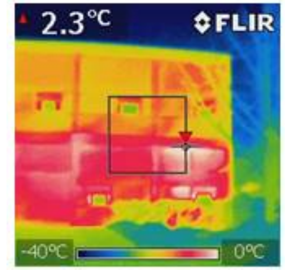
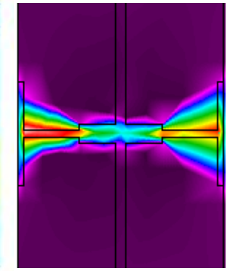
CAE 331/513
Building Science
Fall 2015





Week 10: October 27, 2015
Continuing HVAC systems
Air and water distribution systems

Built
Environment
Research
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Advancing energy, environmental, and sustainability research within the built environment
www.built-envi.com
Twitter: @built_envi

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ASHRAE IIT Chapter

Let me know if you want to be involved in the ASHRAE student chapter

- We need leaders!

http://web.iit.edu/campus-life/get-involved/student-organizations

Deadline to register: November 12, 2015

Special problems course in Spring 2016

http://energy.gov/sites/prod/files/2015/09/f26/RacetoZero_2016_9.16.pdf

Scheduling update

- HW 4 postponed (not due next week)
  - Will be assigned Nov 3 and due Nov 10
- Moves HW 5 back too
  - Updated schedule in syllabus on BB and www.built-envi.com

10	Oct 27	Air and water distribution systems		Wang Ch. 7, 15
	Oct 29	Air and water distribution systems		
11	Nov 3	Ventilation and indoor air quality		Wang Ch. 24
	Nov 5	Ventilation and indoor air quality		
12	Nov 10	Heating load calculations	HW4	Wang Ch. 6
	Nov 12	Cooling load calculations		
13	Nov 17	Cooling load calculations	HW5	
	Nov 19	**Exam 2**		
14	Nov 24	[Mechanical systems site visit on campus]		
	Nov 26	*No class – Thanksgiving Day*		
15	Dec 1	Energy estimation methods, energy efficiency, exergy, and sustainable buildings	HW6	Wang Ch. 5 & 25
	Dec 3	Building performance diagnostics		Wang Ch. 35
Final	Dec 9	**Final exam (comprehensive): 2-4 pm** (Wednesday)		

Review from last time

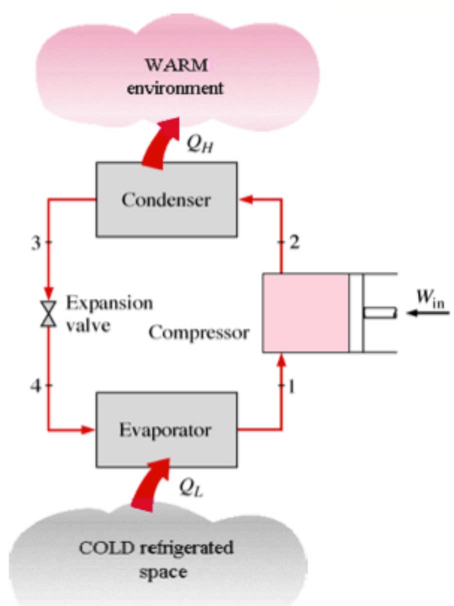
- Heating systems
  - Furnaces
  - Boilers

$$E_t = \frac{100\,(\text{fluid energy output})}{\text{fuel energy input}}$$

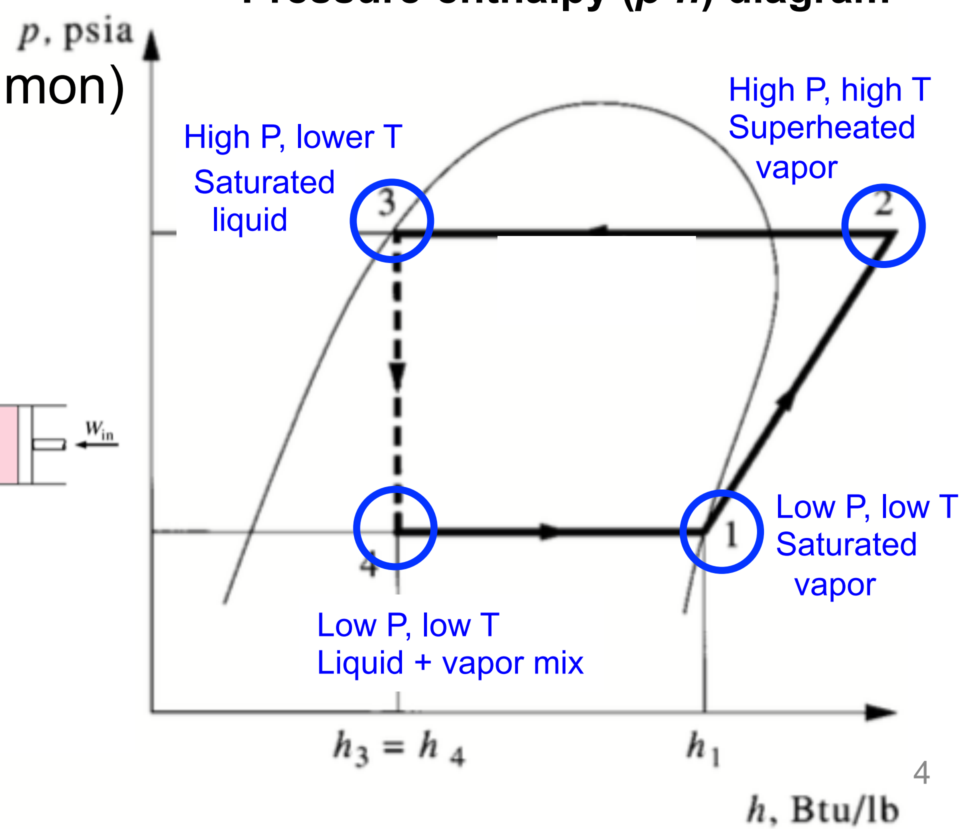
$$\text{AFUE} = \frac{100\,(\text{annual output energy})}{\text{annual input energy}}$$

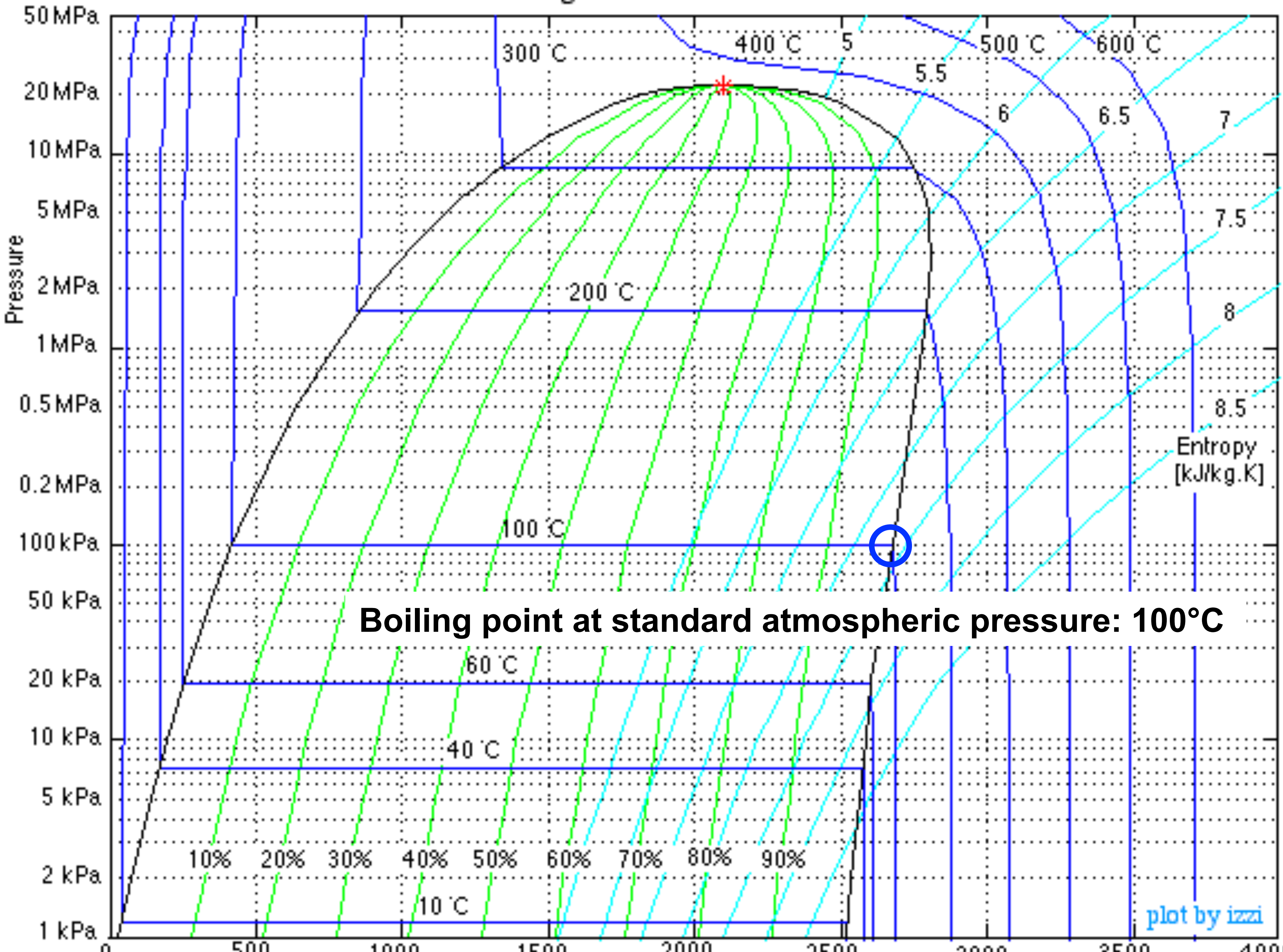
$$E_c = \frac{100 Q_{\text{out}}}{Q_{\text{fuel}}}$$

- Refrigeration systems
  - Vapor compression (most common)
  - Absorption

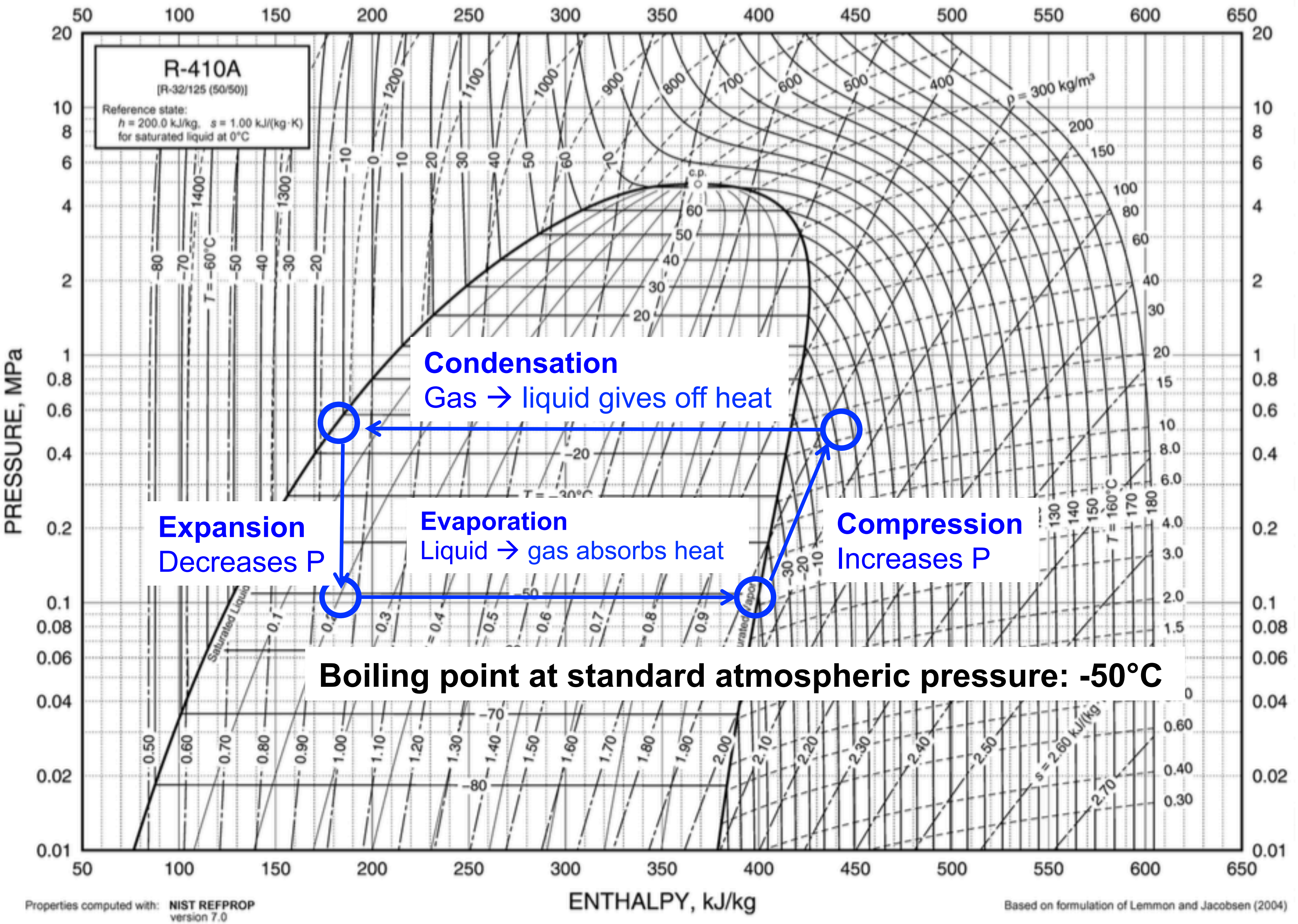


Pressure-enthalpy (*p-h*) diagram





***p-h* diagram for water**



***p-h* diagram for R-410A**

Fig. 16 Pressure-Enthalpy Diagram for Refrigerant 410A

Today's objectives

- Finish vapor compression refrigeration cycles
- Introduce COP, EER, and capacity
  - And how they change with external conditions
- Introduce more complex heating and cooling systems
  - Chillers
  - Cooling towers
  - Air and water distribution systems
  - Economizers

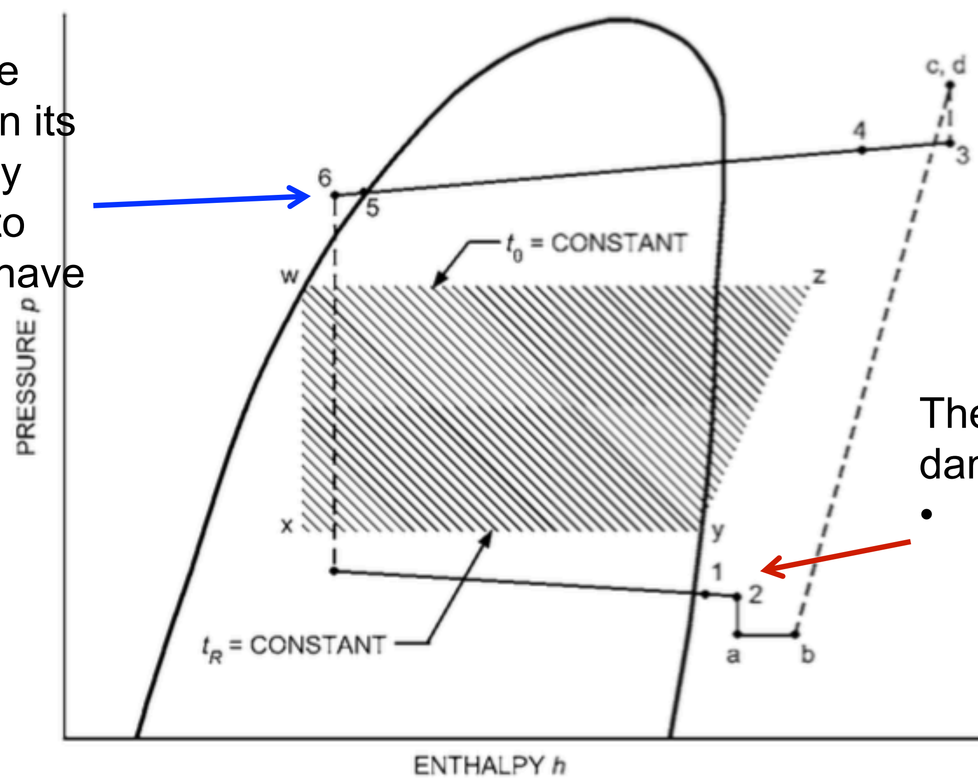
Non-ideal single-stage vapor compression cycle

Actual refrigeration systems differ from ideal cycles

- Pressure drops occur everywhere but the compression process
- Heat transfers between the refrigerant and its environment
- Actual compression process may differ
- Refrigerant might also have some oil mixed in to lubricate
- They all cause irreversibilities in the system that require additional compressor power

The expansion valve needs 100% liquid in its inlet to work properly

- You "**subcool**" to ensure that you have only liquid



The compressor will be damaged if liquid enters

- You "**superheat**" to ensure that you have only vapor

Question: What is the COP?

A. Congressional Observer Publications
B. California Offset Printers
C. Coefficient of Performance ←
D. Slang for a policeman

$$COP = \frac{\text{Provided cooling energy [W or BTU/hr]}}{\text{Used electric energy [W or BTU/hr]}}$$

Equivalent to the efficiency of an air-conditioning unit

Coefficient of performance (COP)

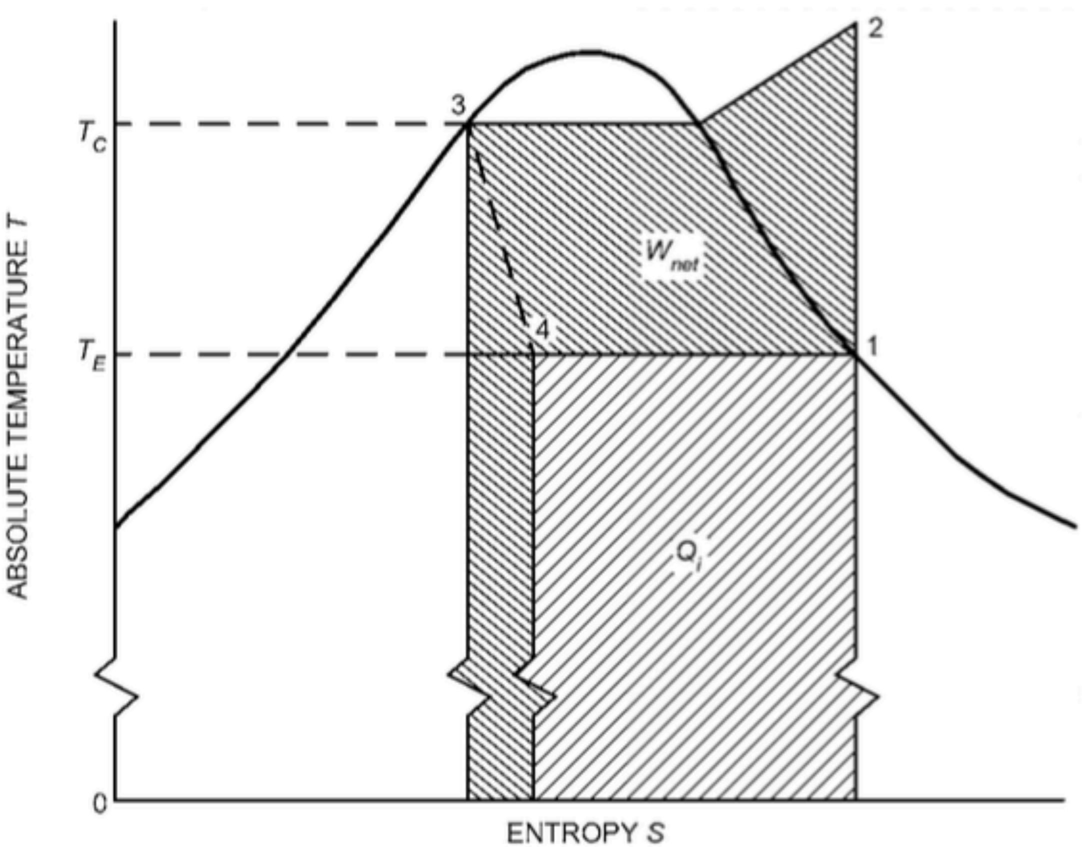
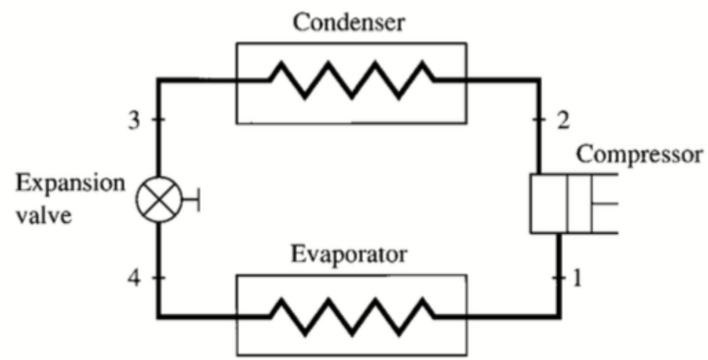


Fig. 10 Areas on *T*- *s* Diagram Representing Refrigerating Effect and Work Supplied for Theoretical Single-Stage Cycle

For an <u>ideal</u> refrigeration cycle:

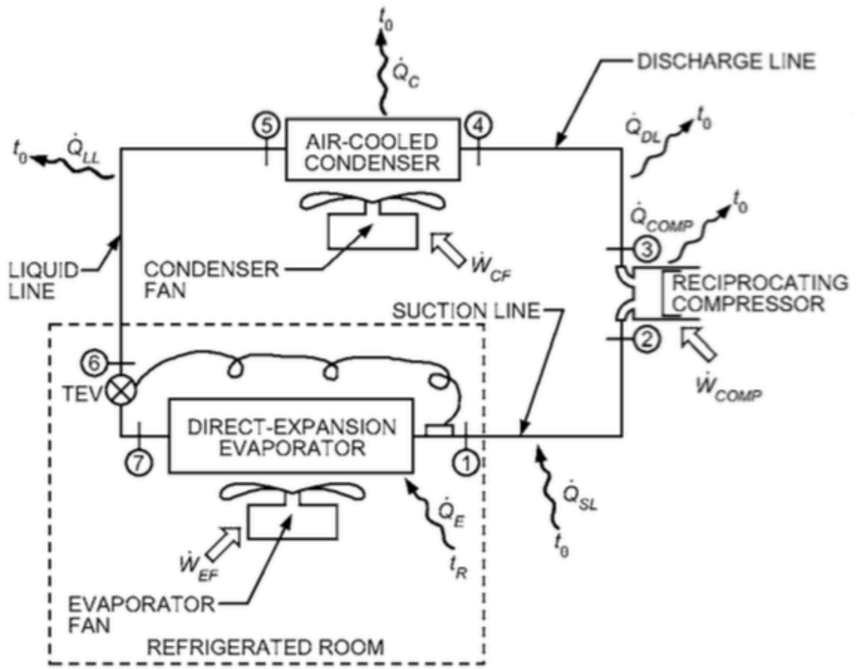
$$COP = \frac{Q_{cool}}{W_{elec}} = \frac{h_1 - h_4}{h_2 - h_1}$$

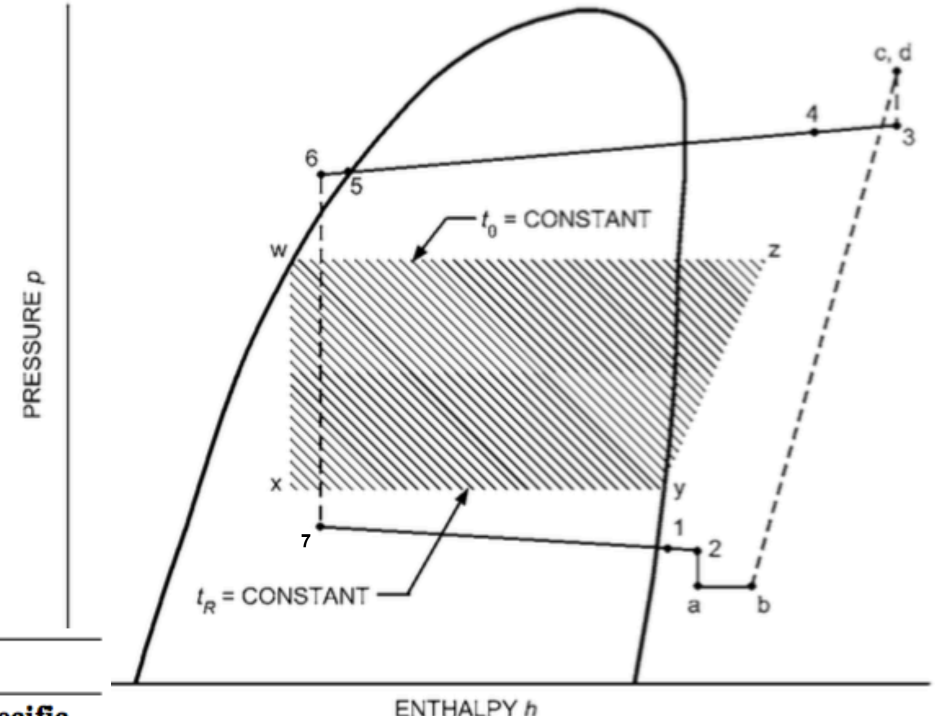


What is the efficiency of a typical residential AC unit?

A. 10%
B. 50%
C. 80%
D. 100%
E. 300% ←

COP example





State	Measured		Computed		
	Pressure, kPa	Temperature, °C	Specific Enthalpy, kJ/kg	Specific Entropy, kJ/(kg·K)	Specific Volume, m^3/kg
1	310.0	–10.0	402.08	1.7810	0.07558
2	304.0	-4.0	406.25	1.7984	0.07946
3	1450.0	82.0	454.20	1.8165	0.02057
4	1435.0	70.0	444.31	1.7891	0.01970
5	1410.0	34.0	241.40	1.1400	0.00086
6	1405.0	33.0	240.13	1.1359	0.00086
7	320.0	–12.8	240.13	1.1561	0.01910

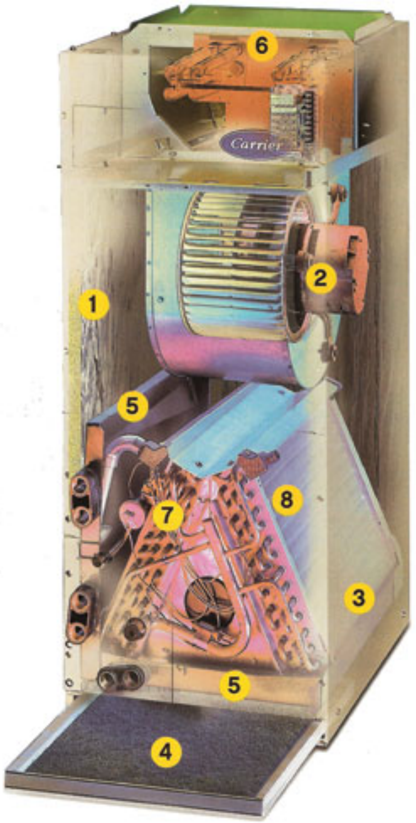
$$COP = \frac{Q_{cool}}{W_{elec}} = \quad ?$$

$$COP = \frac{Q_{cool}}{W_{elec}} = \frac{402-240}{454-406} = 3.38$$

Real life COP example: Residential AC unit

- Capacity = 3 tons
  - 36 kBTU/hr
  - 10.5 kW
- Power draw while operating:
  - 3500 W = 3.5 kW

ΔT_{coil} = 12°C - 24°C
Abs(ΔT_{coil}) = 12 K
$\dot{V}_{air}$ = 400 CFM per ton (typical)
$\dot{V}_{air}$ = 1200 CFM
$\dot{V}_{air}$ = 0.566 m^3/s
Q_{sens} = (1.15 kg/m^3)(1 kJ/kgK)(0.566 m^3/s)(12K)
Q_{sens} = 7.9 kW
SHR = 0.75 (typical)
Q_{total} = 7.9/0.75 = 10.5 kW
COP = 10.5 kW/3.5 kW = 3.0



What do we need to know about cooling systems?

Equipment selection example:

A load calculation determines you need 1.2 tons of water cooling

1 ton = 12000 Btu/hr
1.2 tons = 14,400 Btu/hr

You would choose a 1.35 ton capacity unit

1.35 ton is accurate for:
115°F air condenser temp
and
50°F of leaving water temperature

SPECIFICATIONS	*IK-*	*.25A*	*.33A*	*.5A*	*.75A*	*1A*	*1.5A*	*2A*	*2W*	*3W*	*3A*	*4A*
COMPRESSOR	Capacity[2]	.25	.32	.41	.70	.98	1.35	2	2	3	3	4
	HP each	.25	.33	.50	.75	1	1.5	2	2	3	3	4
	Type[3]	H	H	H	H	H	H	H	H	H	H	H

Notes: 1. Full load amps must be used for sizing disconnects and supply wiring. **2.** Tons of capacity at 12,000 BTU/ton @ 50°F LWT @ 105°F condensing temperature for water-cooled units and 115°F for air-cooled units. Capacities may be +/- 5% as reserved by the compressor manufacturer. Capacity multipliers are 50°F - 1.00; 40°F -.80; 30°F - .60; 20°F - .40. The minimum recommended operating temperature when no glycol is used is 48°F. **3.** H - hermetic compressor used on this model. **4.** Consult factory for 50hz operation. **5.** Approximate unit weight crated for shipment.

AC capacity and efficiency <u>changes</u> with: outdoor temperature, indoor T/RH, and airflow rates

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

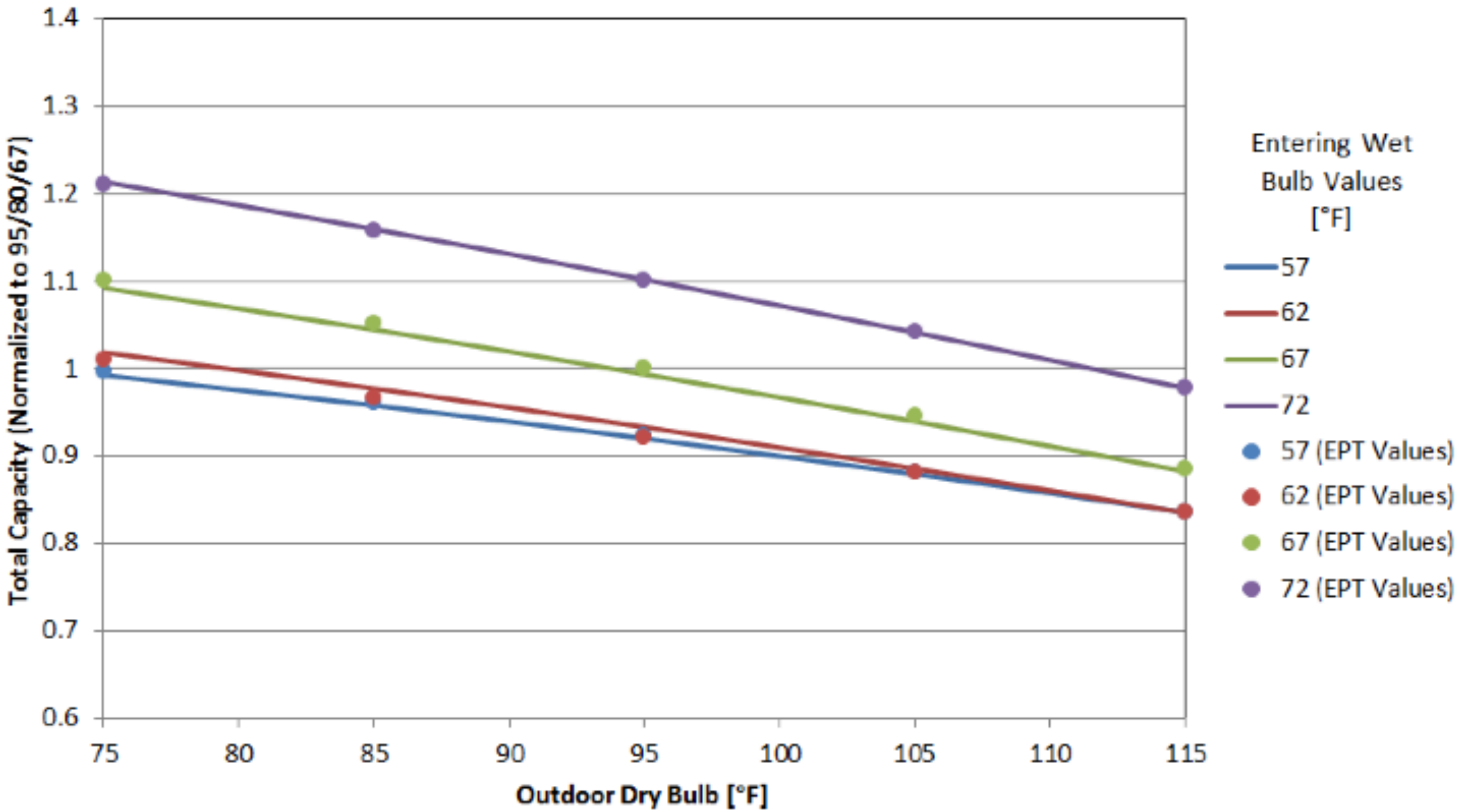
Evaporator Air		Condenser Air °F (°C)								
		75 (23.9)			95 (35)			105 (40.6)		
cfm	EWB °F (°C)	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[1,2]	Total Sys kW[3]	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[2]	Total Sys kW[3]	Capacity kBtu/h Total[1]	Capacity kBtu/h Sens[2]	Total Sys kW[3]
875	72 (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



EER and SEER

- EER = Energy Efficiency Ratio
  - Same as COP but in mixed units: (Btu/hr)/W
  - Example from previous page:

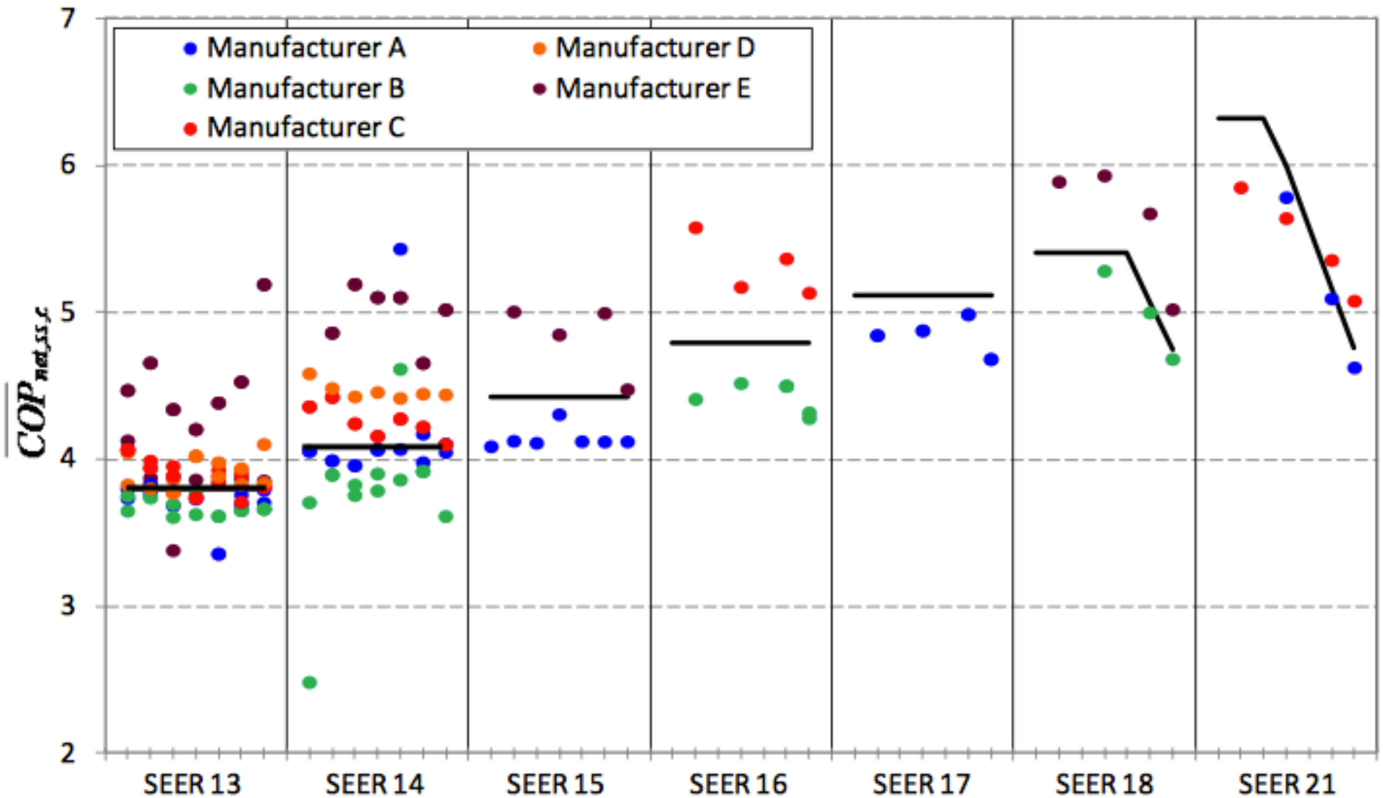
$$COP = \frac{8.5\ [\text{kW}]}{2.48\ [\text{kW}]} = 3.43 \qquad EER = \frac{29.0\ [\text{kBtu/hr}]}{2.48\ [\text{kW}]} = 11.7$$

$$EER = COP \times 3.41$$

- SEER = Seasonal Energy Efficiency Ratio, units: [Btu/Wh]
  - Cooling output during a typical cooling season divided by the total electric energy input during the same period
  - Represents expected performance over a range of conditions

$$EER \approx -0.02 \times SEER^2 + 1.12 \times SEER$$

EER and SEER



- AC units must be 14 SEER (or 12.2 EER) beginning on January 1, 2015 if installed in southeastern region of the US

Using COP to estimate power draw and energy consumption

- If you know the cooling load and you know the COP, you can estimate the instantaneous electric power draw required to meet the load:

$$\mathrm{P}_{elec} = \frac{Q_{cooling,load}}{COP}$$

- If you multiply by the number of hours and sum over a period of operating time, you can estimate energy consumption:

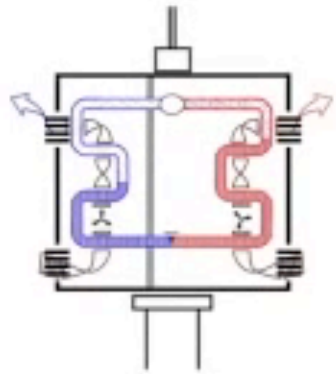
$$E = \sum \mathrm{P}_{elec}\,\Delta t$$

- You can also split data into bins if COP/EER changes with varying conditions

Air conditioning bigger buildings: More complex systems

Air Conditioning for Big Buildings

by: Michael Ermann and Clark Coots



https://www.youtube.com/watch?v=j1nYipLAv0U

HVAC system design options

- We can rely on **central** HVAC systems
  - One system per building
  - May control all zones similarly or different zones differently
    - Depends on system type
- Or we can rely on **distributed** HVAC systems for every zone
  - Motels, strip malls, apartment buildings
- Need to figure out what medium we will use for heat transfer
  - Air, steam, water?
- Need to determine what capacity and efficiency we want
  - Load calculations (later)

Central vs. distributed systems

Central systems

- Large equipment has higher quality, efficiency, and durability
- Maintenance is concentrated in one place
- Noise is removed from zone
- Diversity of loads allows lower installed capacity
- Can use thermal storage solutions

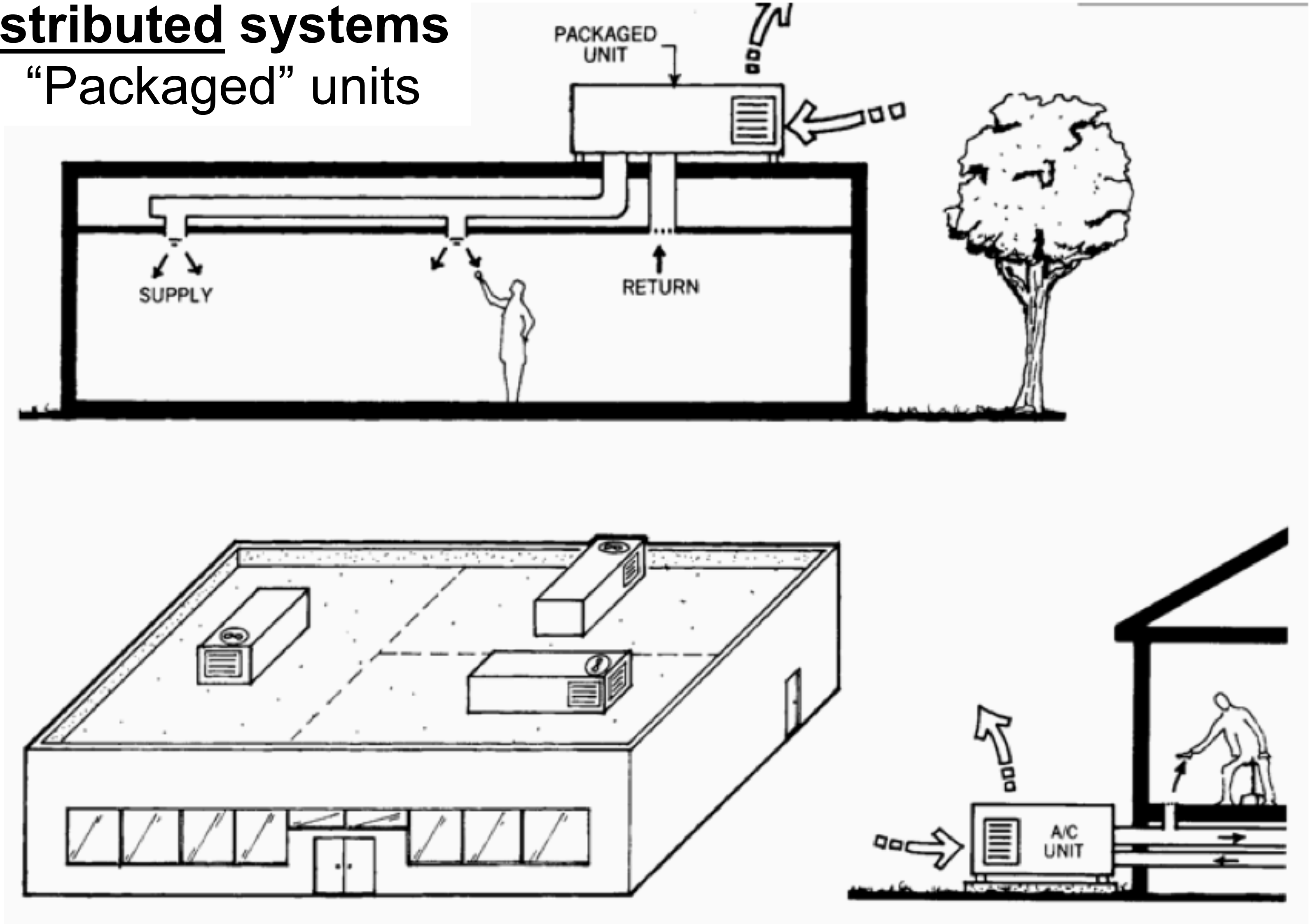
Distributed systems

- Easy to provide zoning
- Direct control by occupants
- Easier independent scheduling for energy savings
- Generally lower capital costs and shorter lead time for equipment
- Don't need dedicated maintenance staff
- Can often install on roof (saves room in the building)

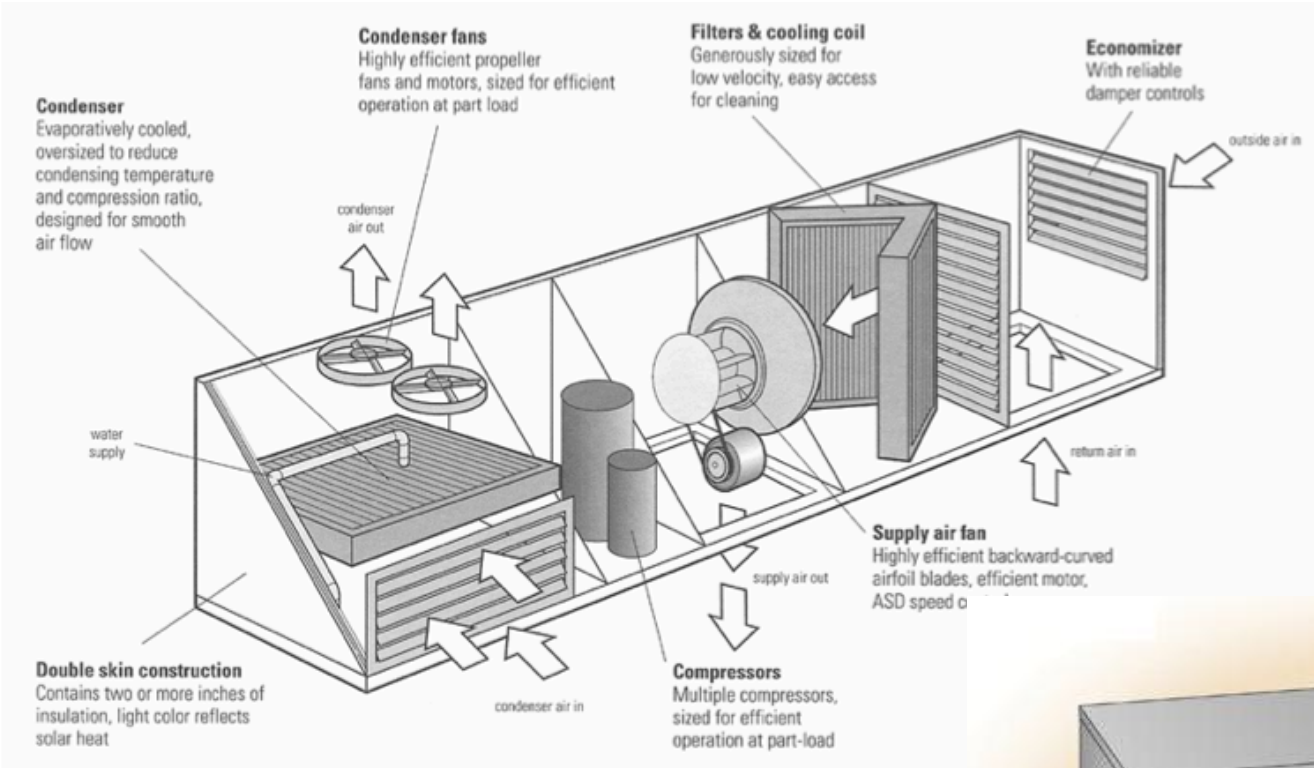
Typical large distributed commercial systems

Distributed systems

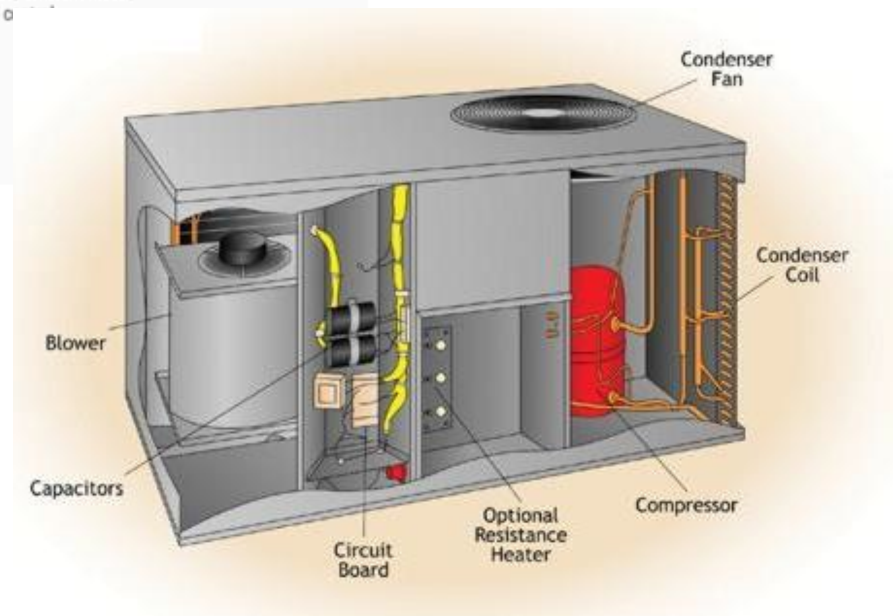
"Packaged" units



Typical large distributed commercial systems



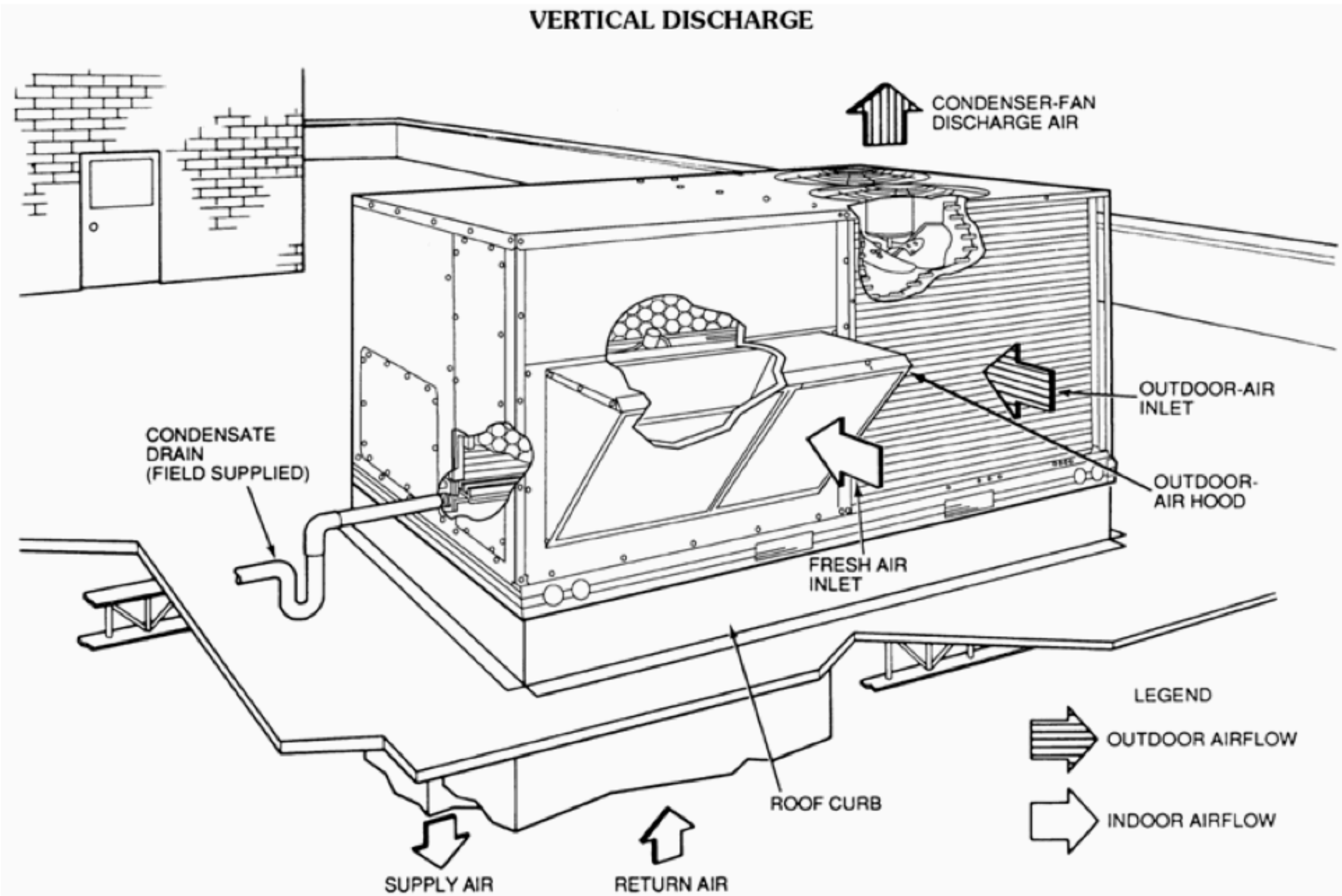
Packaged systems



Typical large distributed commercial systems

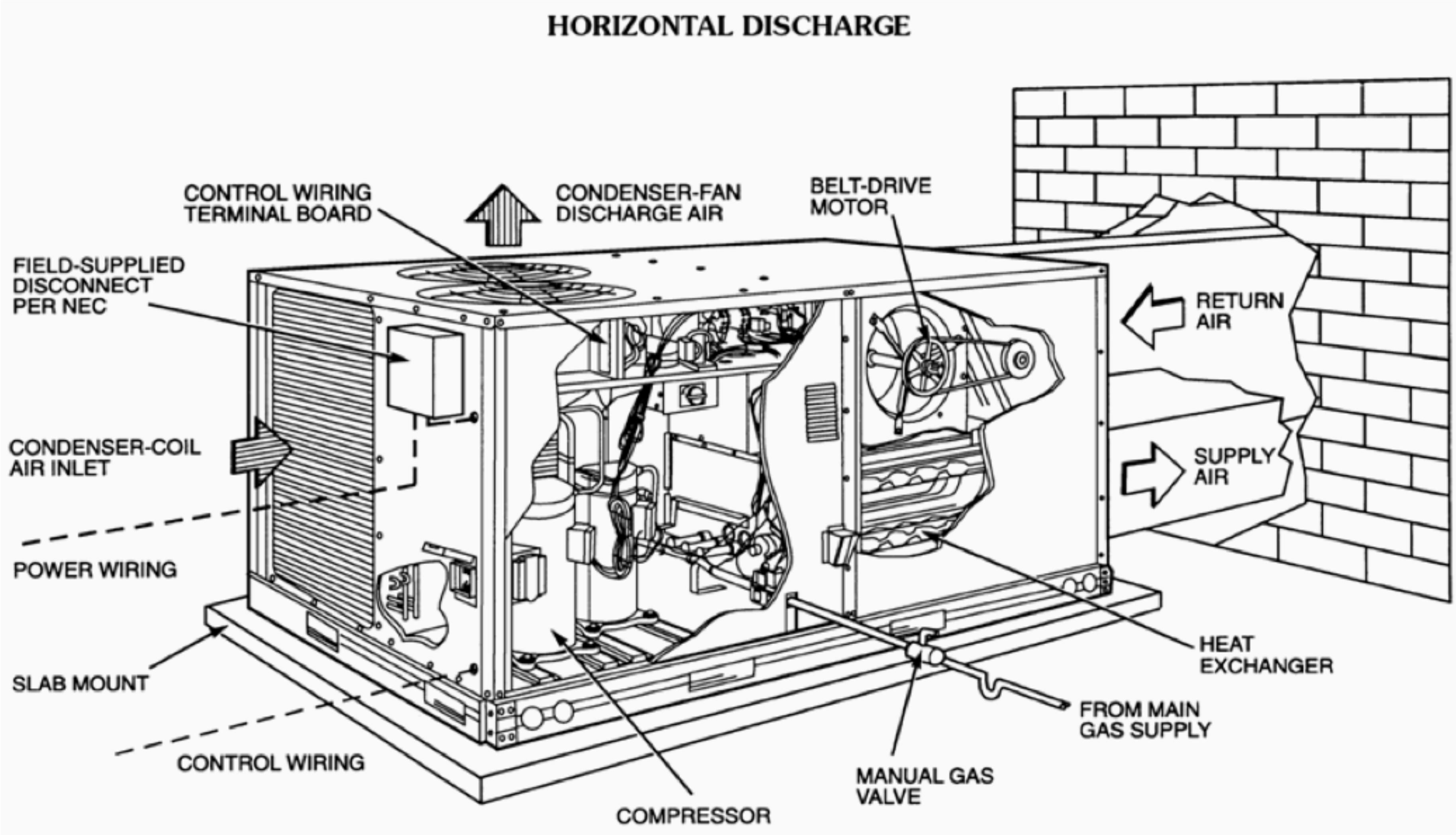
Typical large distributed commercial systems

Packaged roof-top units (RTUs)



Typical large distributed commercial systems

Packaged slab installations

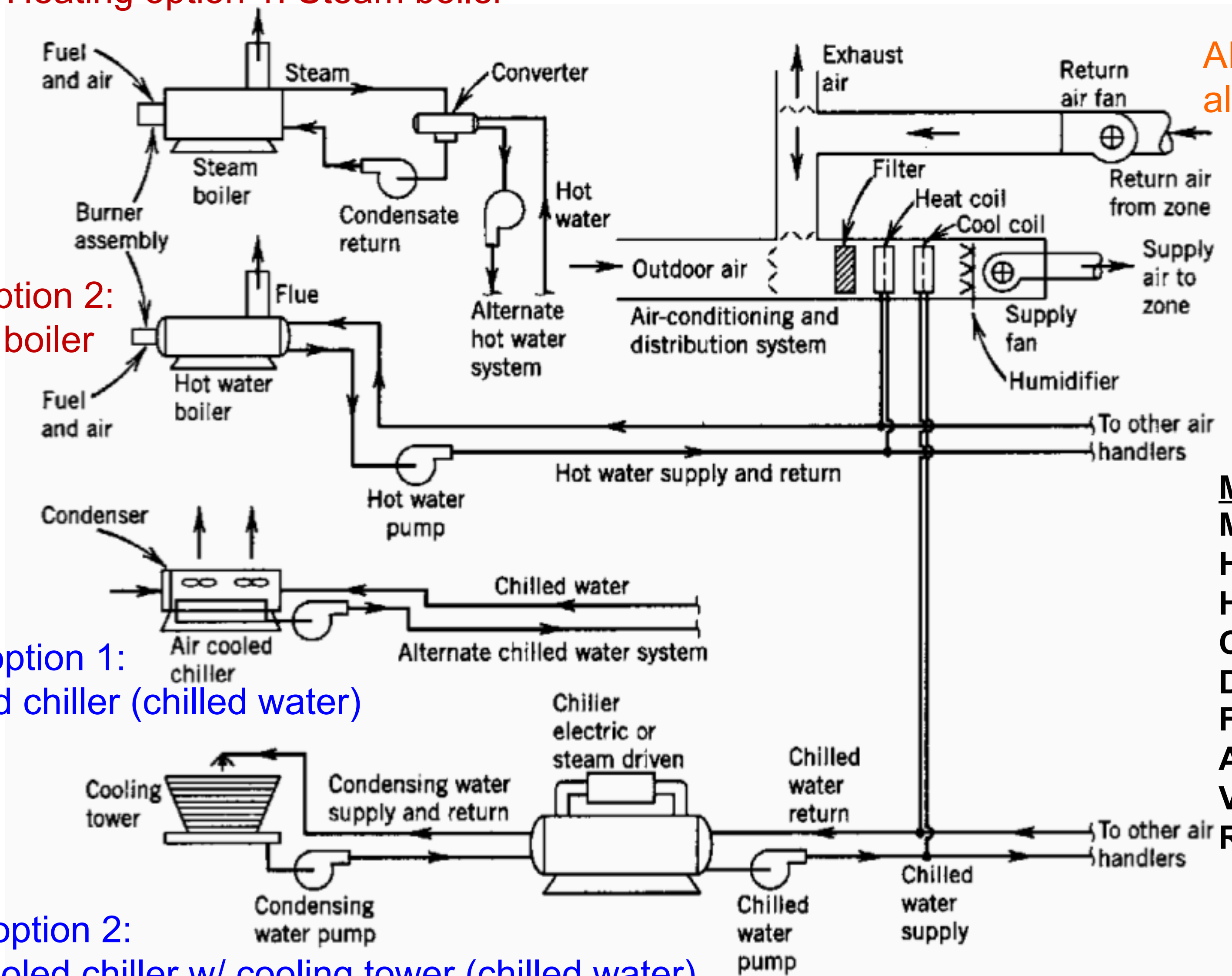


Typical large central commercial systems

Heating option 1: Steam boiler

AHU serves all rooms

Heating option 2:
Hot water boiler



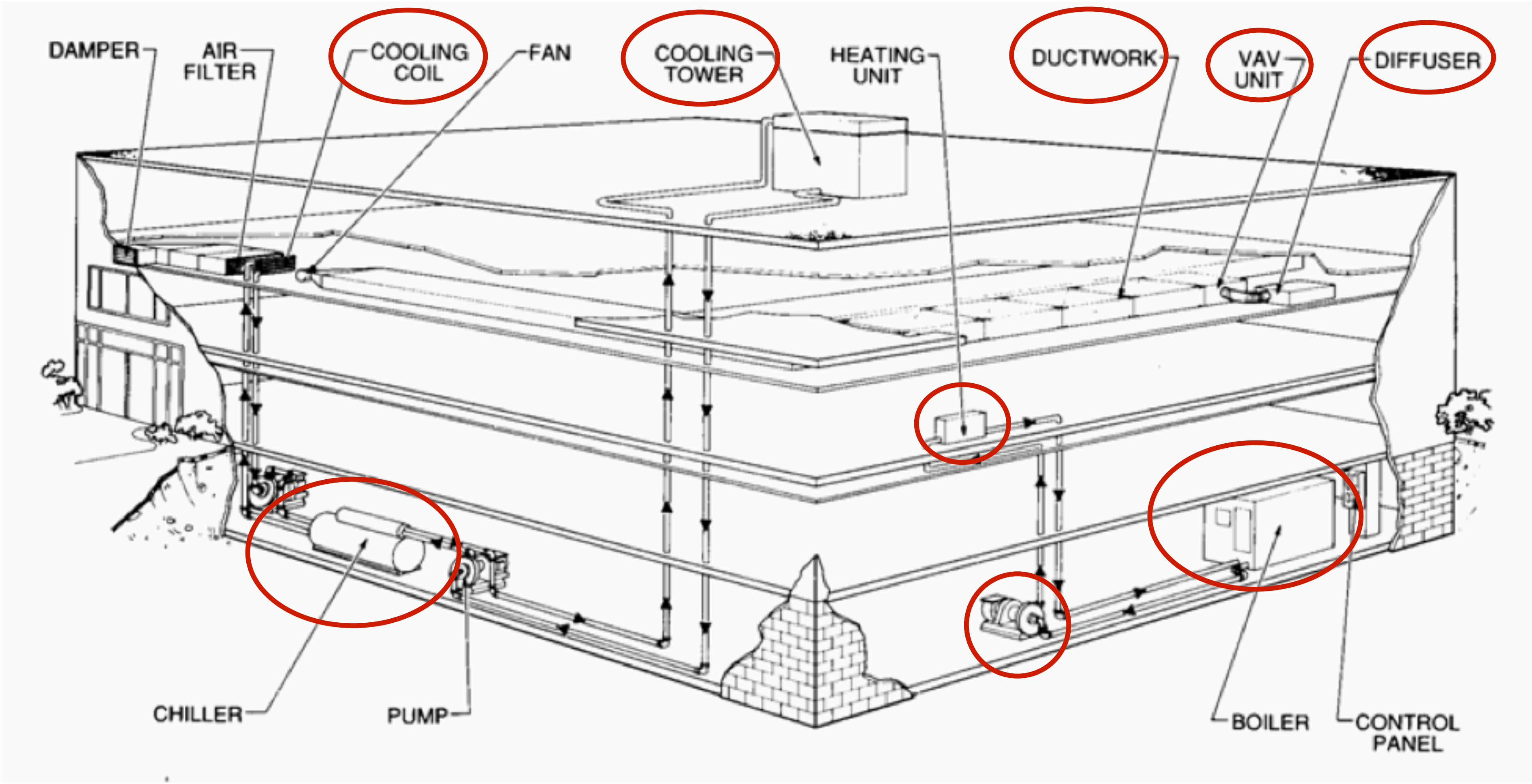
Cooling option 1:
Air cooled chiller (chilled water)

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

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

Typical large central commercial systems

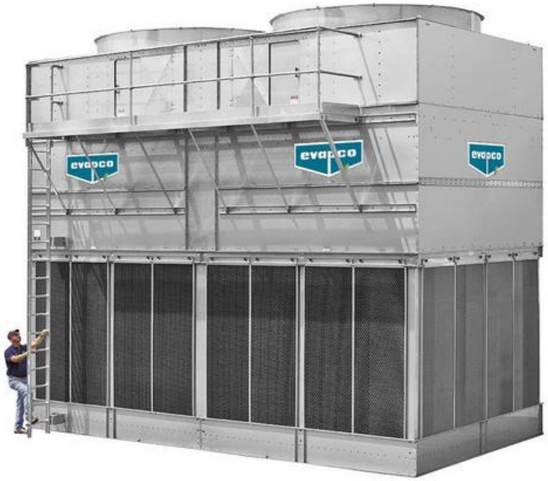
Heating and cooling distribution done separately:



Typical large central commercial system components

Air cooled chiller
Smaller capacity

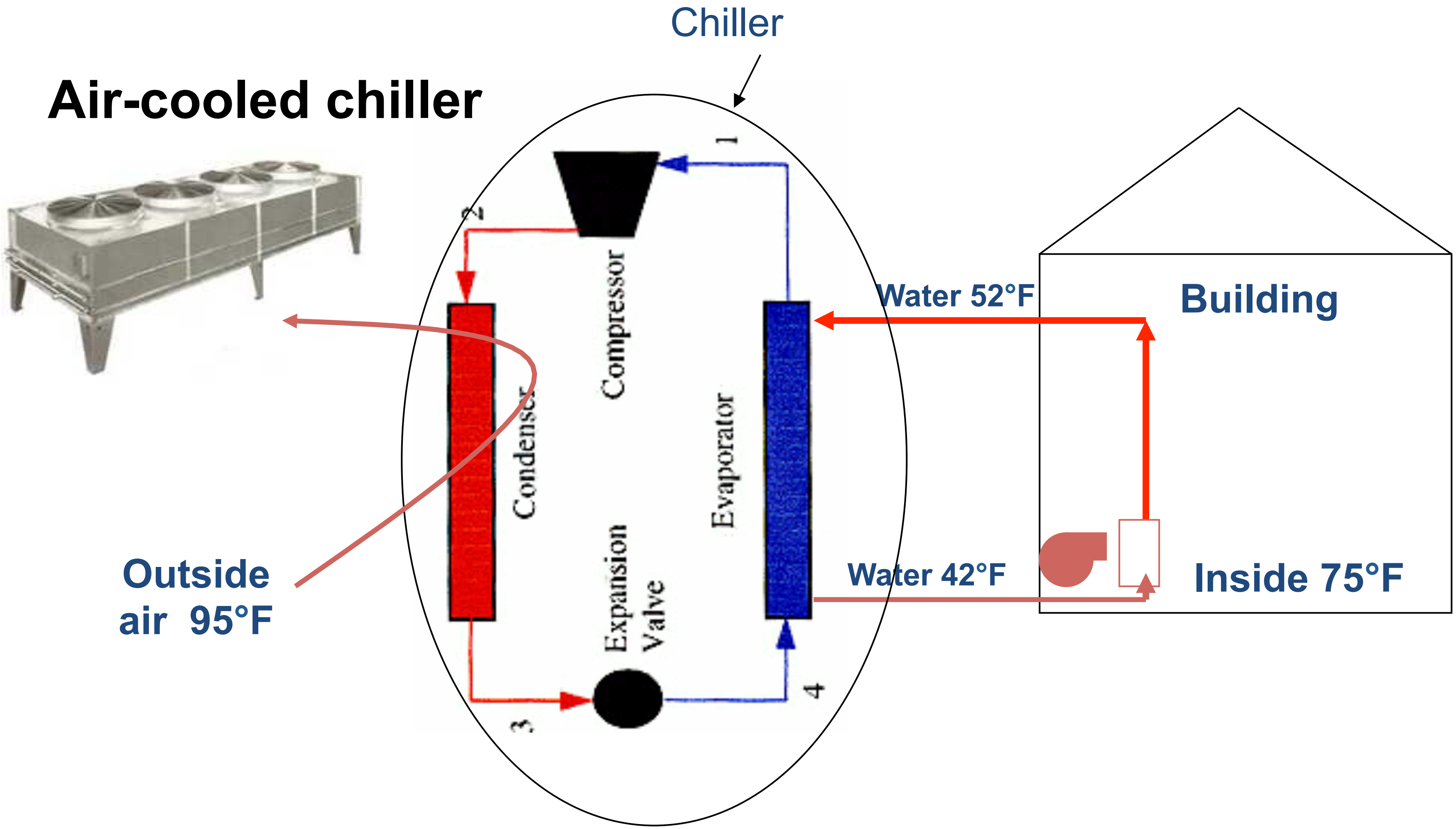
Hot water or steam boiler



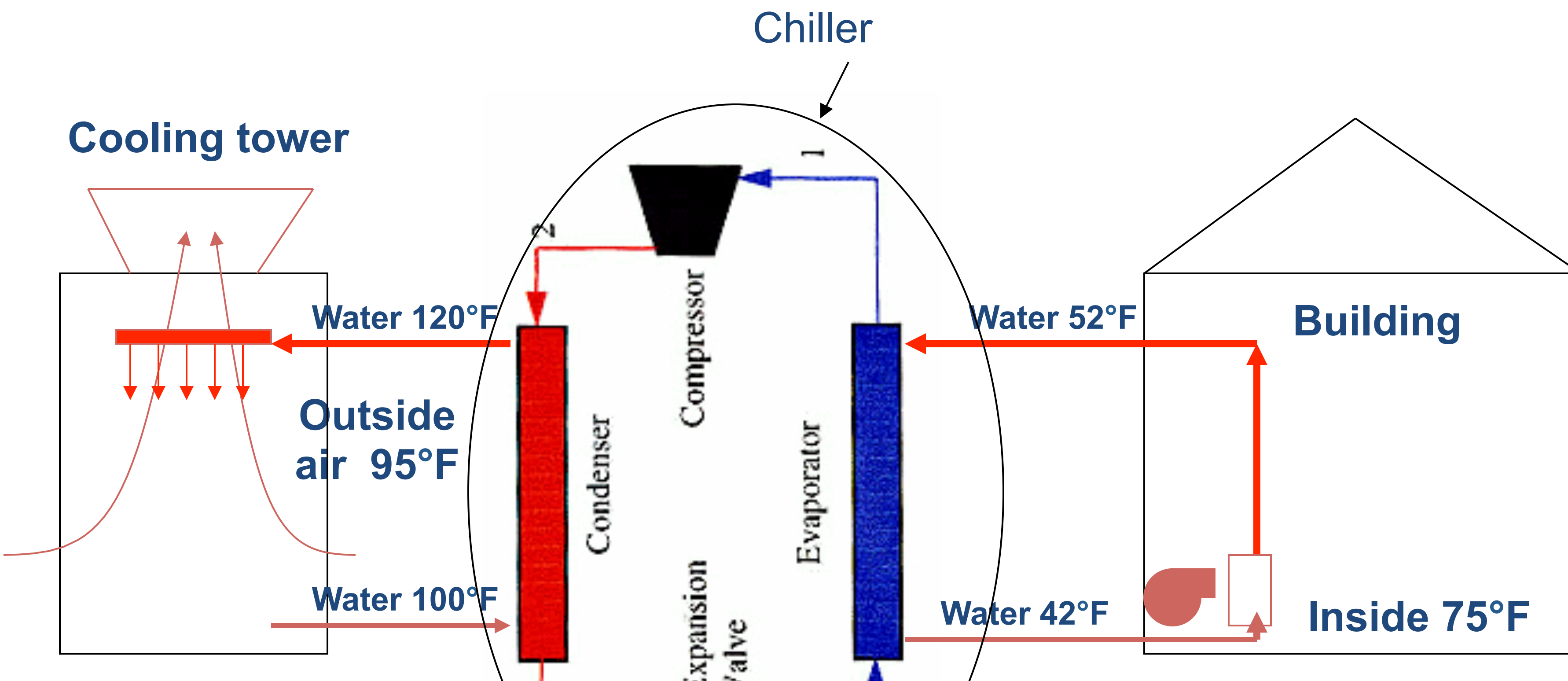
Water-cooled chiller
(w/ cooling tower – larger capacity & more efficient)

Air-cooled chillers

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



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

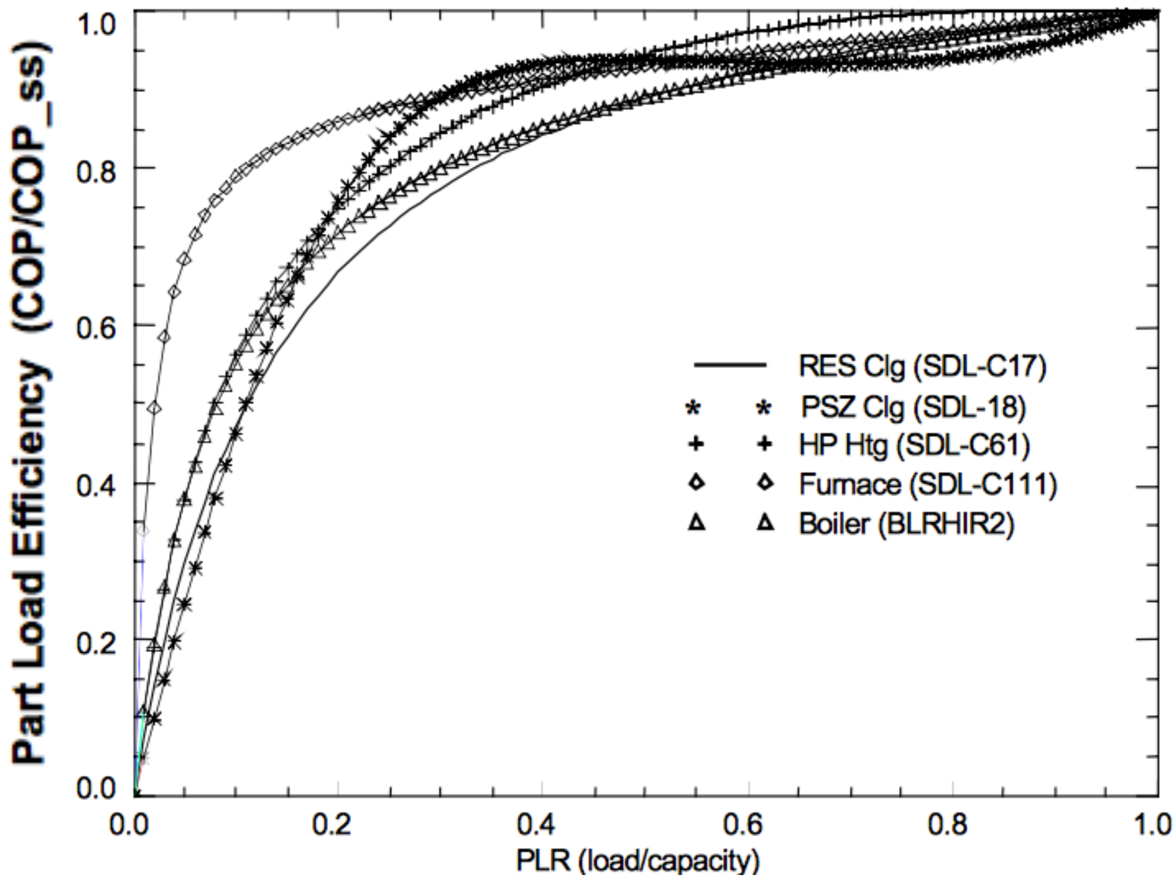


Water- or air-cooled chiller?

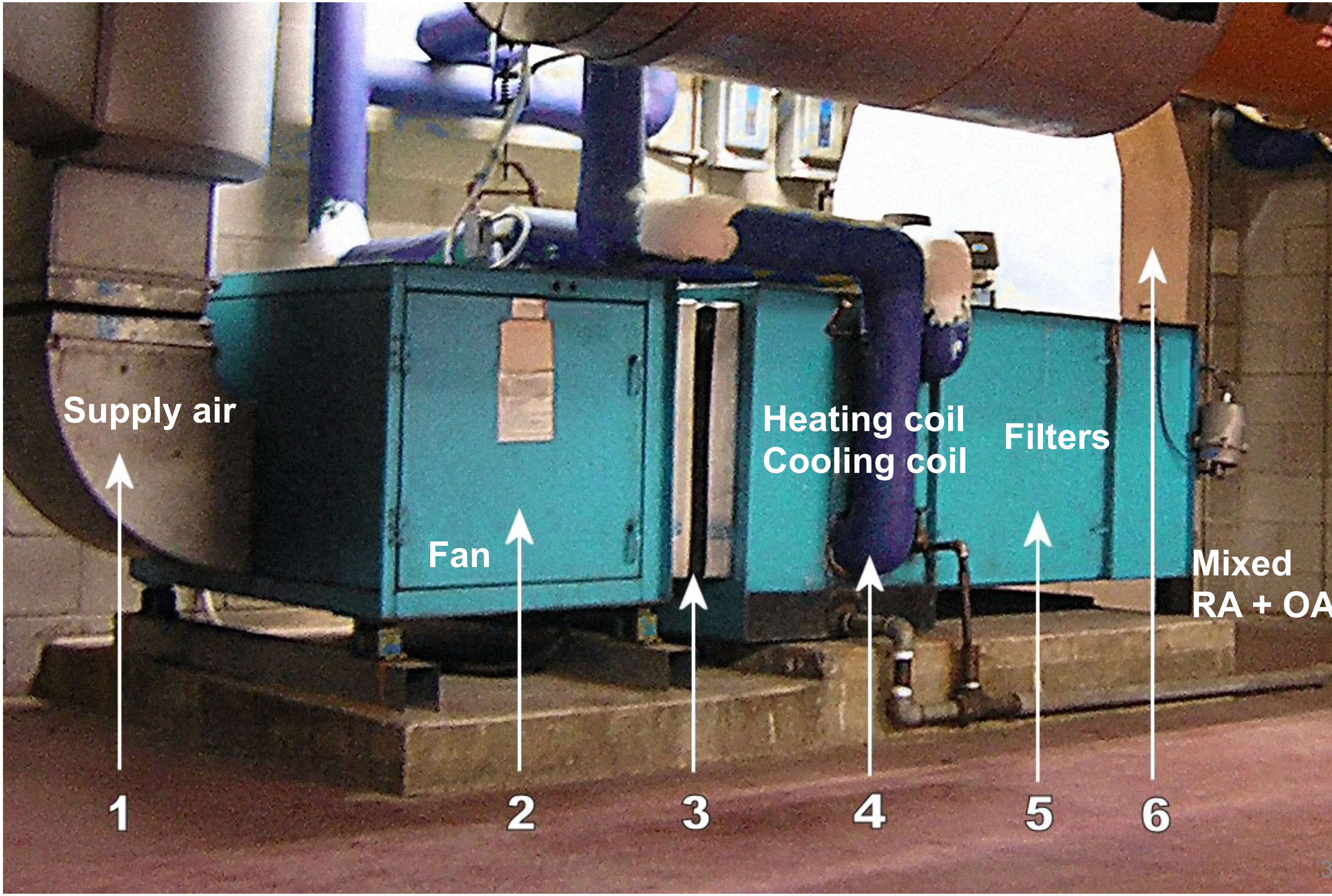
Criteria	Air Cooled	Water Cooled
Heat Transfer Medium	Air	Water
Temperature Effects	Highly dependent on the ambient dry-bulb temperature, lower performance at higher temperatures	Codependency on wet-bulb temperatures offers high performance across temperatures ranges
Efficiency	Least	Best
Footprint	Largest	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)

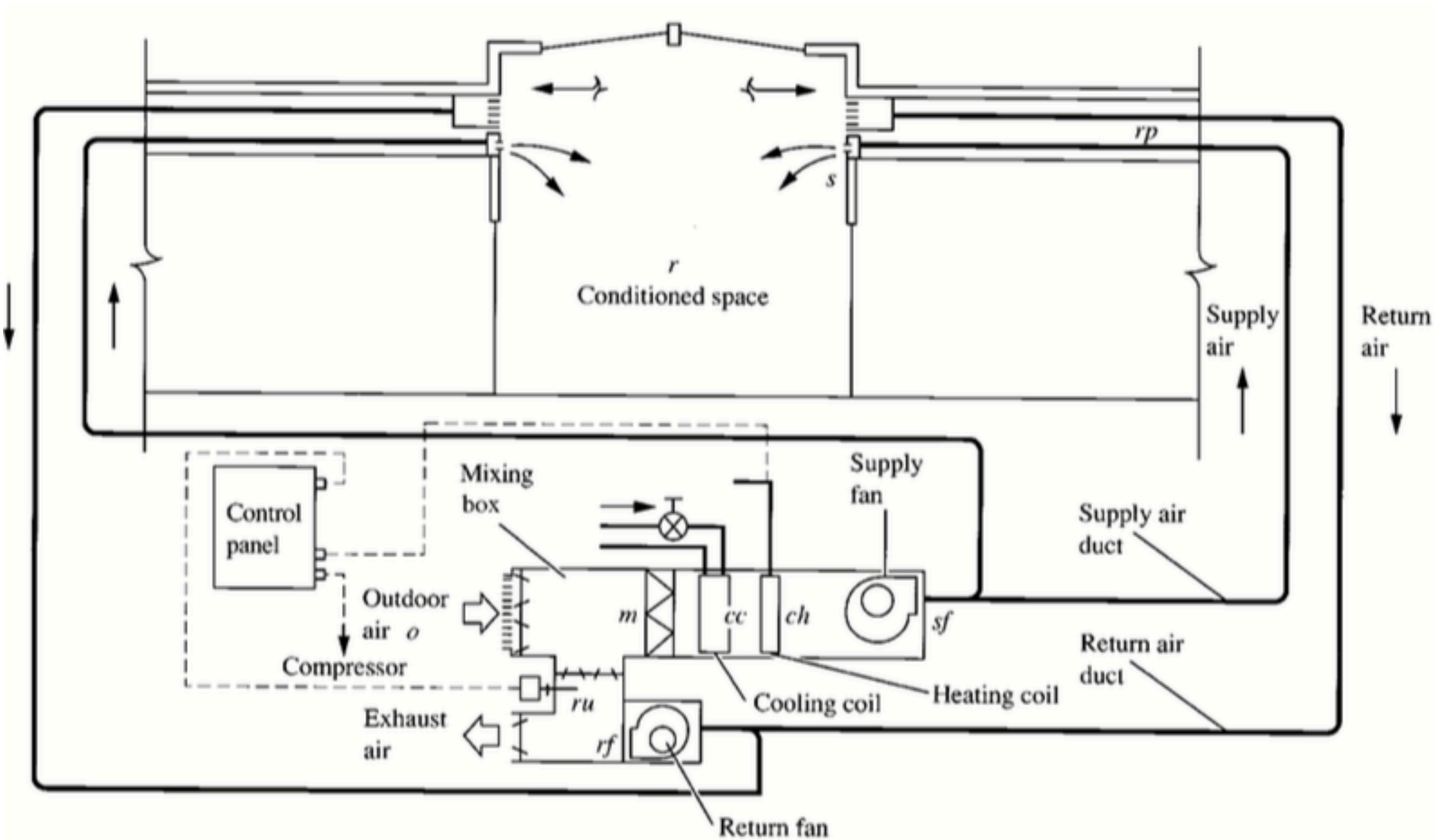
- Many systems operate at their highest efficiency (highest COP) at design load conditions
  - Maximum load
- But systems don't always operate at peak load conditions
  - Part load conditions are common
- The "part-load ratio" quantifies COP at part-load conditions



Typical central commercial HVAC system air handler

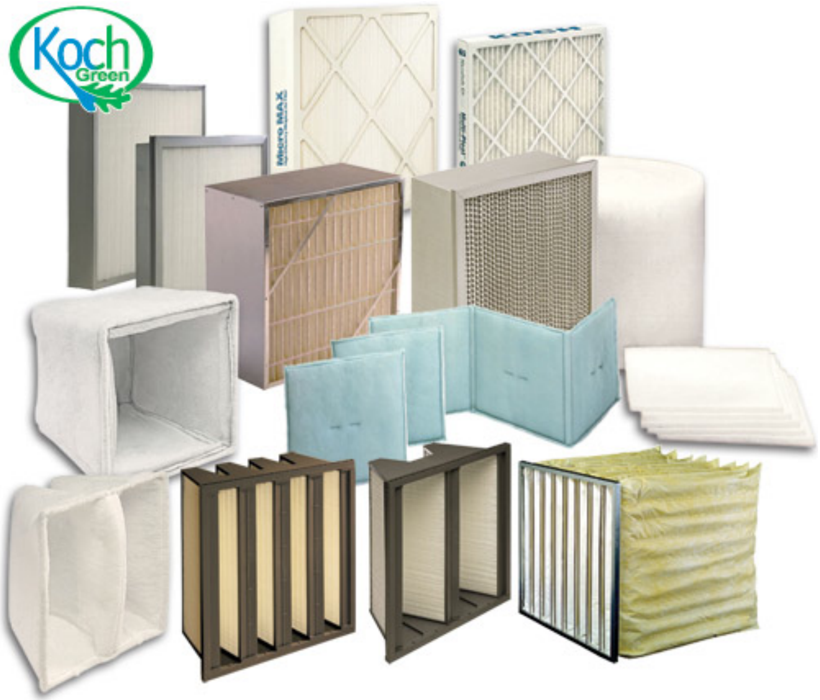


Typical central commercial HVAC system air handler



Typical large central commercial AHU components

Filter bank



Typical large central commercial AHU components

Filter bank

Typical large central commercial AHU components

Fan (or “blower”)

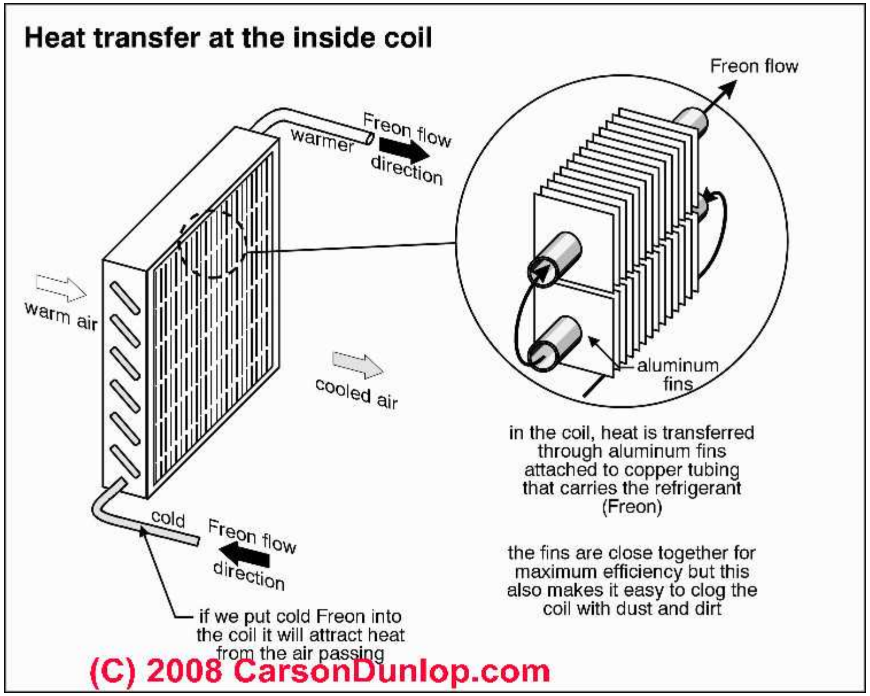
Typical large central commercial AHU components

Mixing box

Dampers

Typical large central commercial AHU components

Heating and cooling coils



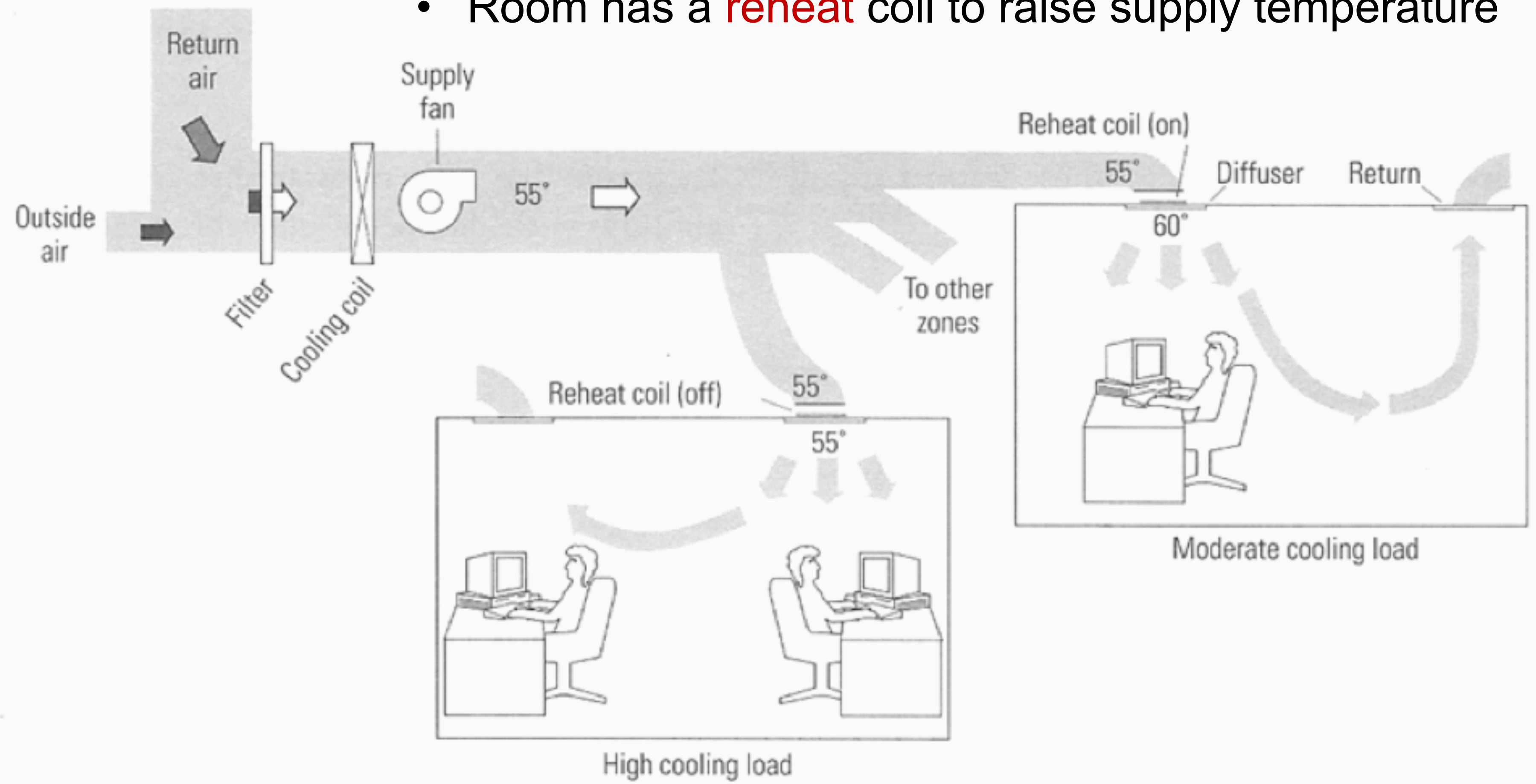
Air distribution: Air handling systems

- Constant air volume (**CAV**)
  - Constant zone airflow rates
  - Meets varying loads by varying supply air temperature
- Variable air volume (**VAV**)
  - Constant zone supply air temperature
  - Meets varying loads by varying supply airflow rates
- Dual duct (**DD**)
  - Mix hot and cold air at each zone
  - Use constant or variable supply airflow rate
- Multizone (**MZ**)
  - Mix hot and cold air for each zone at the air handler

Typical constant air volume (CAV) system

Same airflow rate and temperature to each room

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



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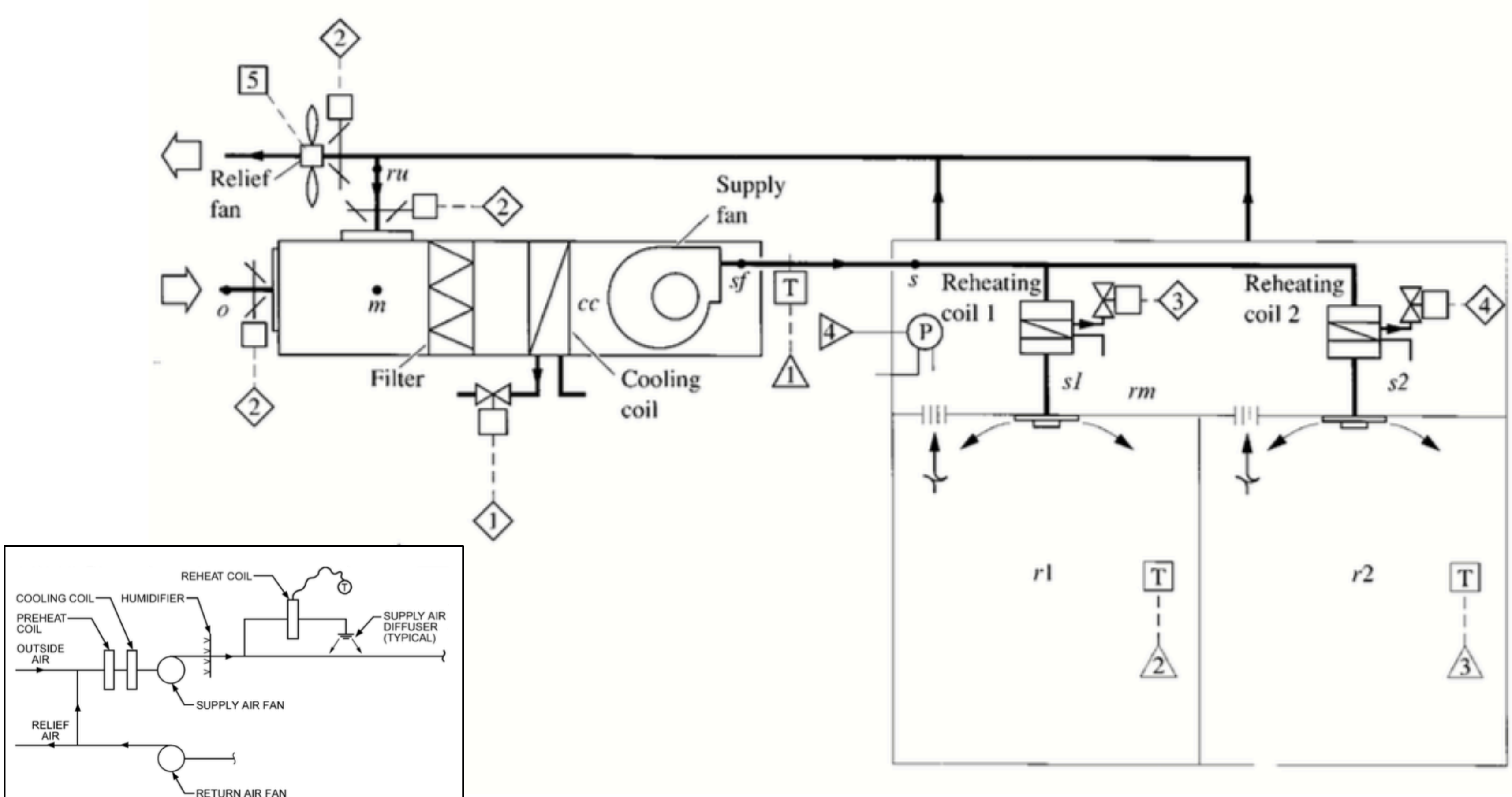
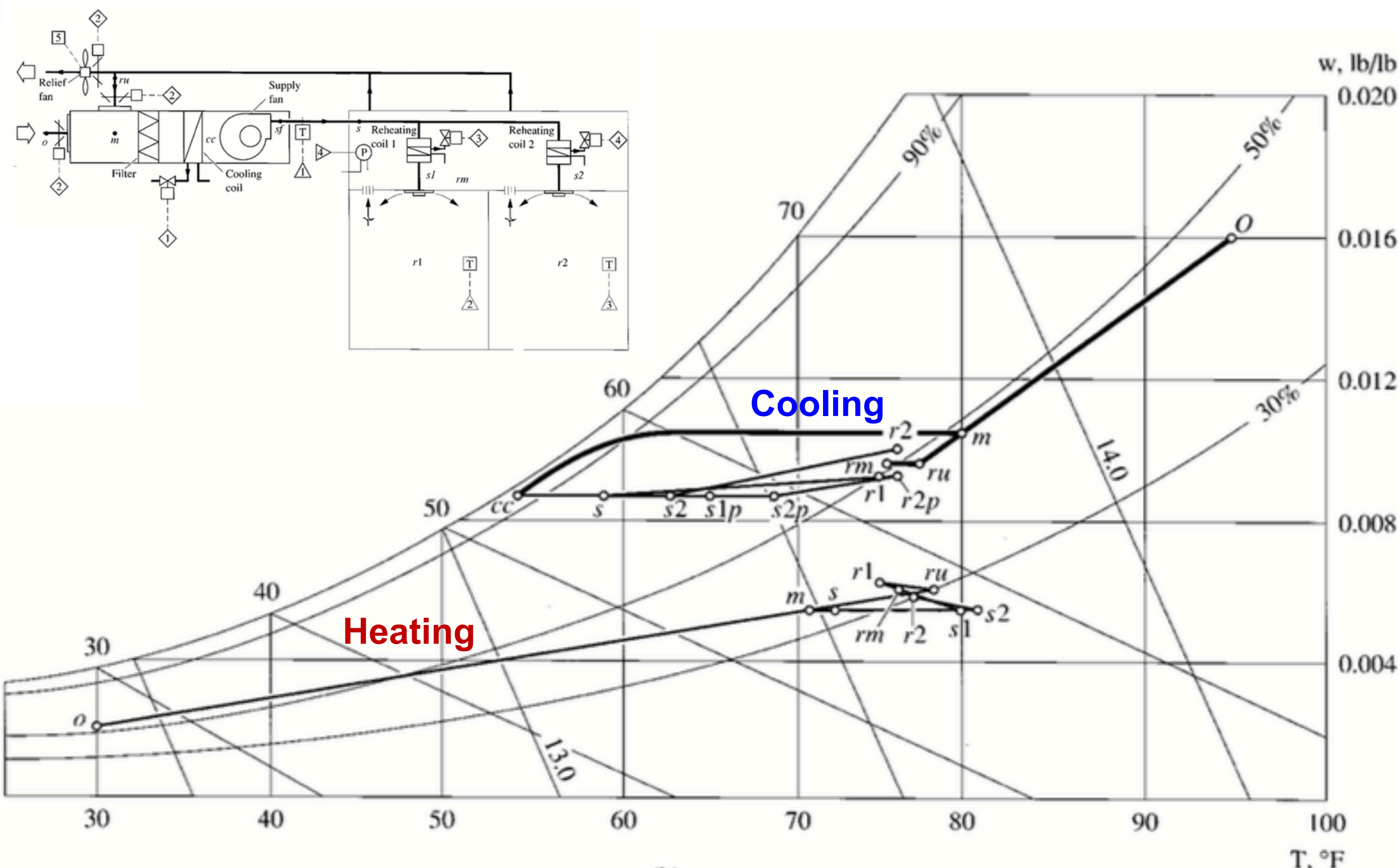


Fig. 9 Constant-Volume System with Reheat

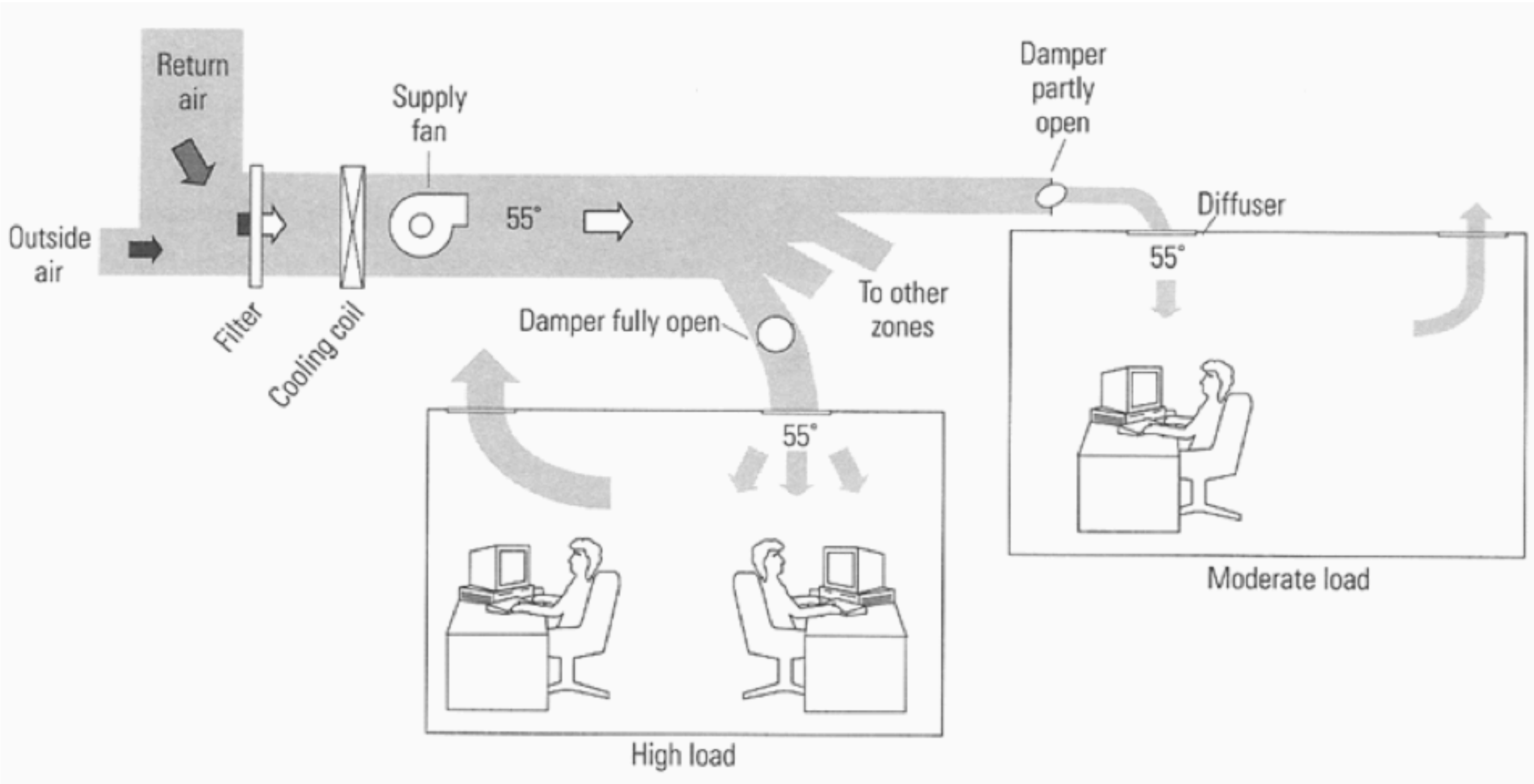
ASHRAE Systems and Equipment Handbook

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

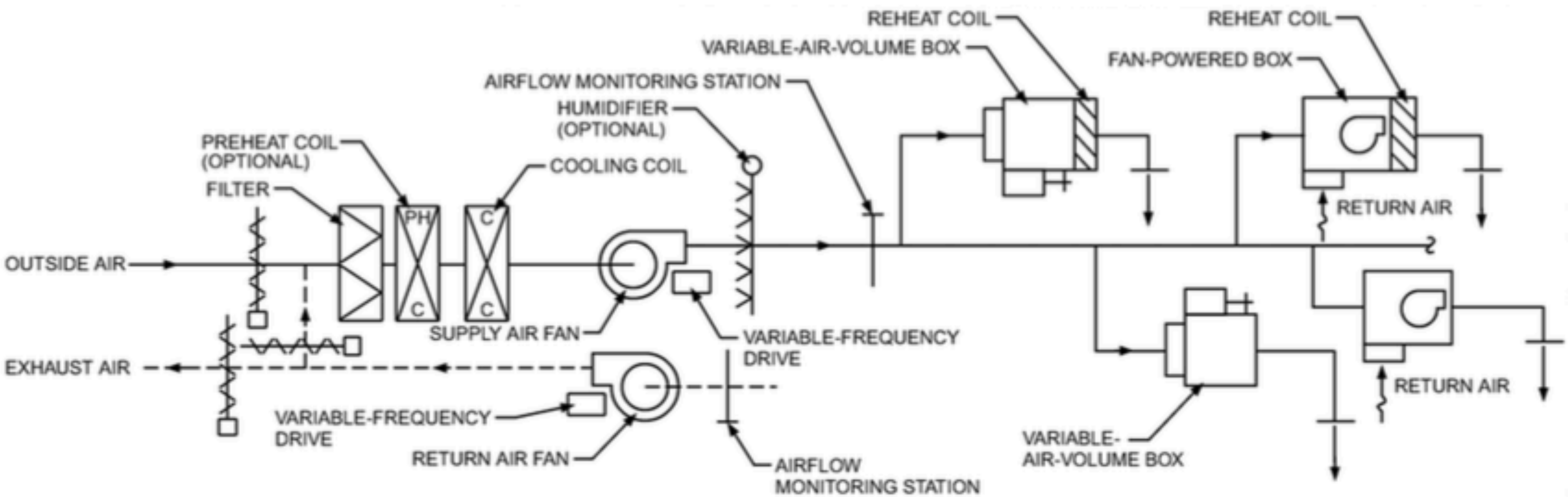
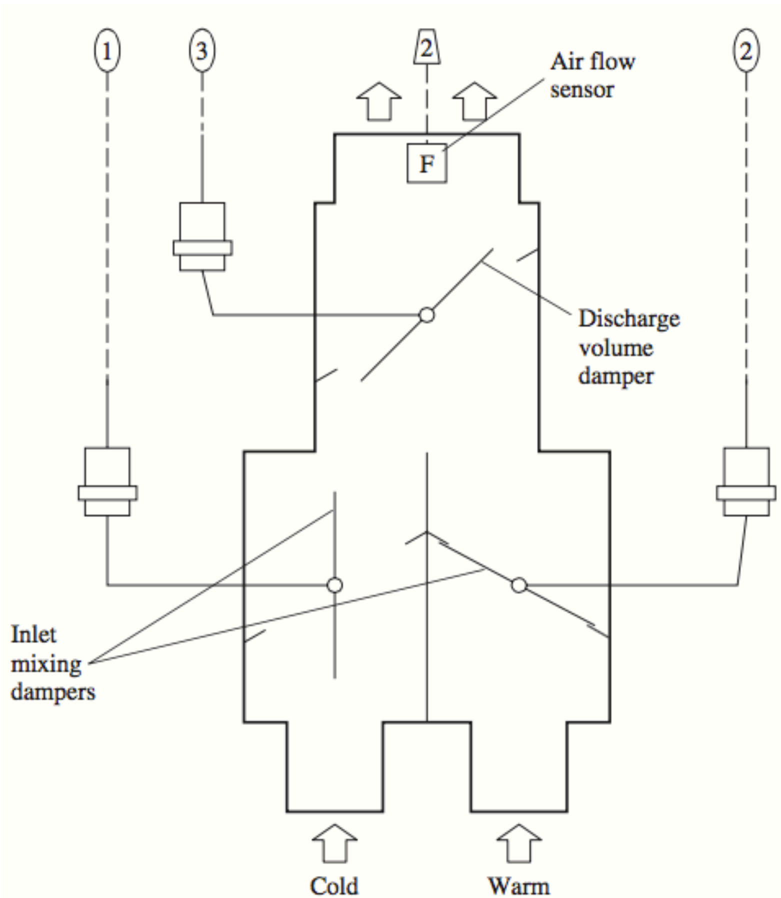
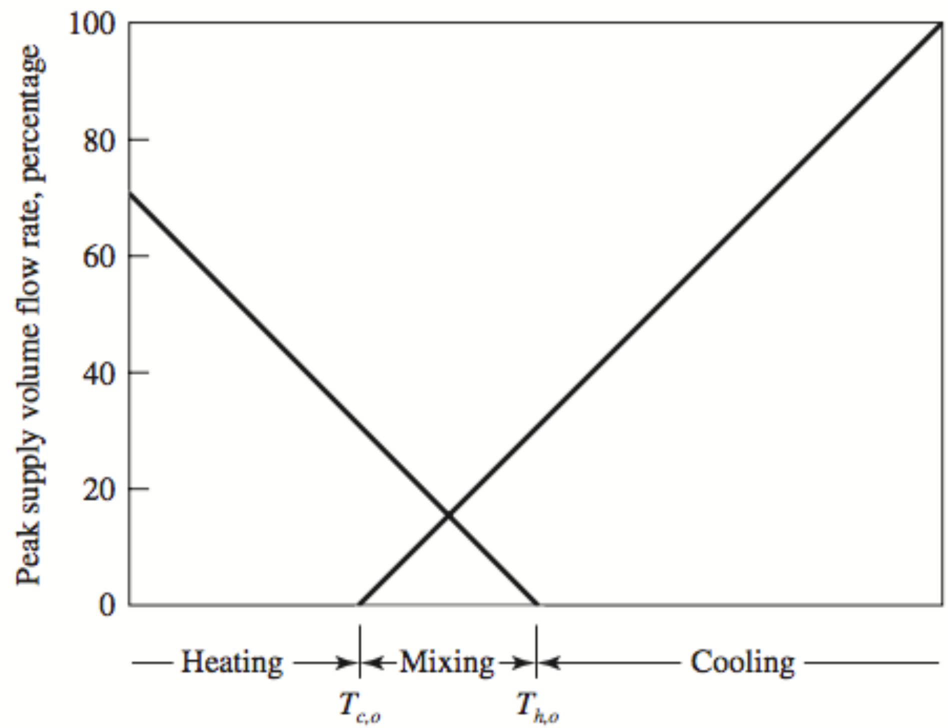


Fig. 10 Variable-Air-Volume System with Reheat and Induction and Fan-Powered Devices

Typical variable air volume (VAV) system



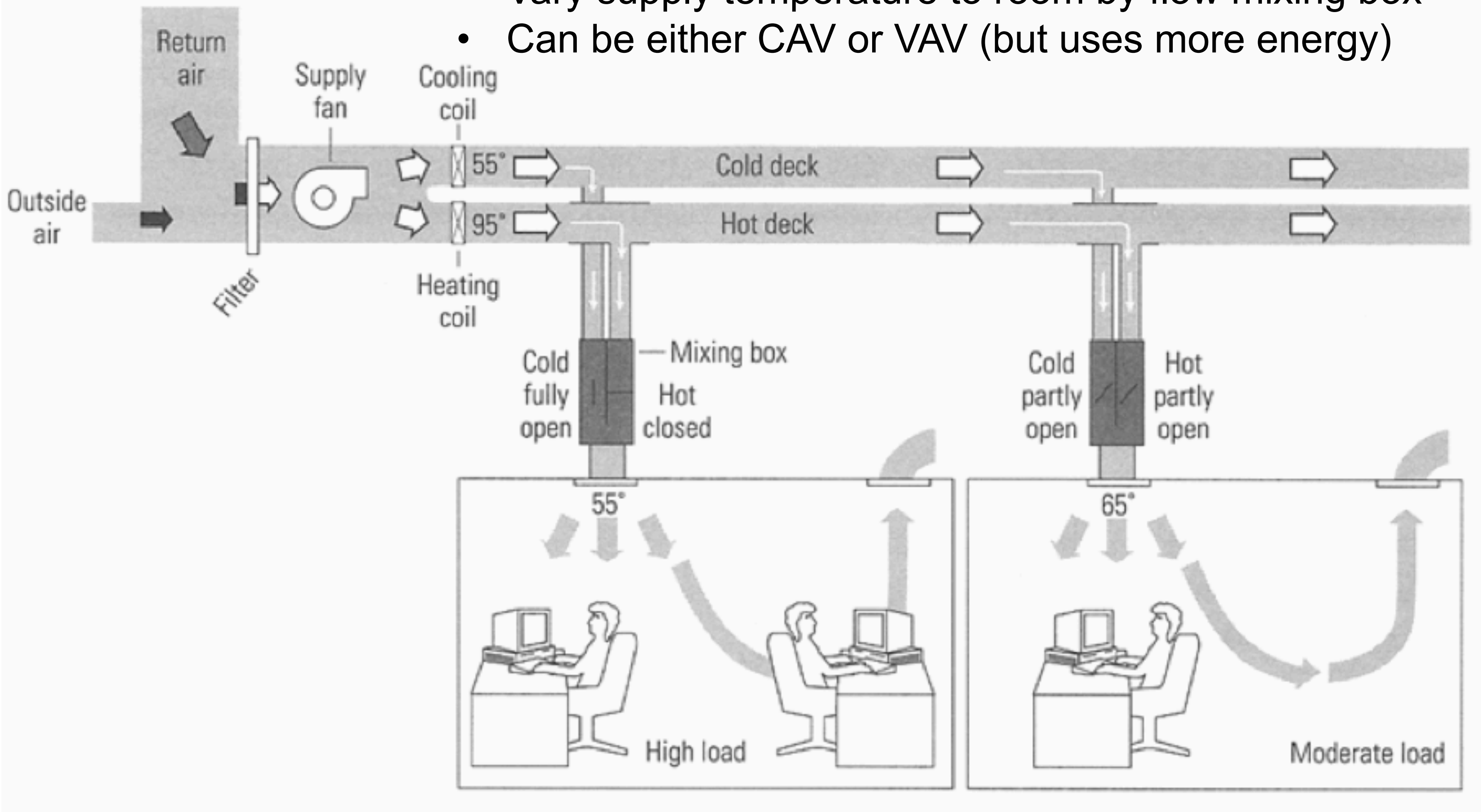
VAV box



Typical dual duct (DD)

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)



Typical dual duct (DD)

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)

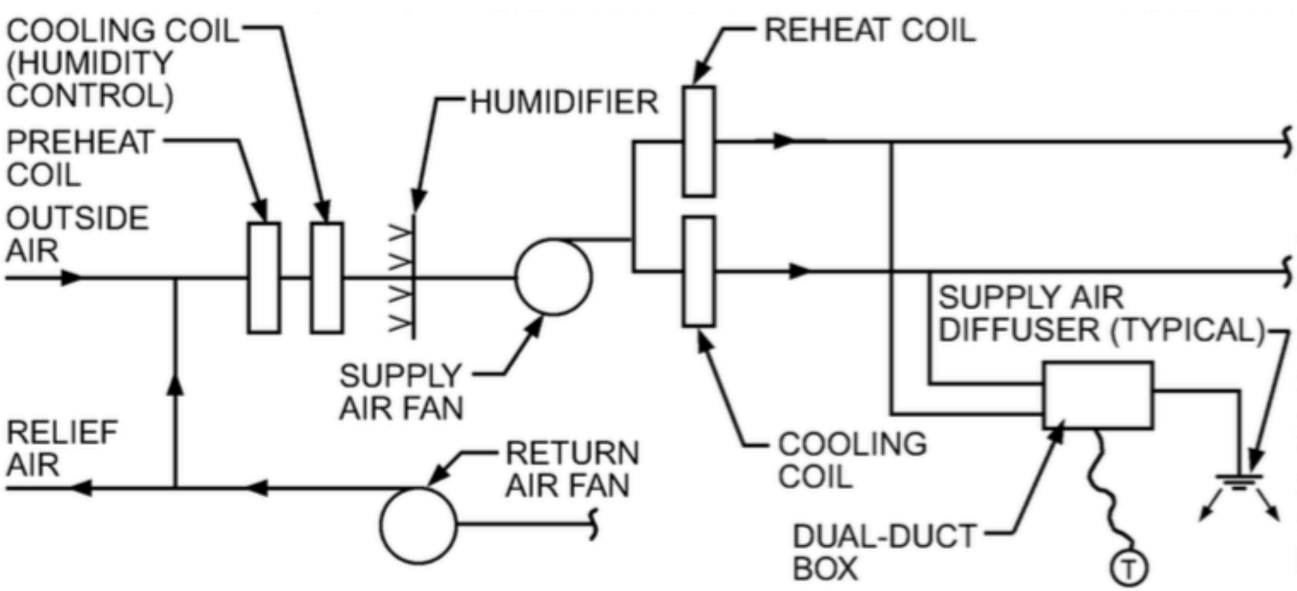


Fig. 11 Single-Fan, Dual-Duct System

Typical dual duct (DD)

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)

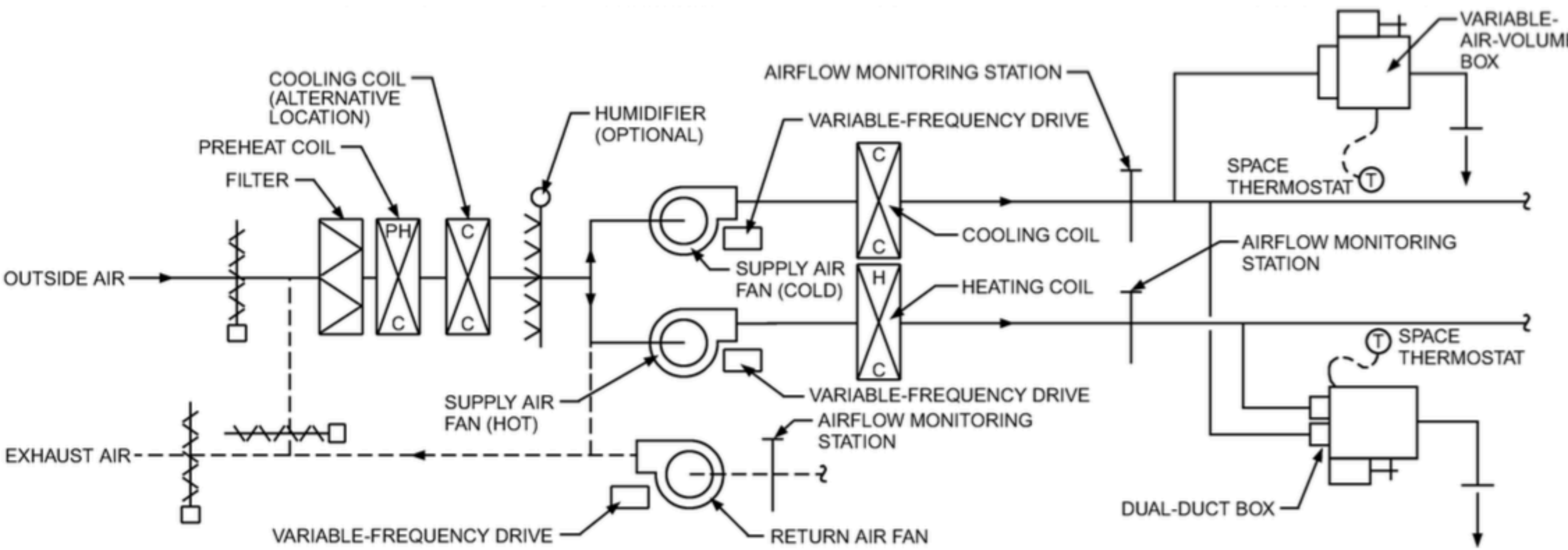
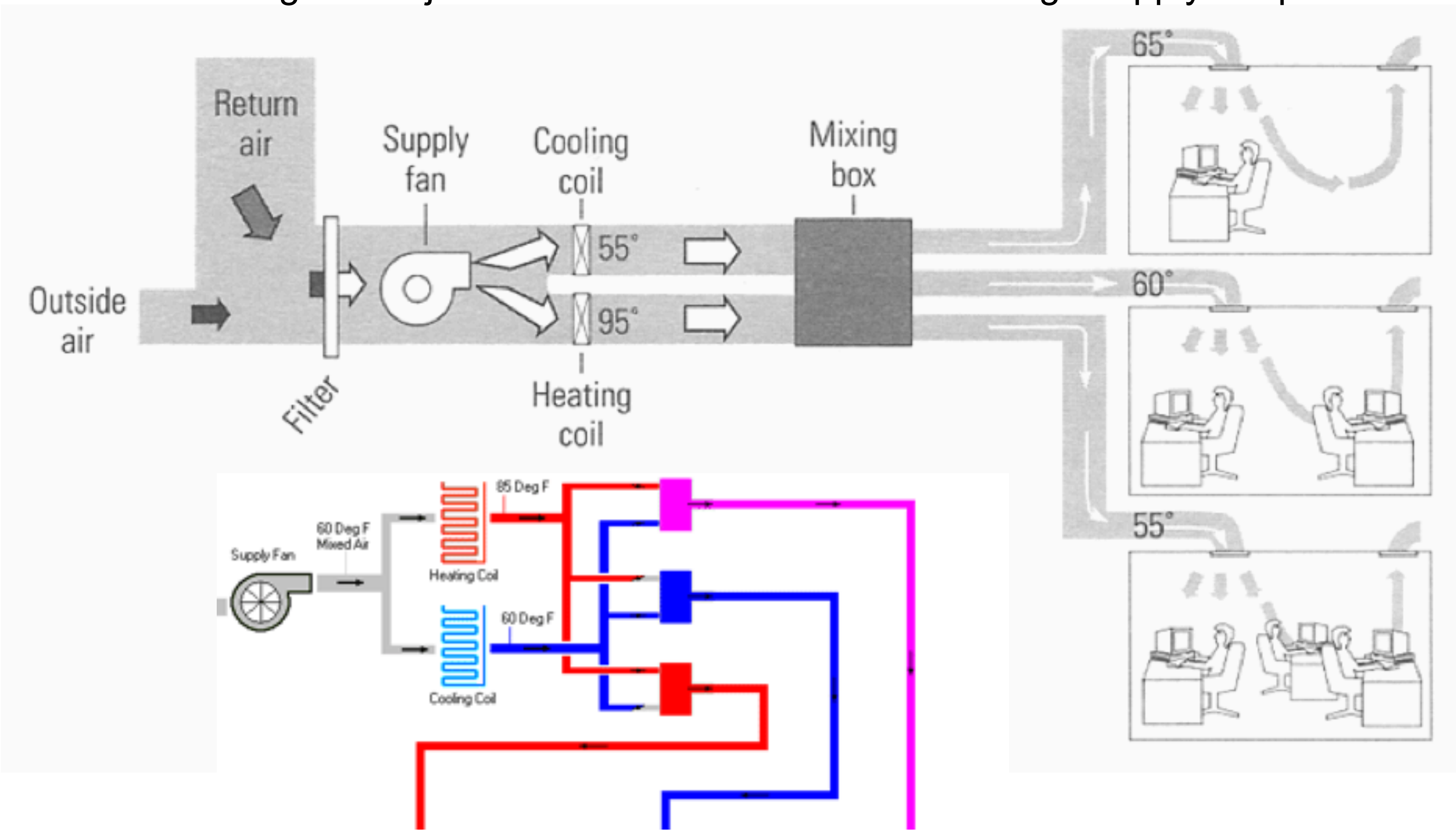


Fig. 12 Dual-Fan, Dual-Duct System

Typical multi-zone (MZ)

Same airflow rate to each room

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



Typical multi-zone (MZ)

Same airflow rate to each room

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

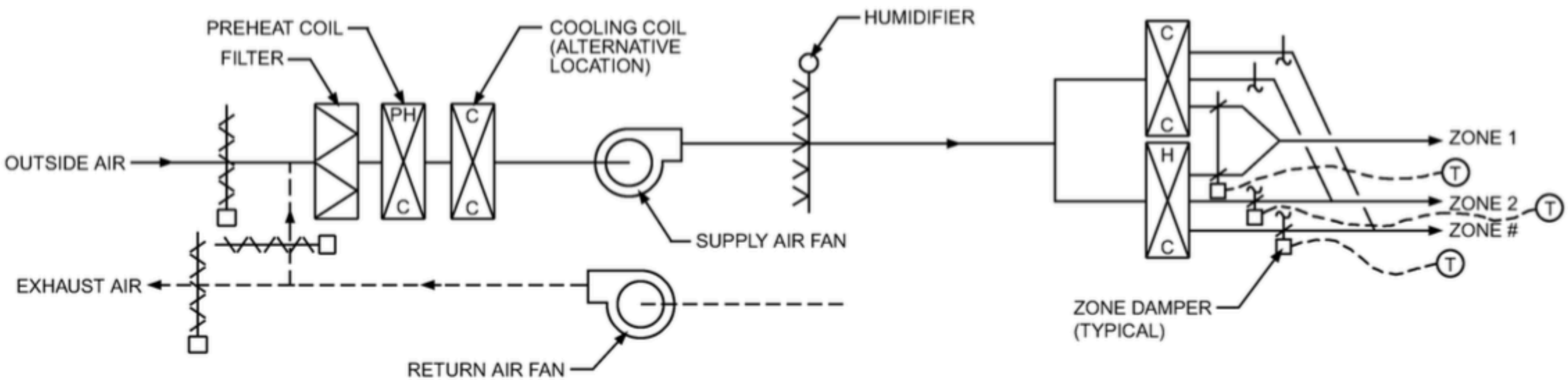
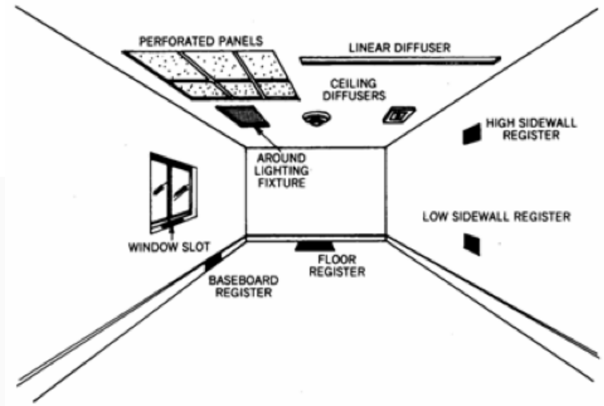
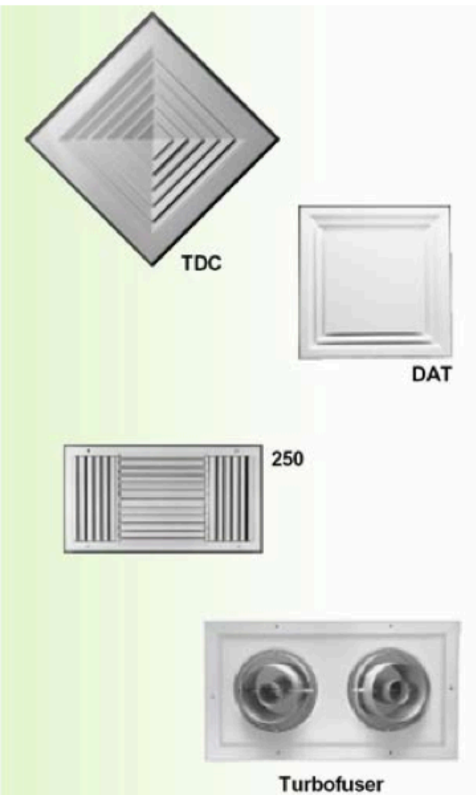


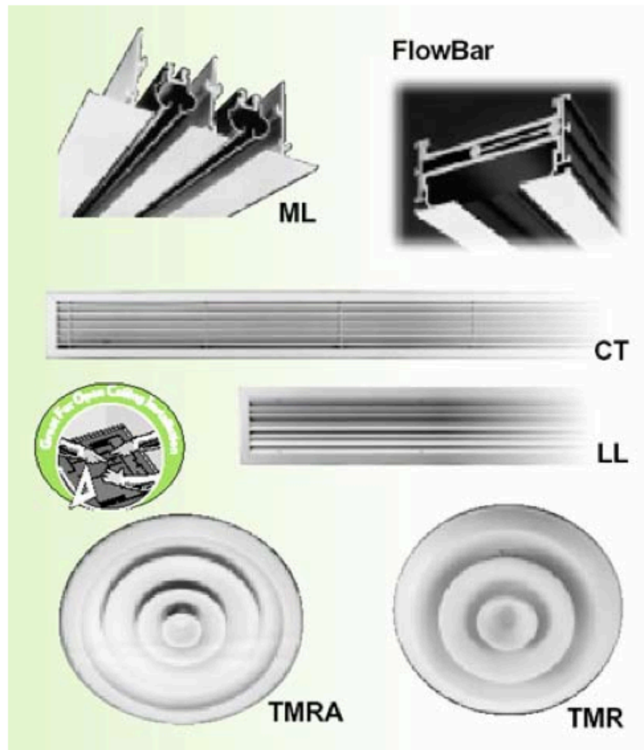
Fig. 13 Multizone System

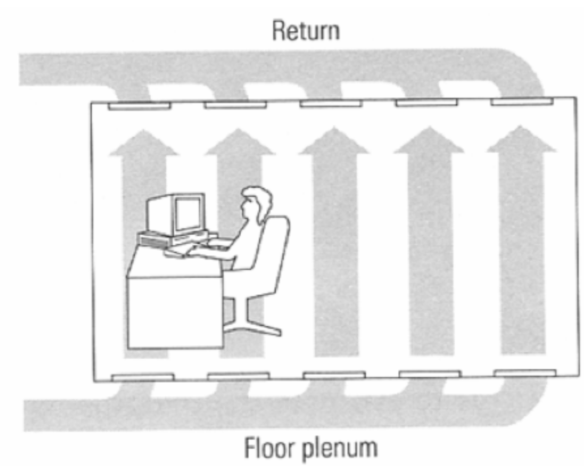
Air supply and diffusers

- Mixed versus displacement ventilation
- Diffuser selection







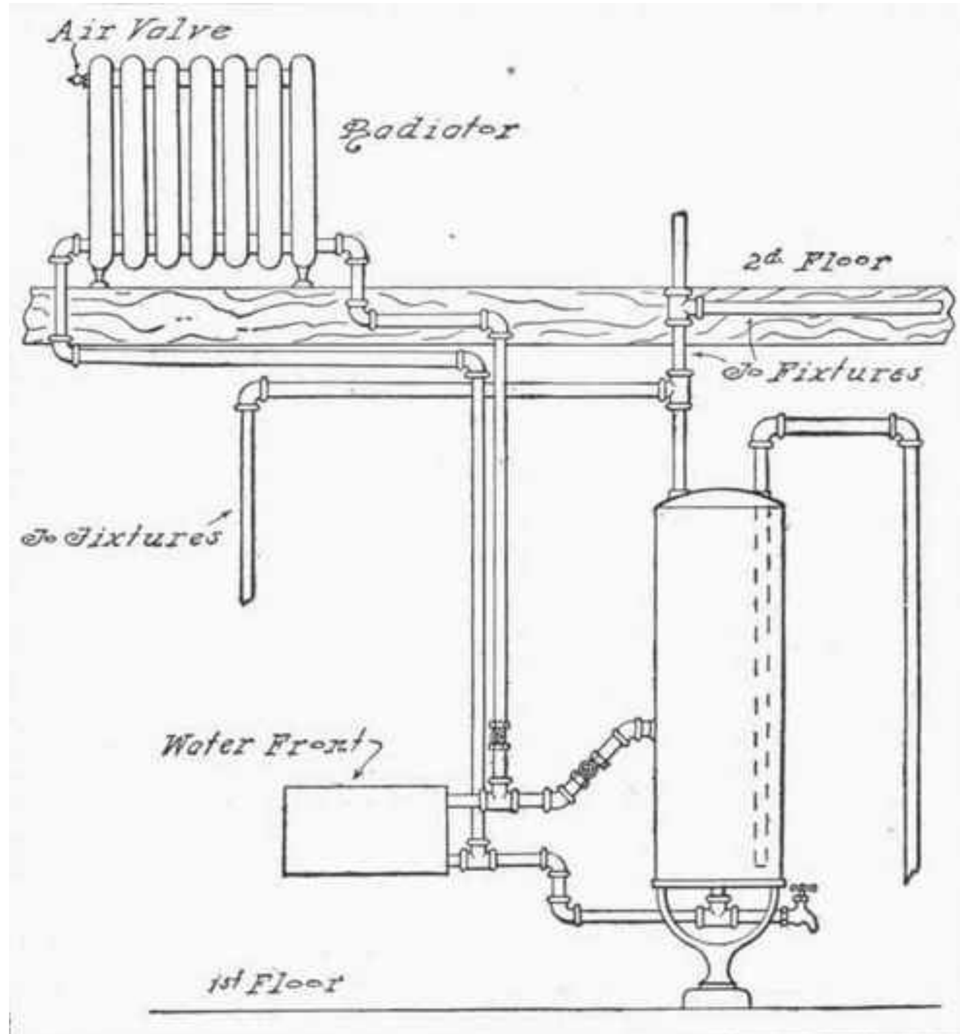


Air-water systems

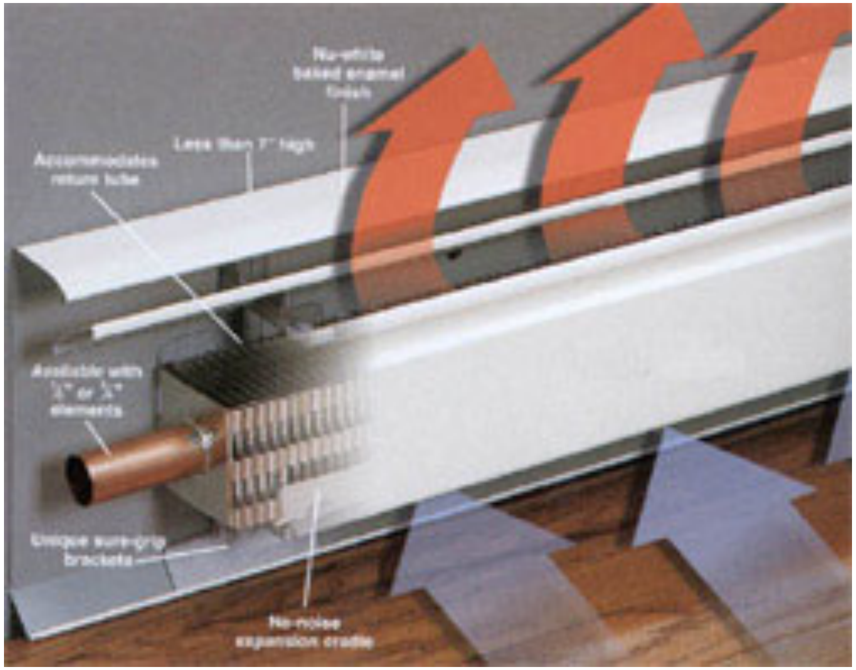
- Many commercial buildings use a combination of conditioned air and zone water coils
- Ventilation requires air movement
- But zone heating and cooling loads can be met with coils
  - We mostly use fan coils now
  - We previously mostly used radiators (like in Alumni)

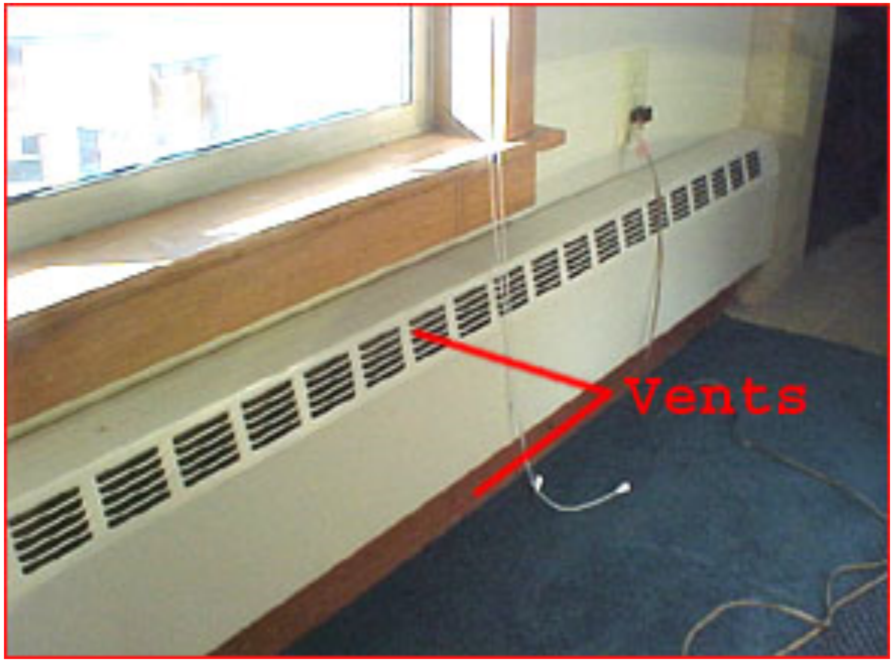
Radiator systems (for heating)

What modes of heat transfer are involved?



Water-based baseboard systems (heating)





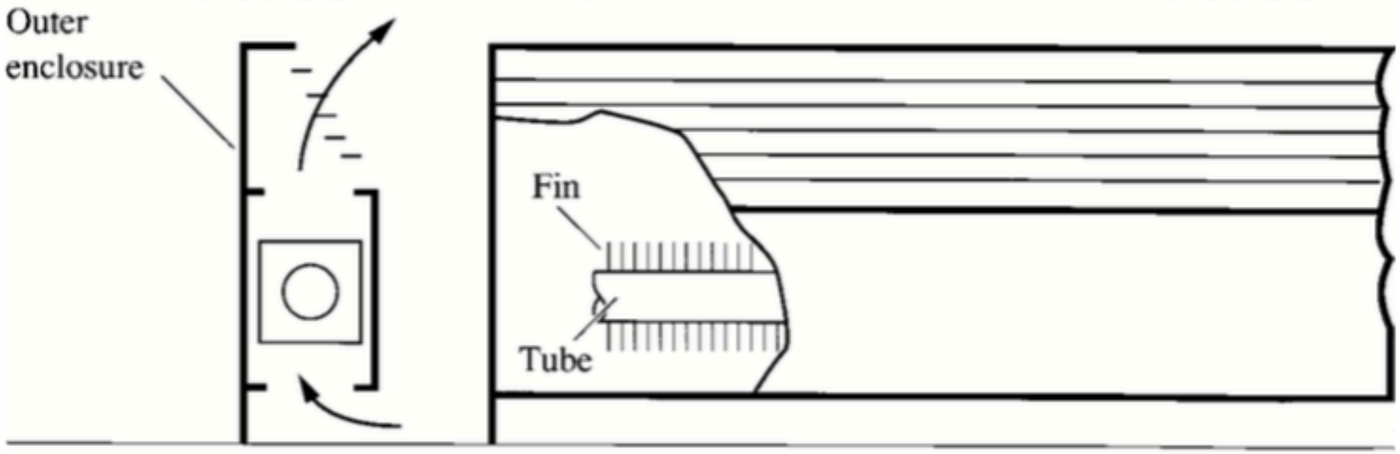


FIGURE 8.8 Baseboard finned-tube heater.

Water-based baseboard systems (heating)

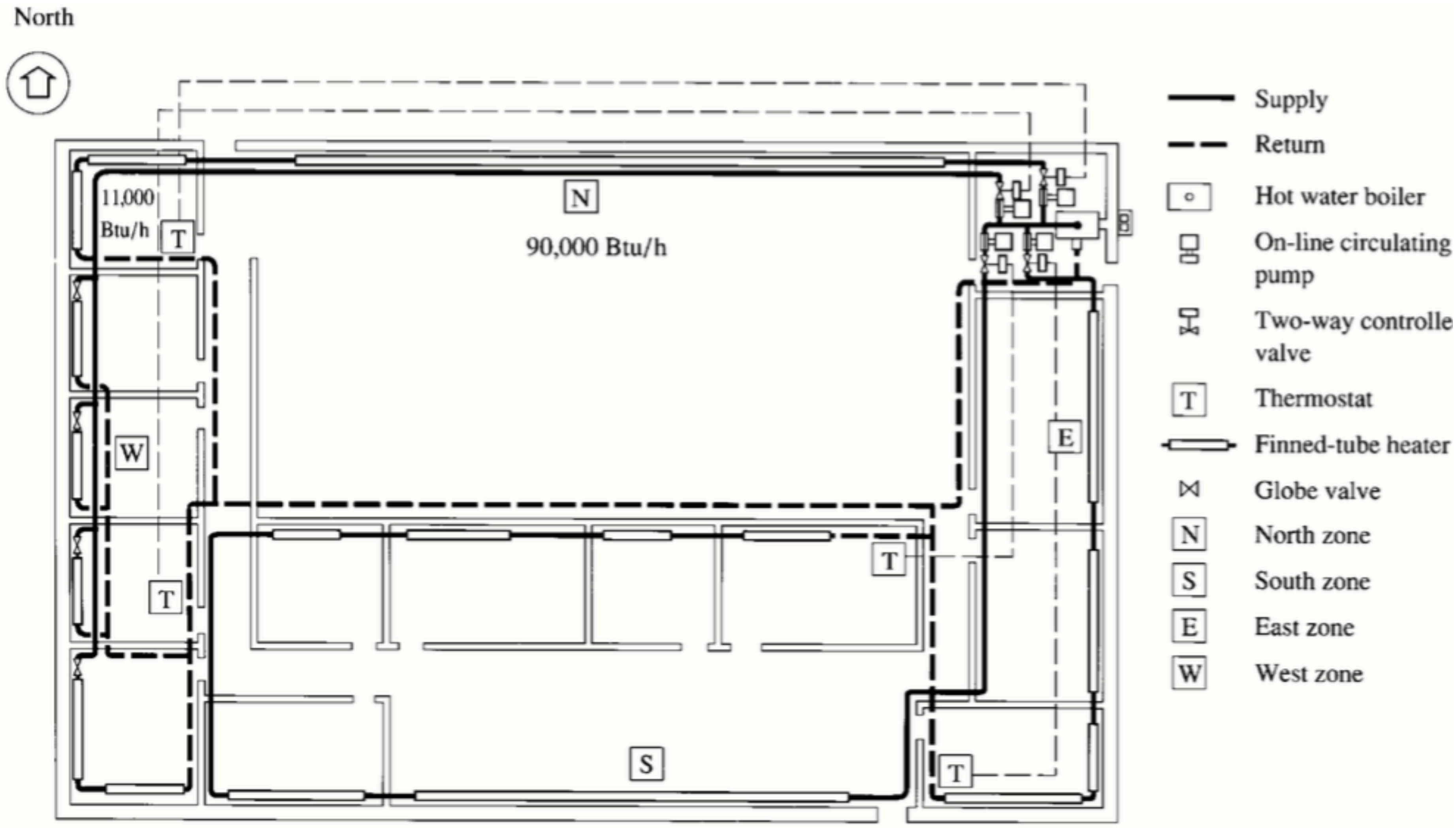
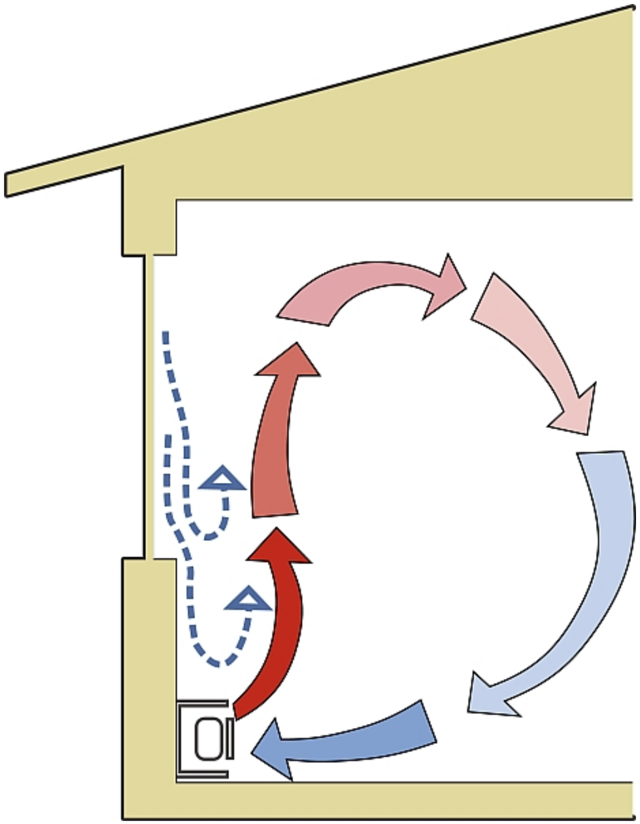
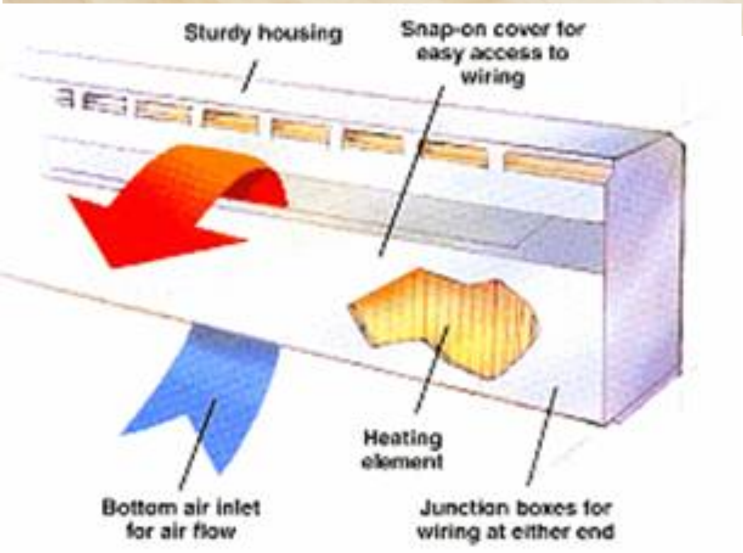


FIGURE 8.7 A two-pipe individual-loop low-temperature hot water heating system for a factory.

Electric baseboard systems (for heating)





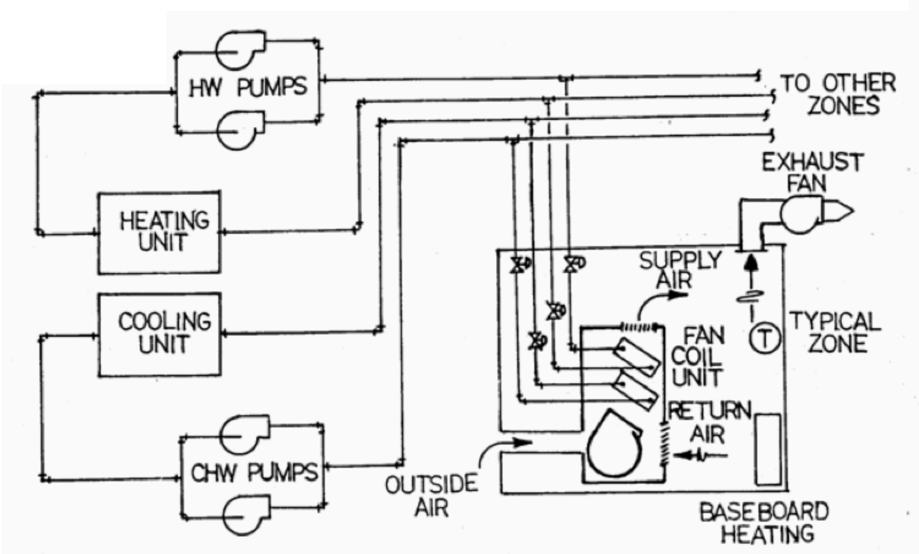
Fan coils: Modern radiator replacement w/ fan

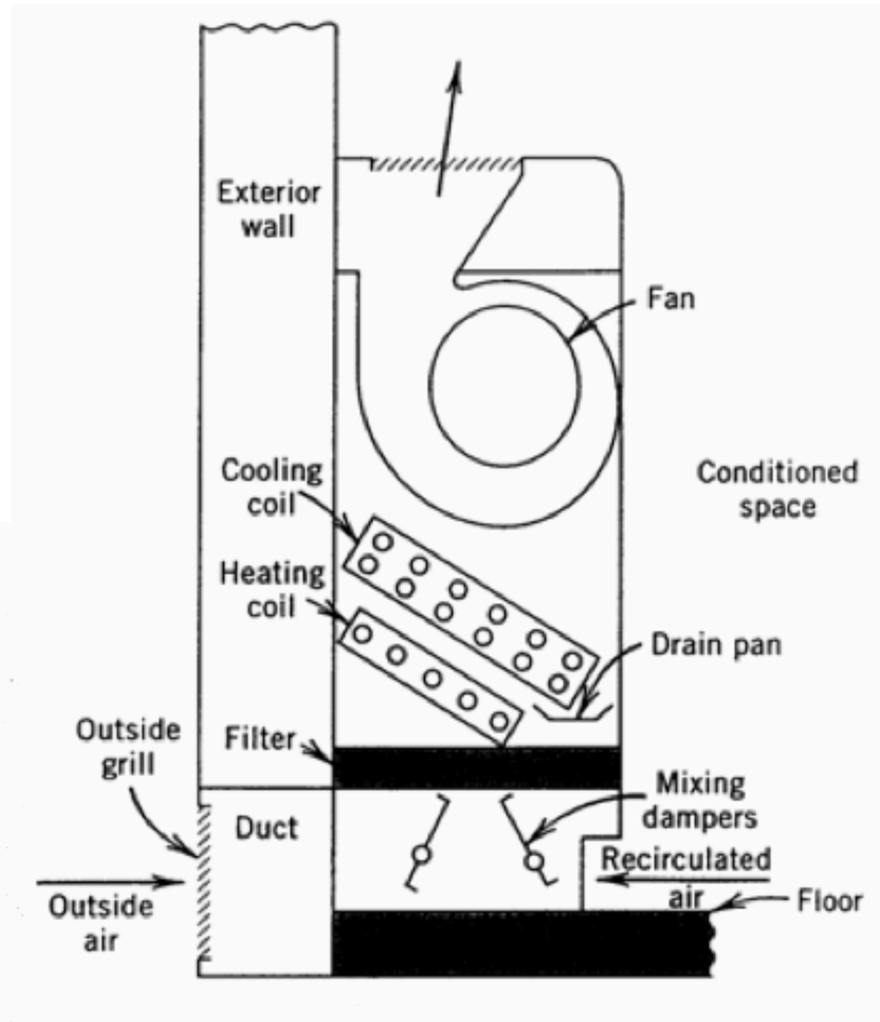
Wall installation

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