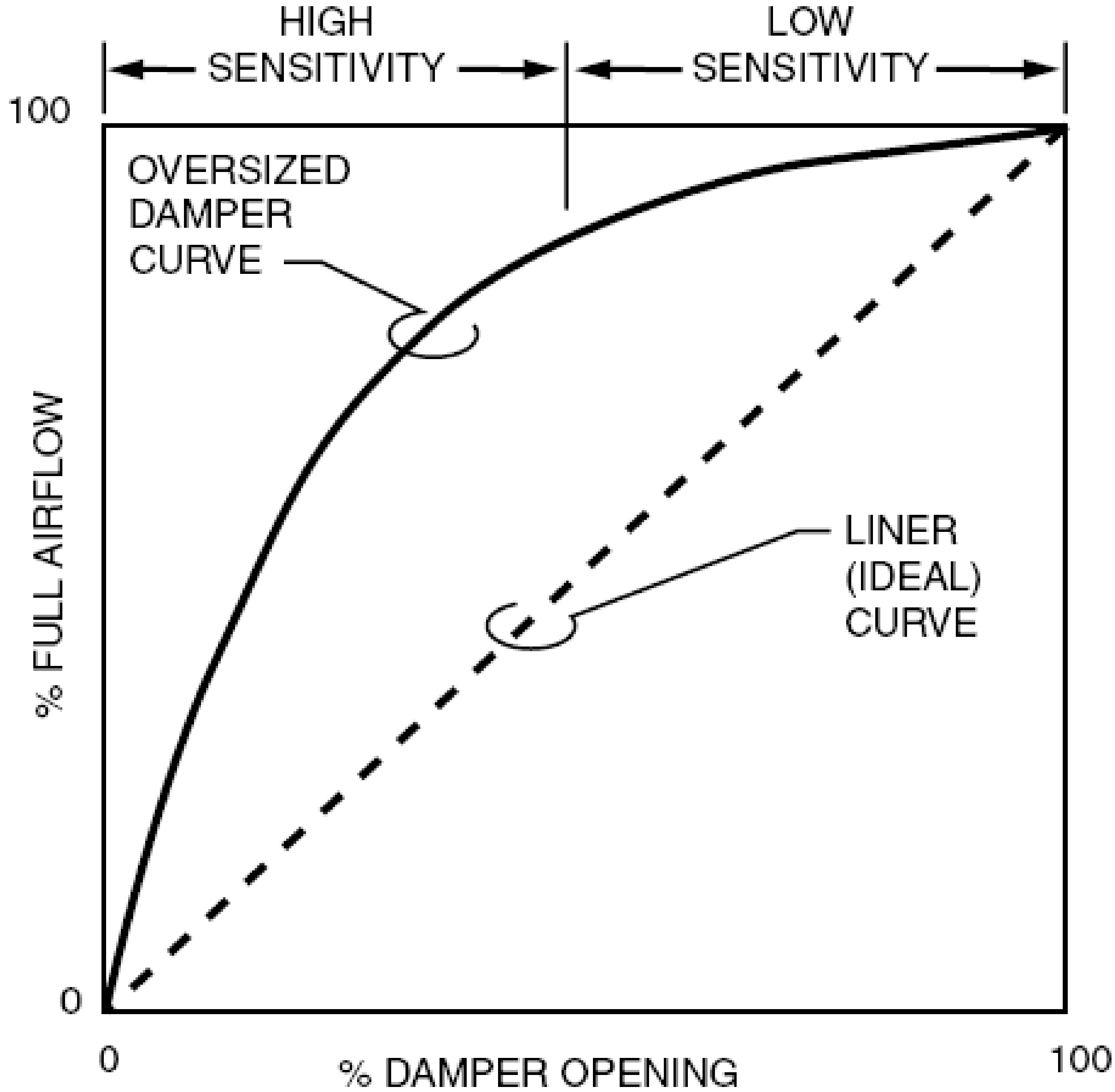
- Sizing control damper
  - Various methods recommended by manufacturers
  - Similar to control valves
    - The greater the pressure drop, the better the modulation
  - Modulating control dampers are sized for a face velocity of about 5-10 m/s
  - Proper sizing of dampers requires
    - Detailed examination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

Comparing oversized parallel and oversized opposed blade dampers



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

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)	Opposed
(without Weather Louver or Bird Screen)	Parallel
Coil Face	Opposed
Bypass	
(with Perforated Baffle)	Opposed
(without Perforated Baffle)	Parallel
Two-Position (all applications)	Parallel

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

Damper sizing procedure

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

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*]

Damper sizing example

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

What will happen if the damper is oversized?

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

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*]

Pressure drop calculation example

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

Had the duct size been 1.50 m^2, the same size as the damper, the pressure drop would have been lower (7.25 Pa).

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

Further reading

- A Complete Guide to Building Automation Systems (BAS) https://beringar.co.uk/a-complete-guide-to-building-automation-systems-bas/
- Videos:
  - What Input Devices are used in BMS? | Building Management System Training (17:20) https://youtu.be/J7aONjo8NfM
  - Control Valve Selection and Sizing | Building Management System Training | BMS Training 2021 (15:18) https://youtu.be/yy_0yf1qIJ0
  - Dampers and Actuators | Building Management System Training | BMS Training 2021 (10:59) https://youtu.be/z7SCuS-IT_Y