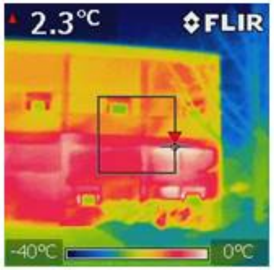
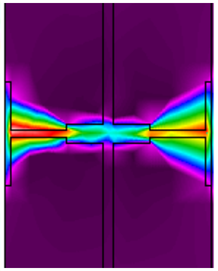
CAE 331/513
Building Science
Fall 2015





Week 10: October 29, 2015
Continuing HVAC systems
Air and water distribution systems

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Dr. Brent Stephens, Ph.D.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu

Review from last time and objectives for today

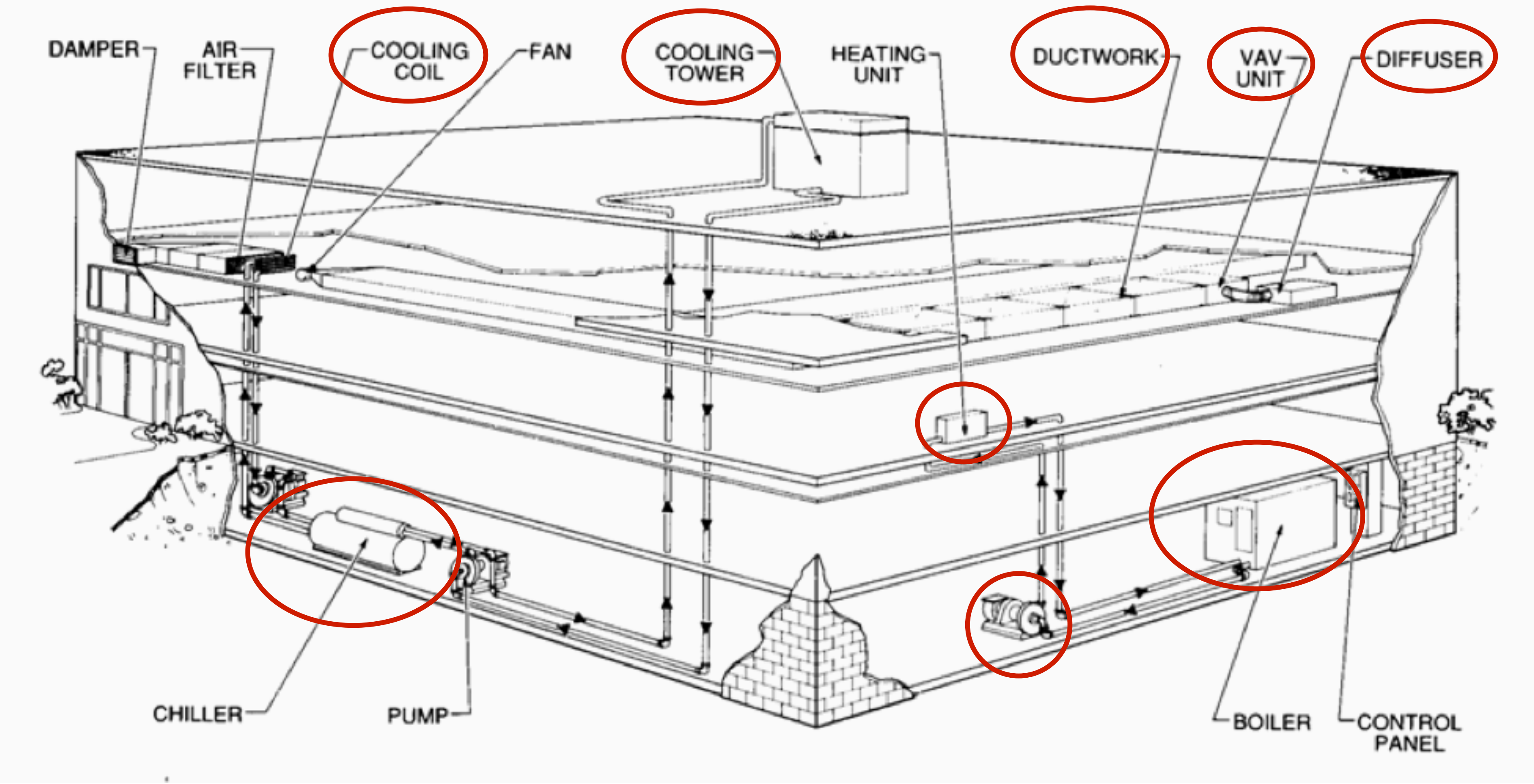
- Introduced COP, EER, and capacity
  - And how they change with external conditions
- Introduced more complex heating and cooling systems
  - Chillers
  - Cooling towers
  - Air and water distribution systems
  - Economizers

Today's objectives:

- Finish heating and cooling systems
- Air- and ground-source heat pumps
- Fluid flow in buildings
  - Finish air and water distribution systems
  - Pressure distributions
  - Fan and pump curves

Typical large central commercial systems

Heating and cooling distribution done separately:

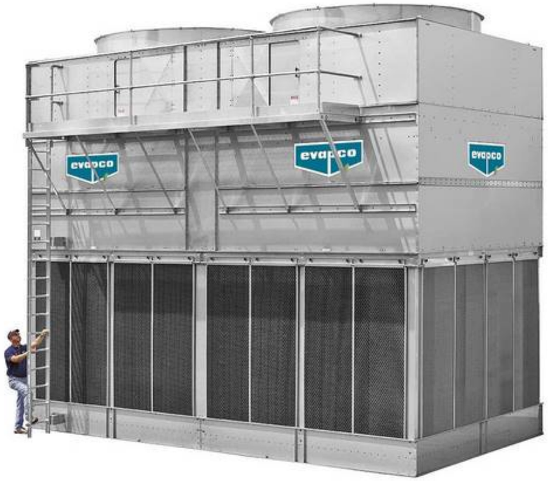


Typical large central commercial system components

Air cooled chiller

Smaller capacity

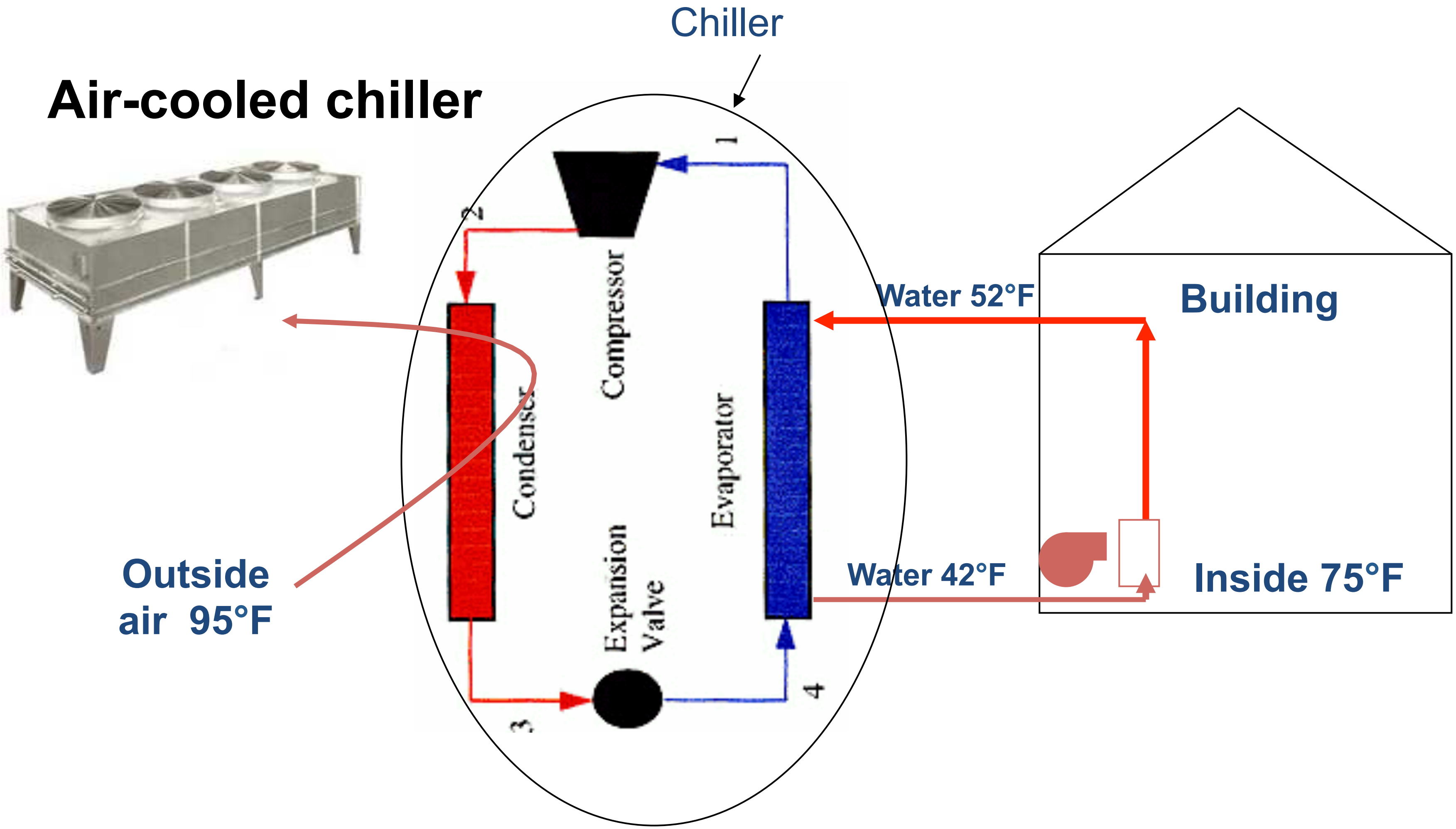
Hot water or steam boiler



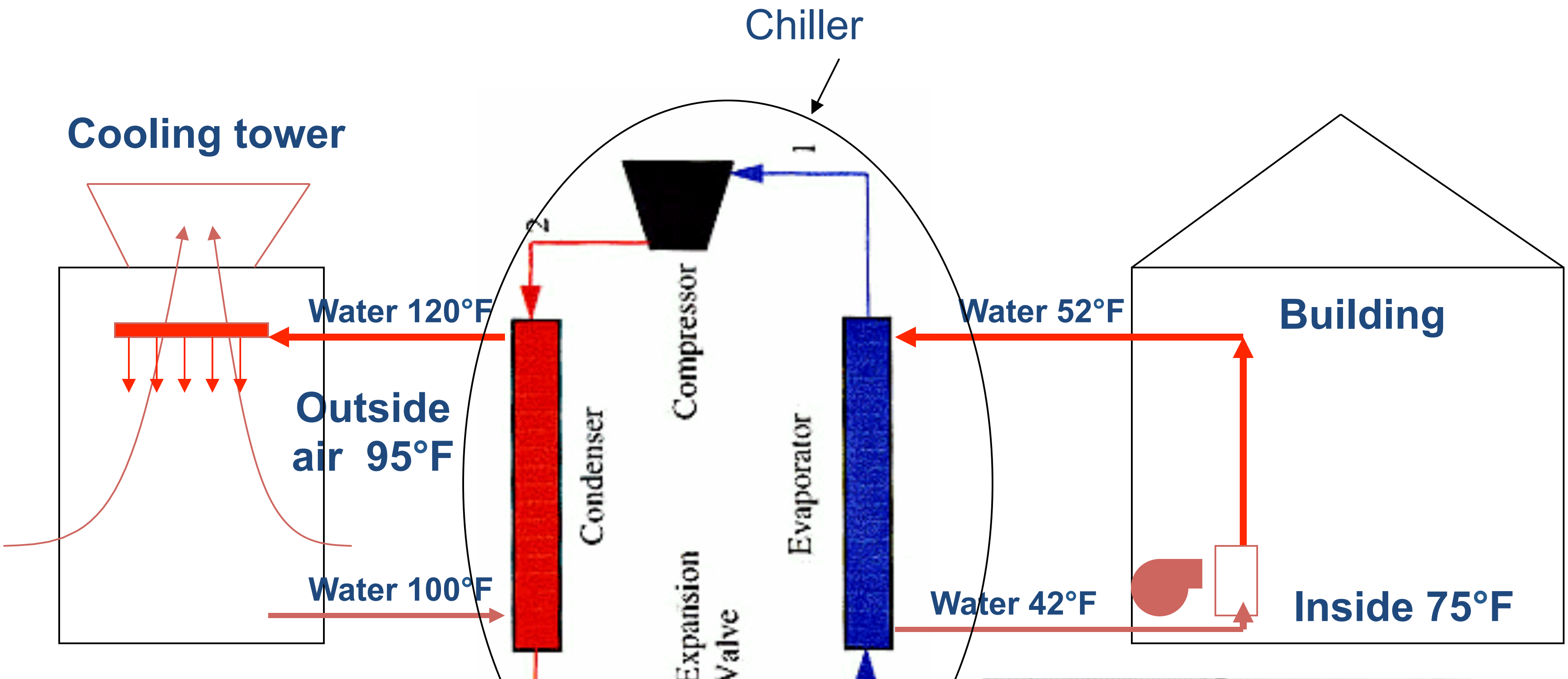
Water-cooled chiller
(w/ cooling tower – larger capacity & more efficient)

Air-cooled chillers

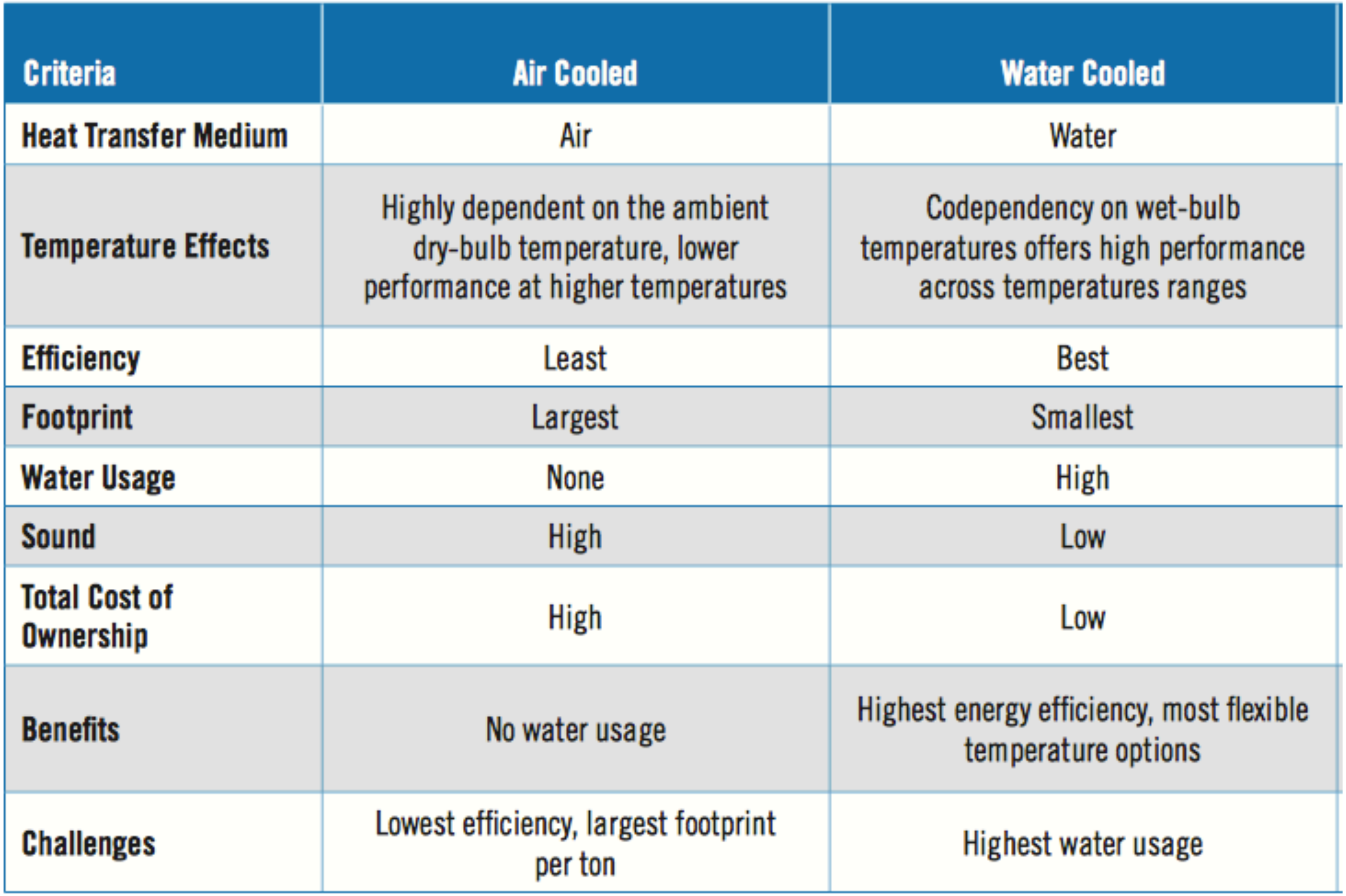
- Chillers use vapor compression or absorption systems to produce chilled water for cooling spaces



Water-cooled chillers (i.e., "cooling tower")



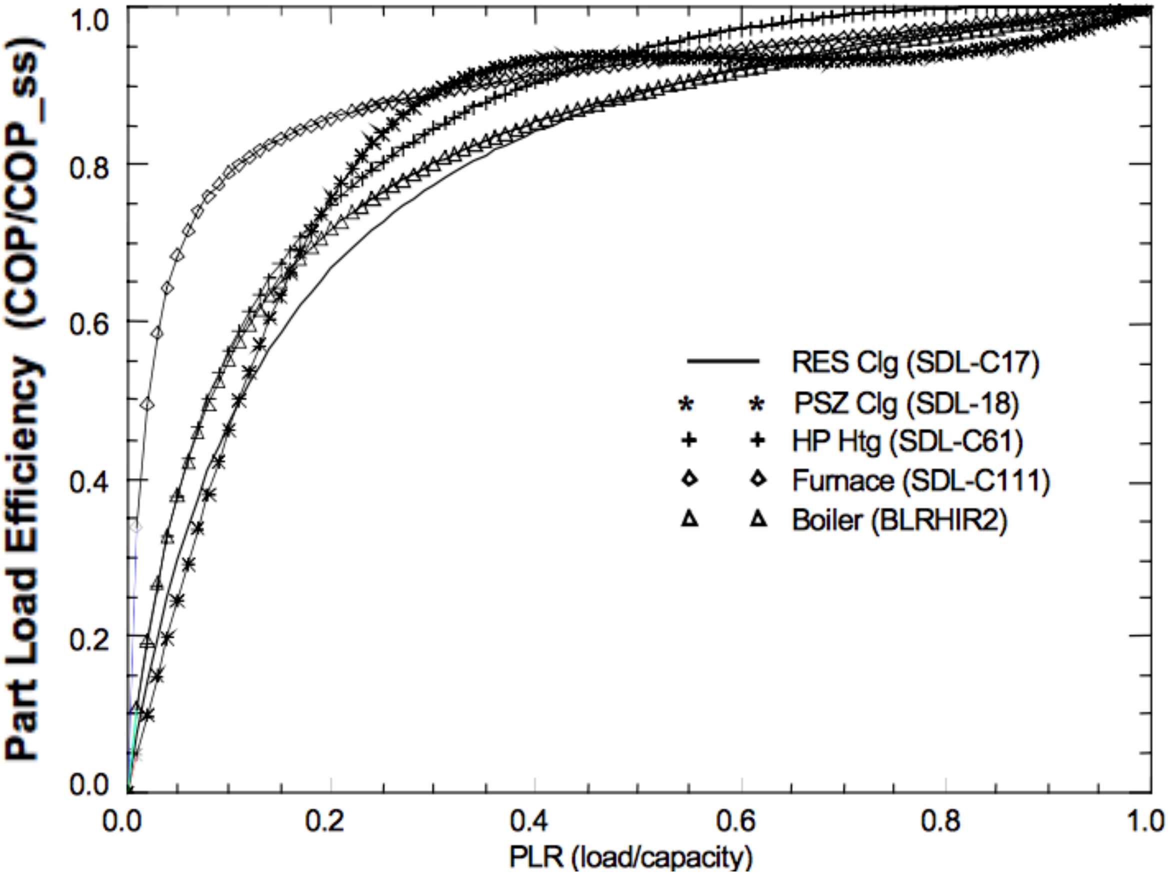
Water- or air-cooled chiller?



Criteria	Air Cooled	Water Cooled
Heat Transfer Medium	Air	Water
Temperature Effects	Highly dependent on the ambient dry-bulb temperature, lower performance at higher temperatures	Codependency on wet-bulb temperatures offers high performance across temperatures ranges
Efficiency	Least	Best
Footprint	Largest	Smallest
Water Usage	None	High
Sound	High	Low
Total Cost of Ownership	High	Low
Benefits	No water usage	Highest energy efficiency, most flexible temperature options
Challenges	Lowest efficiency, largest footprint per ton	Highest water usage

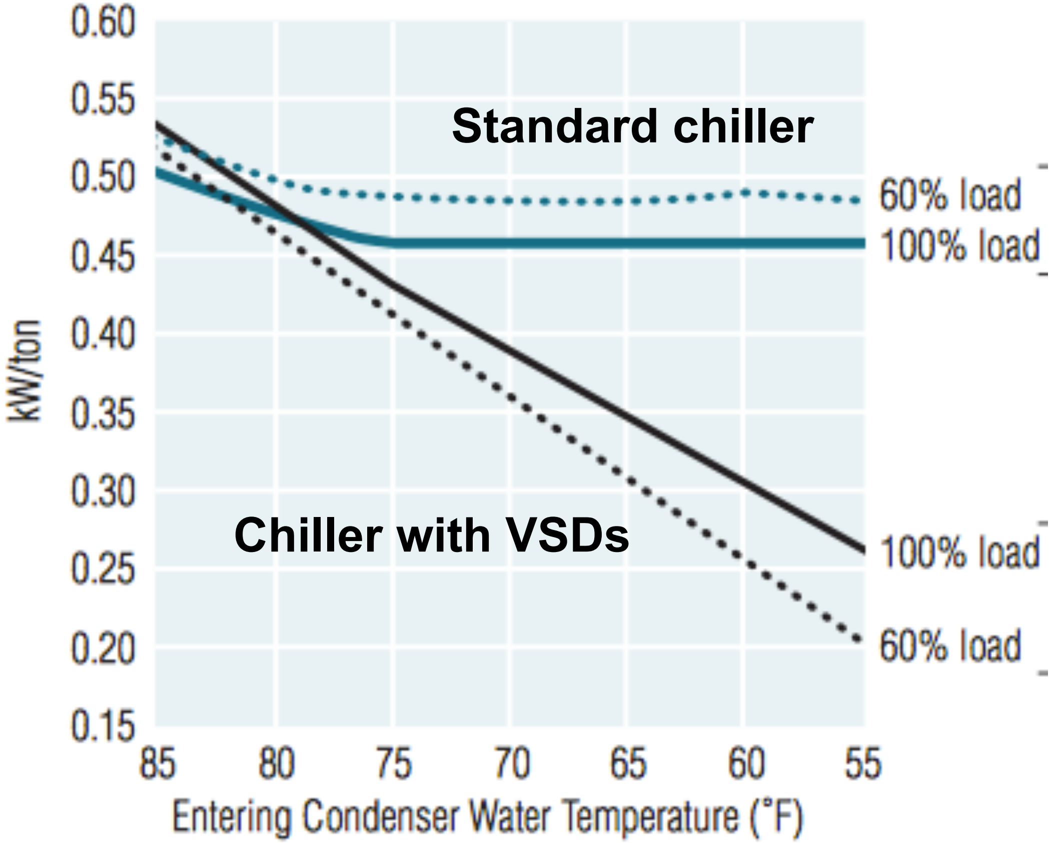
Part-load ratio (PLR)

- Many systems operate at their highest efficiency (highest COP) at design load conditions
  - Maximum load
- But systems don't always operate at peak load conditions
  - "Part-load" conditions are common
- The "part-load ratio" quantifies COP at part-load conditions



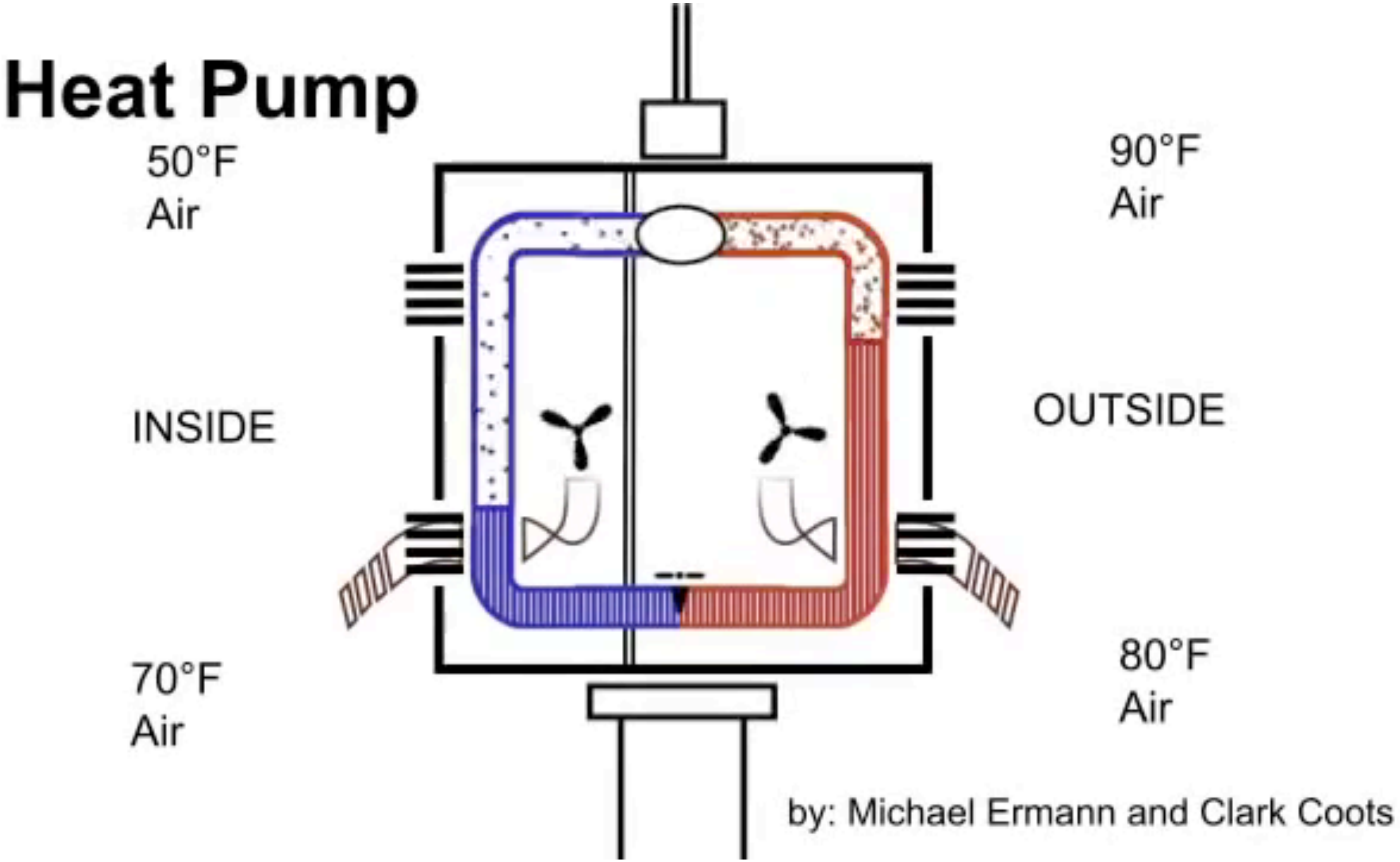
Part-load ratio (PLR) and entering water temp. (EWT)

- Many systems operate at their highest efficiency (highest COP) at design load conditions
  - Maximum load
- But systems don't always operate at peak load conditions
  - "Part-load" conditions are common
- The "part-load ratio" quantifies COP at part-load conditions



HEAT PUMPS

Air- and ground-source heat pumps

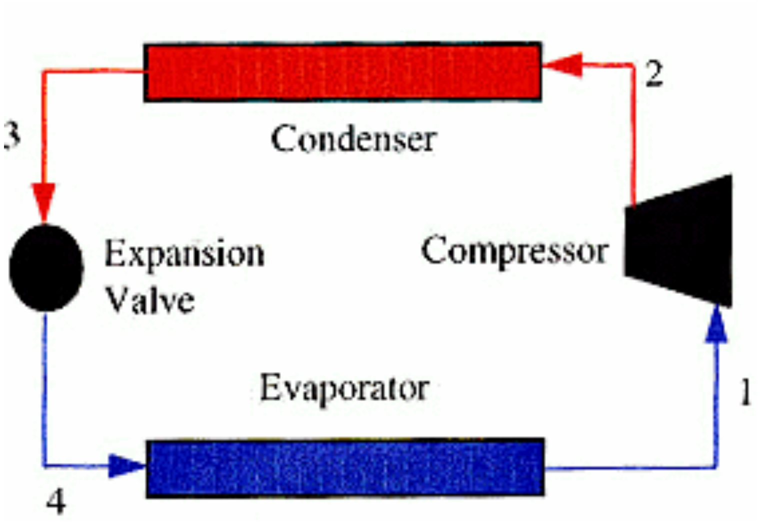


https://www.youtube.com/watch?v=NyNeh7wPQQk

Heat pumps

Cooling

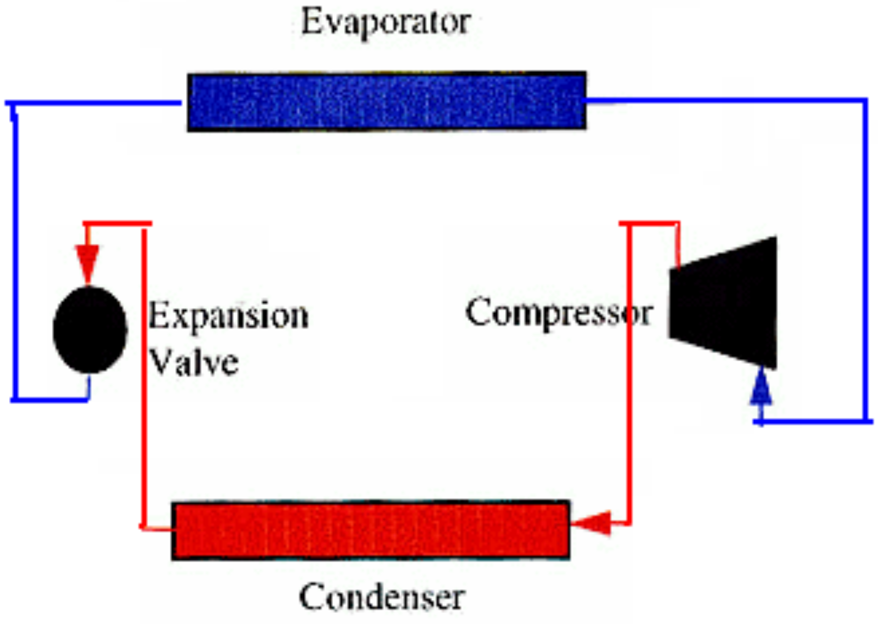
Outside 95°F



Inside 75°F

Heating

Outside 45°F

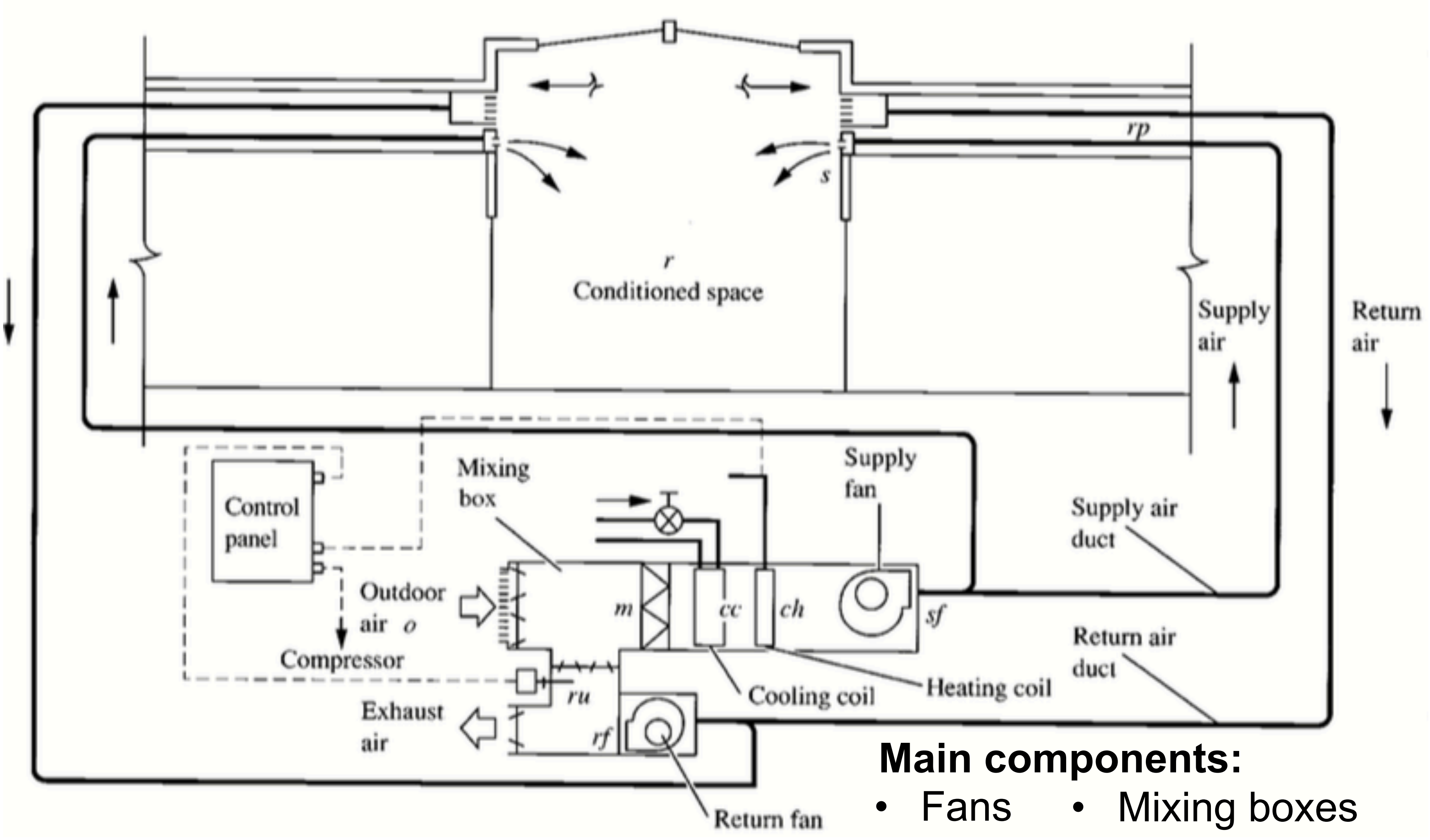


Inside 75°F

Air-conditioner run in reverse

AIR DISTRIBUTION SYSTEMS

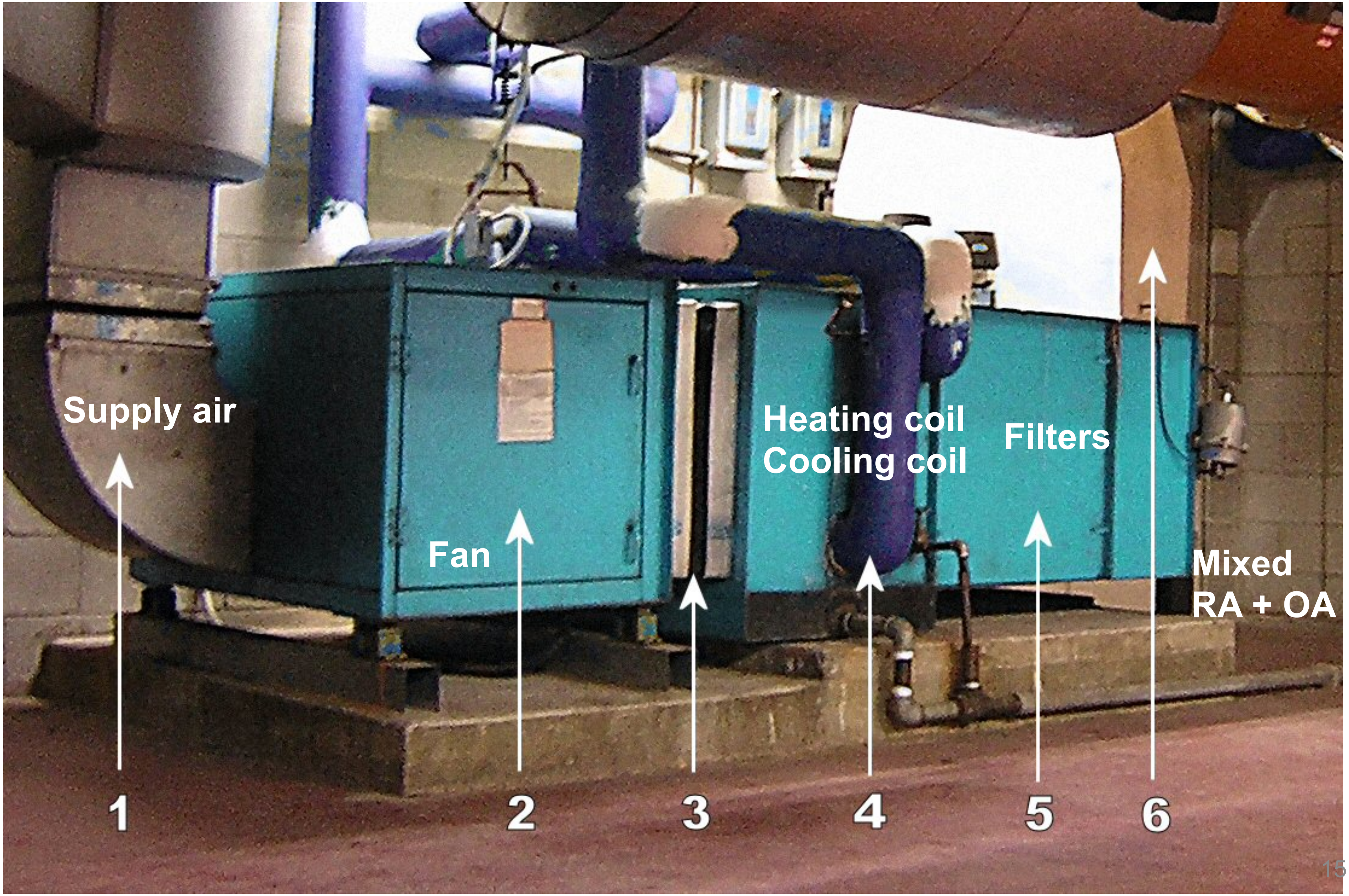
Typical central commercial air distribution system



Main components:

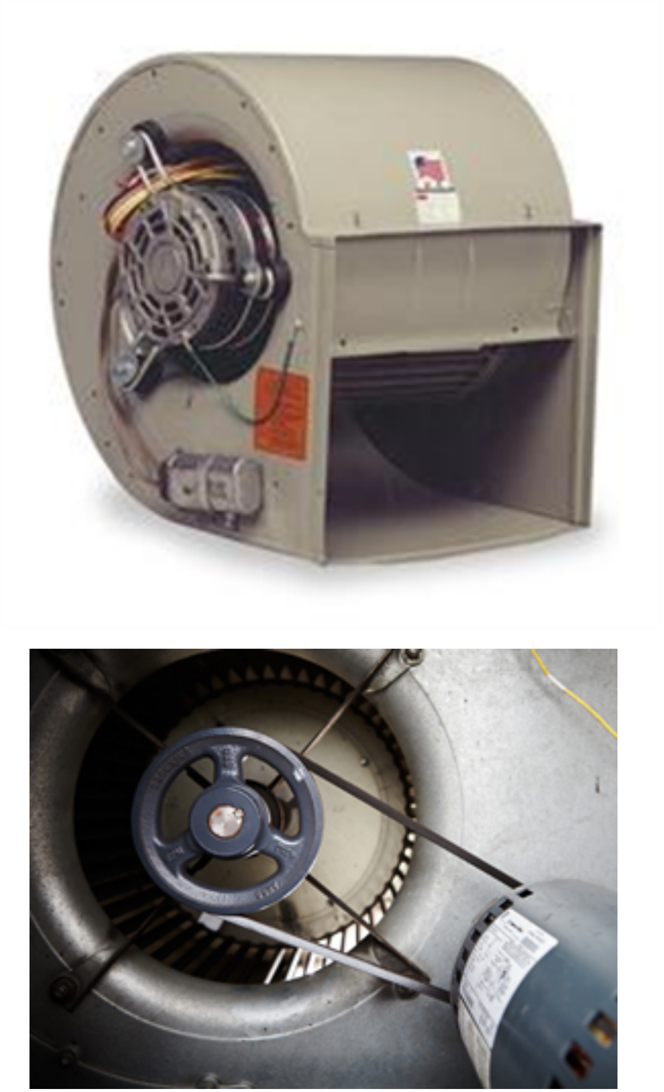
- Fans
- Coils
- Filters
- Mixing boxes
- Ducts
- Diffusers

Typical central commercial air handling unit (AHU)



Typical large central commercial AHU components

Fan (or “blower”)



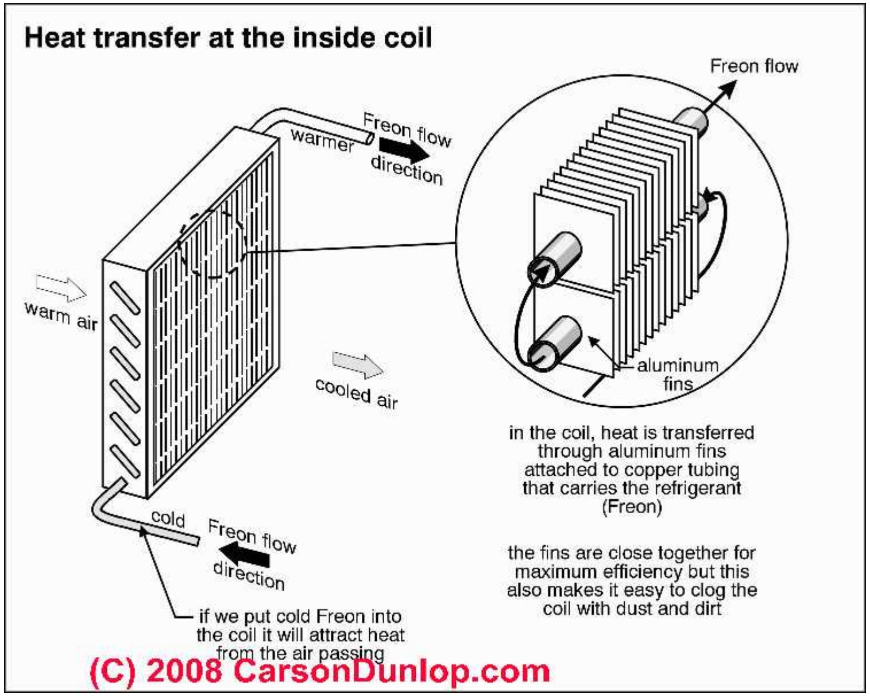
Variable frequency drives (VFDs)

Typical large central commercial AHU components

Mixing box

Typical large central commercial AHU components

Heating and cooling coils



Heat transfer at the inside coil

in the coil, heat is transferred through aluminum fins attached to copper tubing that carries the refrigerant (Freon)

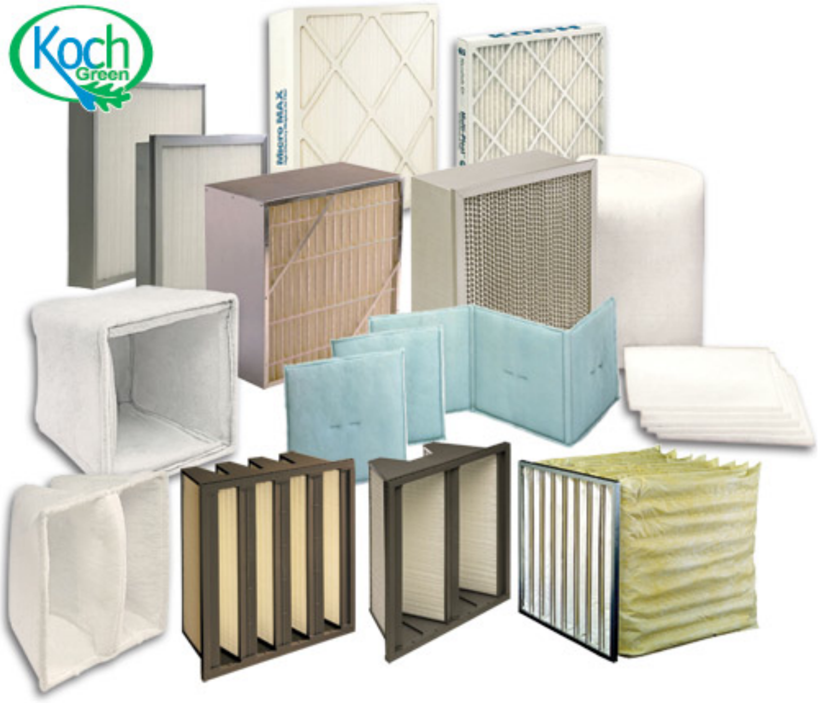
the fins are close together for maximum efficiency but this also makes it easy to clog the coil with dust and dirt

if we put cold Freon into the coil it will attract heat from the air passing

(C) 2008 CarsonDunlop.com

Typical large central commercial AHU components

Filter bank



Typical large central commercial AHU components

Filter bank

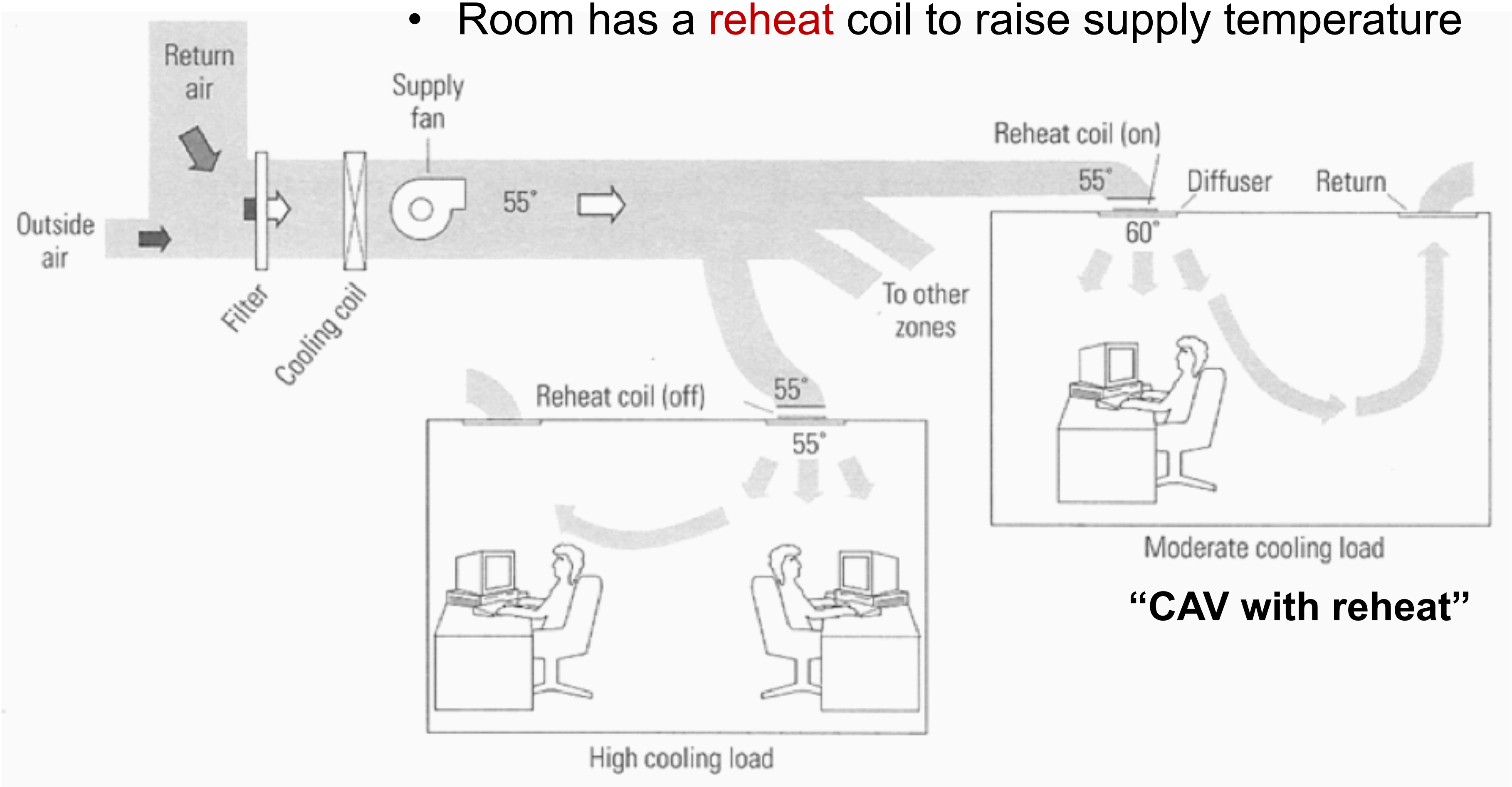
Common commercial air distribution systems

- Constant air volume (**CAV**)
- Variable air volume (**VAV**)
- Dual duct (**DD**)
- Multizone (**MZ**)

Typical constant air volume (CAV) system

Constant airflow rate and temperature to each room

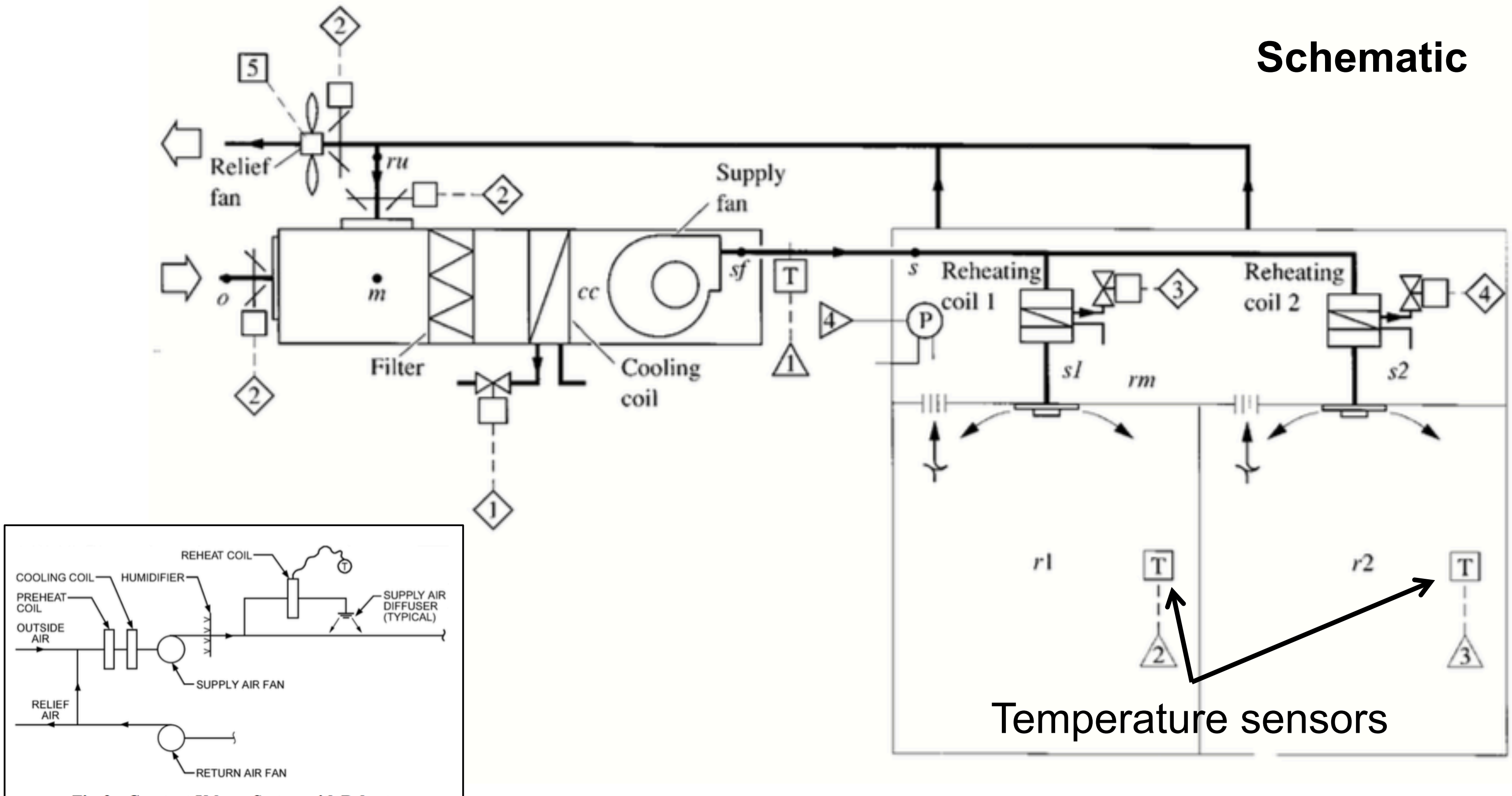
- Cold air delivered to room
- Room has a reheat coil to raise supply temperature



"CAV with reheat"

Typical constant air volume (CAV) system

Schematic



Temperature sensors

Fig. 9 Constant-Volume System with Reheat

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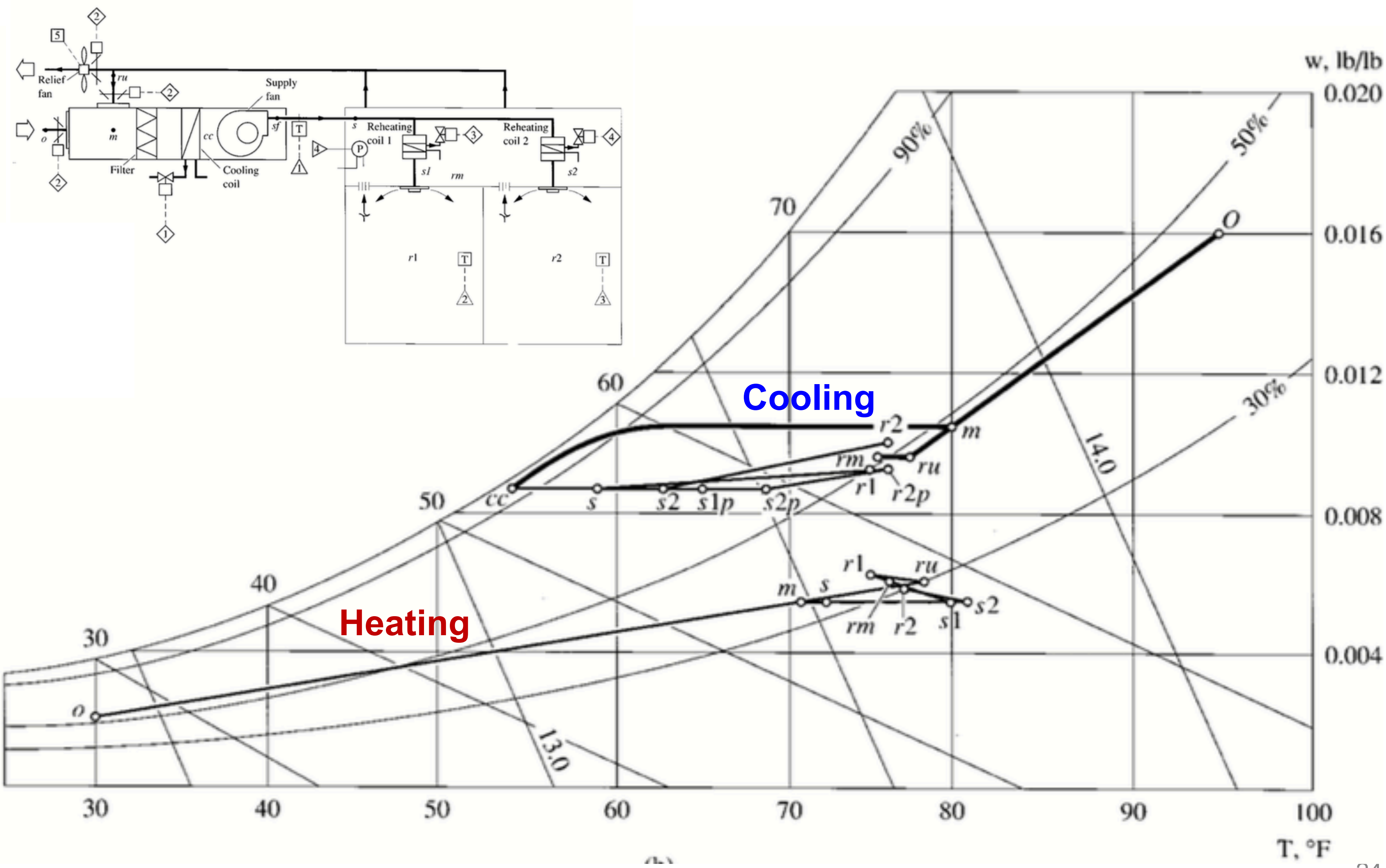
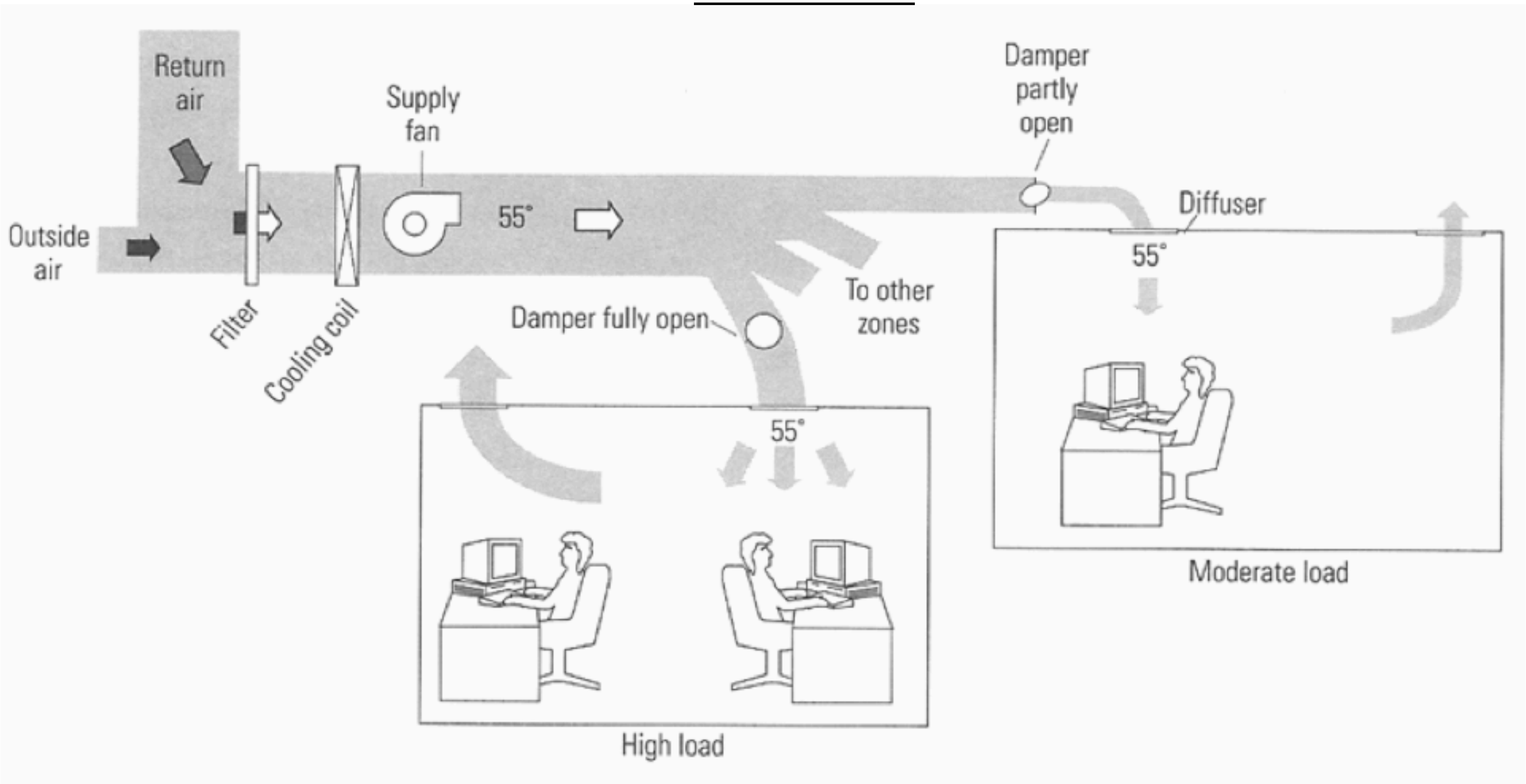
Typical constant air volume (CAV) system



Typical variable air volume (VAV) system

Same temperature air delivered to each room

- Different airflow rate delivered to each room



Typical variable air volume (VAV) system

Same temperature air delivered to each room

- Different airflow rate delivered to each room

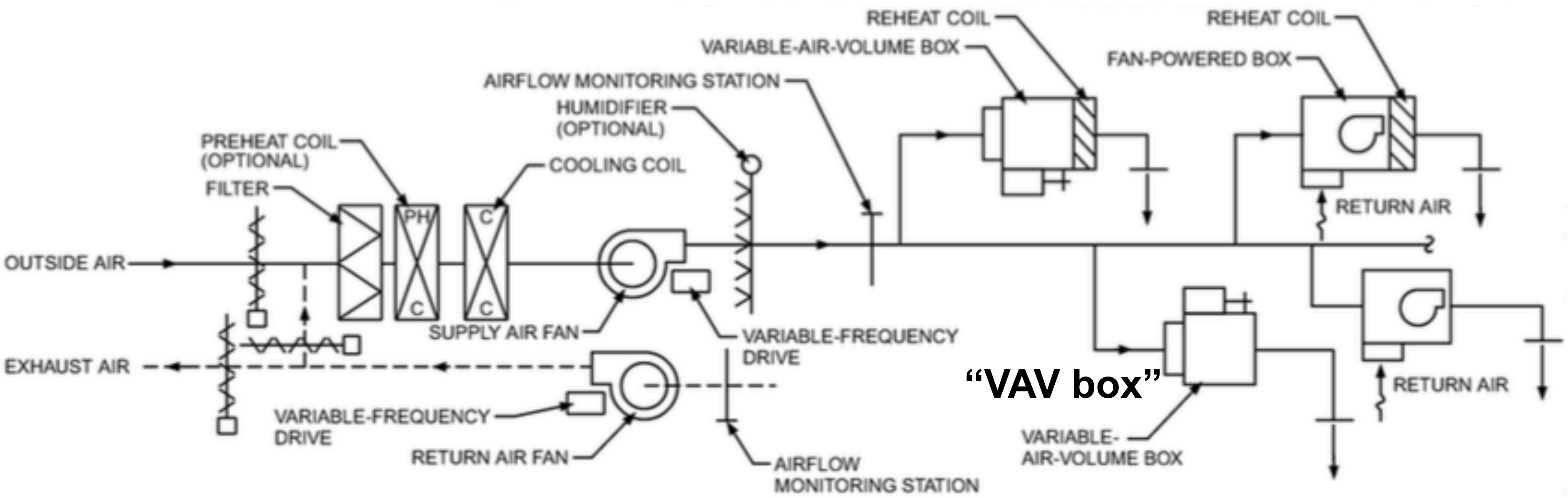
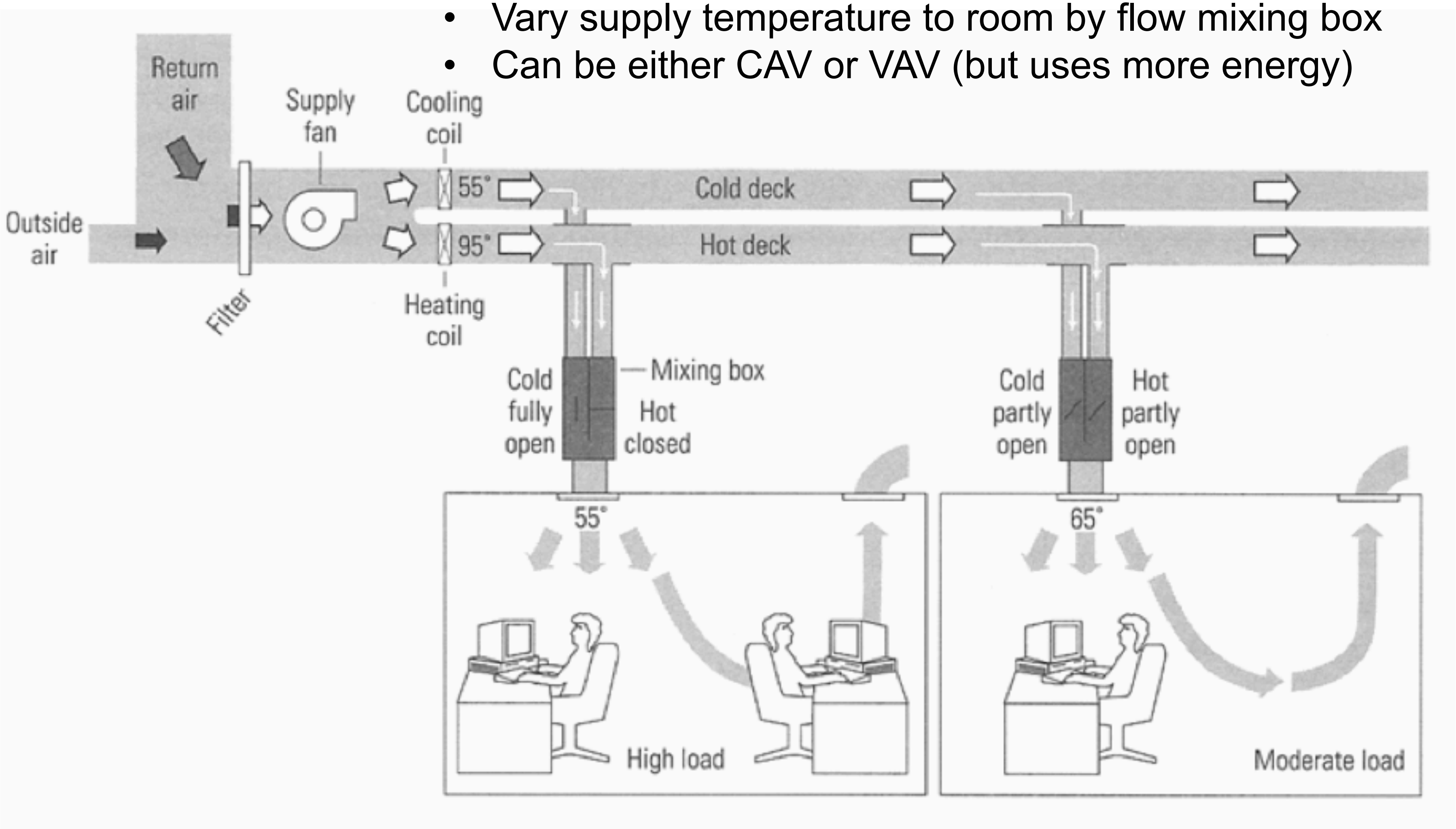


Fig. 10 Variable-Air-Volume System with Reheat and Induction and Fan-Powered Devices

Typical dual duct (DD) system

1 hot deck and 1 cold deck

- Vary supply temperature to room by flow mixing box
- Can be either CAV or VAV (but uses more energy)



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- Vary supply temperature to room by flow mixing box
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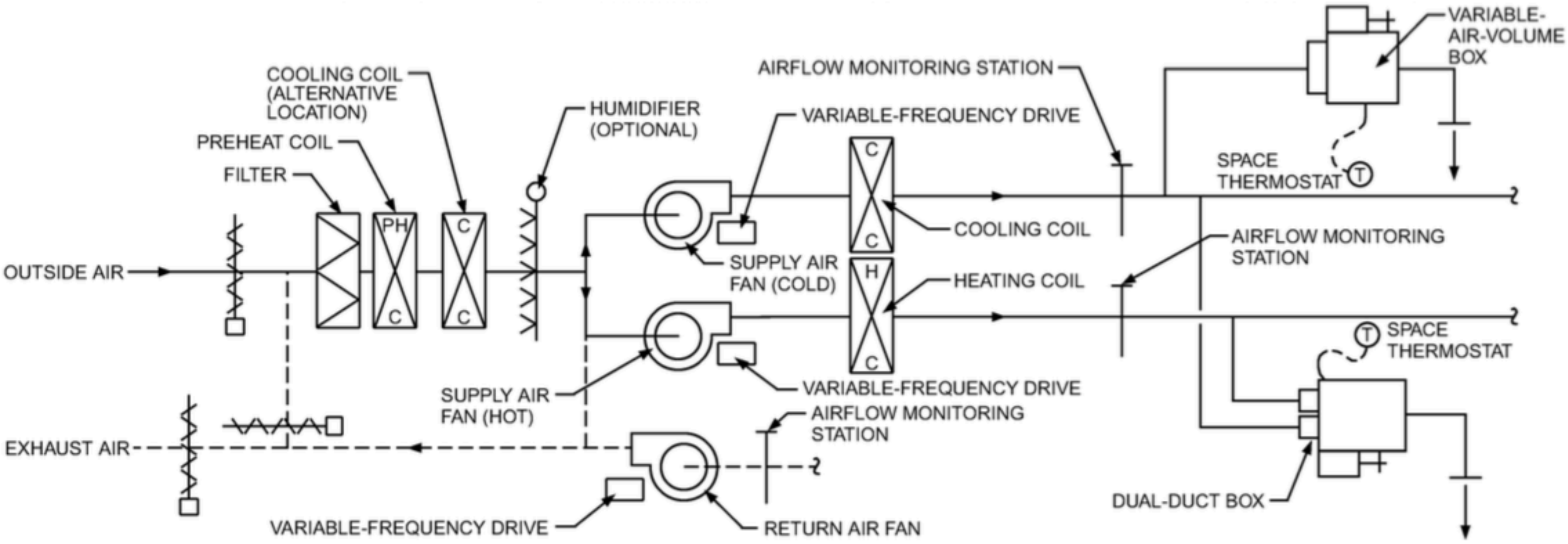
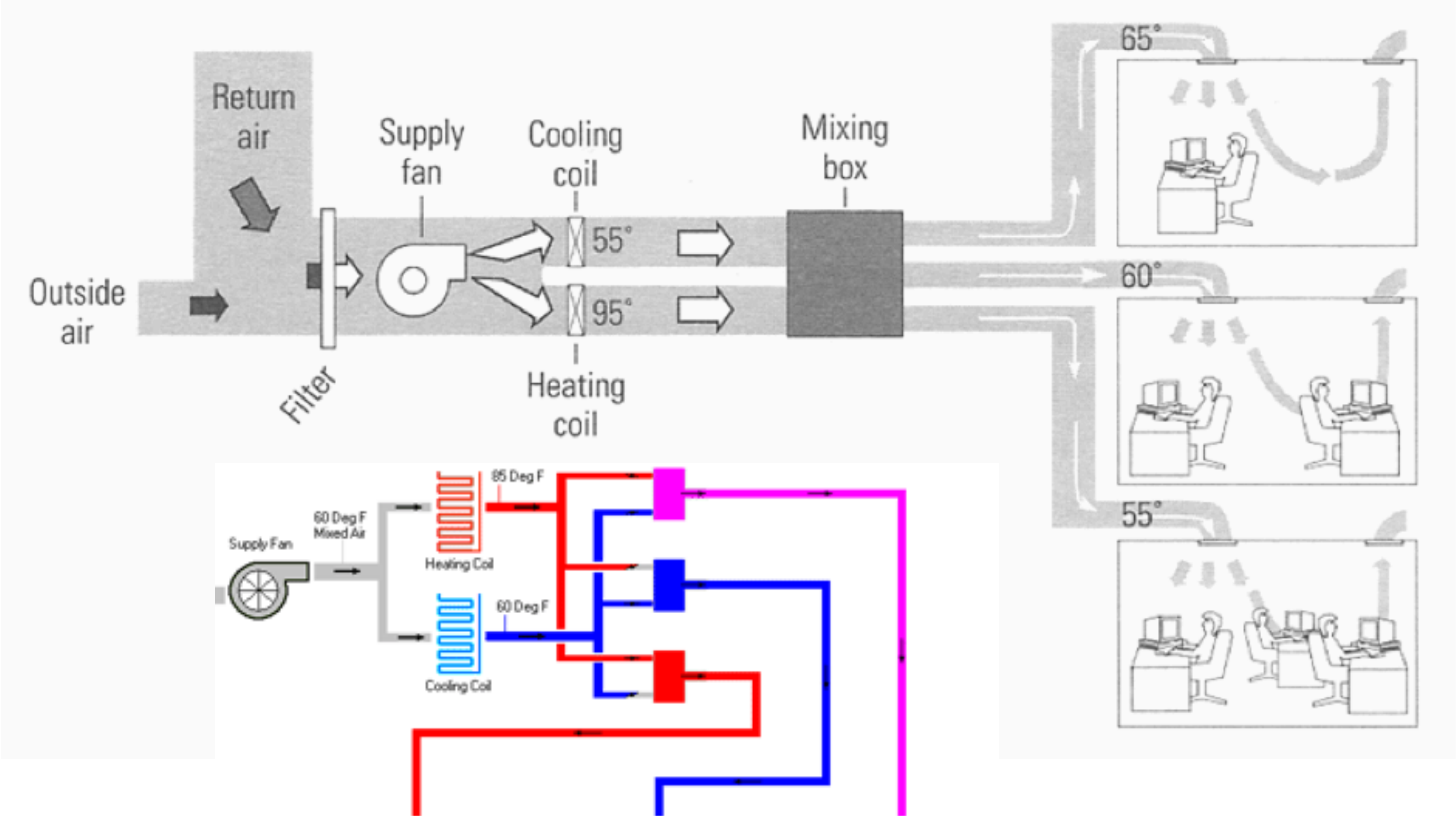


Fig. 12 Dual-Fan, Dual-Duct System

Typical multi-zone (MZ) system

Same airflow rate to each room

- Mixing box adjusts mixture of hot and cold to change supply temperature



Typical multi-zone (MZ) system

Same airflow rate to each room

- Mixing box adjusts mixture of hot and cold to change supply temperature

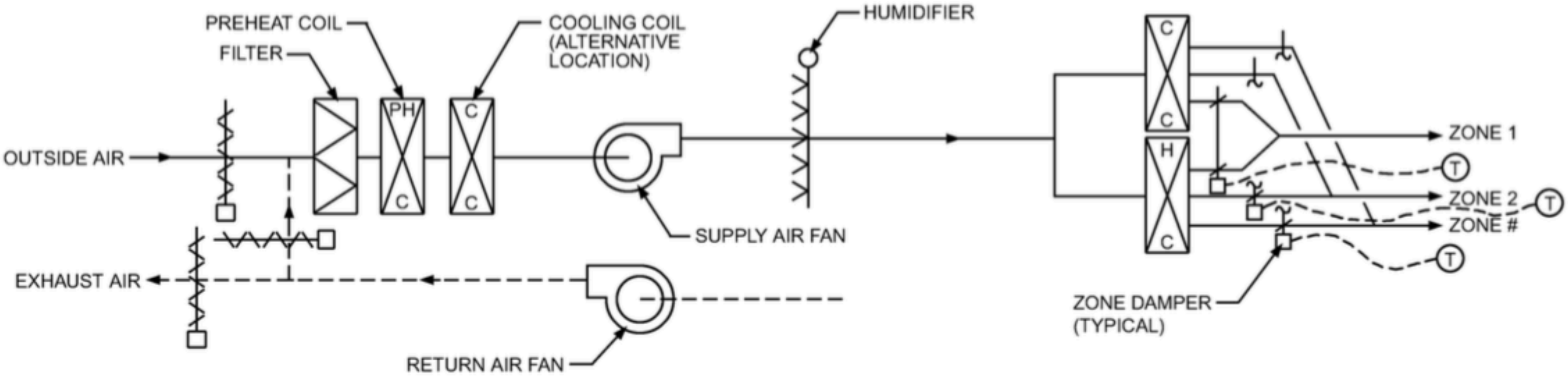
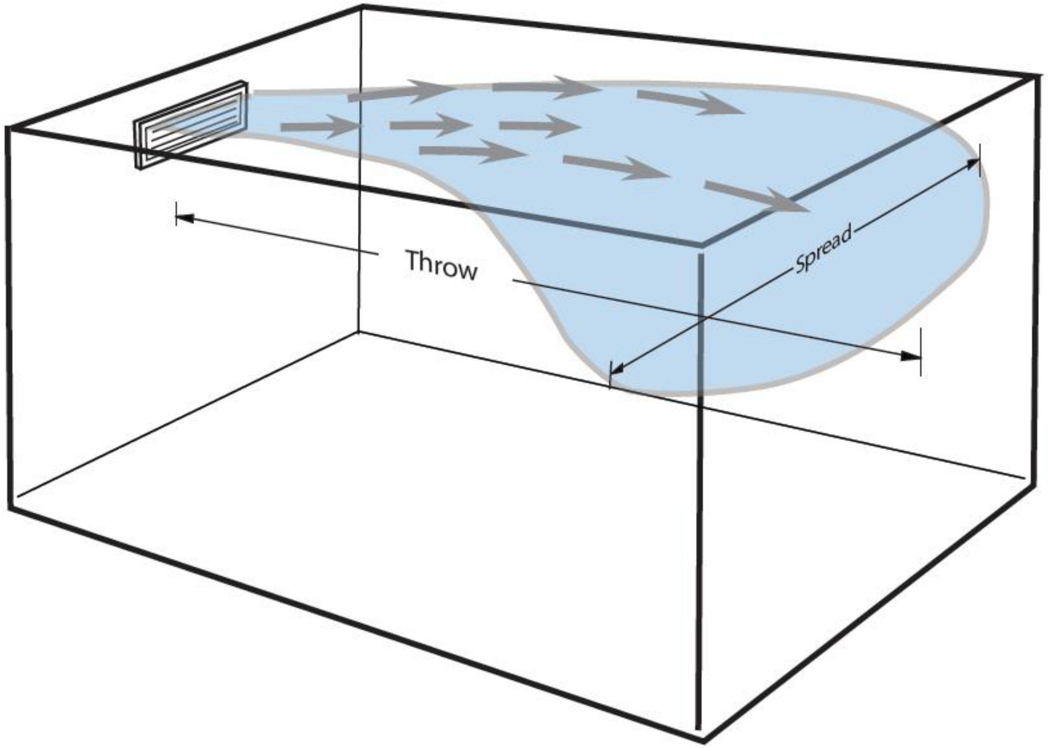
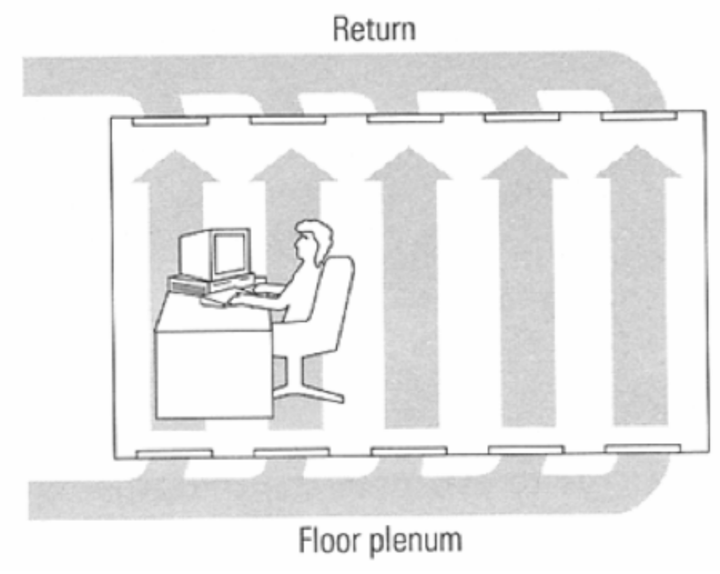


Fig. 13 Multizone System

Air supply and diffusers

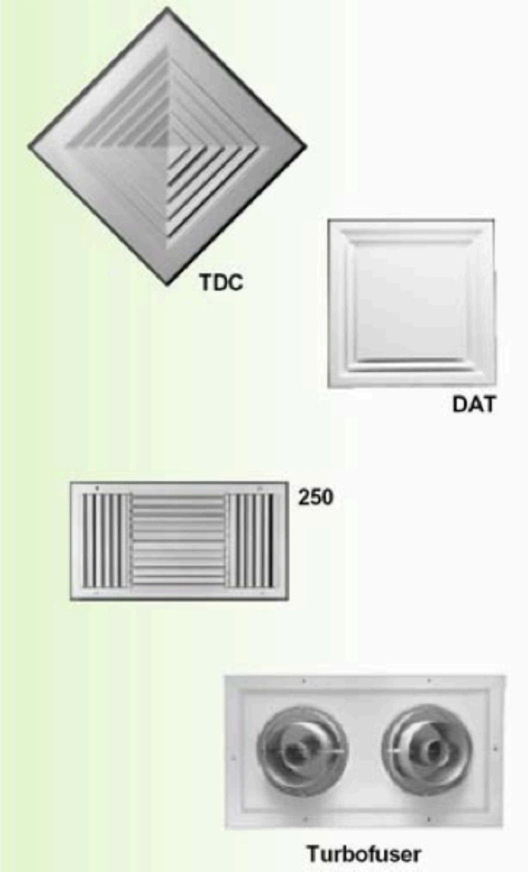
- Mixed versus displacement ventilation
- Diffuser selection





Air supply and diffusers

- Mixed versus displacement ventilation
- Diffuser selection

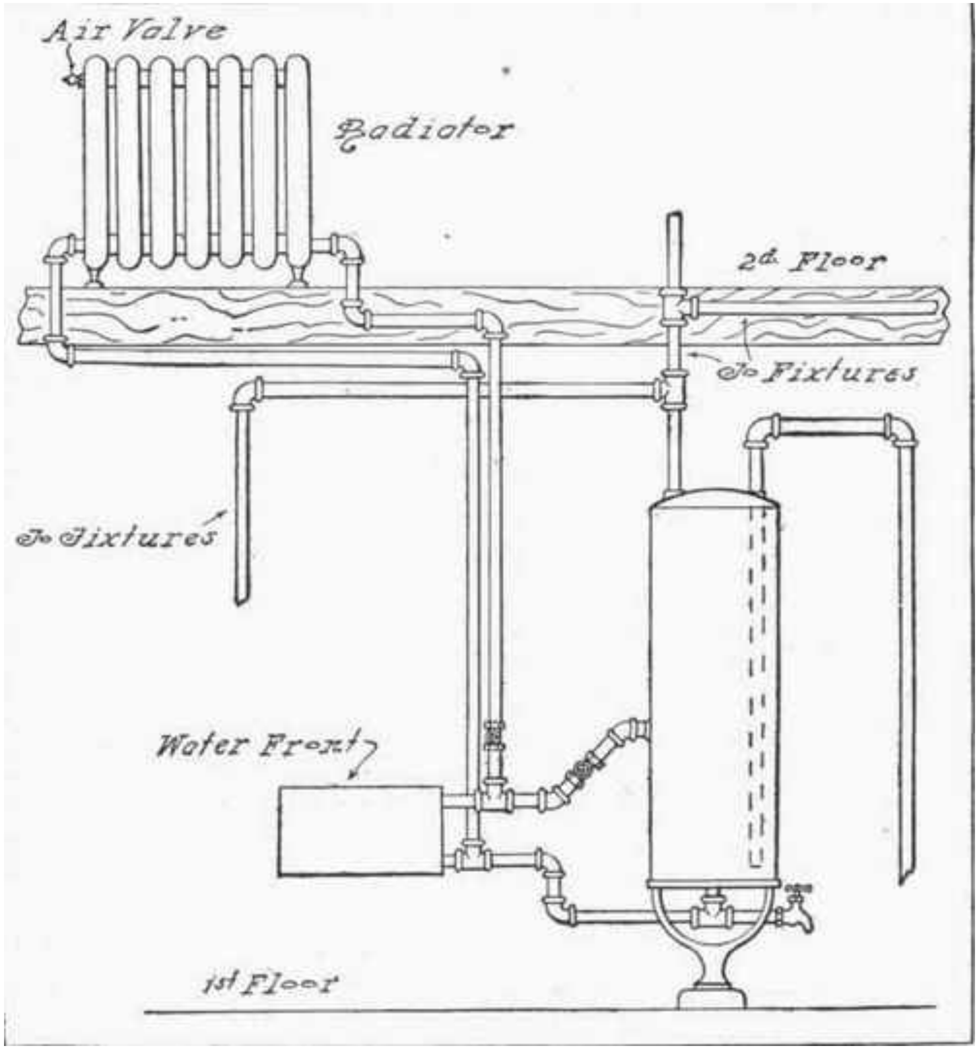


Air + water systems

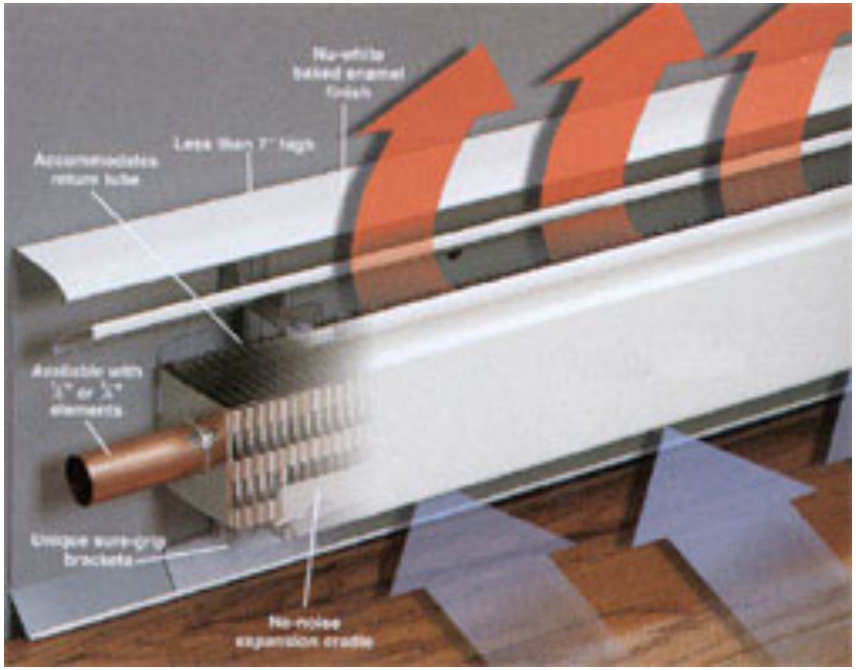
- Many commercial buildings use a combination of conditioned air and zone water coils
- Ventilation requires air movement
- But zone heating and cooling loads can be met with coils
  - We mostly use fan coils now
  - We previously mostly used radiators (like in Alumni Hall)

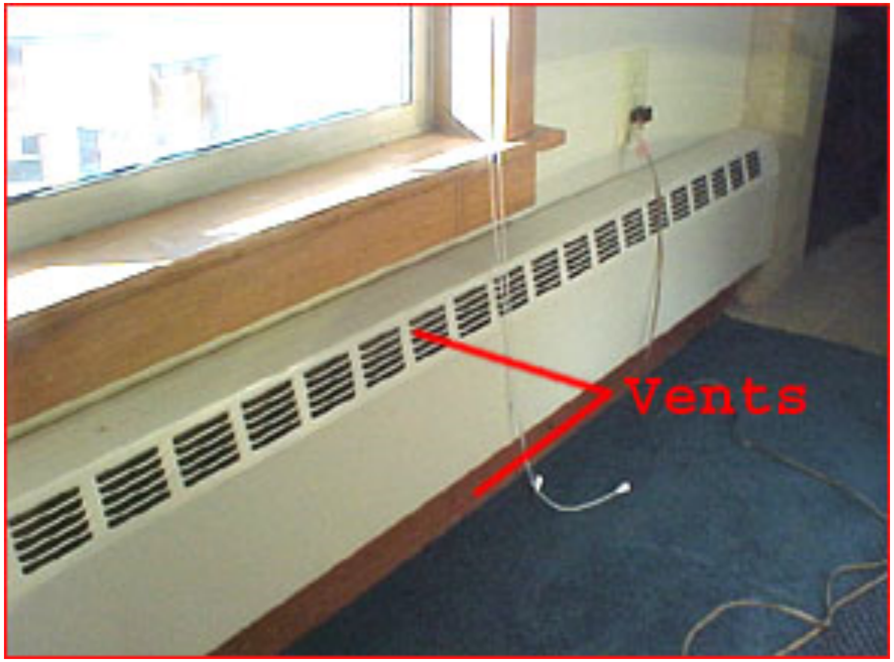
Radiator systems (for heating)

What modes of heat transfer are involved?



Water-based baseboard systems (heating)





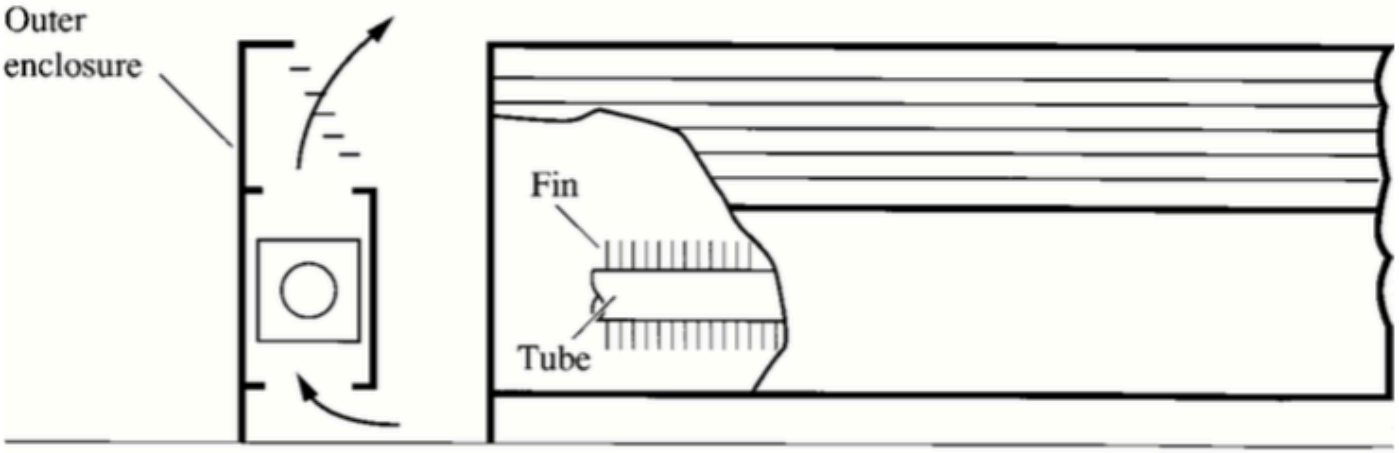


FIGURE 8.8 Baseboard finned-tube heater.

Water-based baseboard systems (heating)

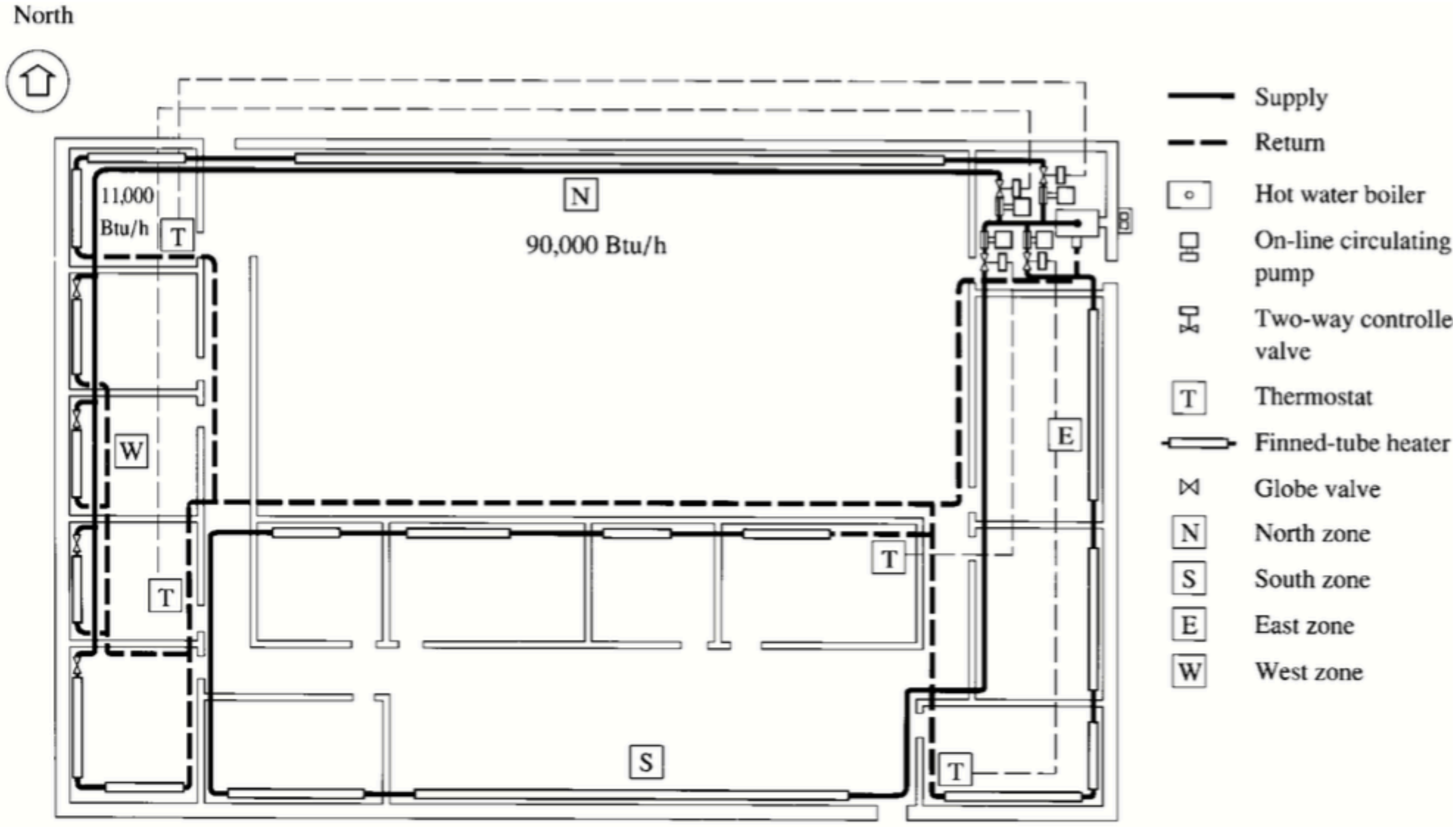
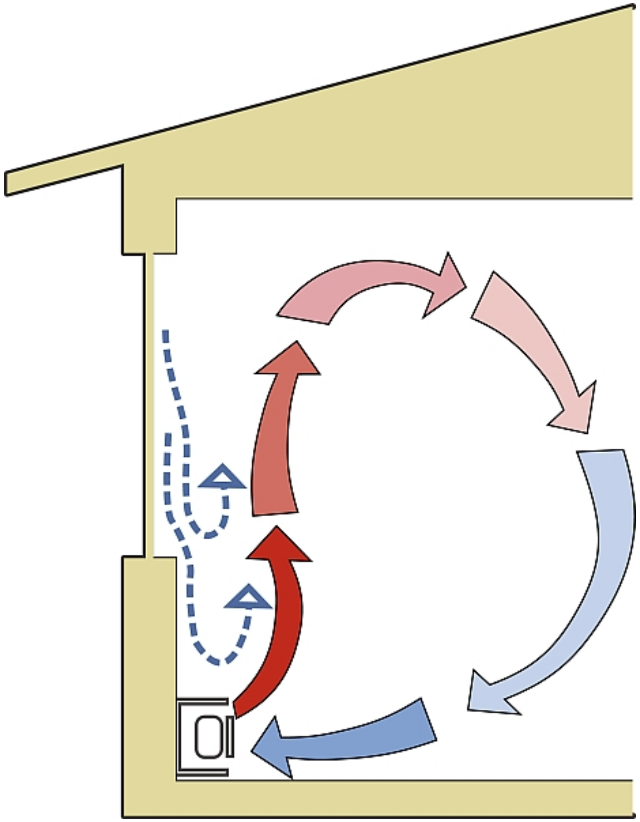
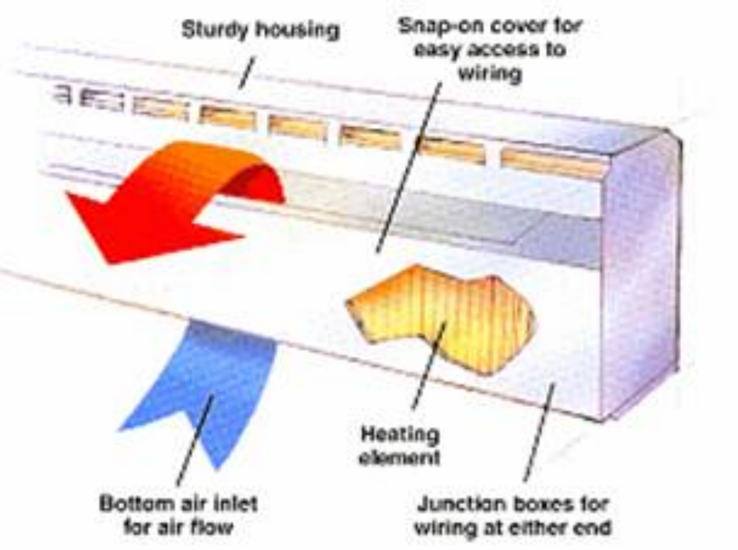


FIGURE 8.7 A two-pipe individual-loop low-temperature hot water heating system for a factory.

Electric baseboard systems (for heating)





Fan coils: Modern radiator replacement w/ fan

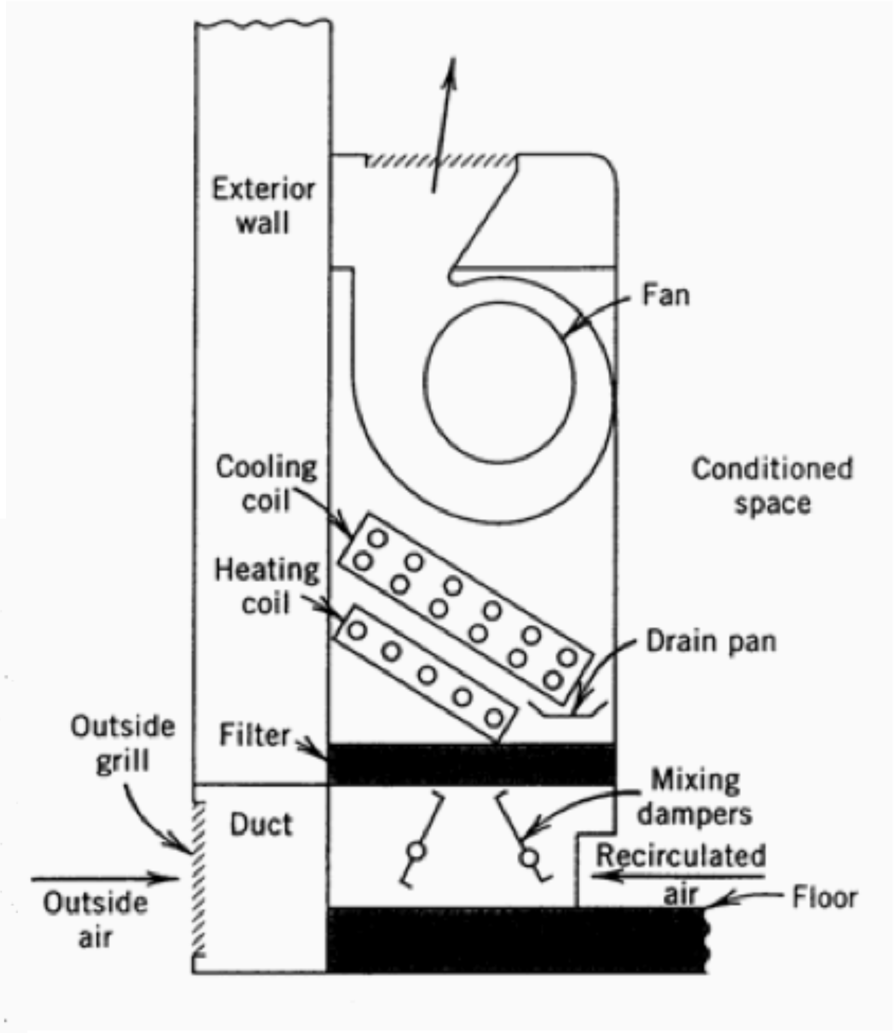
Combines air and water

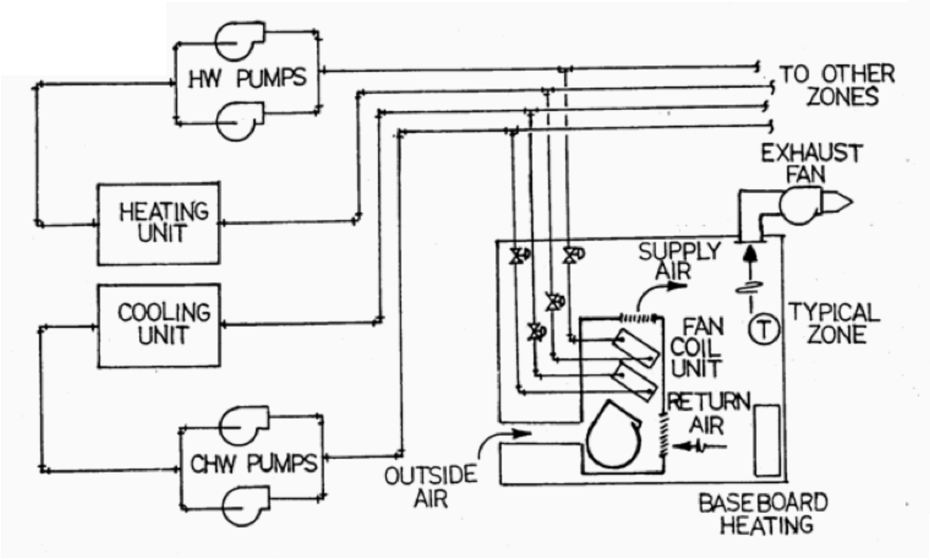
Wall installation

Overhead/ceiling installation

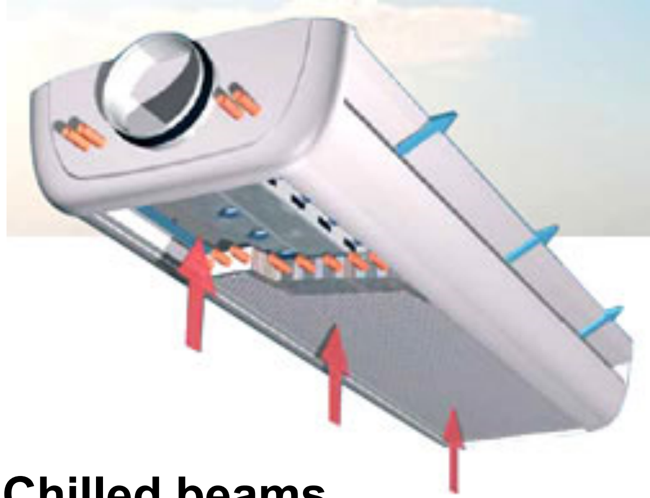
Fan coils: Modern radiator replacement w/ fan

- One or two coils (H or C)
- Thermostat controls water flow
- Ventilation is met with conditioned or unconditioned outdoor air





Other: Chilled beams and radiant panels



Chilled beams

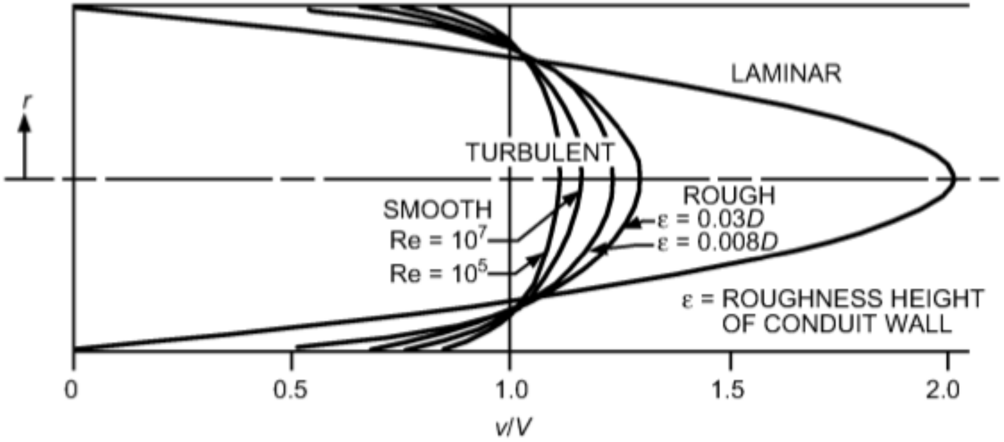
Radiant panels

FLUID FLOWS AND FAN/PUMP POWER

For distribution systems

Air and water distribution systems

- We use **fans** to move air around buildings
- We use **pumps** to move water/steam around buildings
- There are a few principles we need to understand to characterize **fan/pump energy and performance**



$$\mathrm{Re} = \frac{\rho v L}{\mu}$$

Fig. 4 Velocity Profiles of Flow in Pipes

Fluid flows in buildings: Overcoming pressure losses

- We use liquids and gases to deliver/extract heating or cooling energy in building mechanical systems
  - Water, refrigerants, and air
- We often need to understand fluid motion, pressure losses, and pressure rises by pumps and fans in order to correctly size systems and predict their performance
- We can use the Bernoulli equation to describe fluid flows in HVAC systems

$$\mathrm{p}_1 + \frac{1}{2}\rho_1 v_1^2 + \rho_1 g h_1 = \mathrm{p}_2 + \frac{1}{2}\rho_2 v_2^2 + \rho_2 g h_2 + p_{friction}$$

Static pressure

Velocity pressure

Pressure head

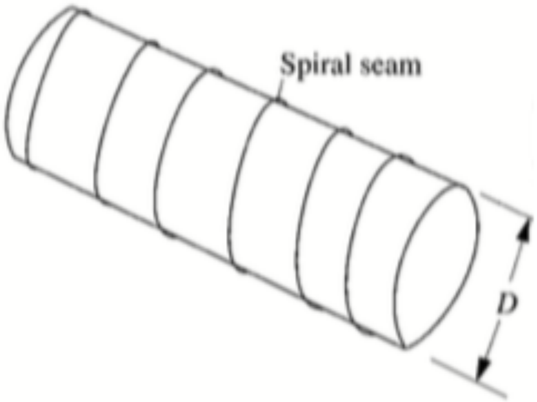
Friction losses

If friction and head are negligible, we can relate velocity to pressure:

$$v = \sqrt{\frac{2\Delta \mathrm{P}}{\rho}}$$

Pressure losses

- We often need to find the pressure drop in pipes and ducts
  - Most flows in HVAC systems are turbulent



$$\Delta \mathrm{p}_{friction} = f\left(\frac{L}{D_h}\right)\left(\frac{1}{2}\rho v^2\right) = K\left(\frac{1}{2}\rho v^2\right)$$

$$D_h = \frac{4A}{P} = \text{hydraulic diameter}$$

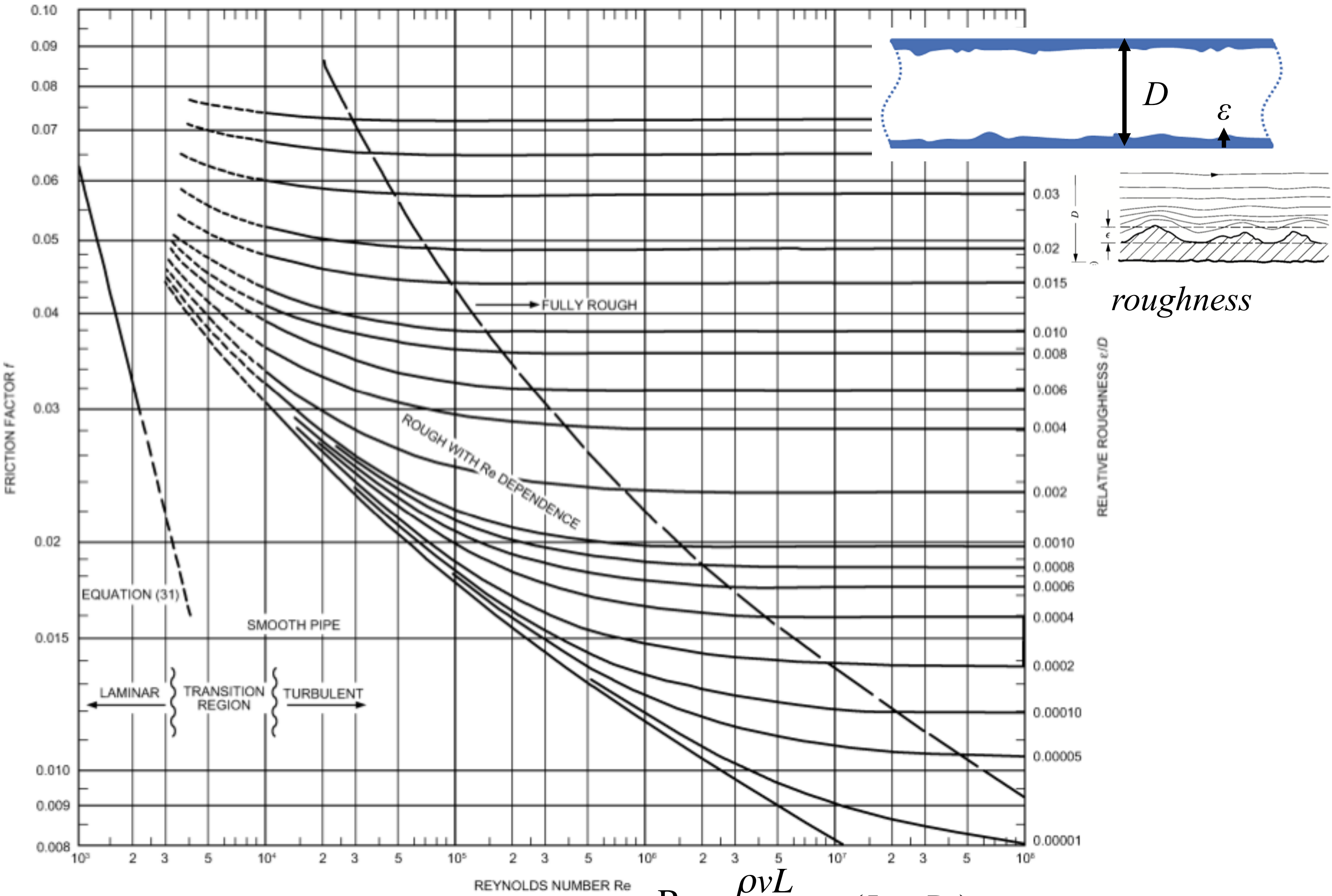
f = friction factor (-)
L = length (m)
D_h = hydraulic diameter (m)
ρ = fluid density (kg/m^3)
v = fluid velocity (m/s)

$$K = f\left(\frac{L}{D_h}\right)$$ In a straight pipe

$$K = f\left(\frac{L}{D_h} + \sum_{fittings} K_f\right)$$ In a straight pipe with fittings

Friction factor, f

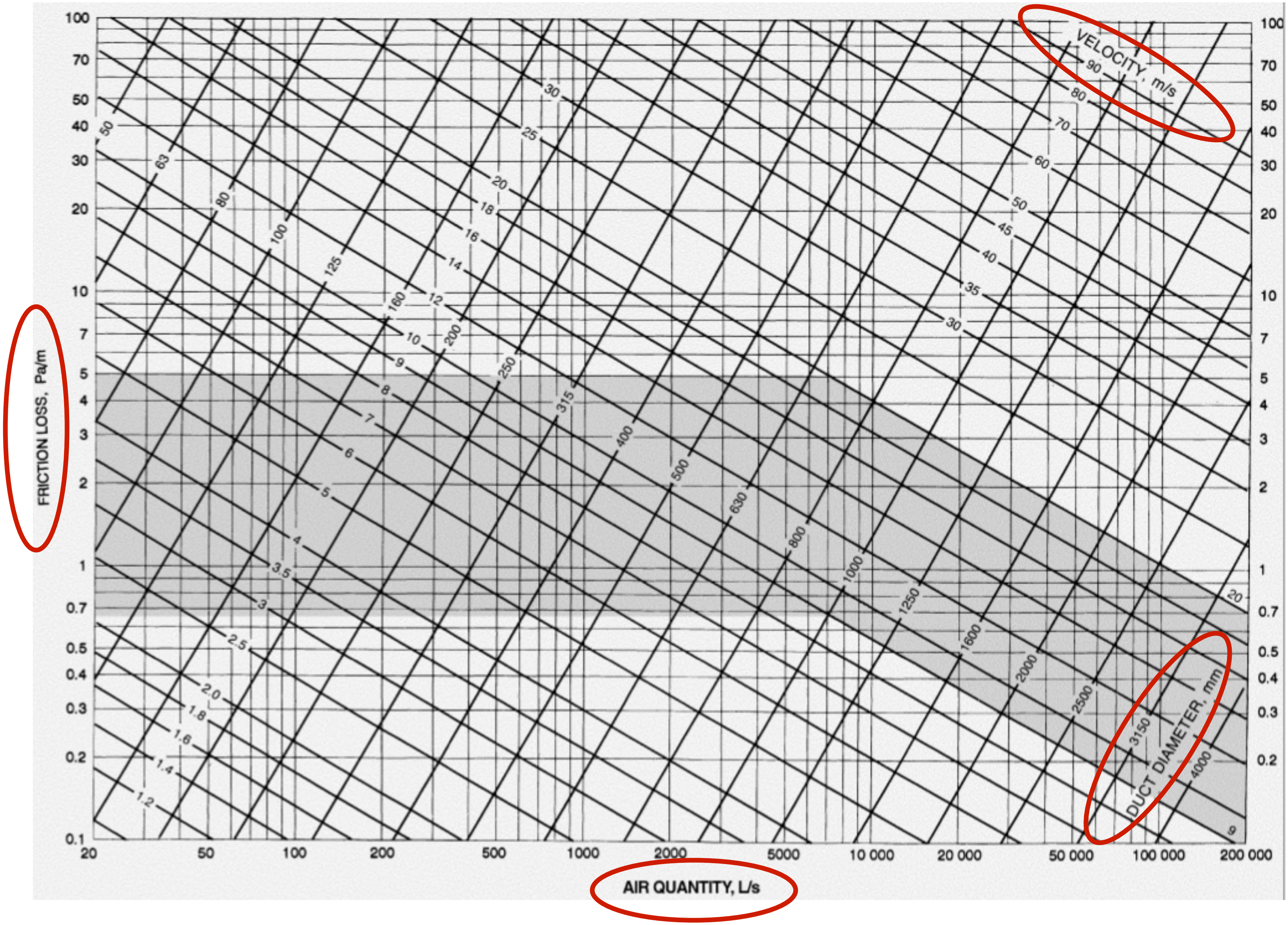
f



roughness

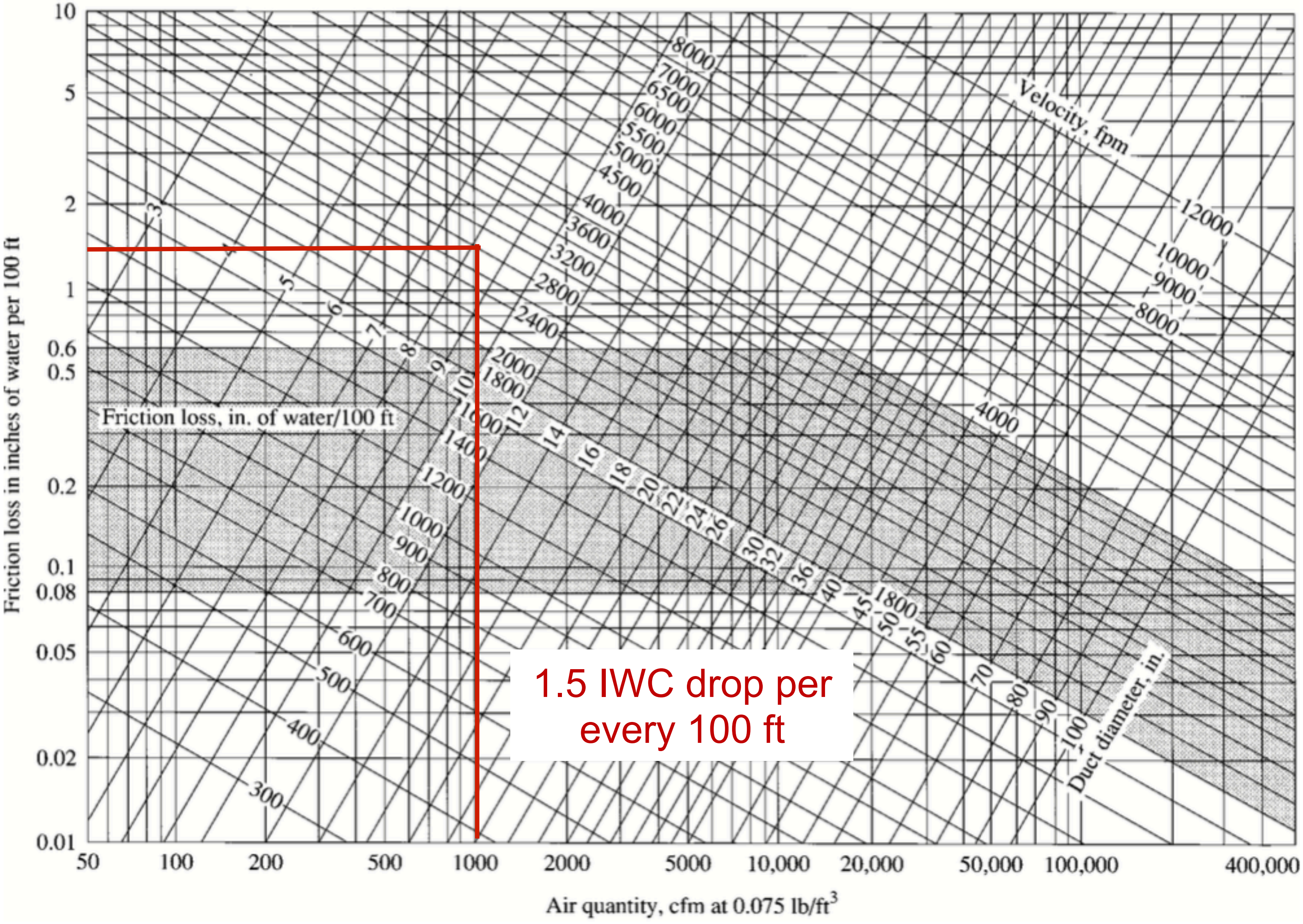
$$\mathrm{Re} = \frac{\rho v L}{\mu} \qquad (L = D_h)$$

Duct friction charts



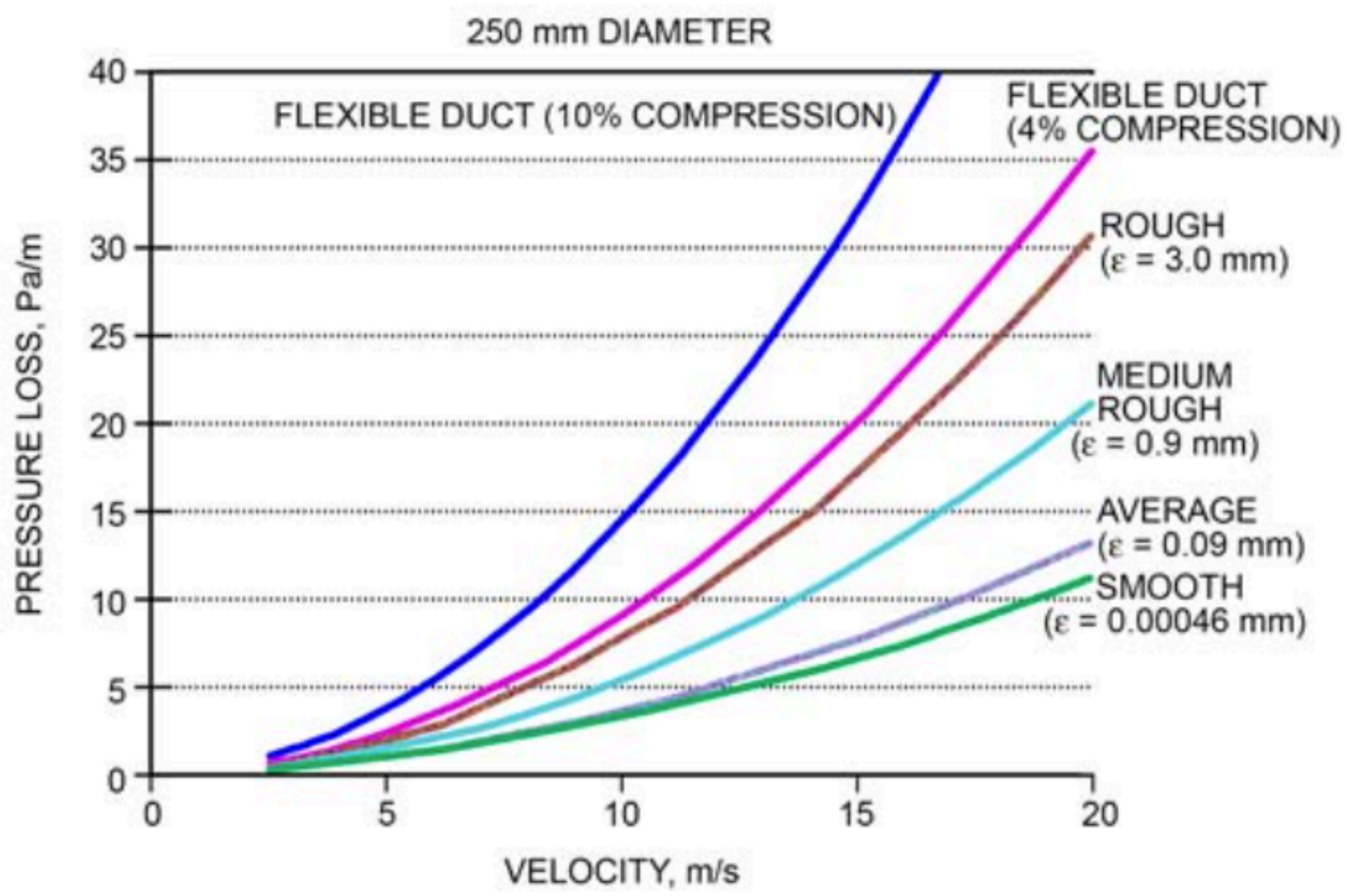
Duct friction charts (IP units)

For an 8” diameter duct at 1000 CFM:

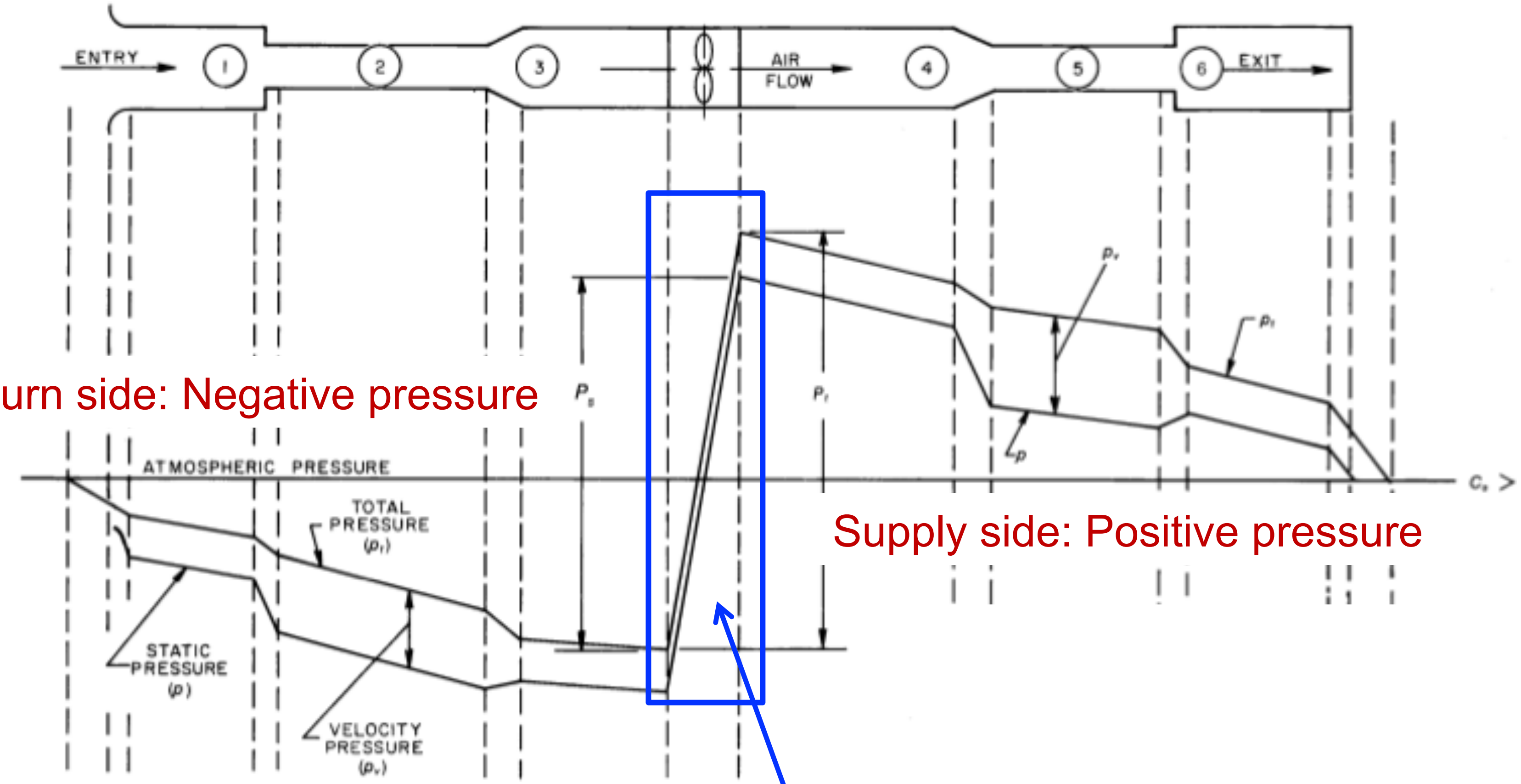


1.5 IWC drop per every 100 ft

Duct friction charts



Pressure losses and rises in HVAC systems



Return side: Negative pressure

Supply side: Positive pressure

Pressure rise:
Energy input into system by fan

Pressure losses and rises in HVAC systems

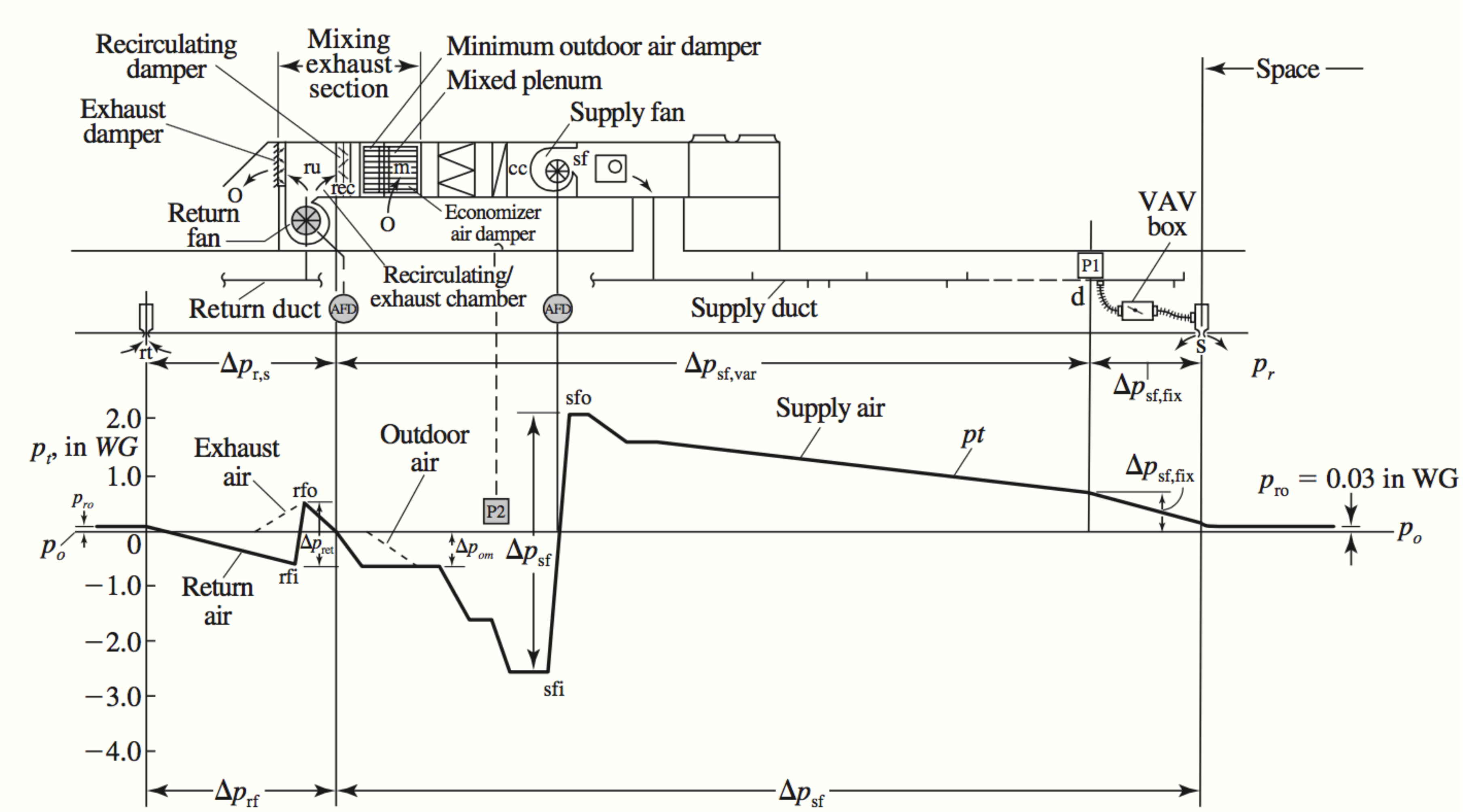
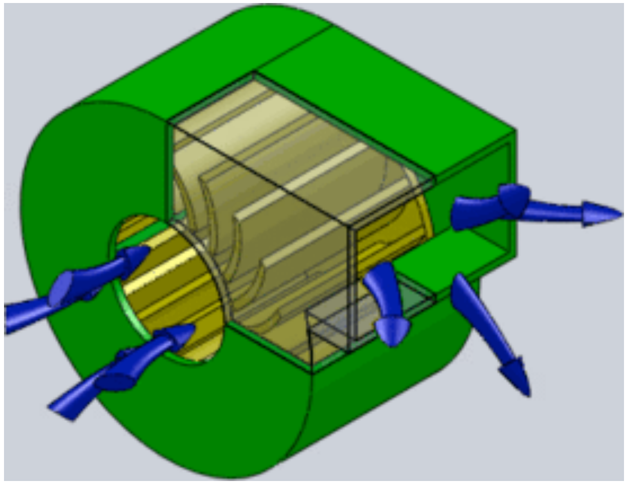


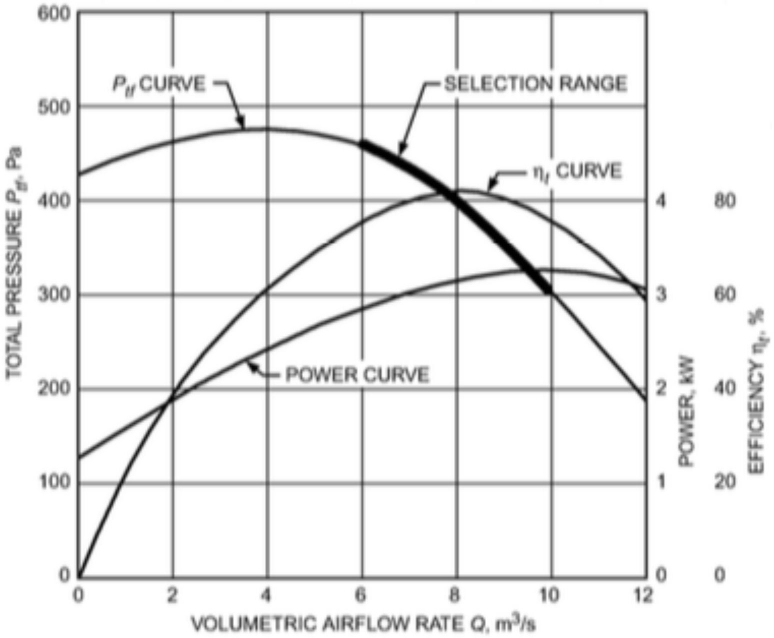
FIGURE 22.1 System pressure diagram for a supply-return fan combination air system (connected in series) (rfi = return fan inlet; rfo = return fan outlet; sfi = supply fan inlet; sfo = supply fan outlet; Δp_{rf} = return fan total pressure; Δpsf = supply fan total pressure; AFD = adjustable-frequency, variable-speed drive).

Intersection of fan curves and system curves

- Fans (and pumps) are used to overcome pressure drops in air and water distribution systems
- Their size and power draw are functions of the magnitude of pressure rise required
- We characterize performance by fan or pump performance curves

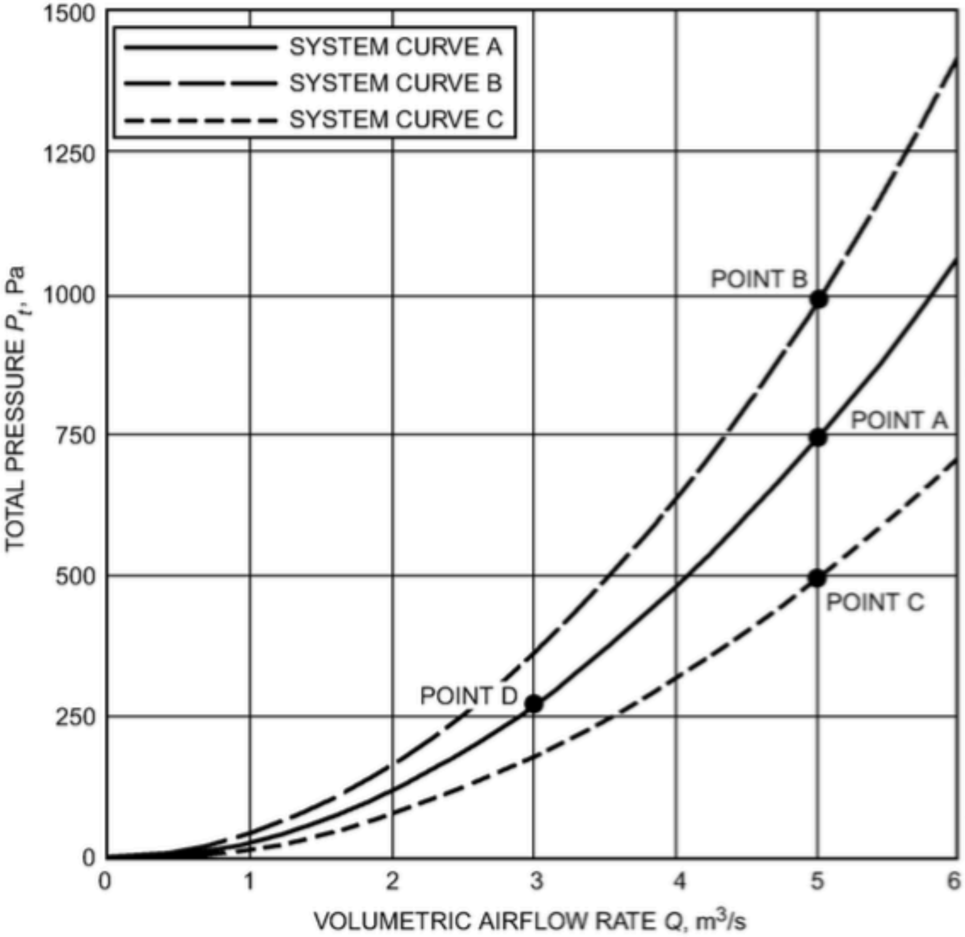


"Fan curve"



Intersection of fan curves and system curves

We characterize distribution systems (e.g., pipes or ducts) with a system curve

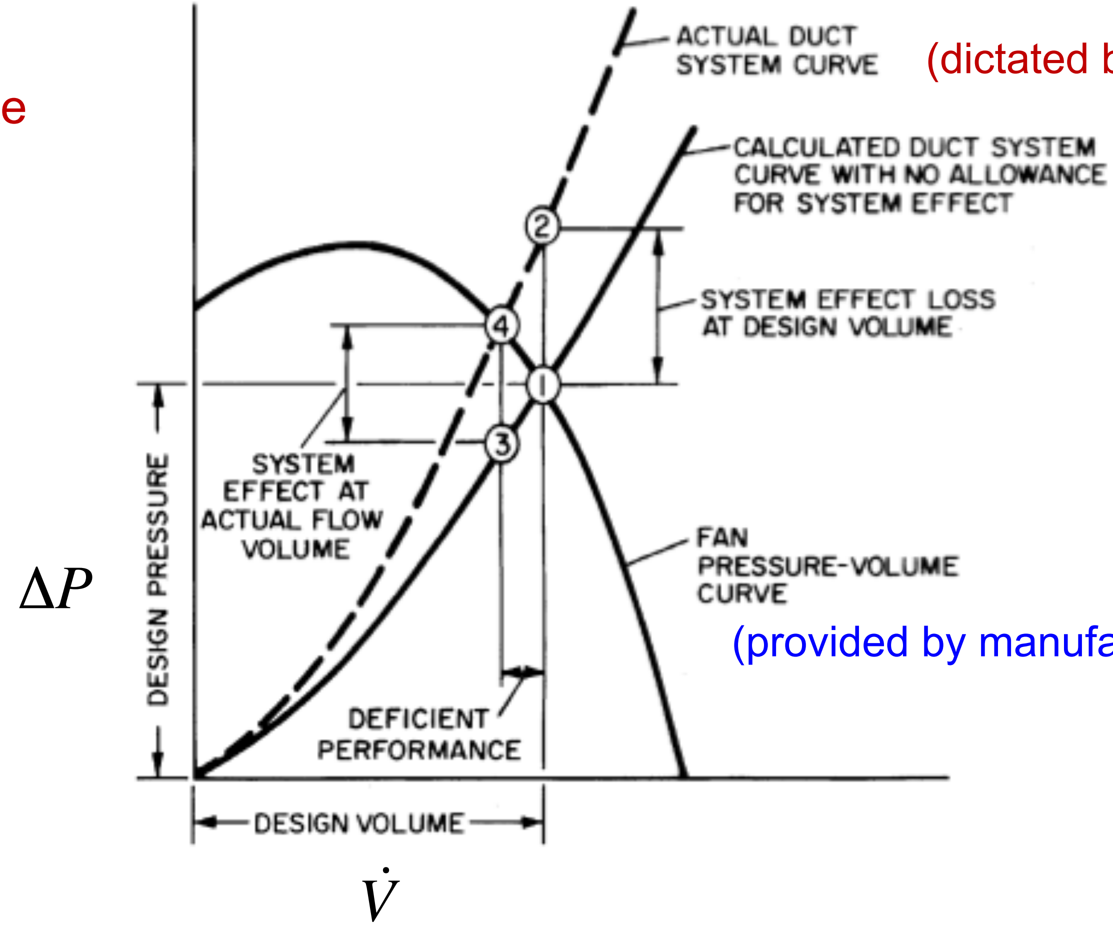


Intersection of fan curves and system curves

We then characterize the performance of a fan (or pump) with the intersection of its fan (or pump) curve and system curve

And we calculate fan (or pump) power draw by:

$$\boxed{W_{fan} = \frac{\Delta P \cdot \dot{V}}{\eta_{fan}}}$$

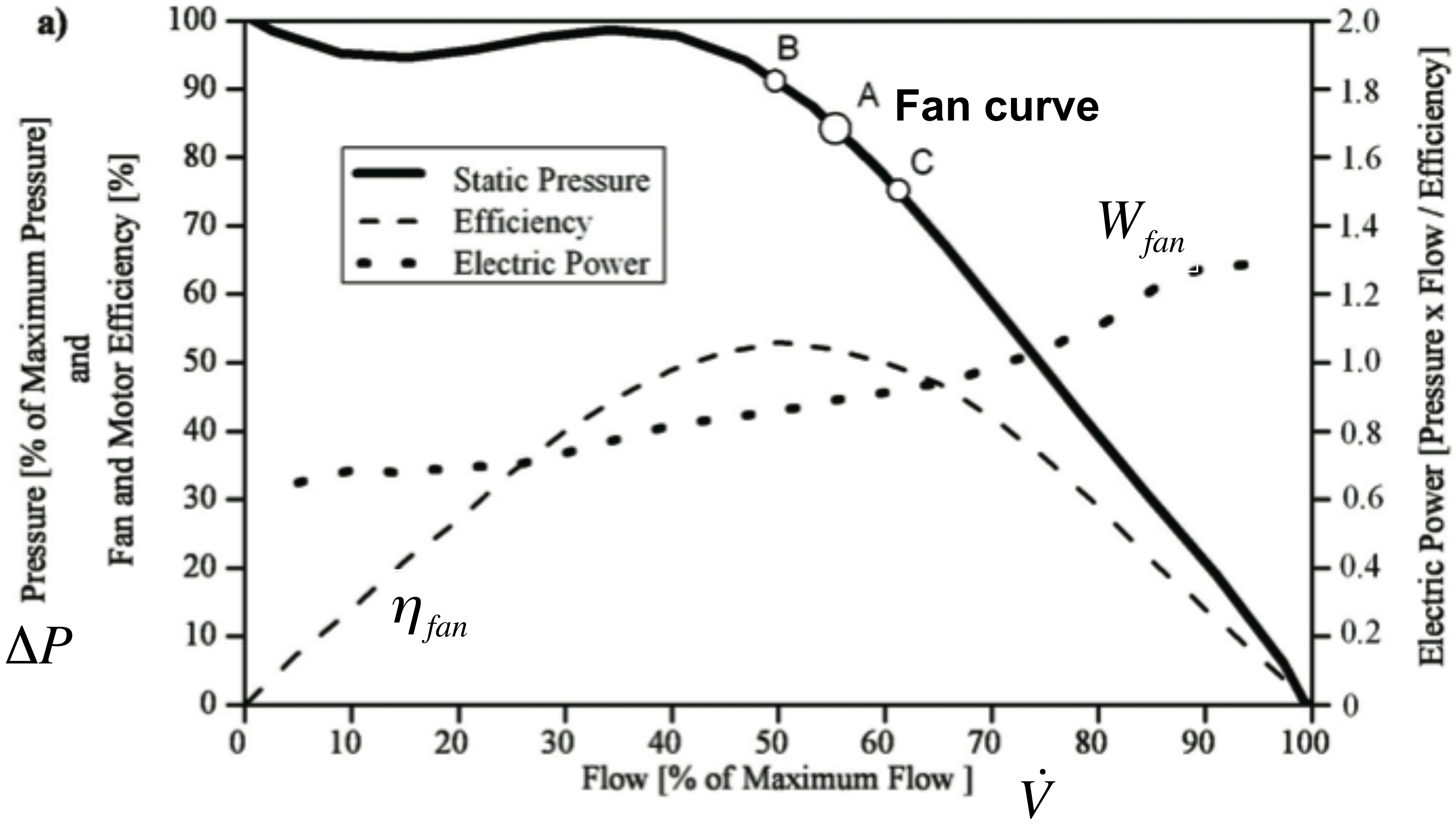


(dictated by duct system)

(provided by manufacturer)

Intersection of fan curves and system curves

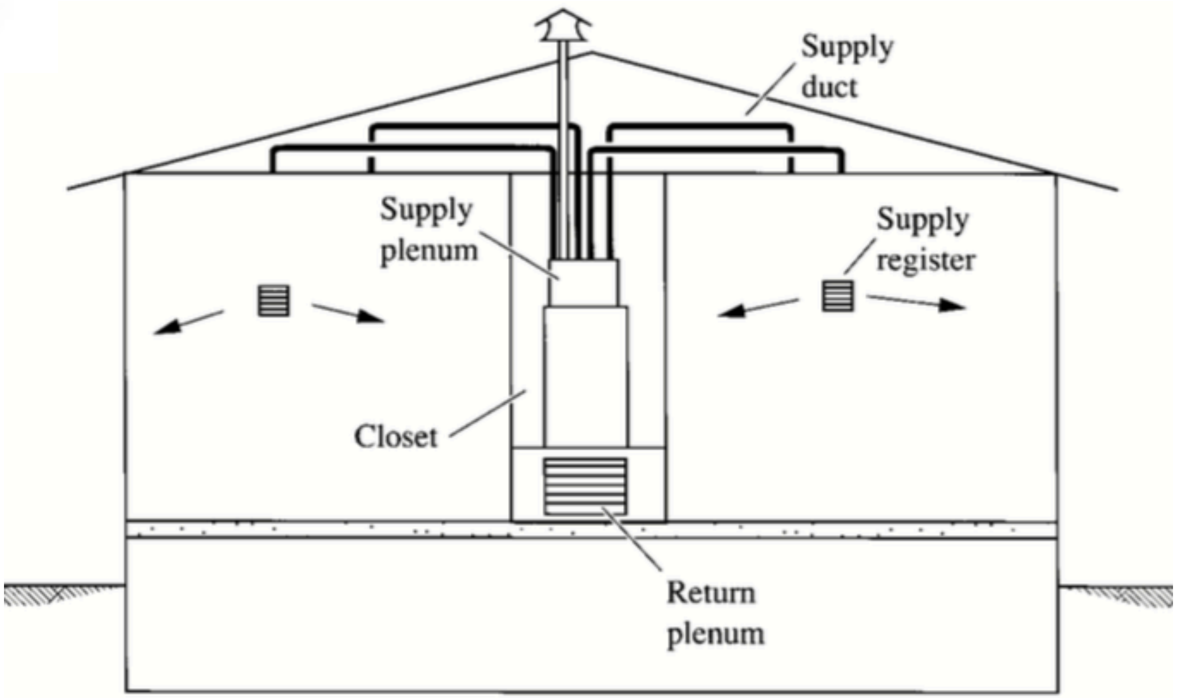
Example:
What is the fan power draw at point A, assuming 250 Pa and 1000 CFM?



One last loss: Duct heat losses or gains

Ducts are not perfectly insulated or sealed

- We often lose heat through ducts when heating
- Or gain heat from ducts when cooling



Duct heat losses

Typical central residential heating system: