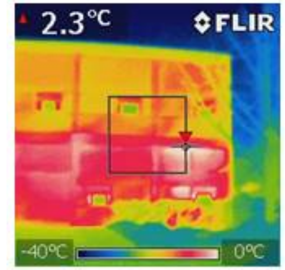
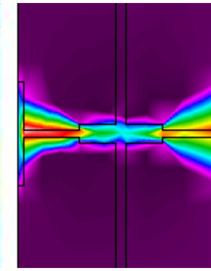
CAE 331/513
Building Science
Fall 2017





October 31, 2017
Air and water distribution systems

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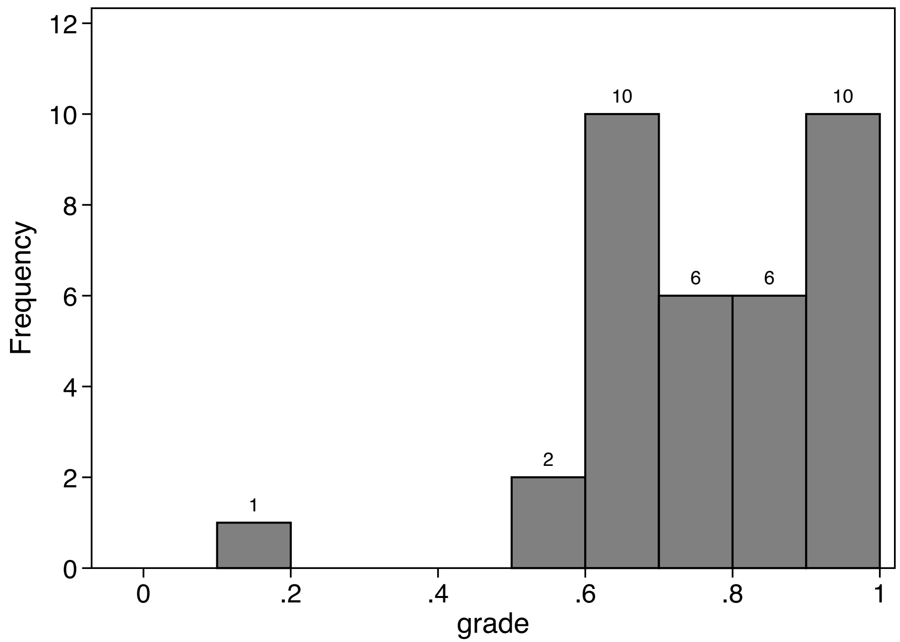
Exam 2 graded

- Average grade = 77.2%
- Minimum = 13%
- Maximum = 100% (3 of these)
- Graduate vs. undergraduate split:
  - Undergraduate student average = 76%
  - Graduate student average = 79%



Last time

- Refrigeration cycles
  - Ideal and non-ideal vapor compression cycles
  - P-h and T-s diagrams
  - COP/EER/SEER

Today

- Finish HVAC systems
  - Including air and water distribution systems

AC capacity and efficiency changes with outdoor T, indoor T/RH, and airflow rates

Table 4. Example Manufacturer EPT (Subset of Data Displayed)

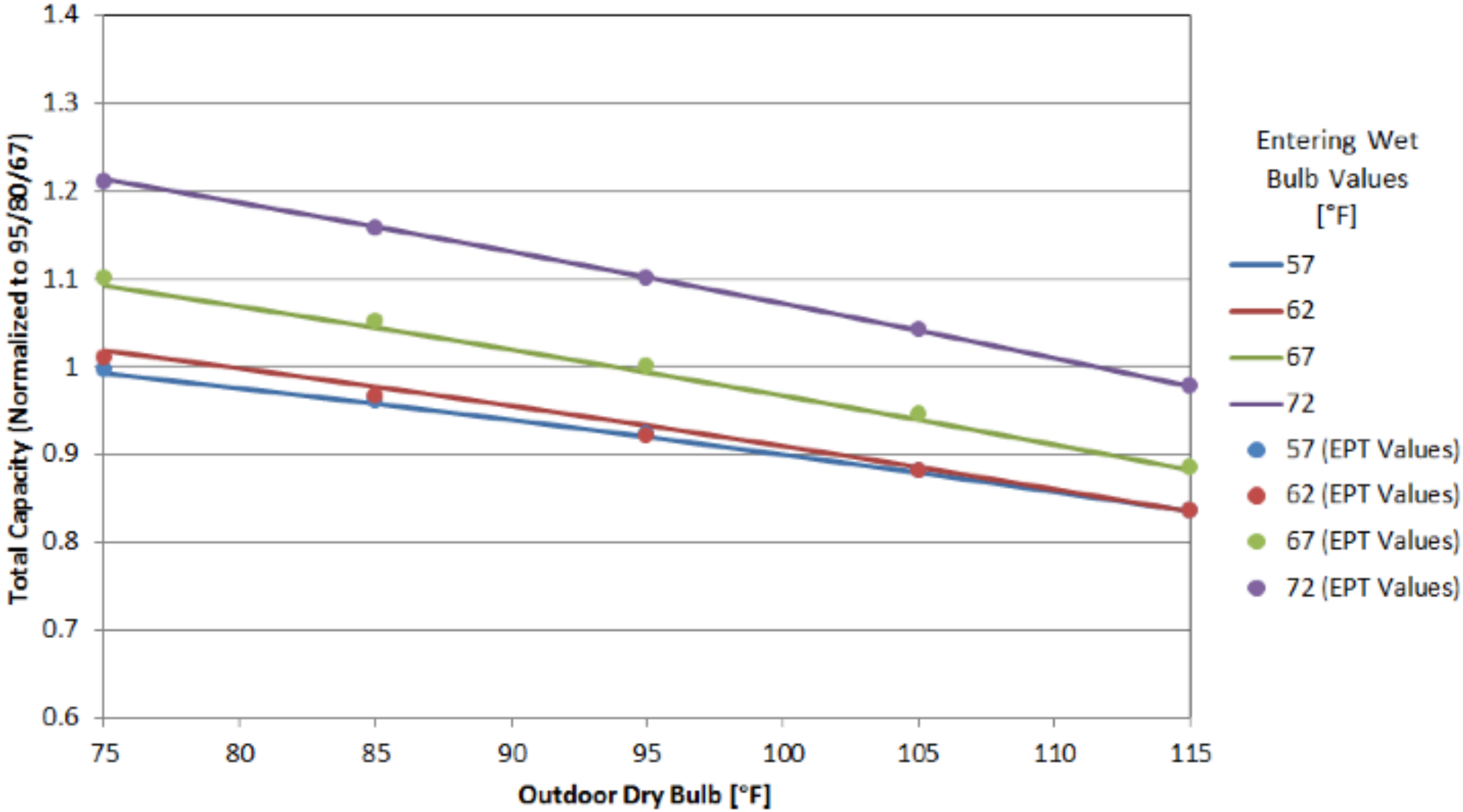
Evaporator Air		Condenser Air °F (°C)								
		75 (23.9)			95 (35)			105 (40.6)		
cfm	EWB °F (°C)	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[1,2]	Total Sys kW[3]	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[2]	Total Sys kW[3]	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[2]	Total Sys kW[3]
875	72 (22)	34.32	17.27	1.96	31.24	16.13	2.44	29.59	15.54	2.71
	67 (19)	31.45	21.21	1.96	28.59	20.05	2.43	27.04	19.44	2.71
	63 (17)	29.35	20.58	1.96	26.66	19.40	2.43	25.19	18.78	2.70
	62 (17)	28.82	25.13	1.95	26.24	23.94	2.43	24.86	23.29	2.70
	57 (14)	28.00	28.00	1.95	25.89	25.89	2.43	24.74	24.74	2.70
1000	72 (22)	34.88	18.05	2.01	31.66	16.90	2.48	29.96	16.30	2.76
	67 (19)	31.98	22.49	2.01	29.00	21.31	2.48	27.40	20.68	2.75
	63 (17)	29.88	21.78	2.00	27.07	20.58	2.48	25.55	19.95	2.75
	62 (17)	29.44	26.90	2.00	26.81	26.81	2.48	25.62	25.62	2.75
	57 (14)	29.10	29.10	2.00	26.85	26.85	2.48	25.62	25.62	2.75
1125	72 (22)	35.27	18.78	2.06	17.61	17.61	2.53	30.22	17.07	2.81
	67 (19)	32.36	23.68	2.05	22.50	22.50	2.53	27.66	21.88	2.80
	63 (17)	30.25	22.90	2.05	21.70	21.70	2.52	25.82	21.07	2.80
	62 (17)	30.02	28.49	2.05	27.62	27.62	2.52	26.32	26.32	2.80
	57 (14)	29.99	29.99	2.05	27.62	27.62	2.52	26.32	26.32	2.80

[1] Total and sensible capacities are net capacities. Blower motor heat has been subtracted.

[2] Sensible capacities shown are based on 80°F (27°C) entering air at the indoor coil. For sensible capacities at other than 80°F (27°C), deduct 835 Btu/h (245 W) per 1000 cfm (480 L/S) of indoor coil air for each degree below 80°F (27°C), or add 835 Btu/h (245 W) per 1000 cfm (480 L/s) of indoor coil air per degree above 80°F (27°C).

[3] System kilowatt is the total of indoor and outdoor unit kilowatts.

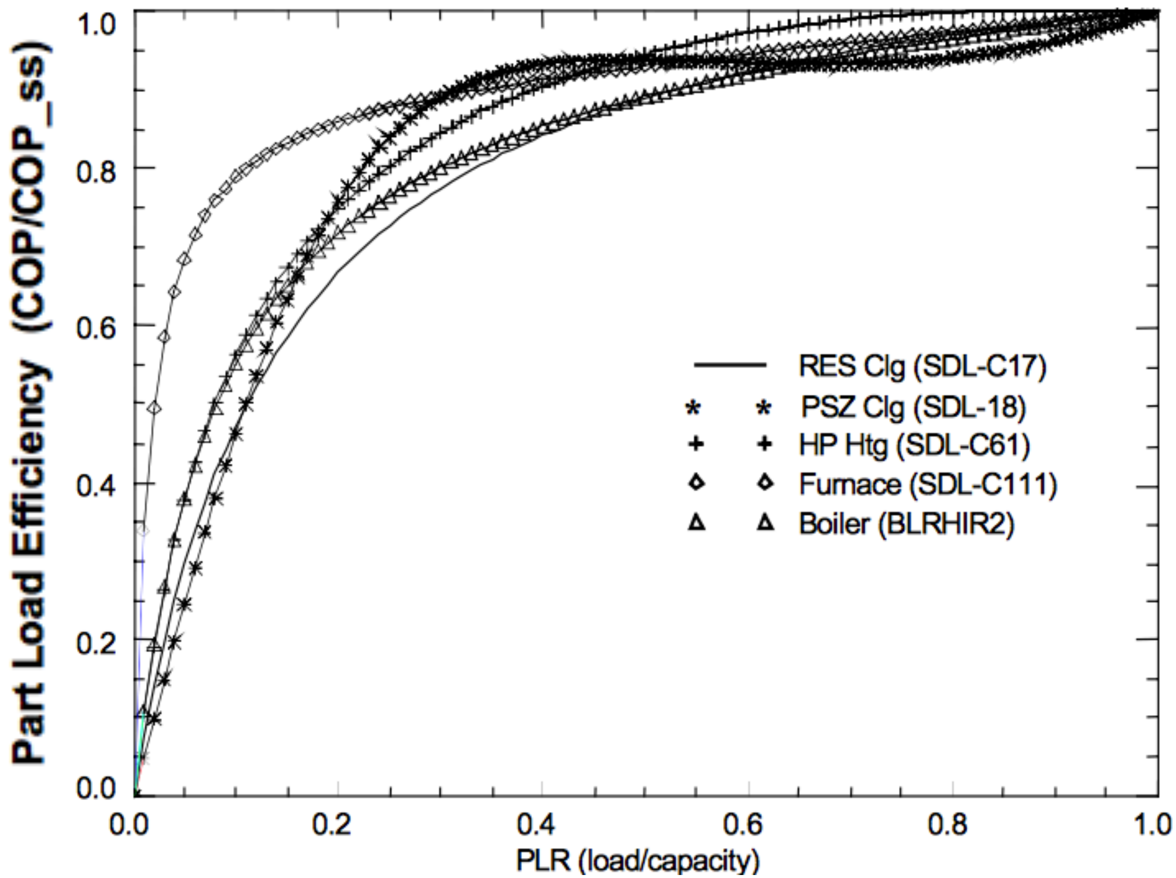
AC capacity and efficiency changes with outdoor T, indoor T/RH, and airflow rates



Dynamic conditions affect HVAC performance

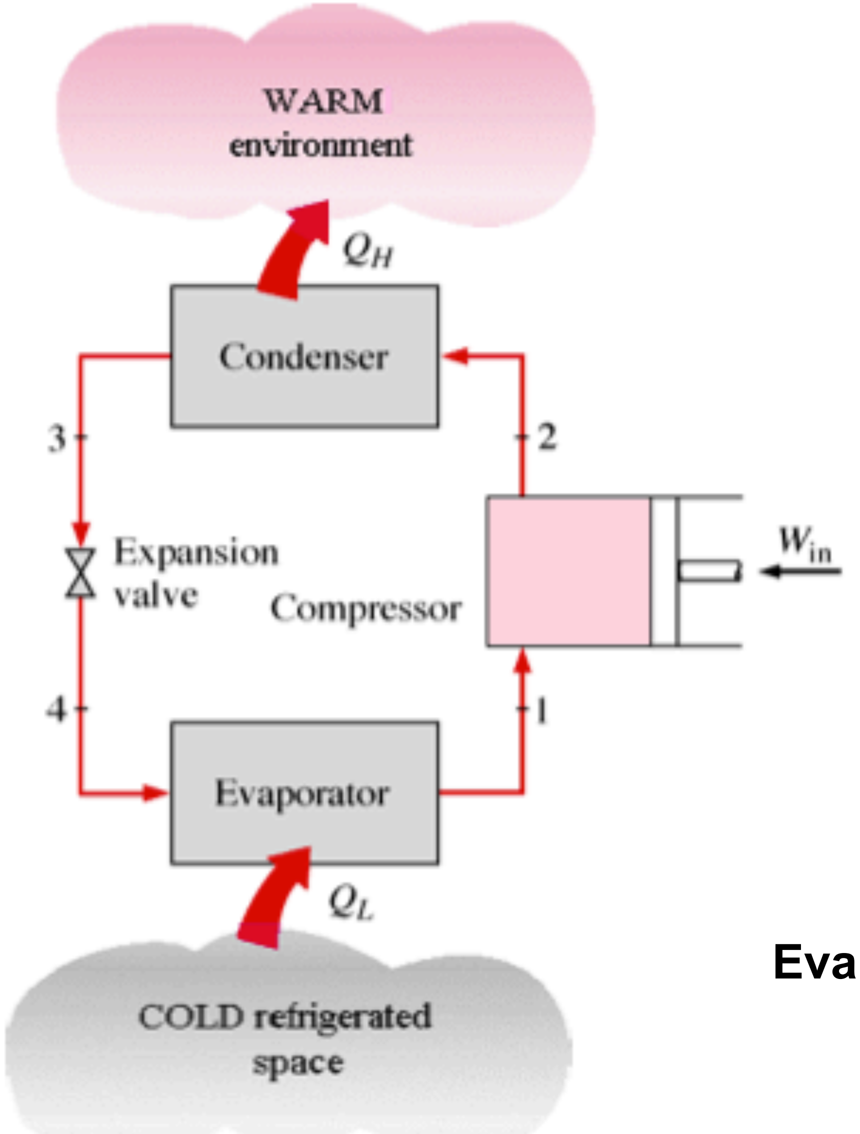
- Many systems operate at their highest efficiency (highest COP) at design load conditions
  - Maximum load
- But systems don't always operate at peak load conditions
  - "Part-load" conditions are common
- The "part-load ratio" quantifies COP at part-load conditions

Part-load ratio (PLR)



COMMERCIAL COOLING EQUIPMENT

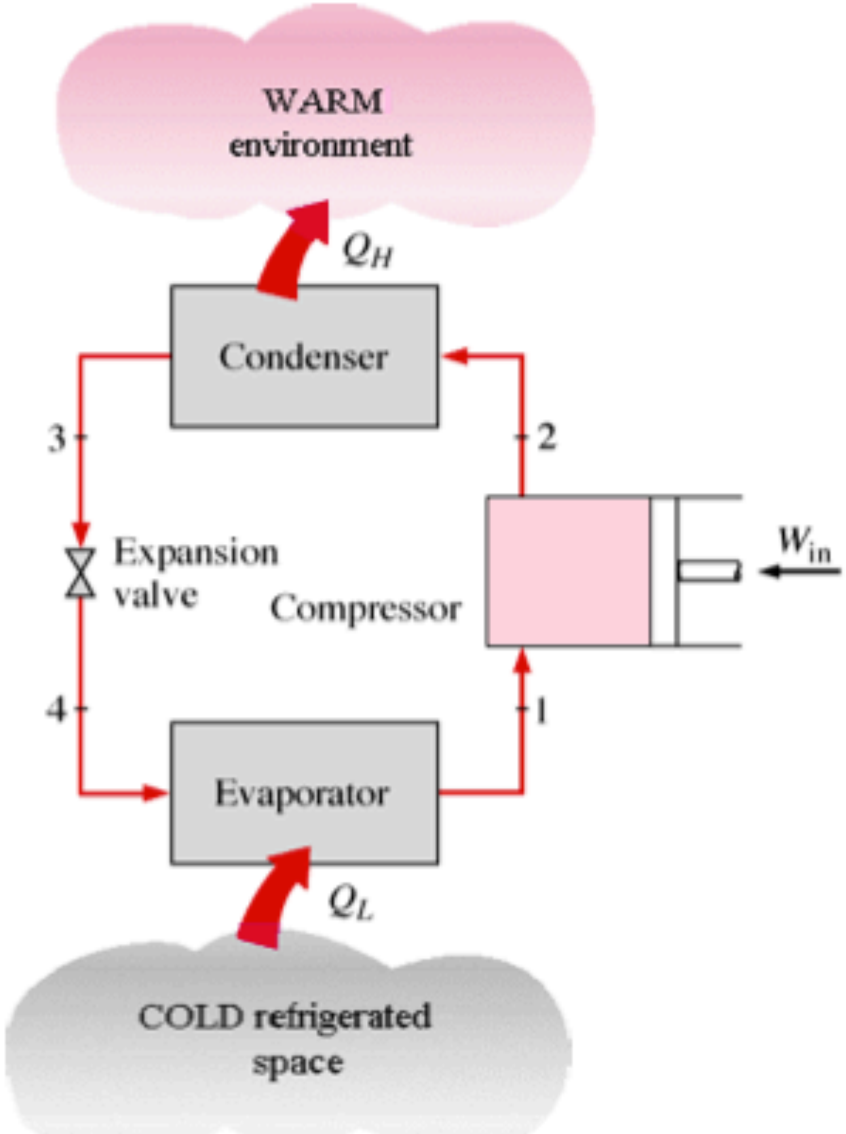
Single-stage vapor compression cycle



Expansion valve
(creates the high P restriction)

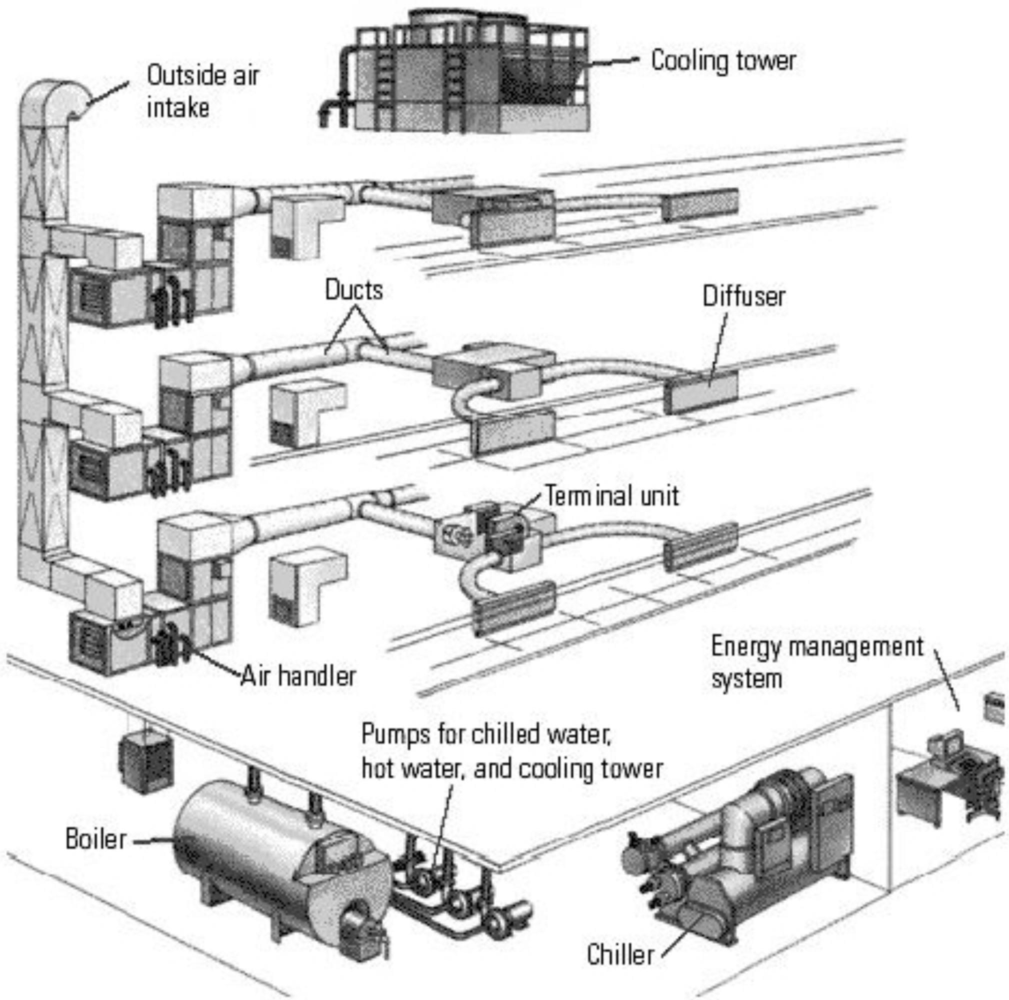
Evaporator coil

Single-stage vapor compression cycle



Commercial buildings: Chillers

- In bigger commercial buildings, central systems use chillers to produce chilled water for cooling spaces

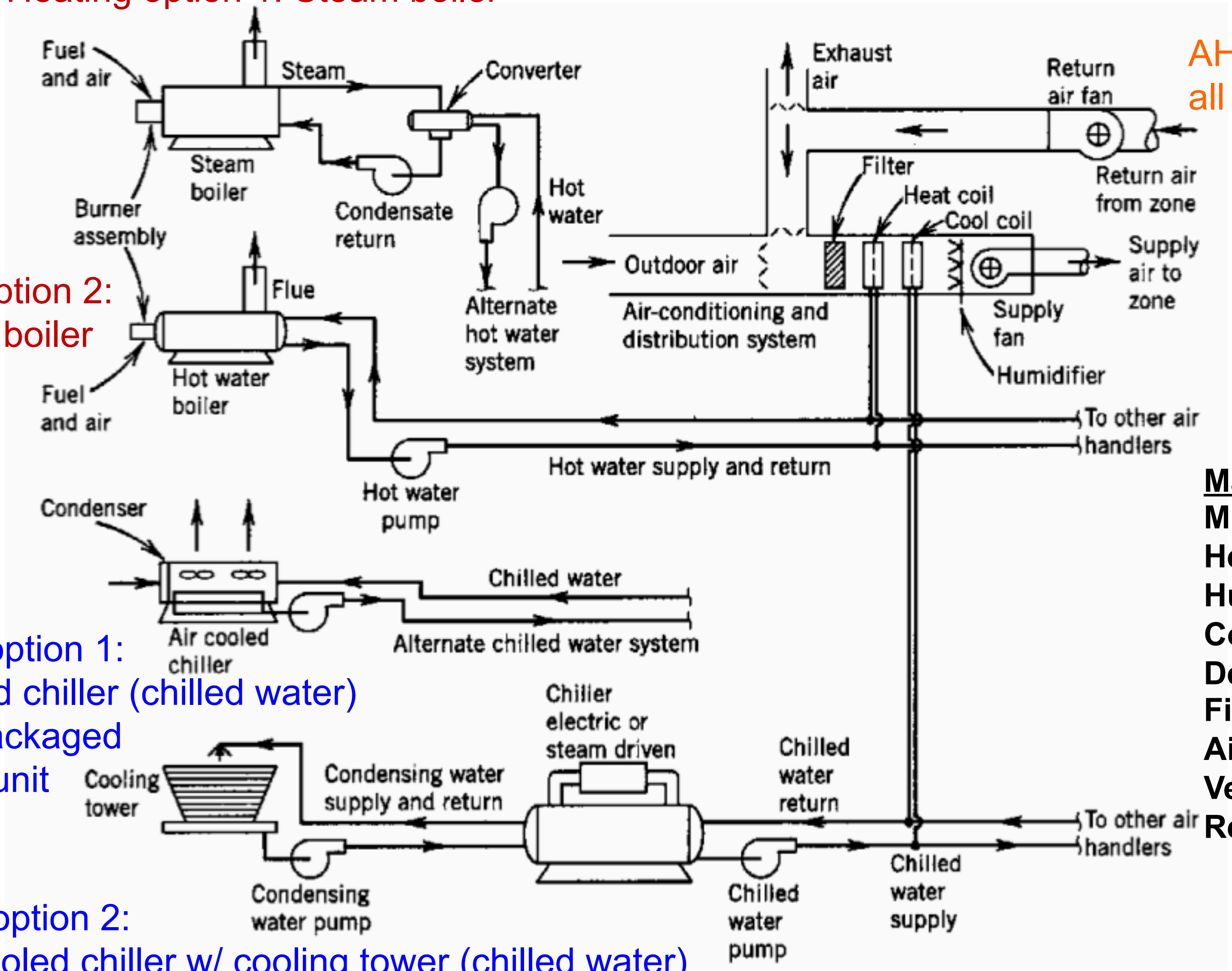


Commercial buildings: Chillers

Heating option 1: Steam boiler

AHU serves all rooms

Heating option 2: Hot water boiler



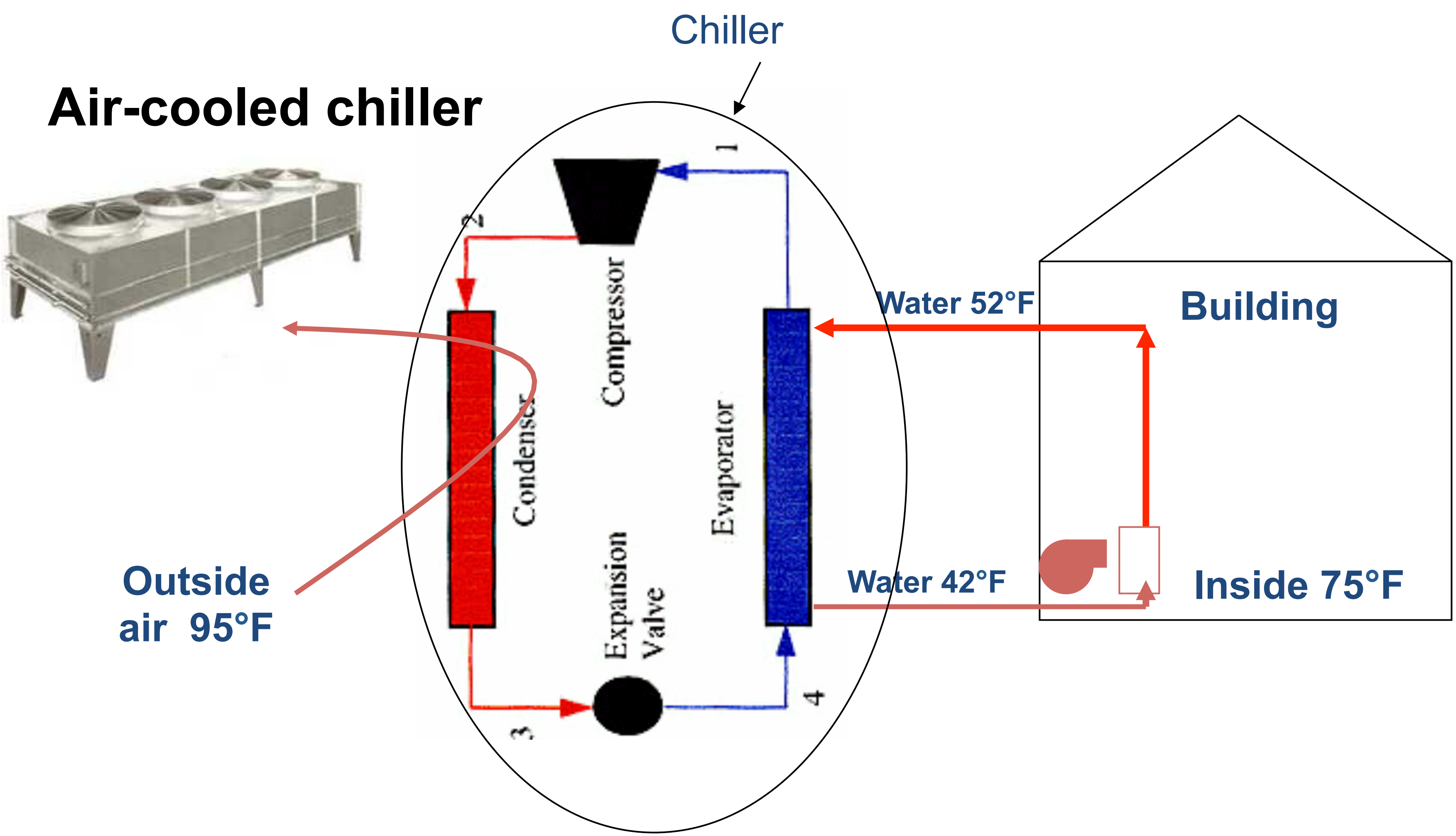
Cooling option 1:
Air cooled chiller (chilled water)
*Often packaged into one unit

Cooling option 2:
Water cooled chiller w/ cooling tower (chilled water)

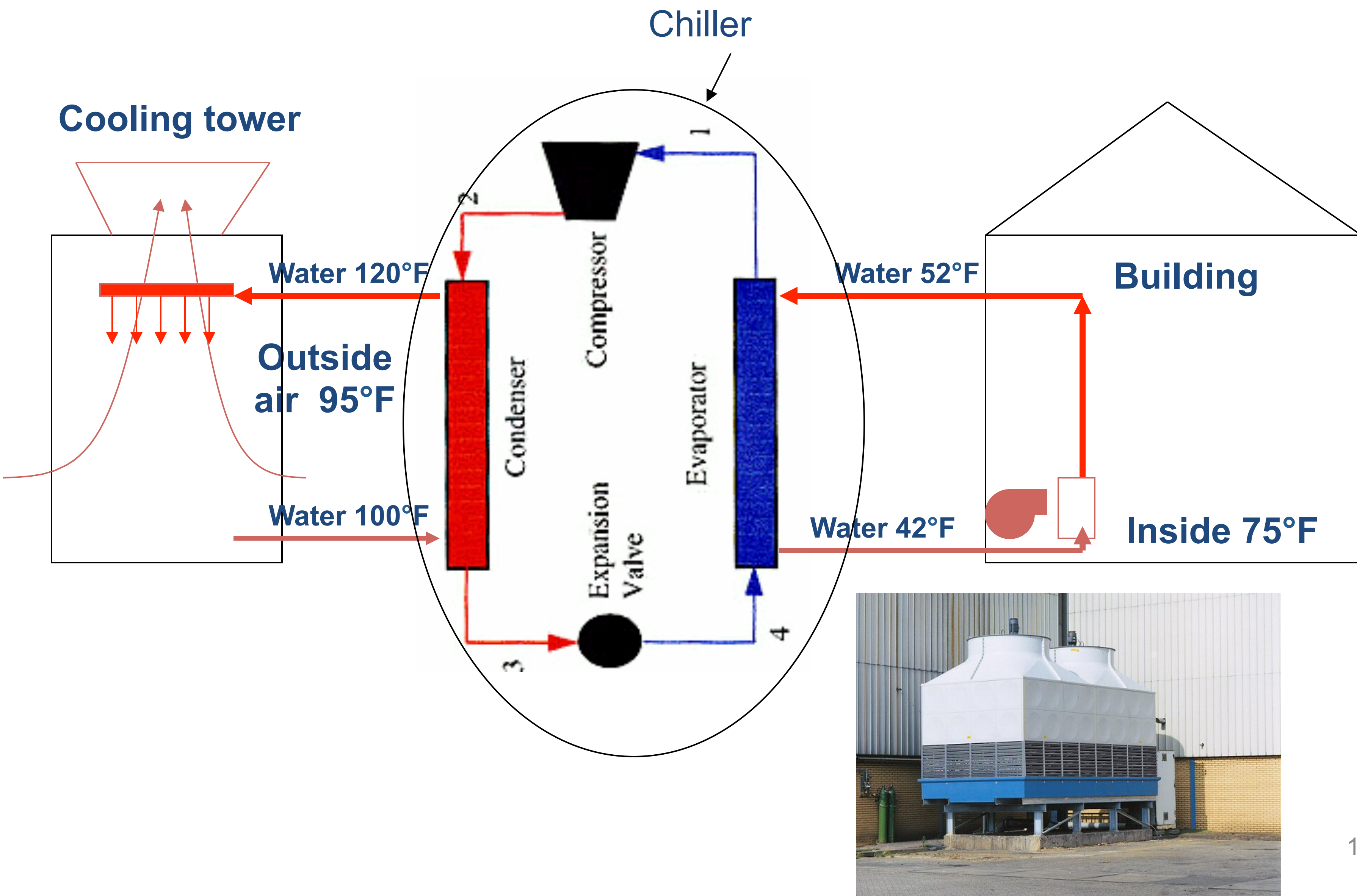
Main processes:
Mixing
Heating
Humidification
Cooling
Dehumidification
Filtration
Air distribution
Ventilation
Recirculation

Air-cooled chillers

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

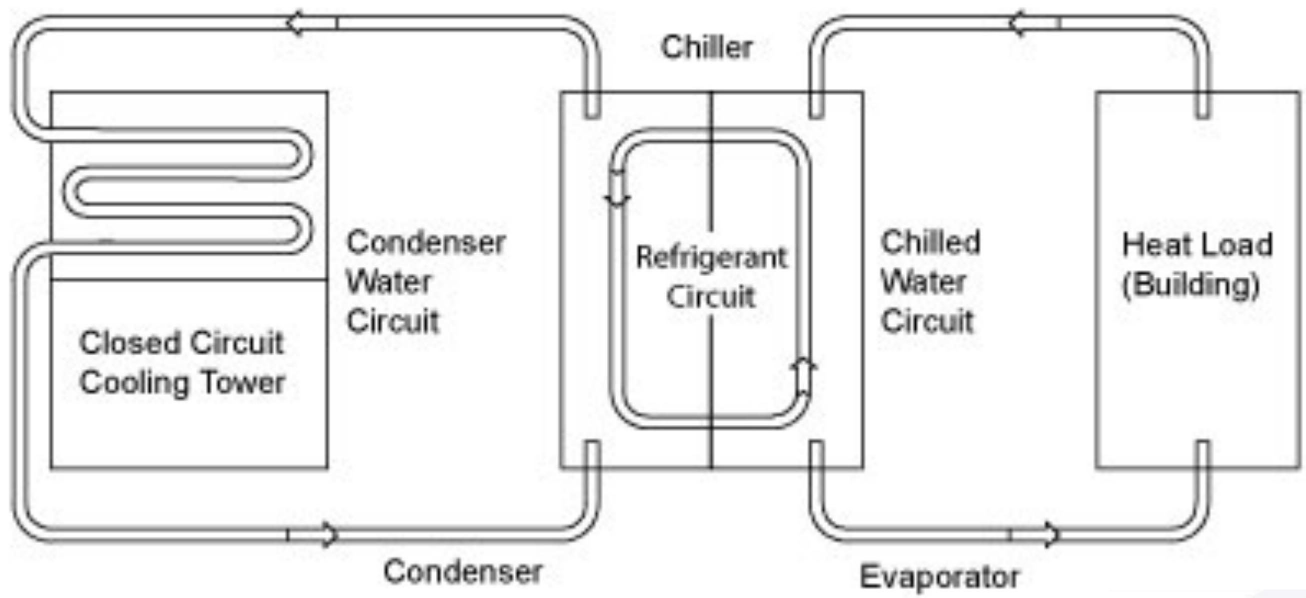


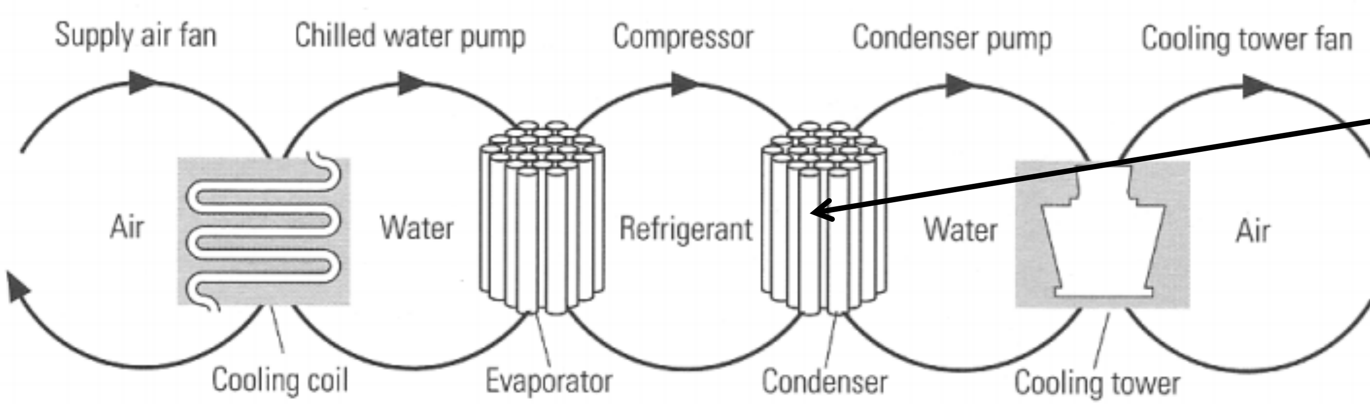
Water-cooled chillers (i.e., “cooling tower”)

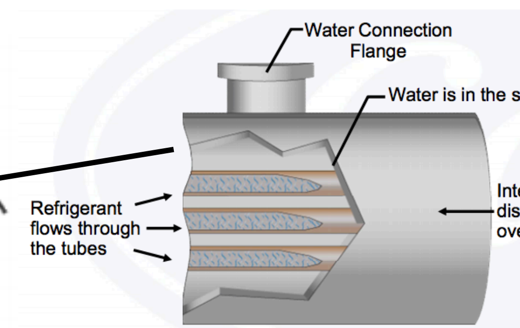


Water-cooled chillers (i.e., “cooling tower”)

Water loop







Air vs. water cooled chillers

Air-Cooled Chiller Advantages

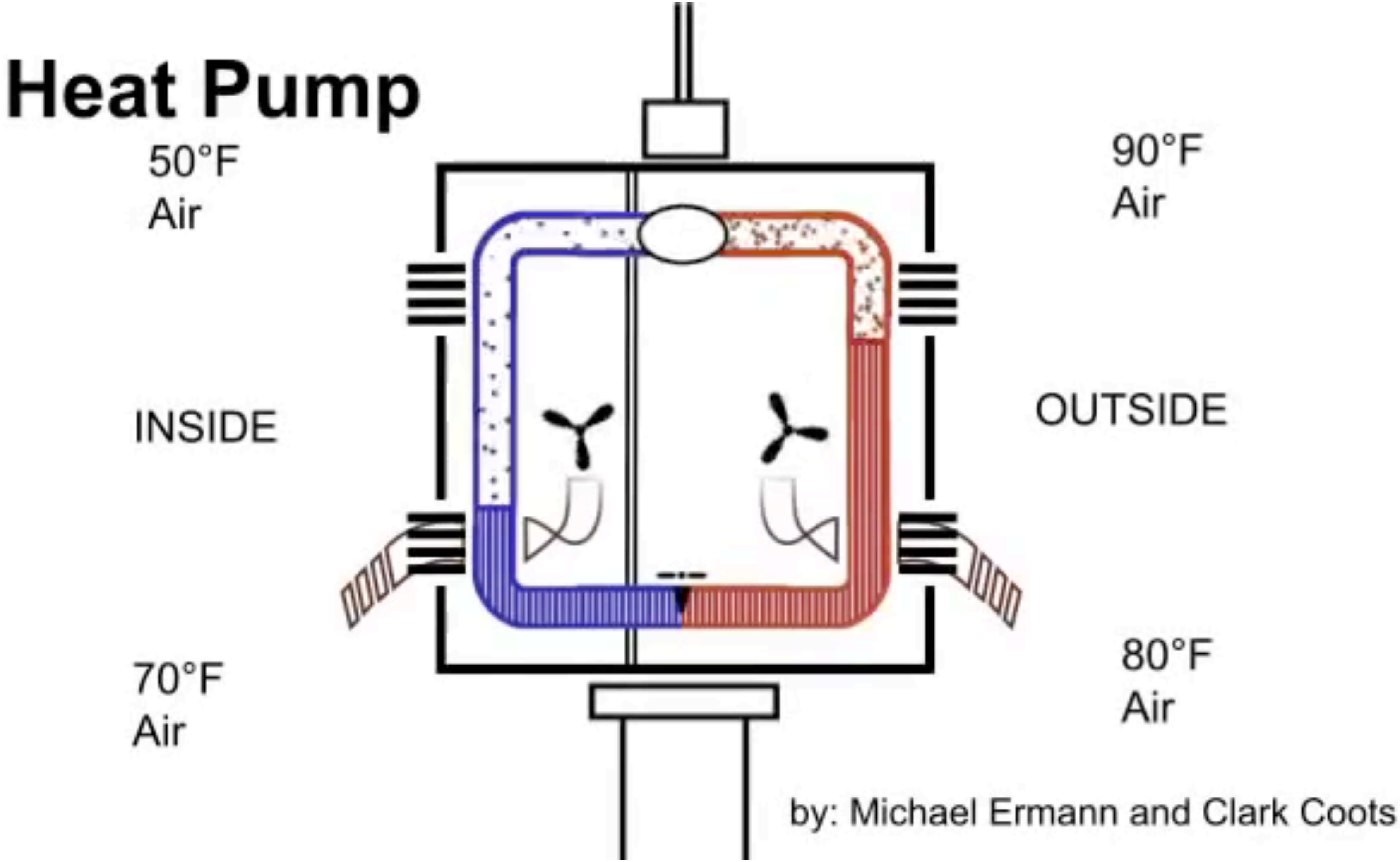
- Lower installed cost
- Quicker availability
- No cooling tower or condenser pumps required
- Less maintenance
- No mechanical room required

Water-Cooled Chiller Advantages

- Higher efficiency
- Custom selections in larger sizes
- Large tonnage capabilities
- Indoor chiller location
- Longer life

HEAT PUMPS

Air- and ground-source heat pumps

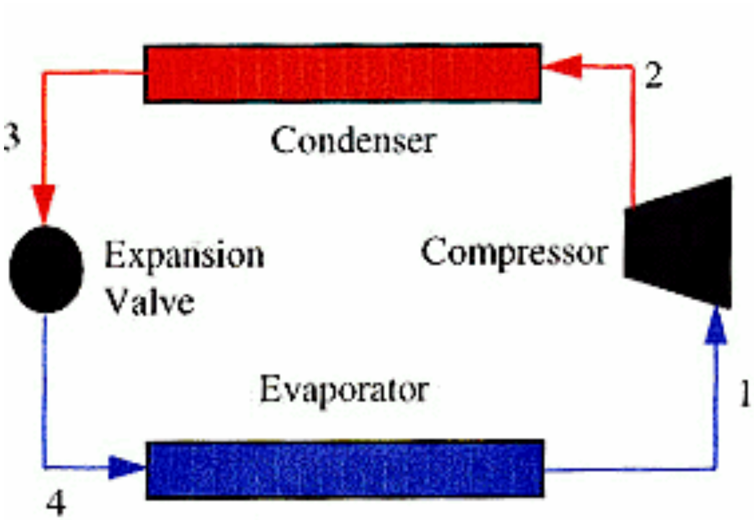


https://www.youtube.com/watch?v=NyNeh7wPQQk

Heat pumps

Cooling

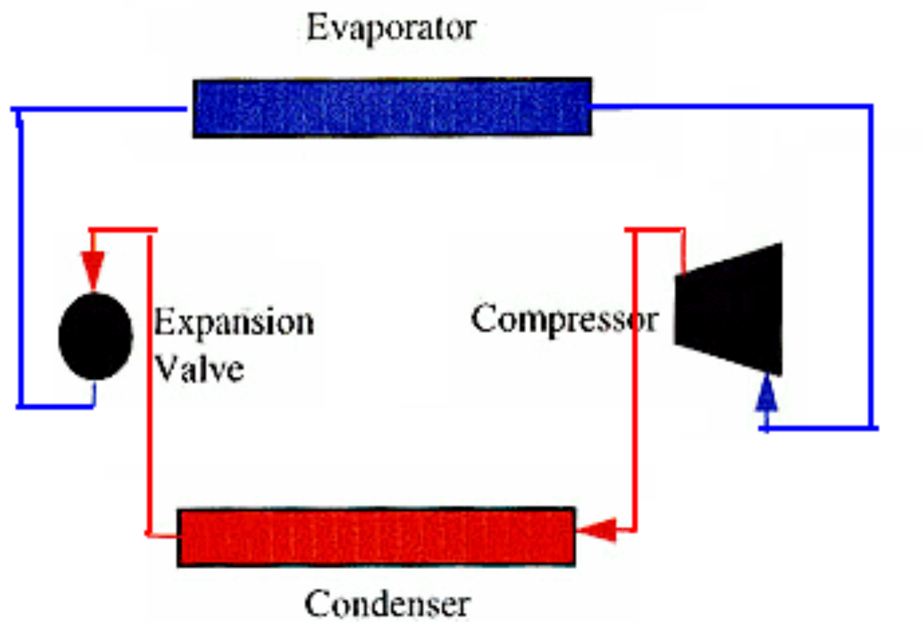
Outside 95°F



Inside 75°F

Heating

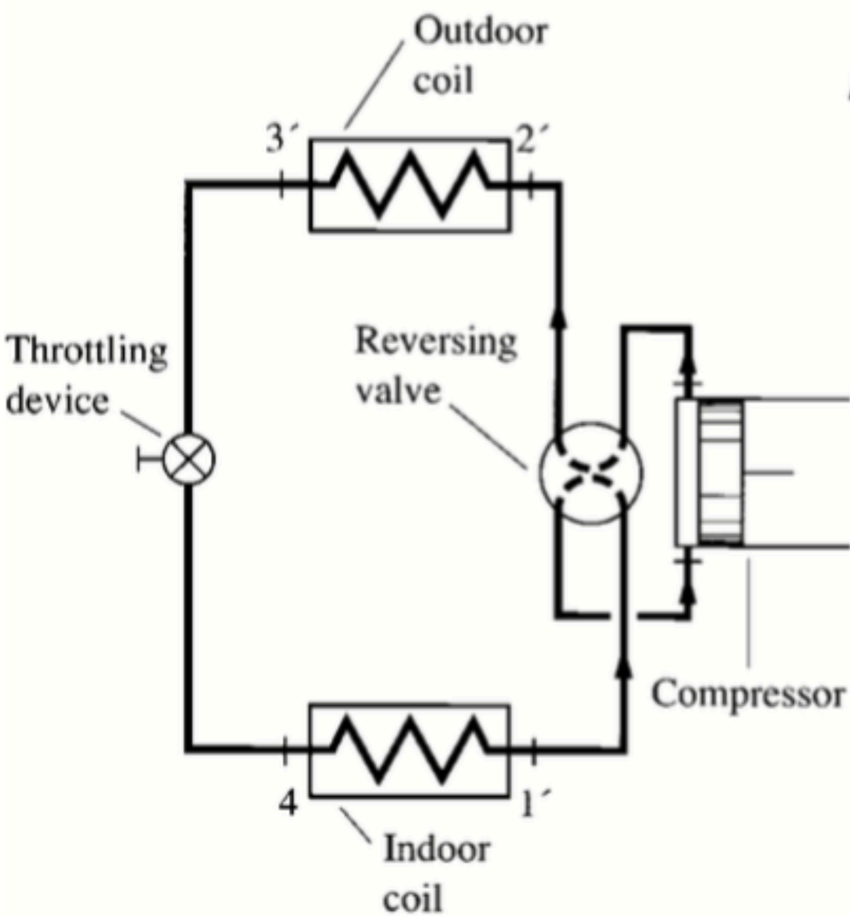
Outside 45°F



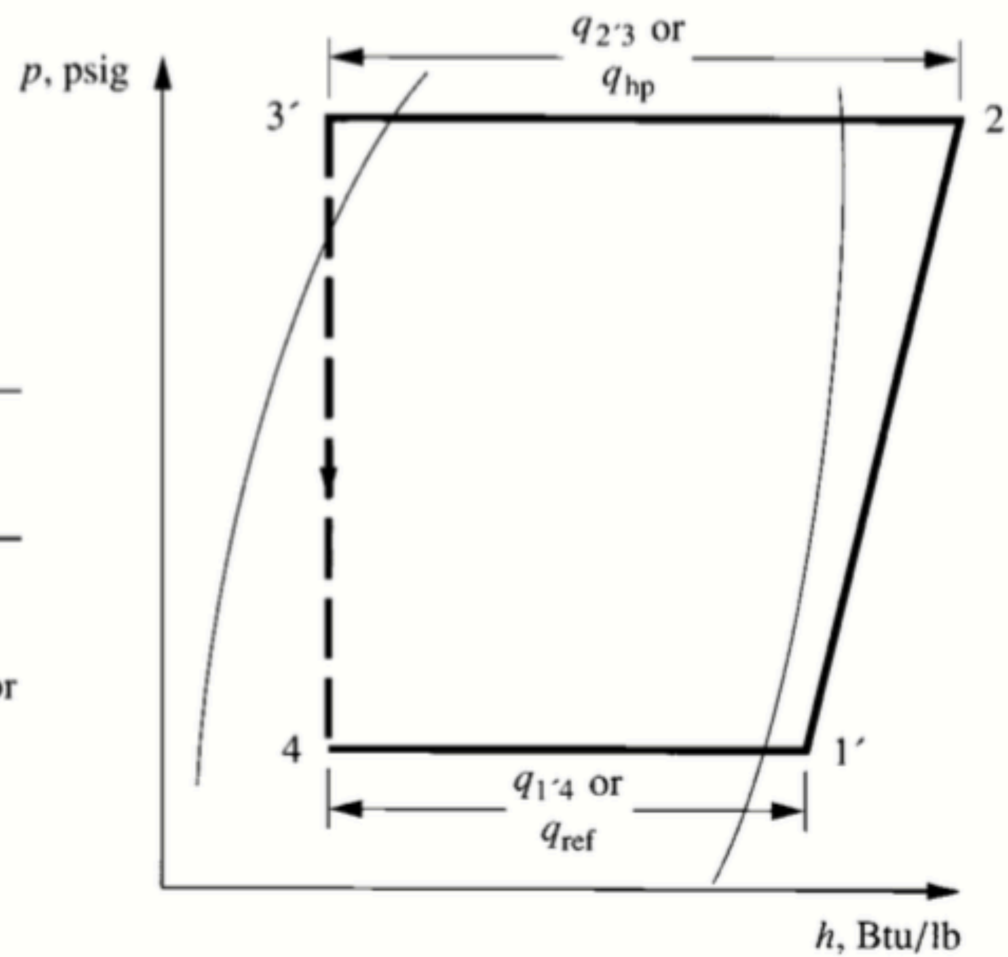
Inside 75°F

Heat pumps are basically air-conditioners run in reverse

Heat pumps

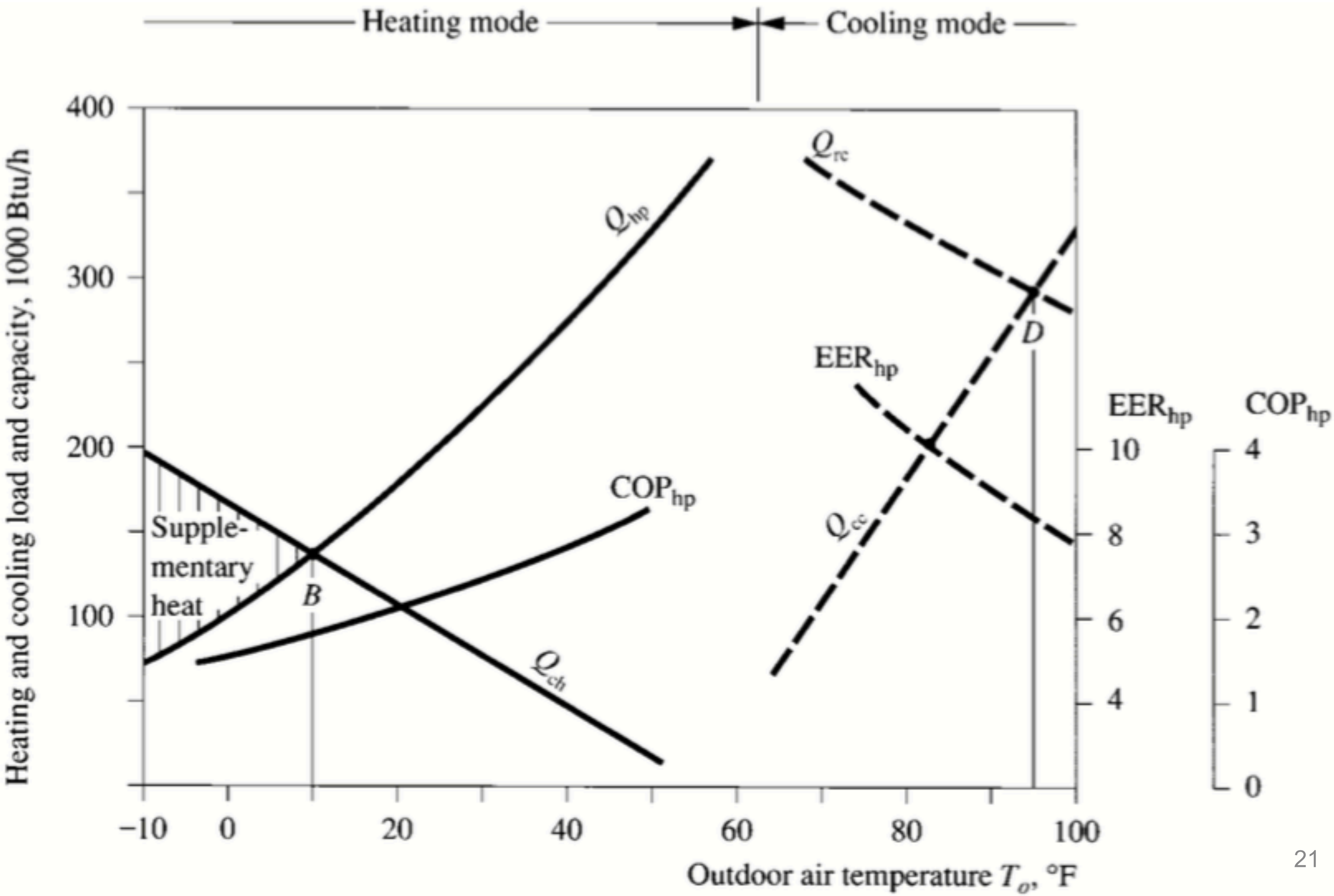


Outdoor
coil
3′
2′
Throttling
device
Reversing
valve
Compressor
4
1′
Indoor
coil



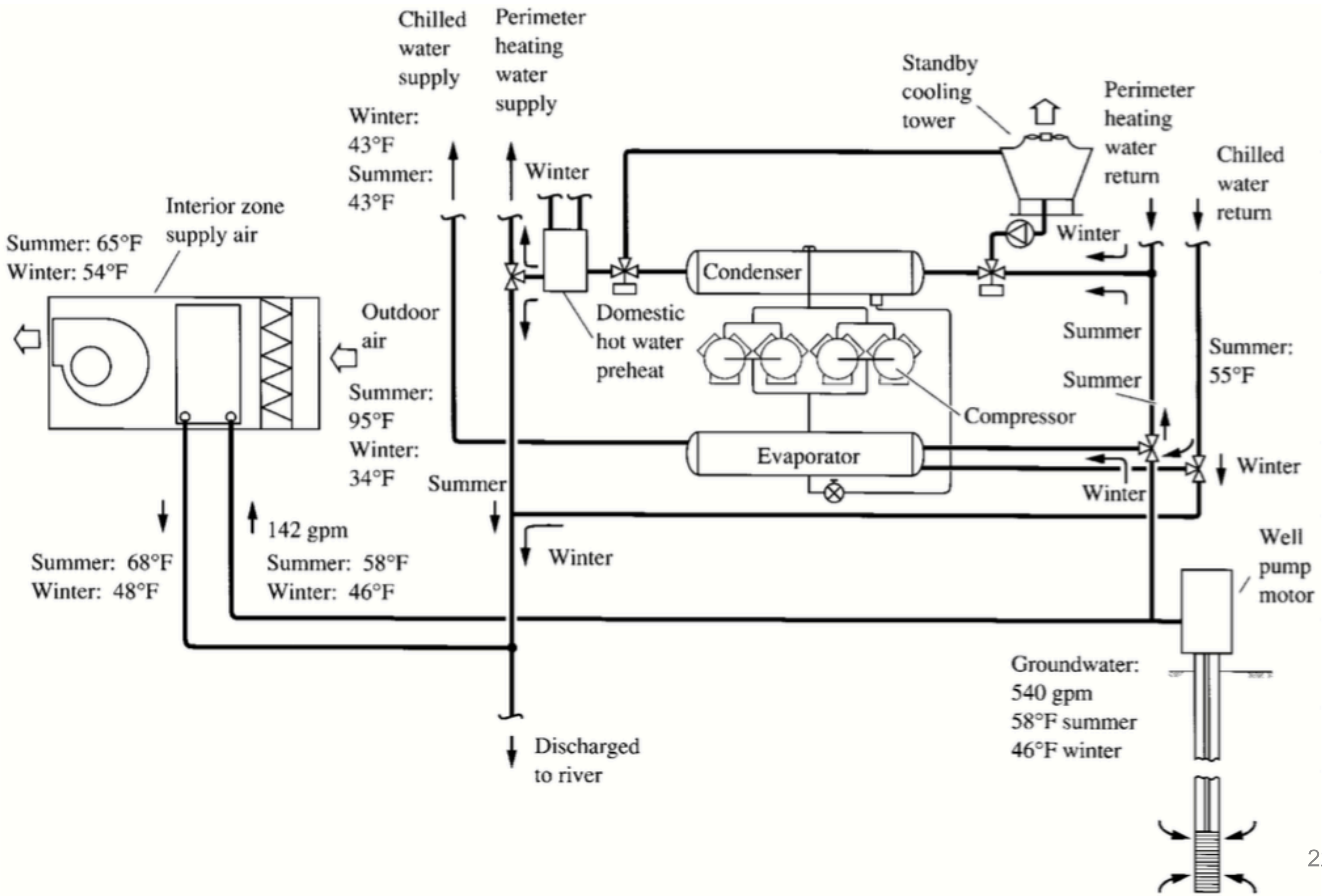
p, psig
q2′3 or
qhp
3′
2′
4
1′
q1′4 or
qref
h, Btu/lb

Heat pumps

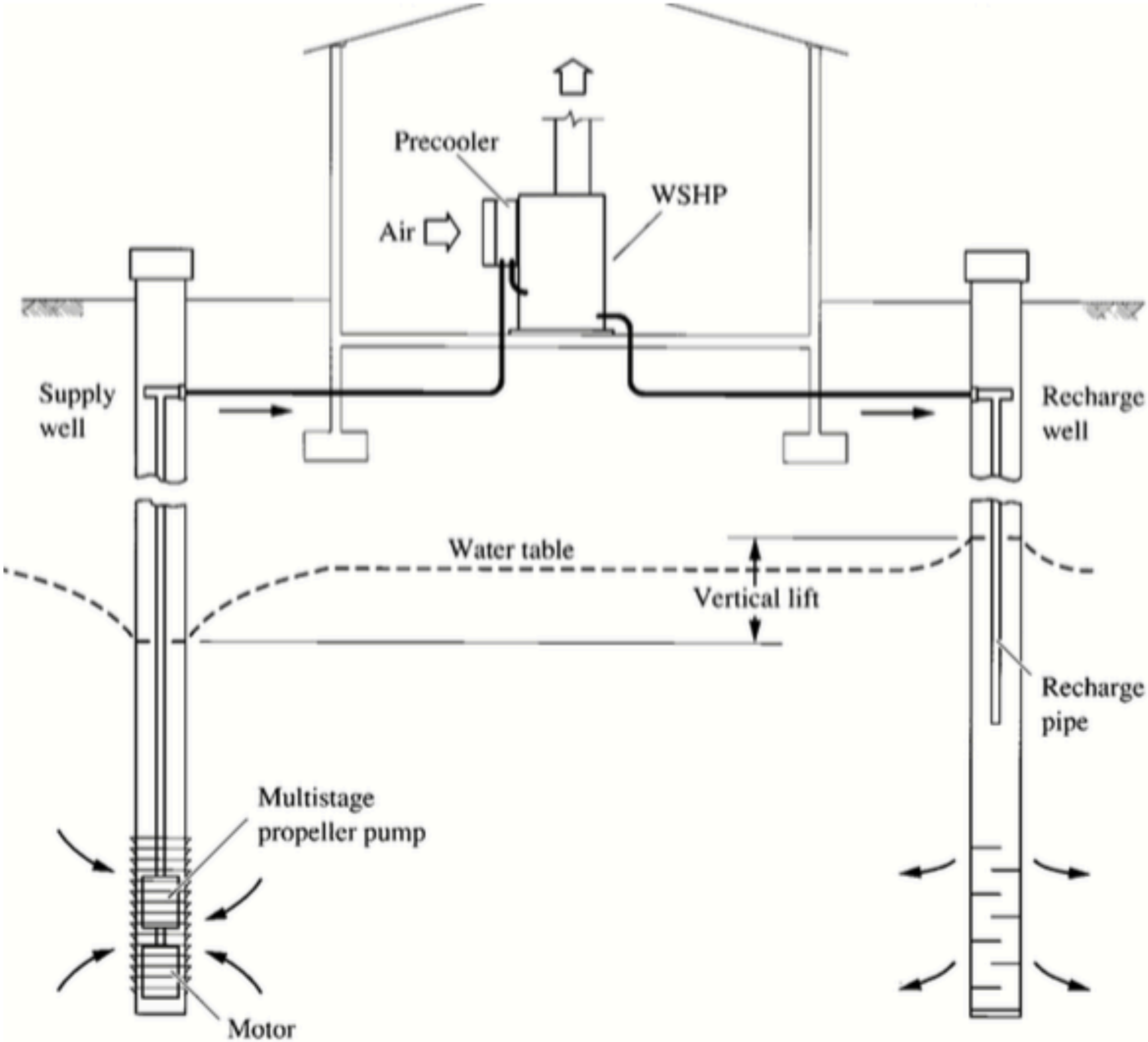


Heating mode
Cooling mode
Heating and cooling load and capacity, 1000 Btu/h
400
300
200
100
Q_{hp}
Q_{rc}
Q_{cc}
Q_{ch}
COP_{hp}
EER_{hp}
Supple-
mentary
heat
B
D
EER_{hp}
10
8
6
4
COP_{hp}
4
3
2
1
0
−10
0
20
40
60
80
100
Outdoor air temperature T_o, °F

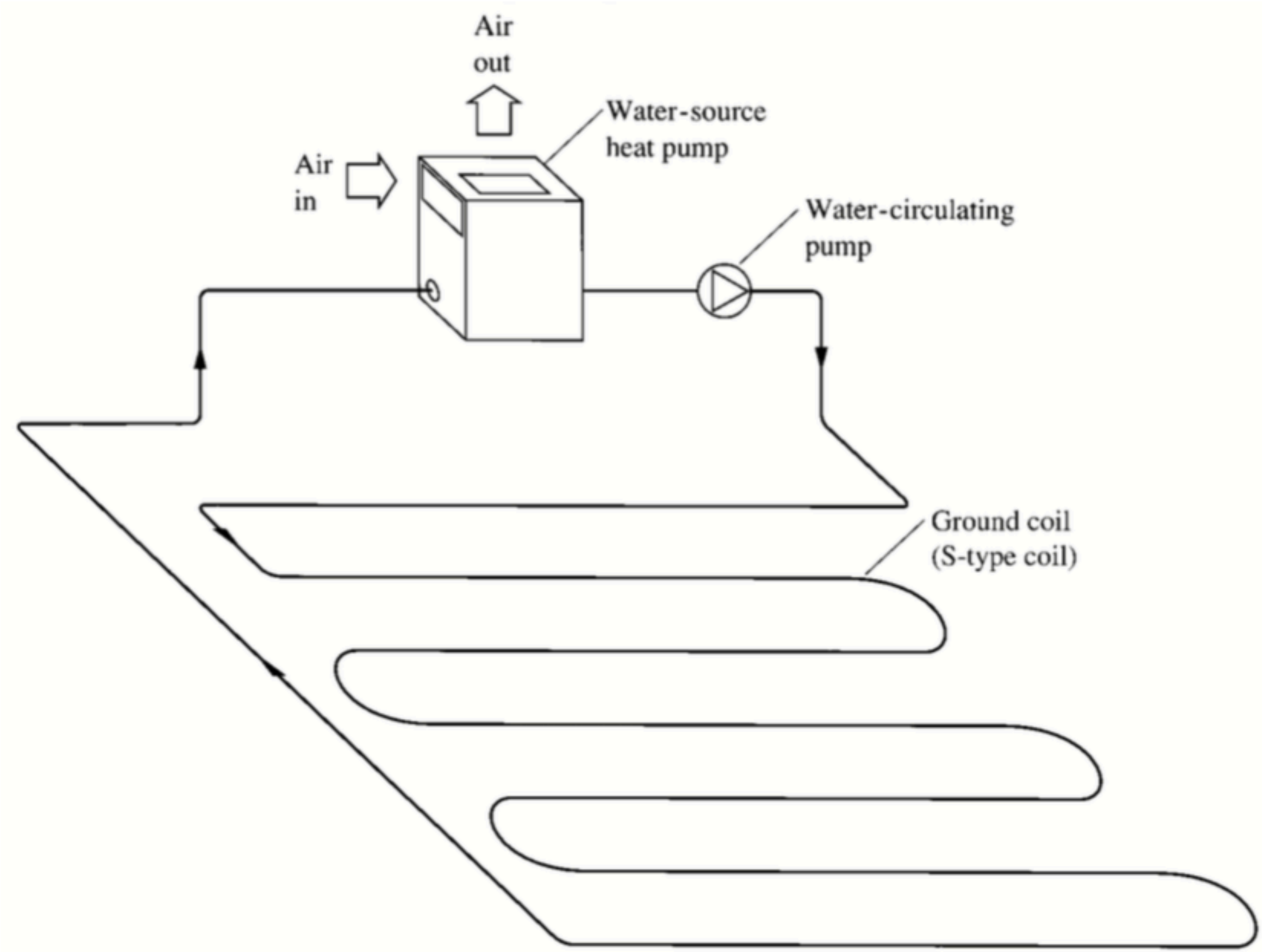
Ground source heat pumps



Ground source heat pumps



Ground coupled heat pumps

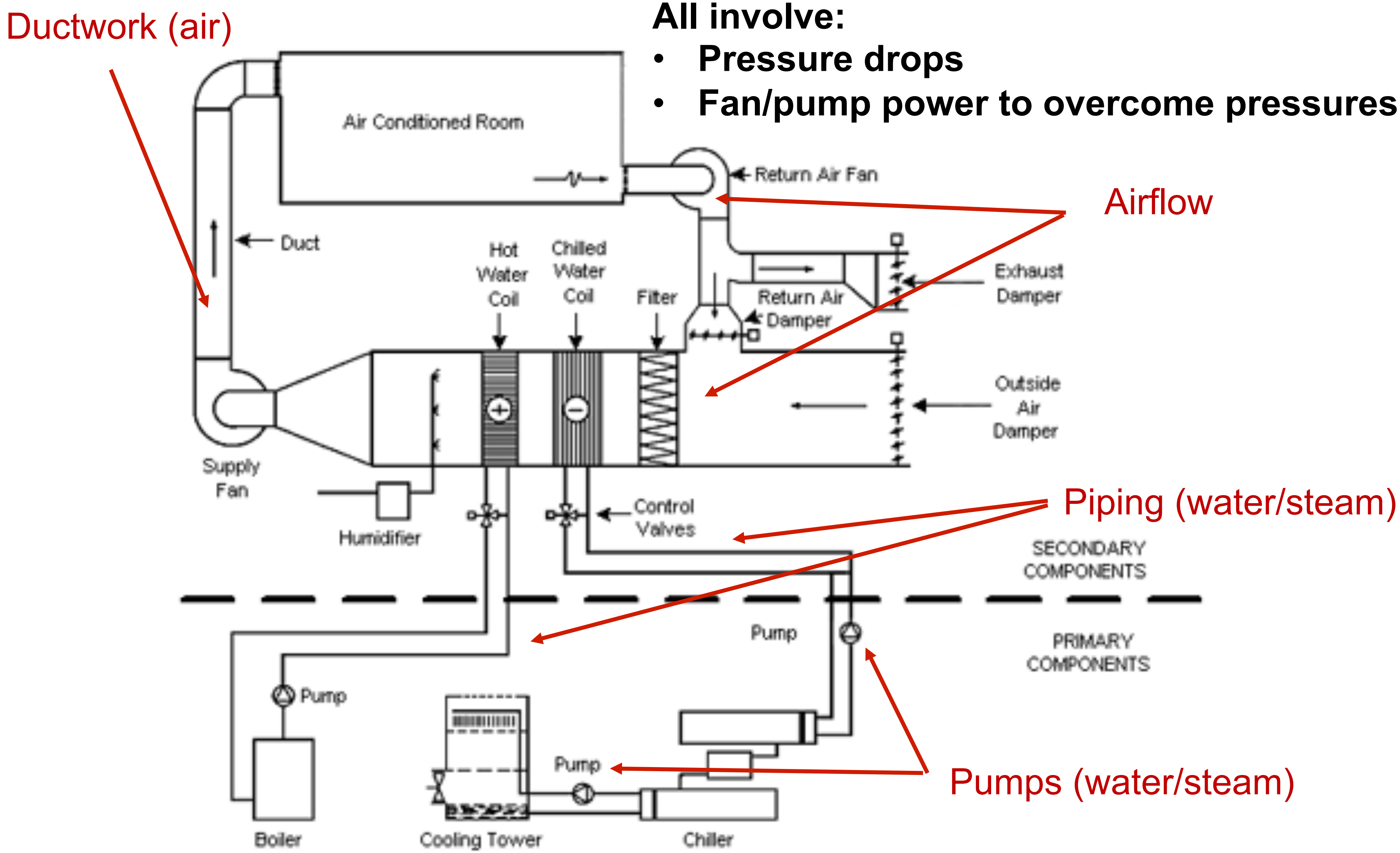


AIR AND WATER DISTRIBUTION SYSTEMS

Fluid flows and fan/pump power

Air and water distribution systems

All involve:
- **Pressure drops**
- **Fan/pump power to overcome pressures**



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**

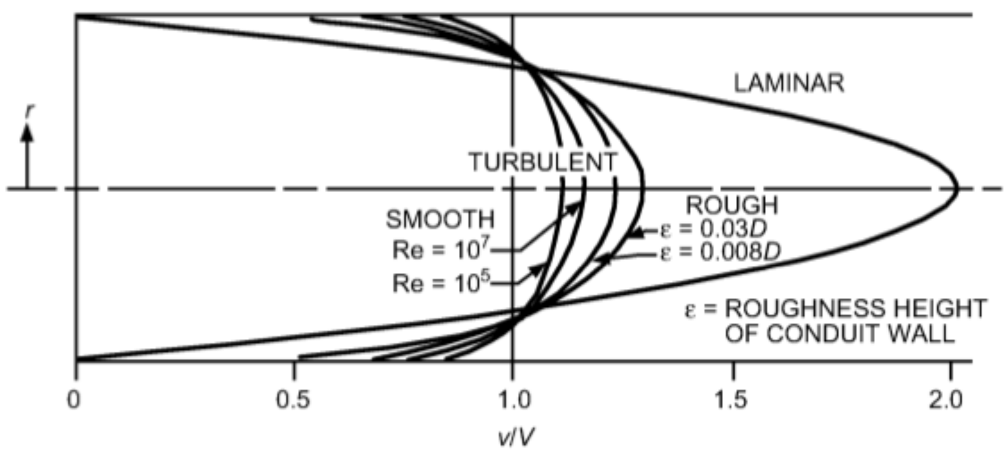


Fig. 4 Velocity Profiles of Flow in Pipes

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

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

$$p_1 + \frac{1}{2}\rho_1 v_1^2 + \rho_1 g h_1 = p_2 + \frac{1}{2}\rho_2 v_2^2 + \rho_2 g h_2 + p_{friction}$$

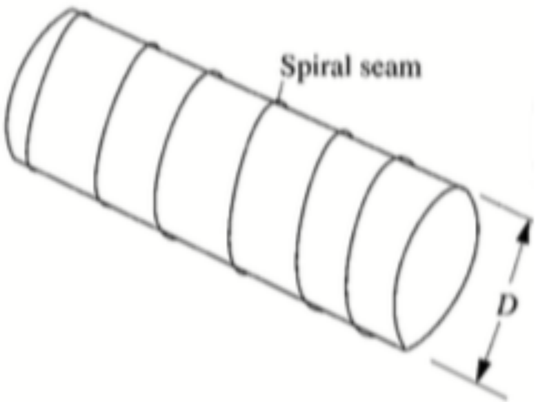
Static pressure | Velocity pressure | Pressure head | Friction losses

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

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

Pressure losses

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



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

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

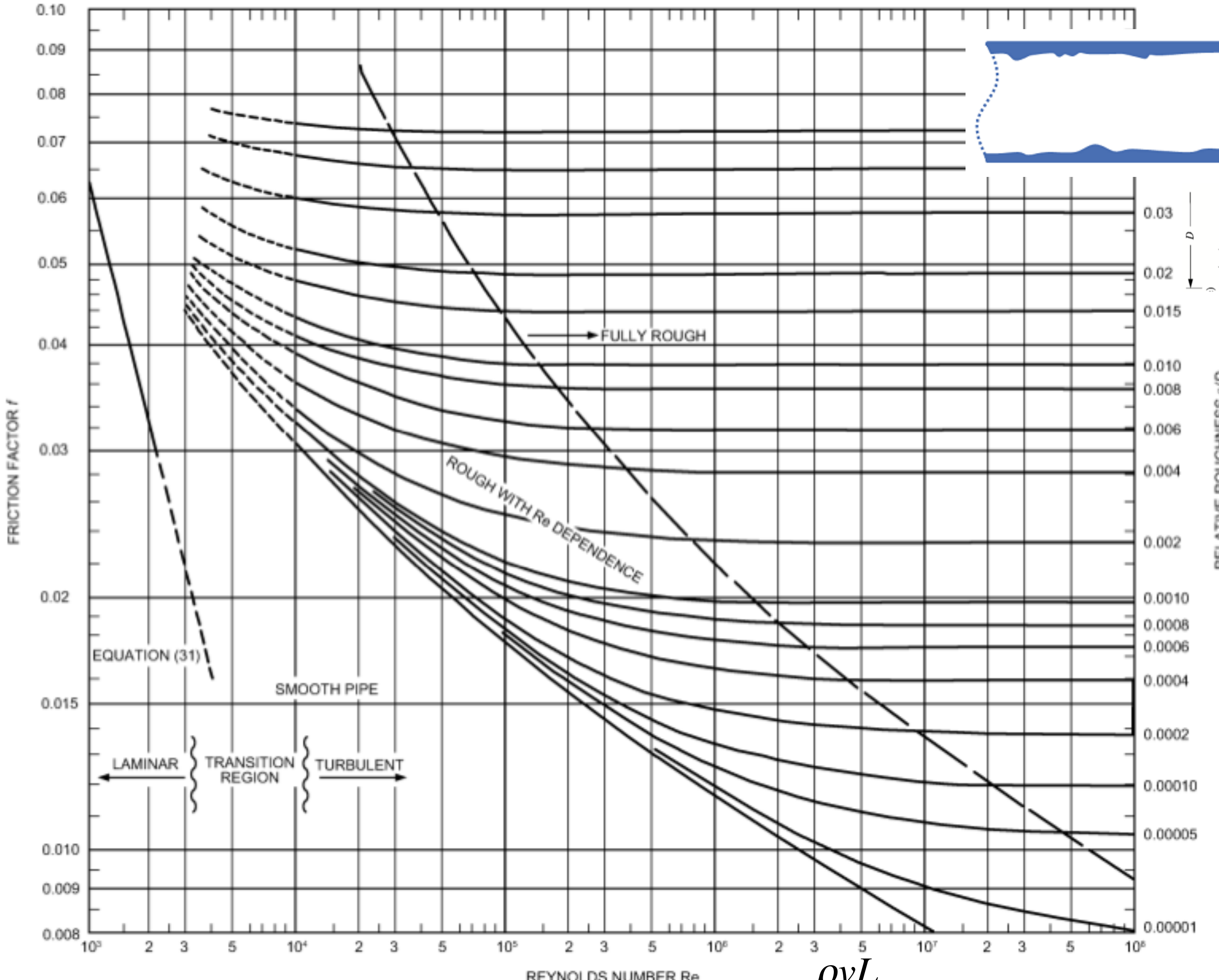
f = friction factor (-)
L = length (m)
D_h = hydraulic diameter (m)
ρ = fluid density (kg/m^3)
v = fluid velocity (m/s)

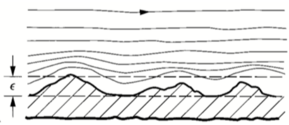
$$K = f\left(\frac{L}{D_h}\right)$$ In a straight pipe

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

Friction factor, f

f

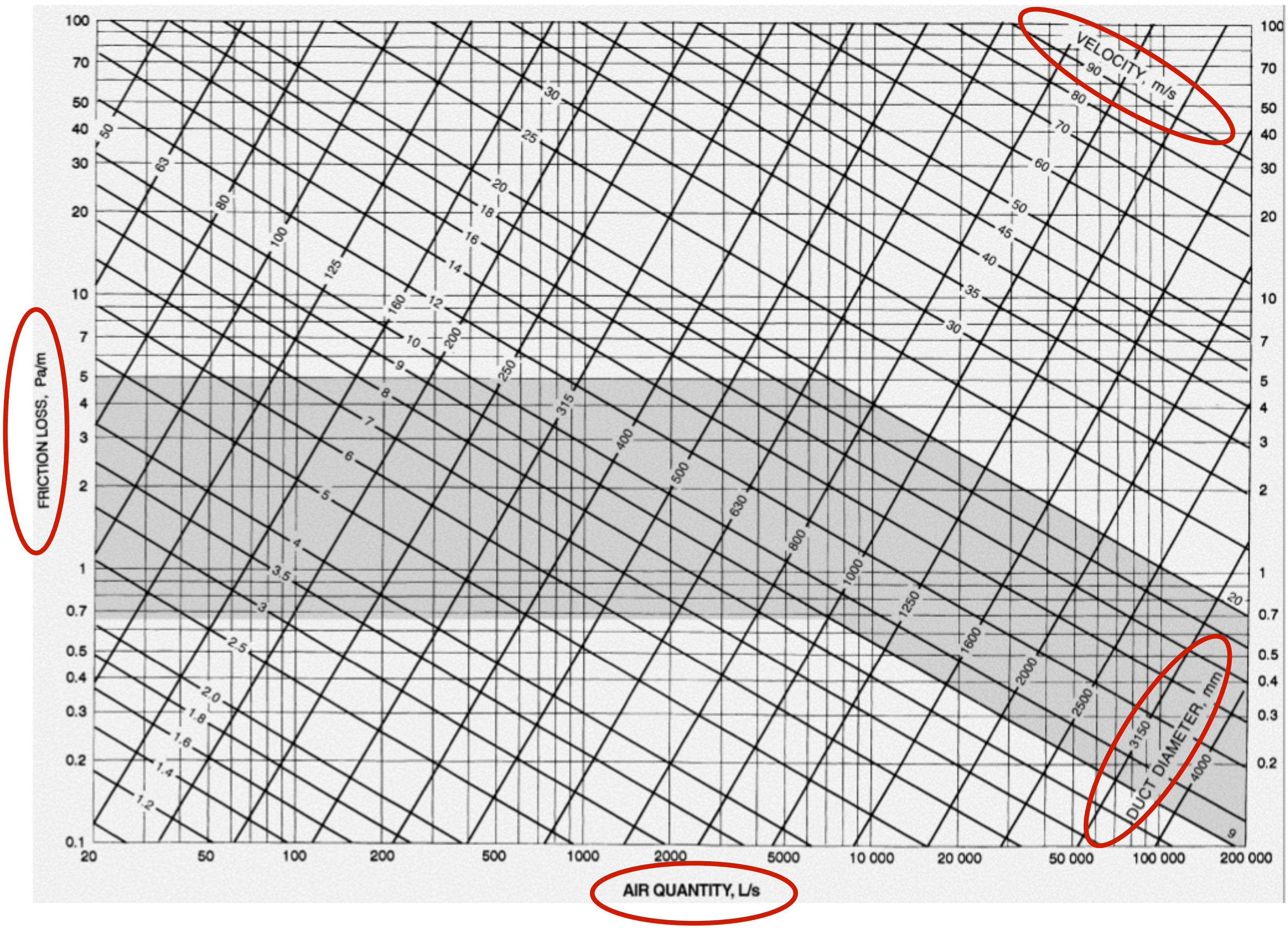




roughness

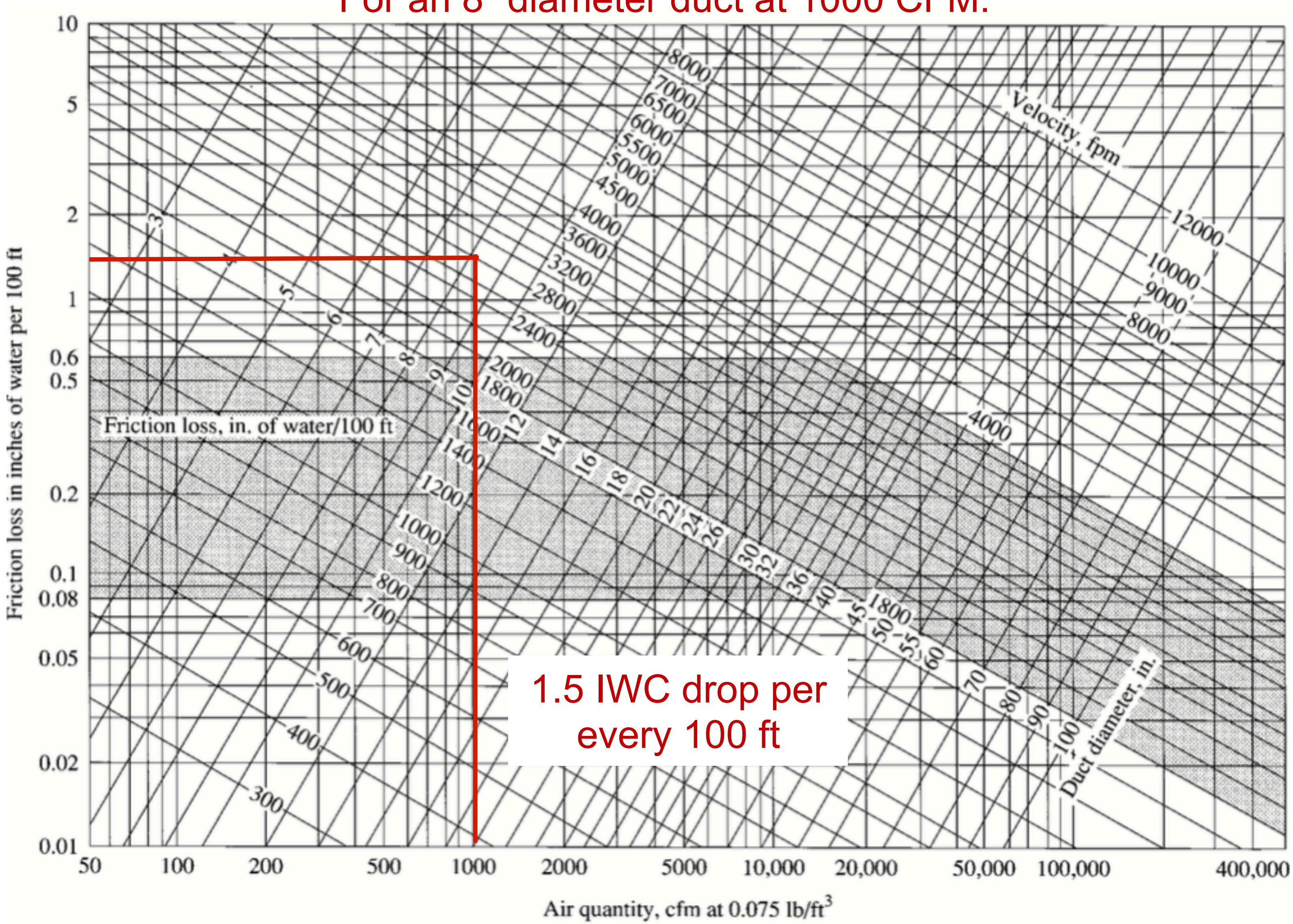
$$\mathrm{Re} = \frac{\rho v L}{\mu} \qquad (L = D_h)$$

Duct friction charts

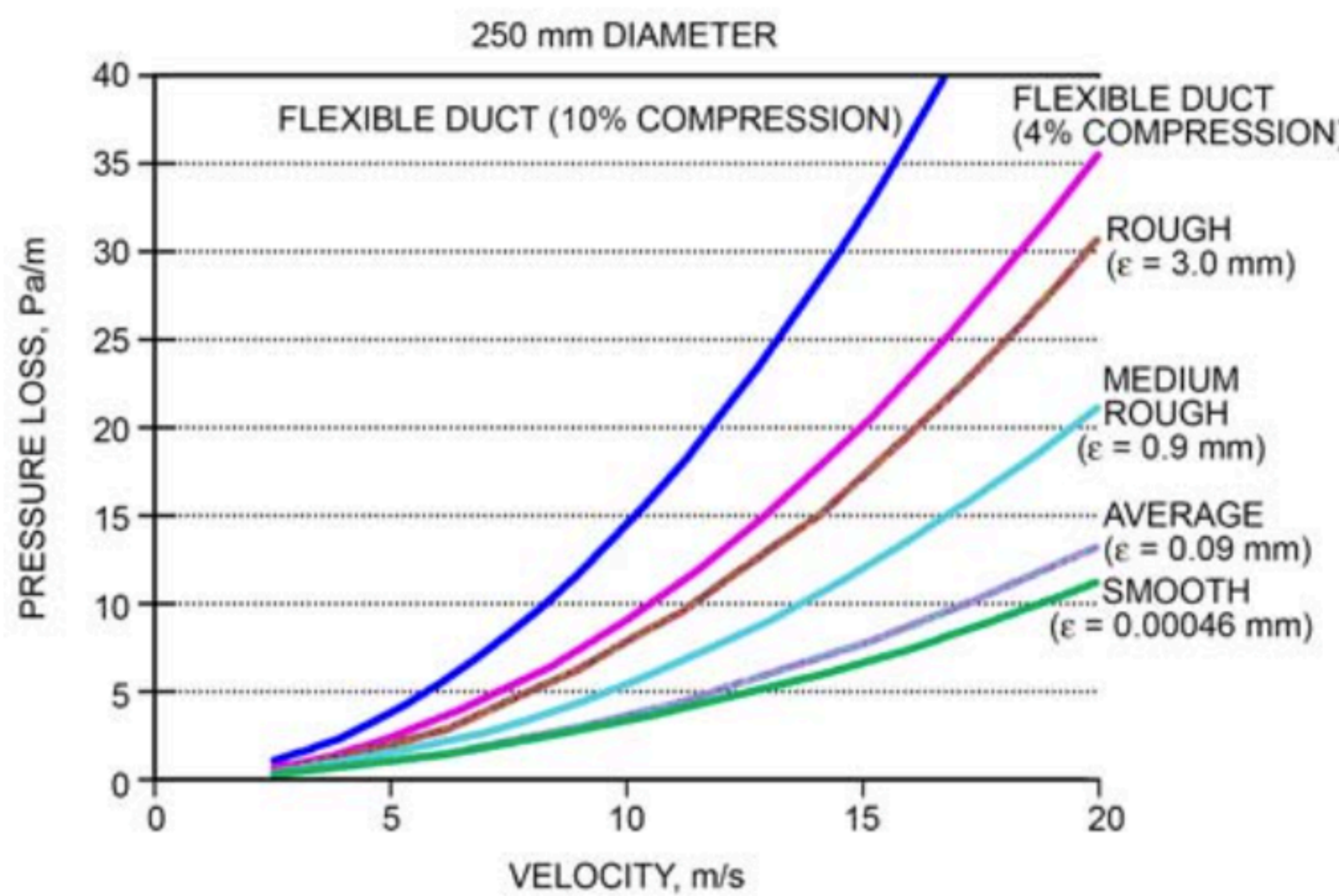


Duct friction charts (IP units)

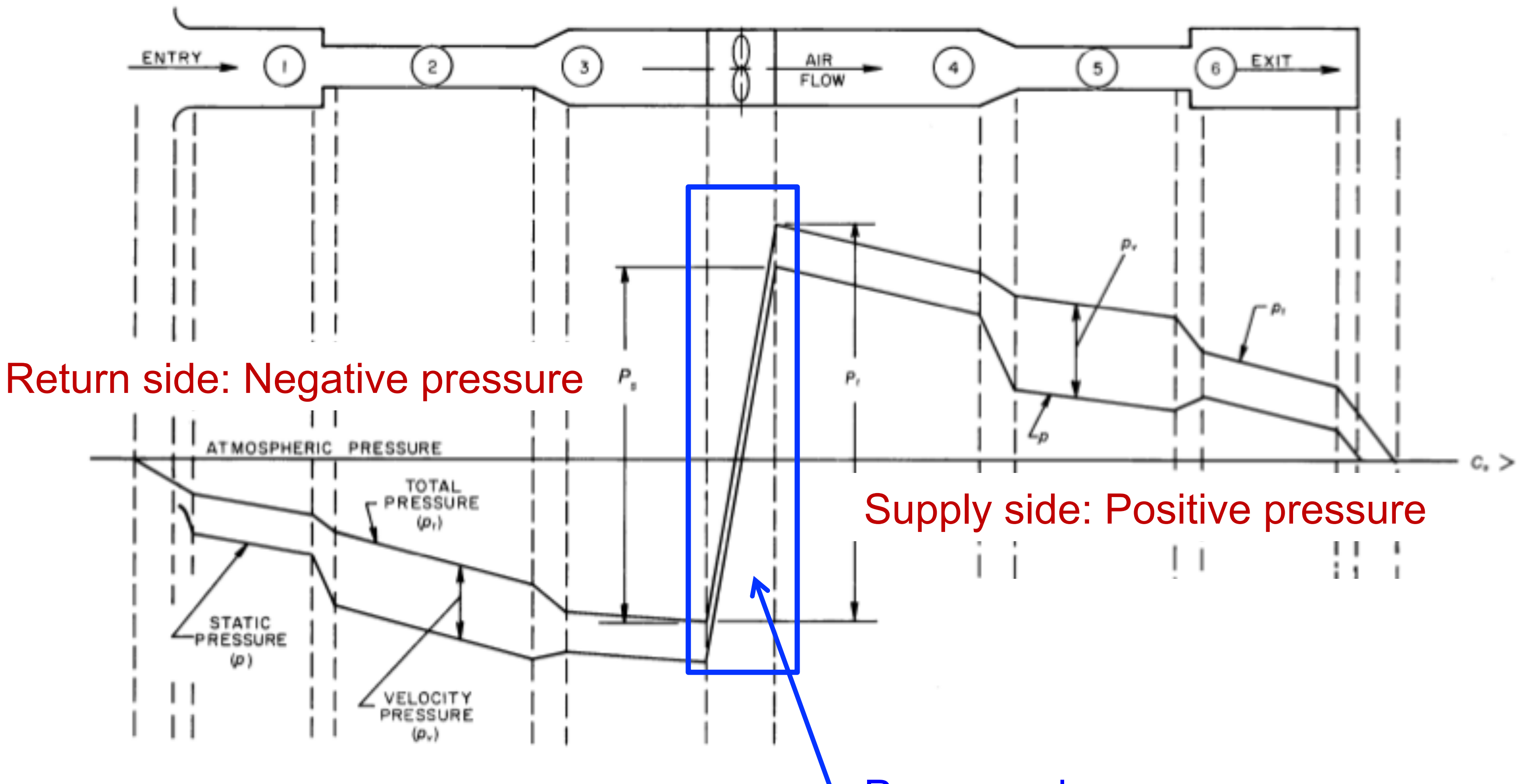
For an 8" diameter duct at 1000 CFM:



Duct friction plots



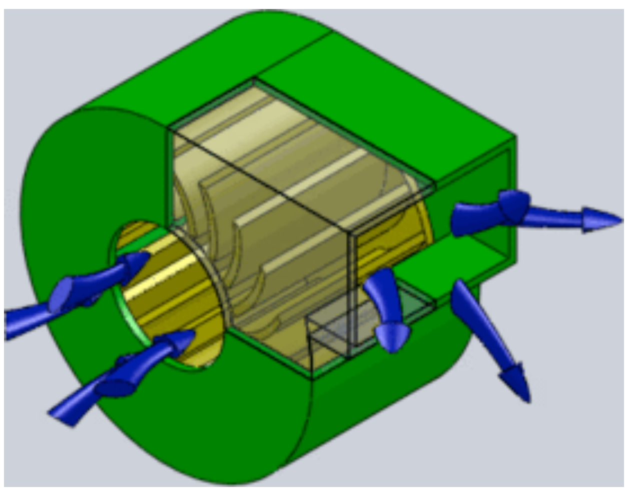
Pressure losses and rises in HVAC systems



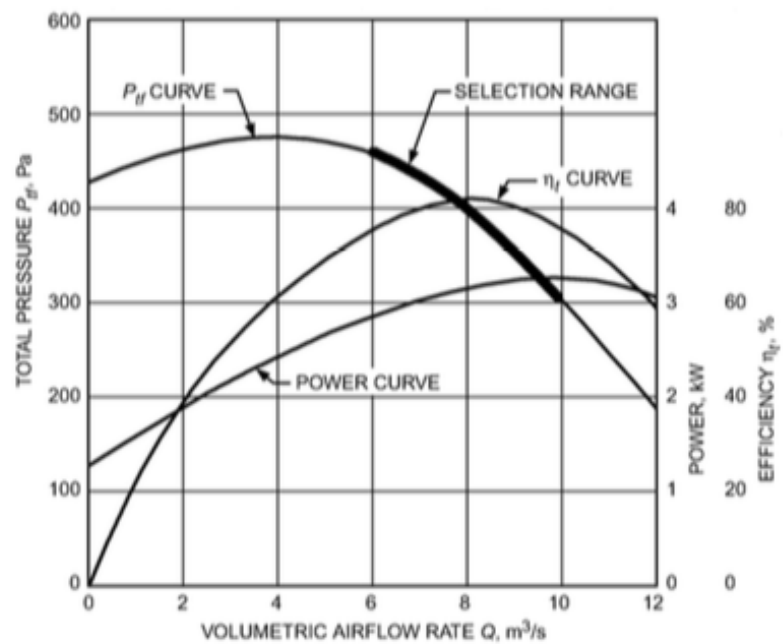
Pressure rise:
Energy input into system by fan

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 <u>fan or pump performance curves</u>

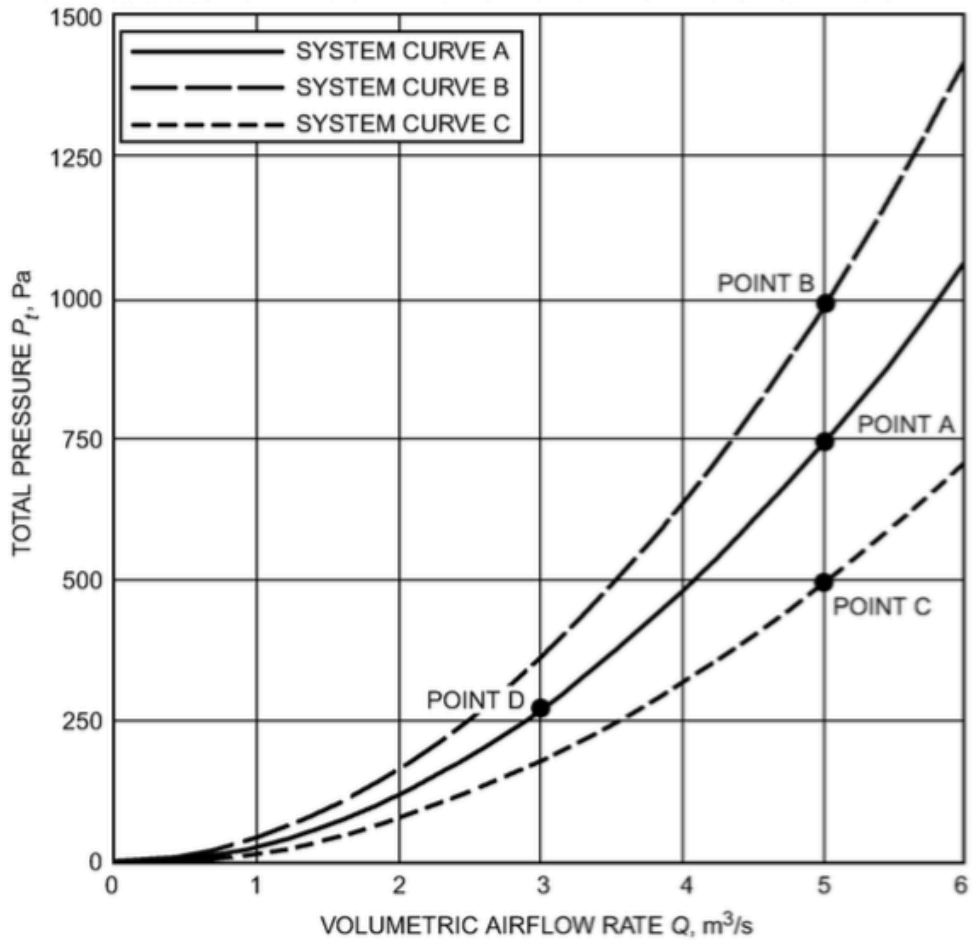


"Fan curve"



Intersection of fan curves and system curves

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

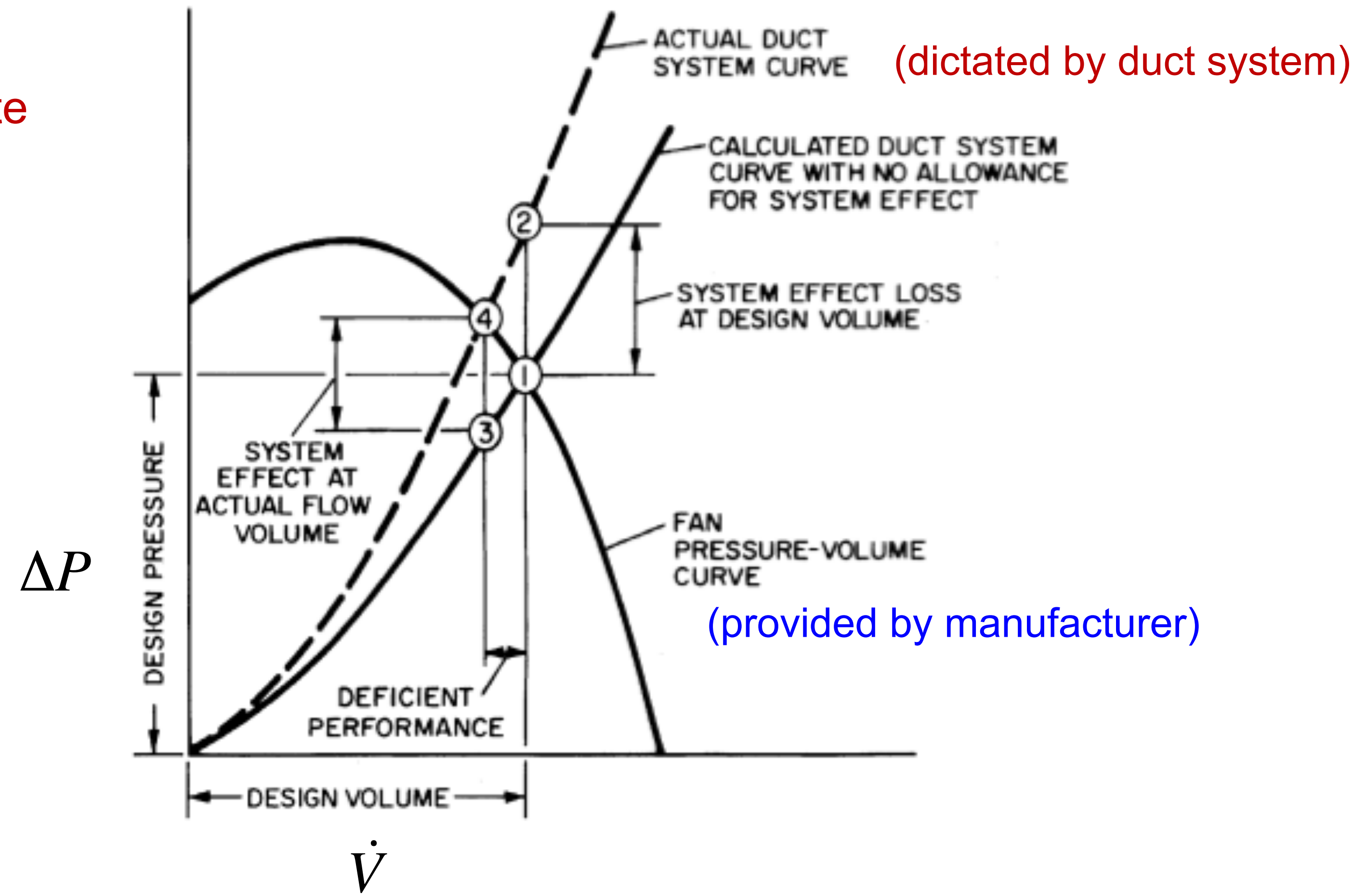


Intersection of fan curves and system curves

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

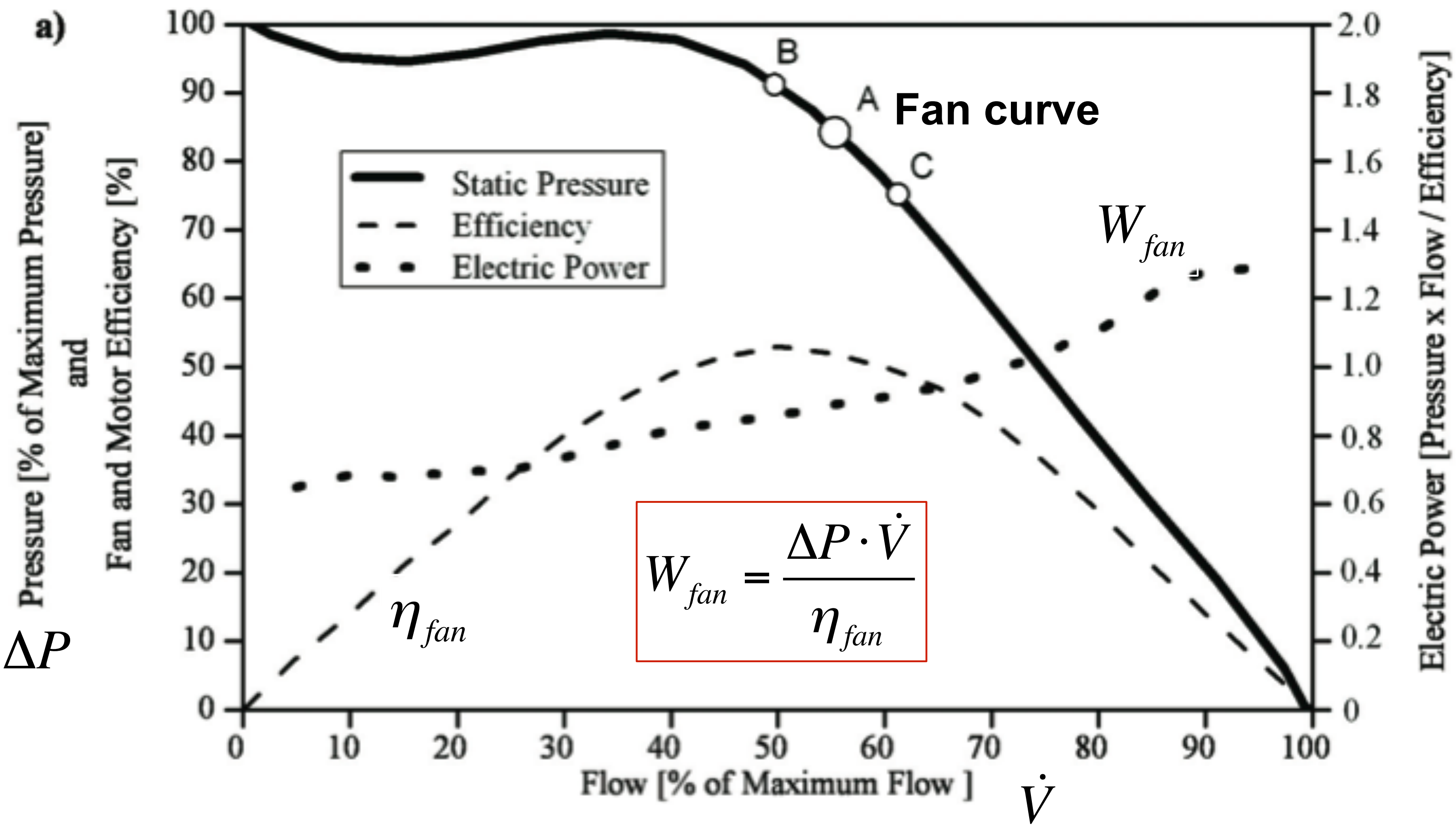
And we calculate fan (or pump) power draw by:

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



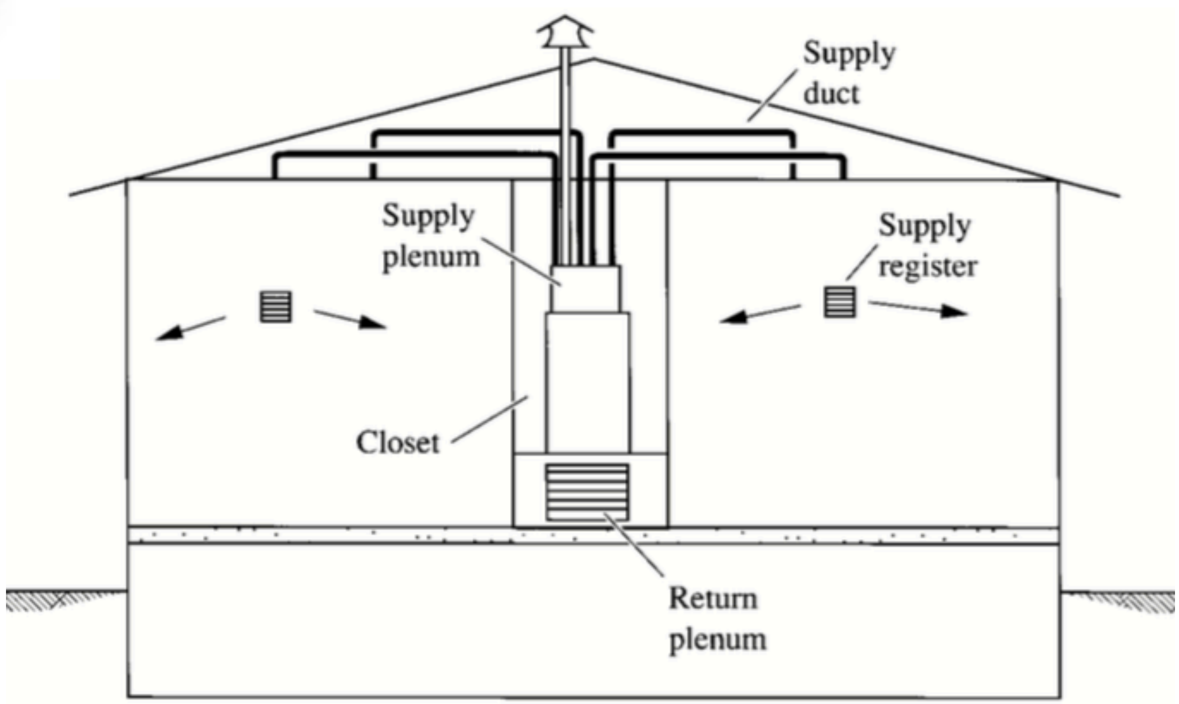
Intersection of fan curves and system curves

Example:
What is the fan power draw at point A, assuming 250 Pa and 0.5 m^3/s?



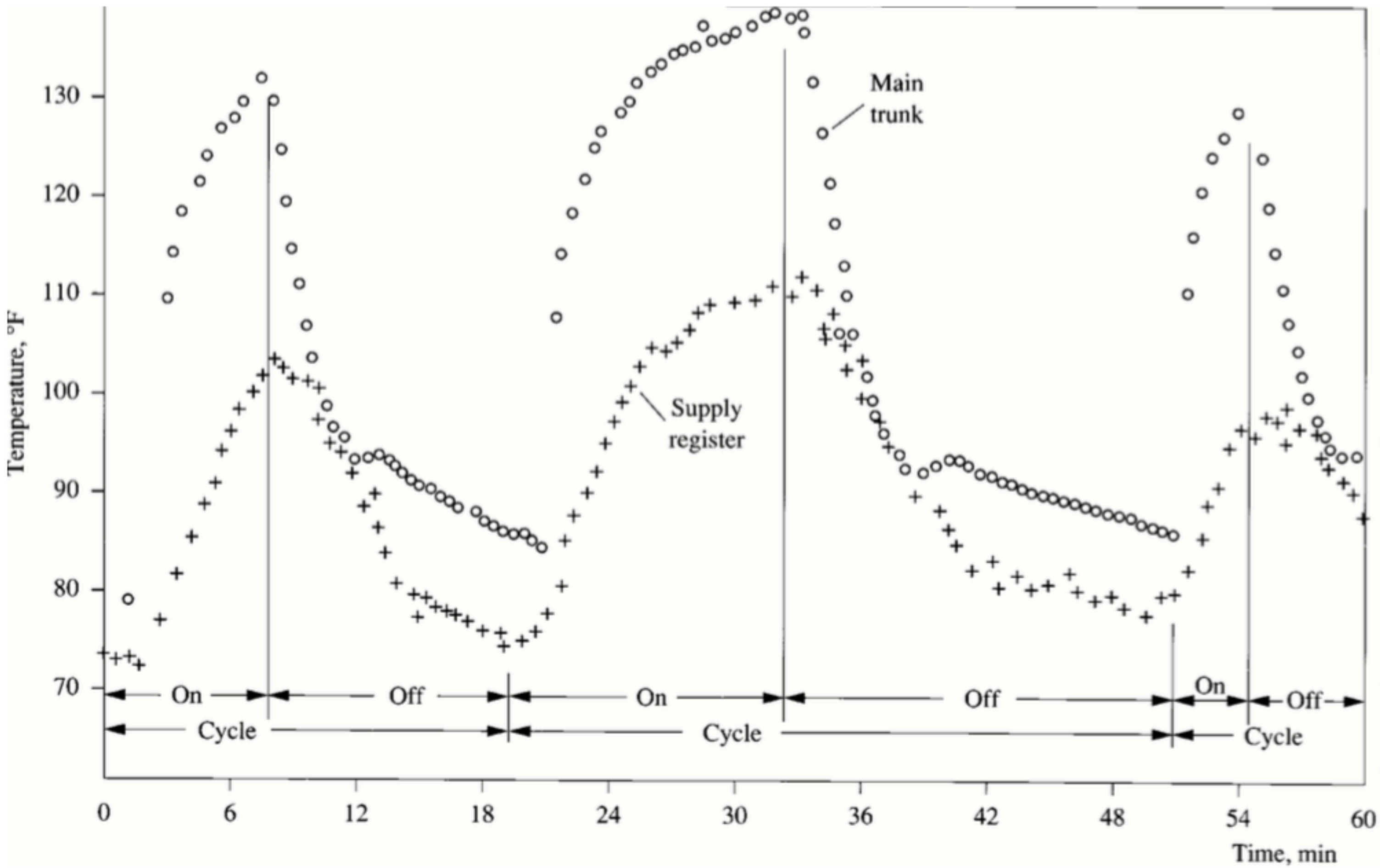
One last inefficiency: Duct heat losses or gains

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:



Investigation of HVAC system in this room