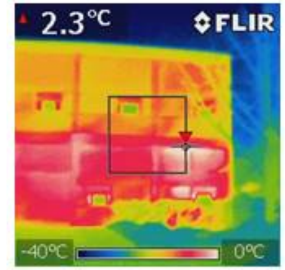
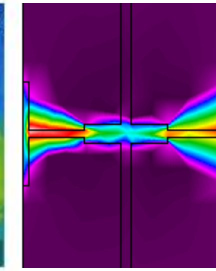
CAE 331/513
Building Science
Fall 2014



Week 6: October 2, 2014
Introduction to HVAC systems

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Review from last time

Psychrometric processes

$$Q_{total} = Q_{sensible} + Q_{latent}$$

$$Q_{total} = \dot{m}_{air}(h_{exit} - h_{inlet})$$

$$Q_{sens} = \dot{m}c_p(T_{exit} - T_{inlet}) = \dot{V}\rho c_p(T_{exit} - T_{inlet})$$

$Q_{sens} > 0$ for heating

$Q_{sens} < 0$ for cooling

$$Q_{lat} = \dot{m}_w h_{fg}$$

h_{fg} = latent heat of vaporization

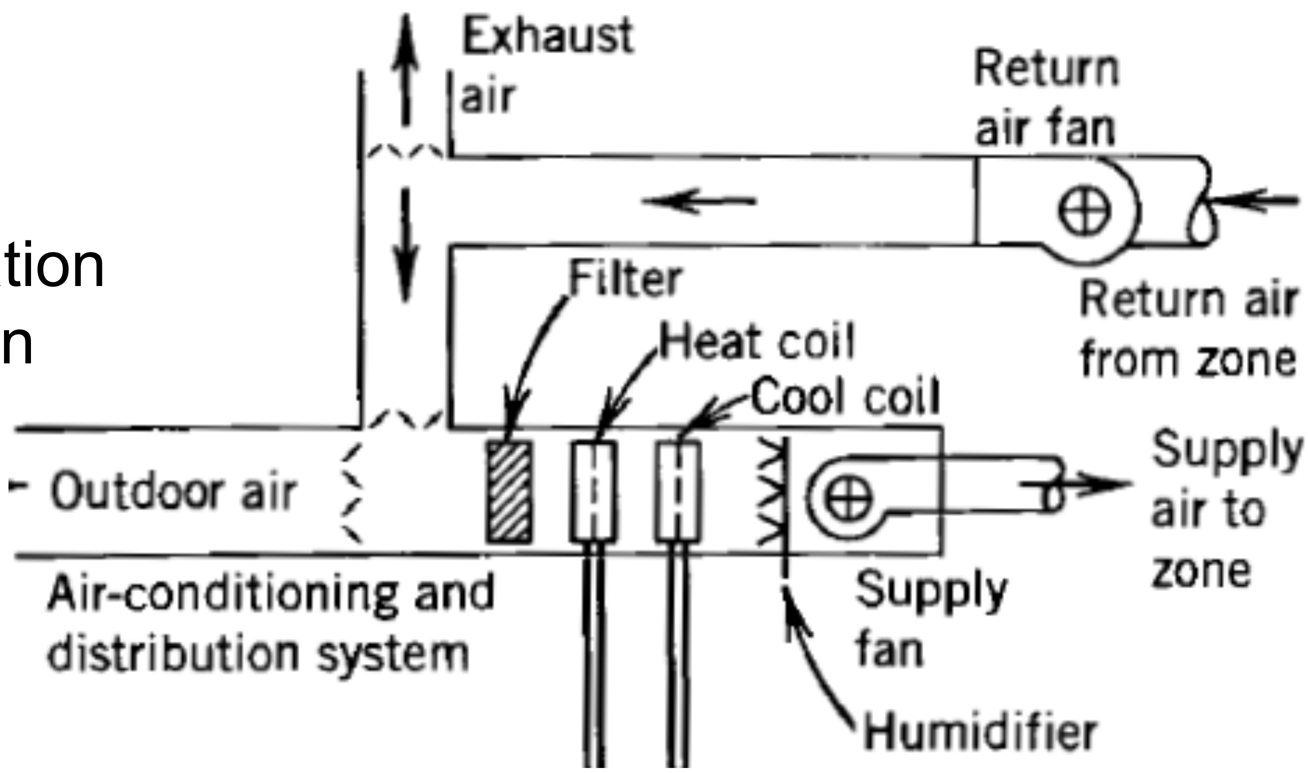
(h_{fg} = 2260 kJ/kg for water)

$$SHR = \frac{Q_{sens}}{Q_{total}} = \frac{\Delta h_{sens}}{\Delta h_{total}}$$

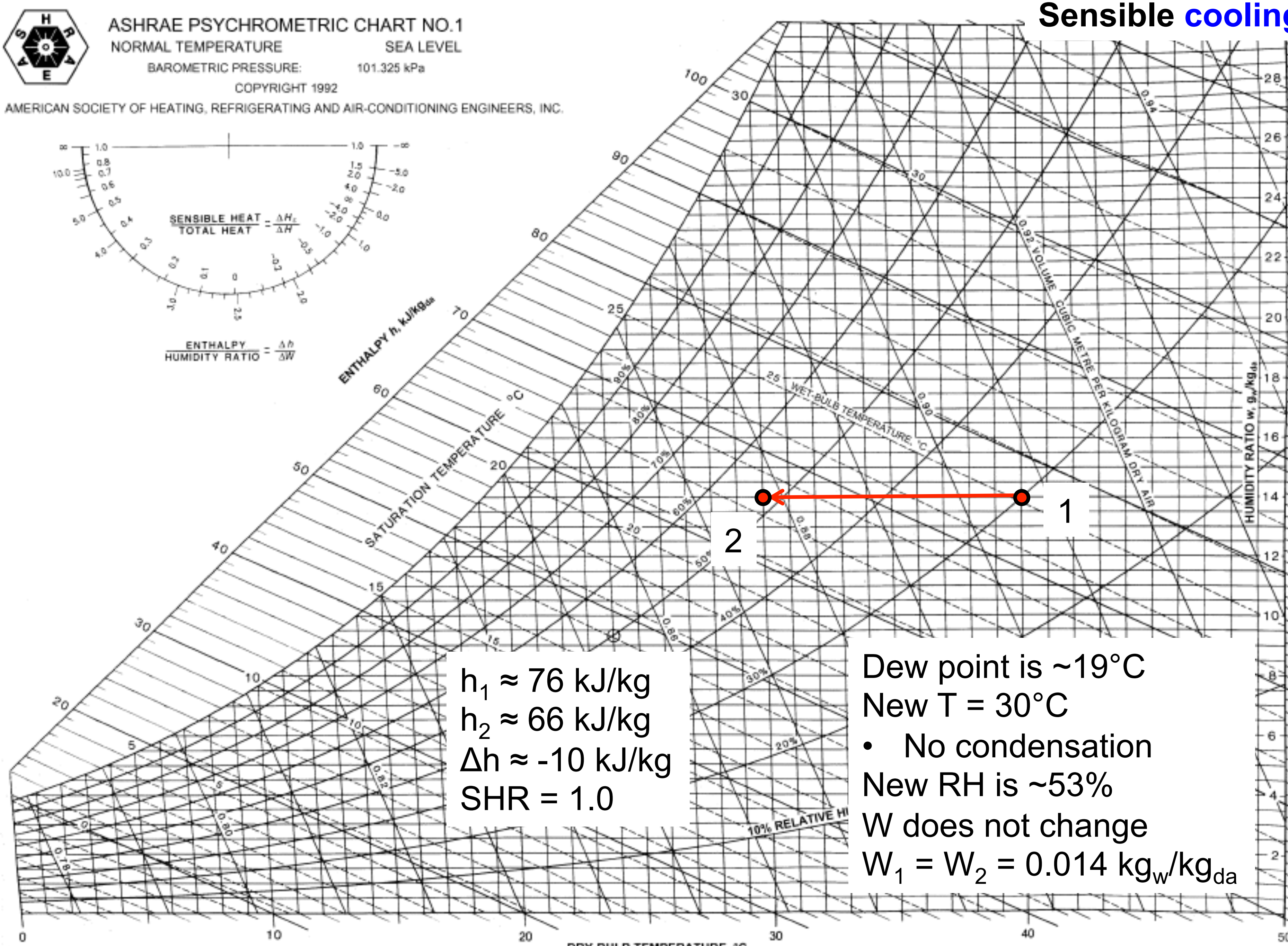
Typical forced air distribution system

Common processes:

- Air mixing
- Heating
- Cooling
- Dehumidification
- Humidification



Sensible cooling



$h_1 \approx 76$ kJ/kg
$h_2 \approx 66$ kJ/kg
$\Delta h \approx -10$ kJ/kg
SHR = 1.0

Dew point is ~19°C
New T = 30°C
- No condensation

New RH is ~53%
W does not change
$W_1 = W_2 = 0.014\ kg_w/kg_{da}$

Sensible cooling

$$Q_{total} = \dot{m}_{air}(h_{exit} - h_{inlet}) = \rho_{air}\dot{V}_{air}(h_{exit} - h_{inlet})$$

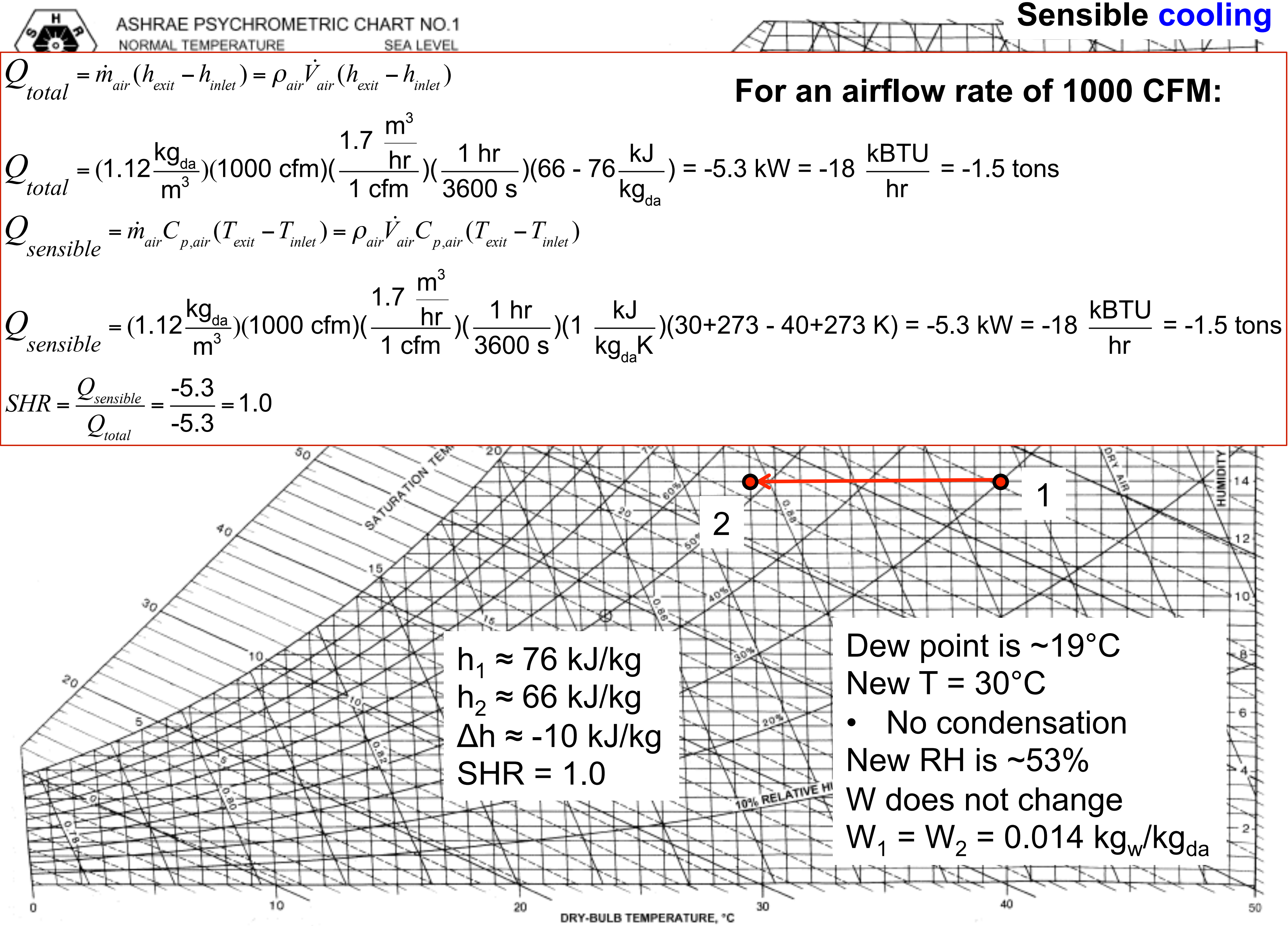
For an airflow rate of 1000 CFM:

$$Q_{total} = (1.12\frac{\text{kg}_{da}}{\text{m}^3})(1000\ \text{cfm})(\frac{1.7\ \frac{\text{m}^3}{\text{hr}}}{1\ \text{cfm}})(\frac{1\ \text{hr}}{3600\ \text{s}})(66 - 76\frac{\text{kJ}}{\text{kg}_{da}}) = -5.3\ \text{kW} = -18\ \frac{\text{kBTU}}{\text{hr}} = -1.5\ \text{tons}$$

$$Q_{sensible} = \dot{m}_{air}C_{p,air}(T_{exit} - T_{inlet}) = \rho_{air}\dot{V}_{air}C_{p,air}(T_{exit} - T_{inlet})$$

$$Q_{sensible} = (1.12\frac{\text{kg}_{da}}{\text{m}^3})(1000\ \text{cfm})(\frac{1.7\ \frac{\text{m}^3}{\text{hr}}}{1\ \text{cfm}})(\frac{1\ \text{hr}}{3600\ \text{s}})(1\ \frac{\text{kJ}}{\text{kg}_{da}\text{K}})(30+273 - 40+273\ \text{K}) = -5.3\ \text{kW} = -18\ \frac{\text{kBTU}}{\text{hr}} = -1.5\ \text{tons}$$

$$SHR = \frac{Q_{sensible}}{Q_{total}} = \frac{-5.3}{-5.3} = 1.0$$



$h_1 \approx 76$ kJ/kg
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- No condensation

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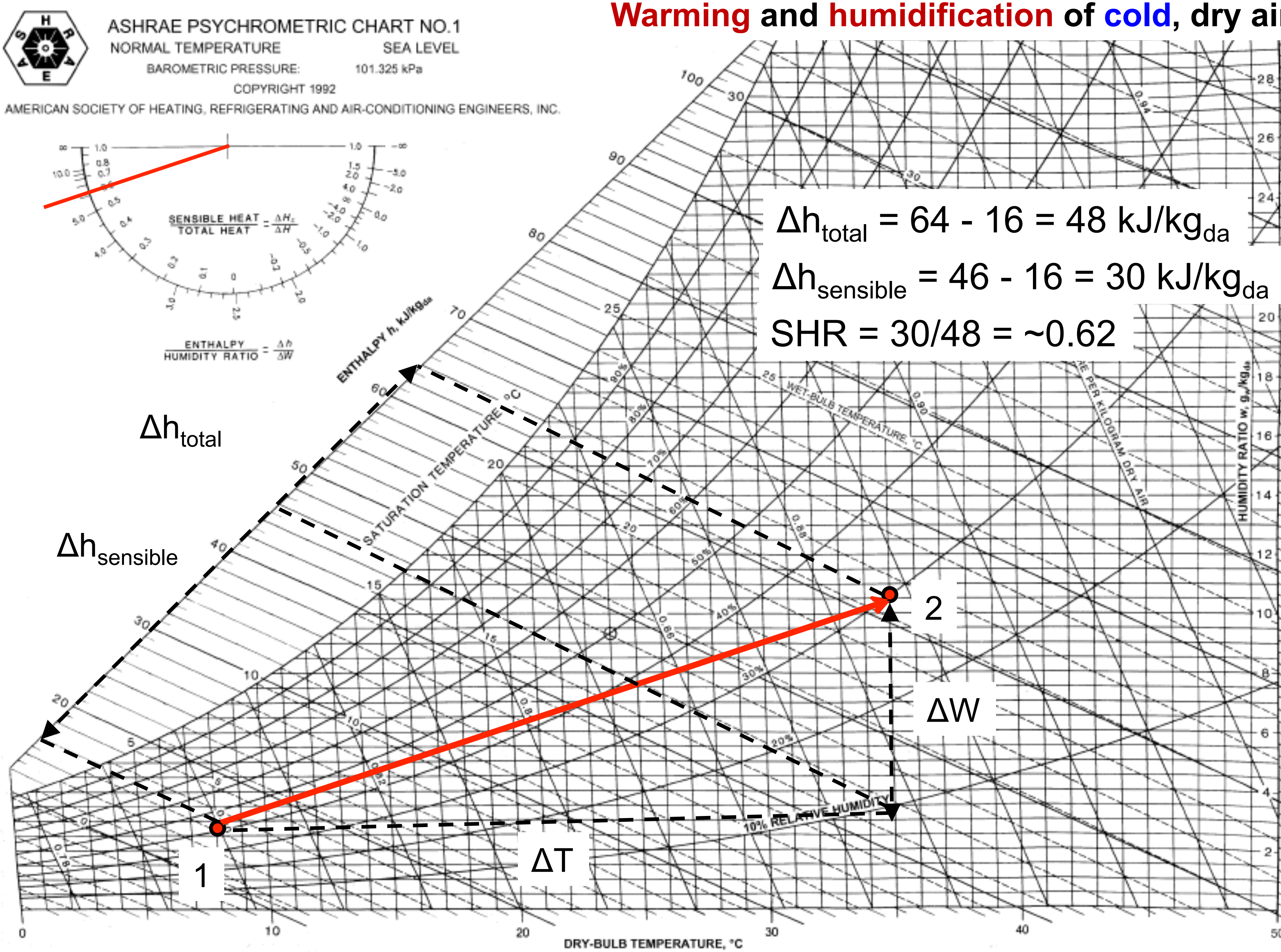
W does not change
$W_1 = W_2 = 0.014\ \text{kg}_w/\text{kg}_{da}$

Warming and humidification of cold, dry air



Warming and humidification of cold, dry air

For an airflow rate of 1000 CFM:

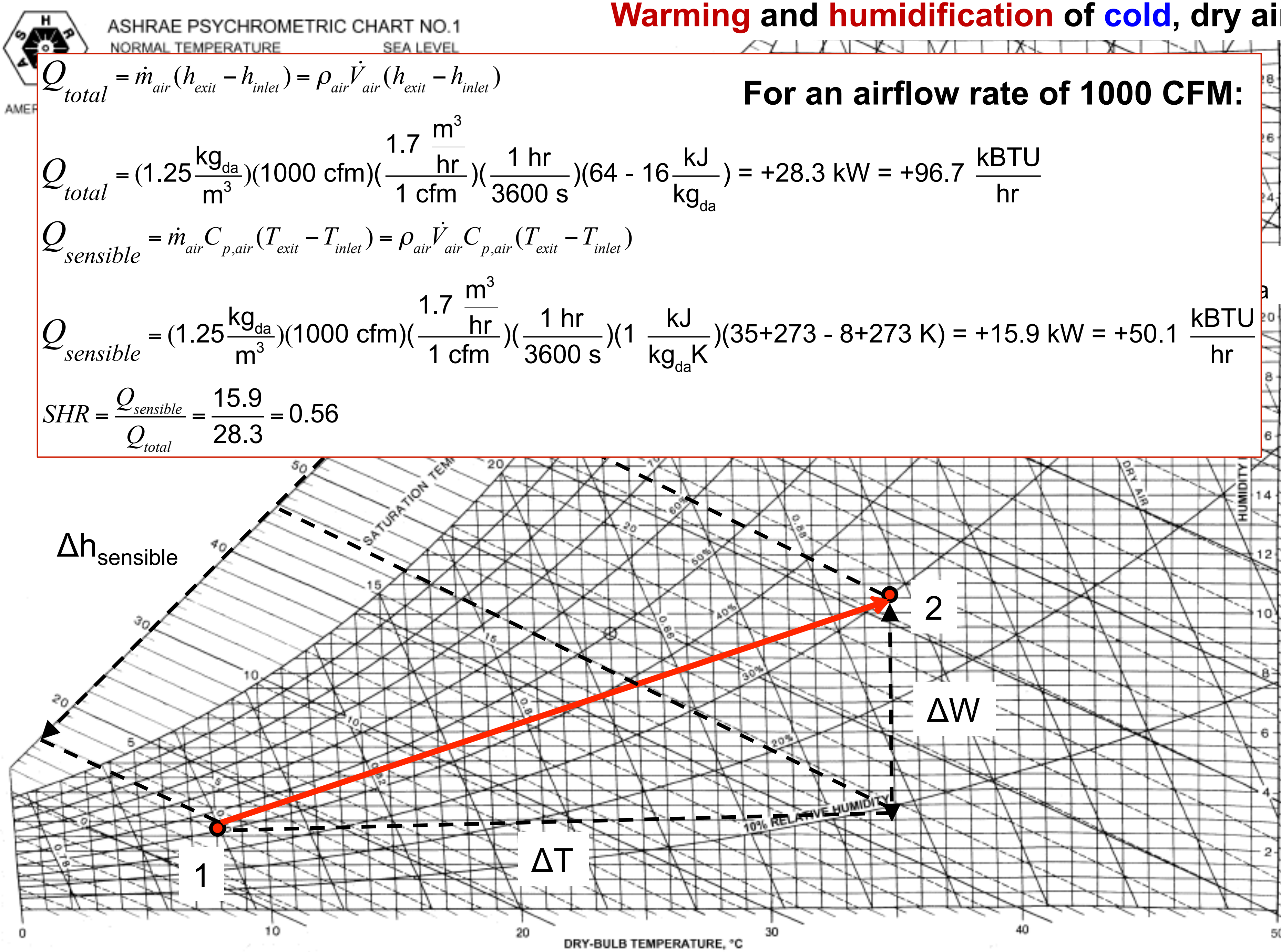
$$Q_{total} = \dot{m}_{air}(h_{exit} - h_{inlet}) = \rho_{air}\dot{V}_{air}(h_{exit} - h_{inlet})$$

$$Q_{total} = (1.25\frac{\text{kg}_{da}}{\text{m}^3})(1000\text{ cfm})(\frac{1.7\ \frac{\text{m}^3}{\text{hr}}}{1\text{ cfm}})(\frac{1\text{ hr}}{3600\text{ s}})(64 - 16\frac{\text{kJ}}{\text{kg}_{da}}) = +28.3\text{ kW} = +96.7\ \frac{\text{kBTU}}{\text{hr}}$$

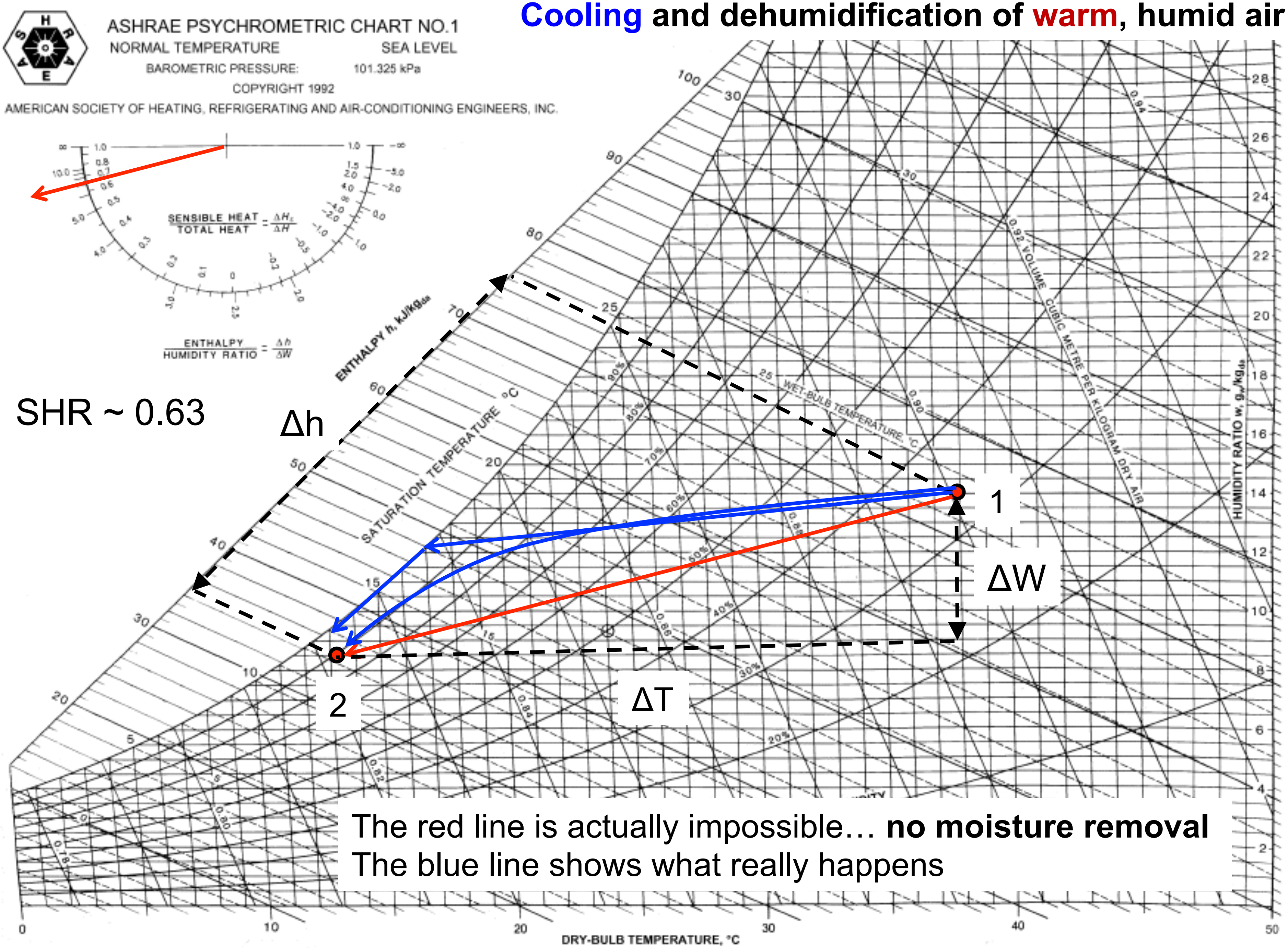
$$Q_{sensible} = \dot{m}_{air}C_{p,air}(T_{exit} - T_{inlet}) = \rho_{air}\dot{V}_{air}C_{p,air}(T_{exit} - T_{inlet})$$

$$Q_{sensible} = (1.25\frac{\text{kg}_{da}}{\text{m}^3})(1000\text{ cfm})(\frac{1.7\ \frac{\text{m}^3}{\text{hr}}}{1\text{ cfm}})(\frac{1\text{ hr}}{3600\text{ s}})(1\ \frac{\text{kJ}}{\text{kg}_{da}\text{K}})(35+273 - 8+273\text{ K}) = +15.9\text{ kW} = +50.1\ \frac{\text{kBTU}}{\text{hr}}$$

$$SHR = \frac{Q_{sensible}}{Q_{total}} = \frac{15.9}{28.3} = 0.56$$



Cooling and dehumidification of warm, humid air



The red line is actually impossible… **no moisture removal**

The blue line shows what really happens

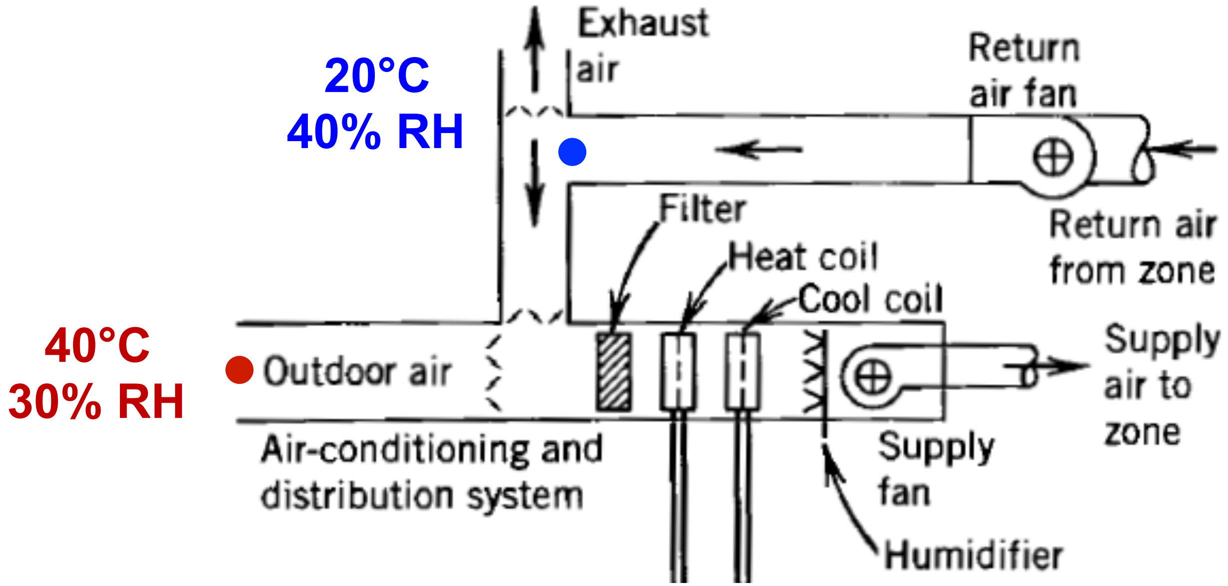
Mixing of air streams

- Often in HVAC systems we mix airstreams adiabatically
  - **Adiabatically** = Without the addition or extraction of heat
  - e.g. outdoor air mixed with a portion of return/recirculated air

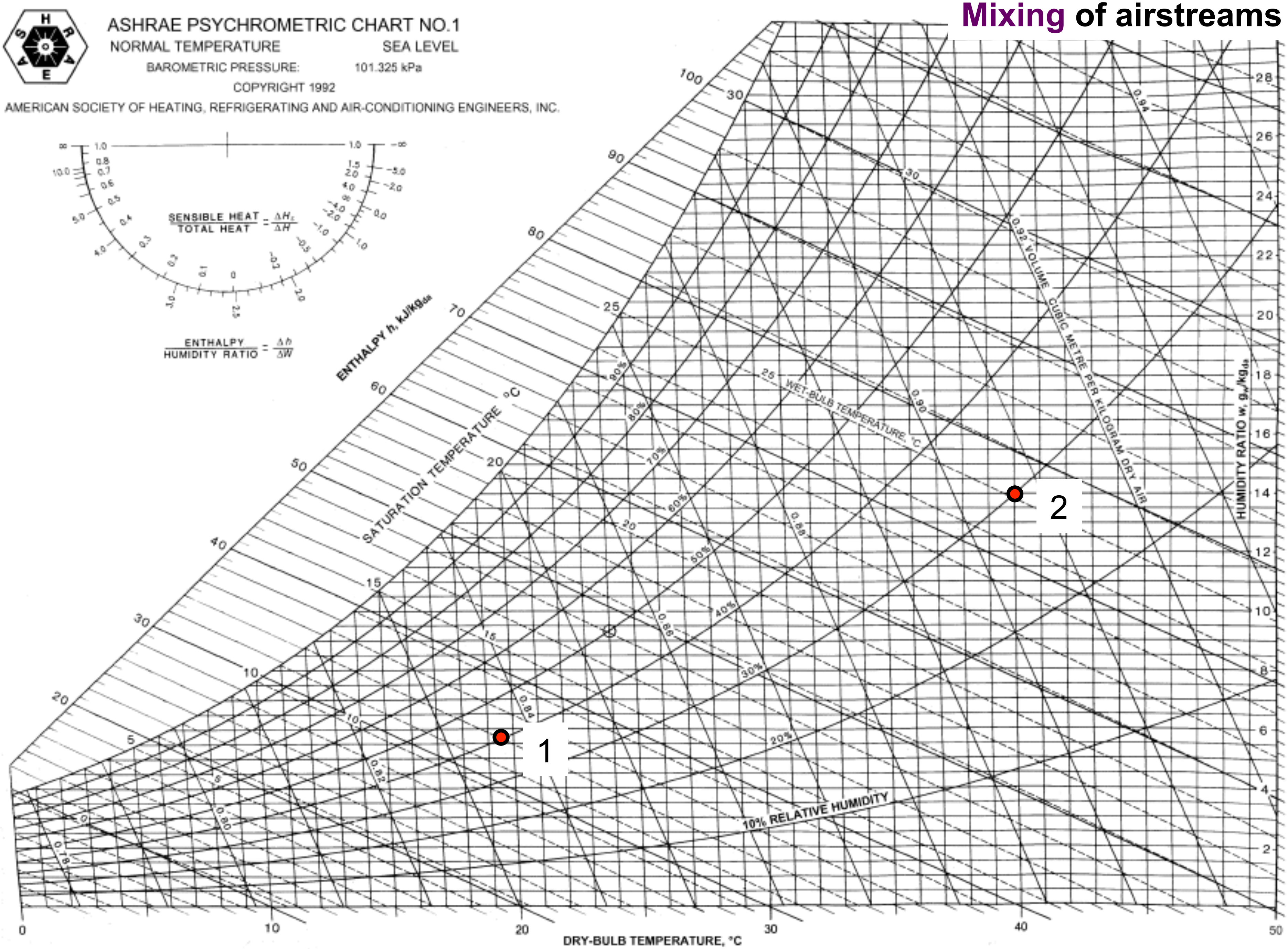
- For most parameters, the outlet conditions end up being the weighted-averages of the input conditions
  - Dry bulb temperature
  - Humidity ratio
  - Enthalpy
  - (not RH)

Mixing of airstreams example

- Hot, humid outdoor air is mixed with recirculated indoor air at an outdoor air fraction of about 35%
  - Q1: What is T, W, RH, and h at the mixed condition?

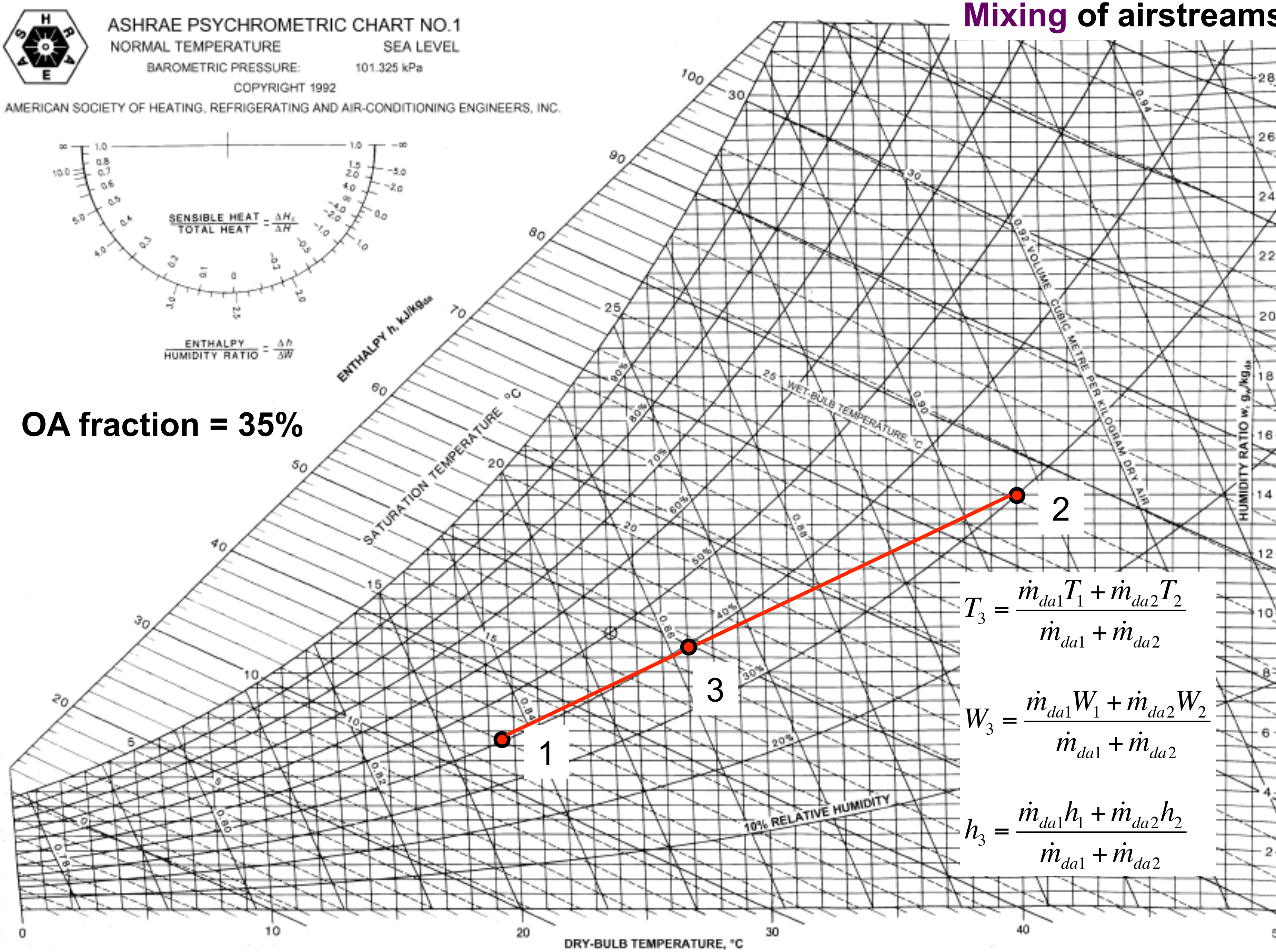


Mixing of airstreams



Mixing of airstreams

OA fraction = 35%

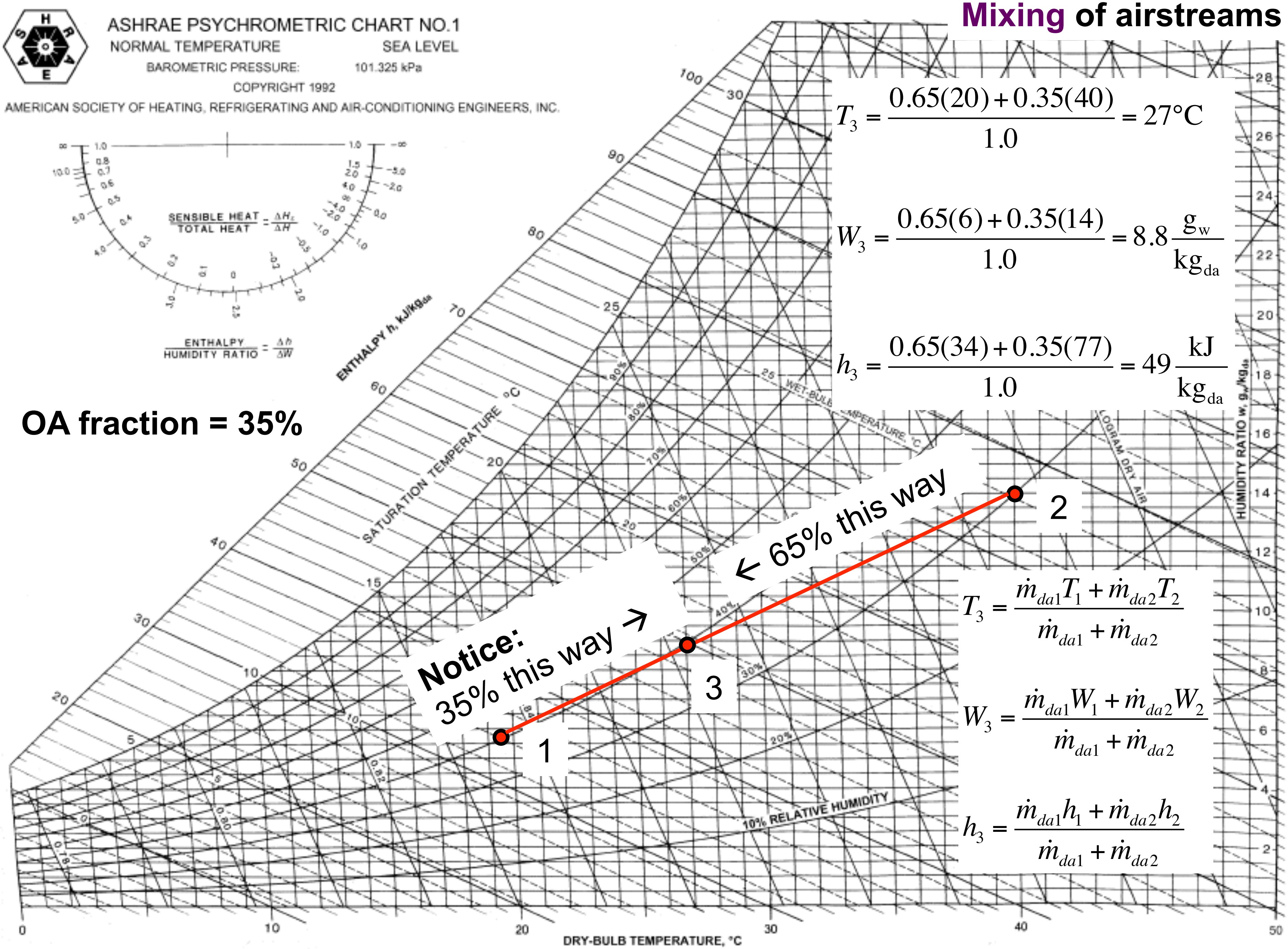


$$T_3 = \frac{\dot{m}_{da1}T_1 + \dot{m}_{da2}T_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

$$W_3 = \frac{\dot{m}_{da1}W_1 + \dot{m}_{da2}W_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

$$h_3 = \frac{\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

Mixing of airstreams



OA fraction = 35%

$$T_3 = \frac{0.65(20) + 0.35(40)}{1.0} = 27°\mathrm{C}$$

$$W_3 = \frac{0.65(6) + 0.35(14)}{1.0} = 8.8\,\frac{\mathrm{g_w}}{\mathrm{kg_{da}}}$$

$$h_3 = \frac{0.65(34) + 0.35(77)}{1.0} = 49\,\frac{\mathrm{kJ}}{\mathrm{kg_{da}}}$$

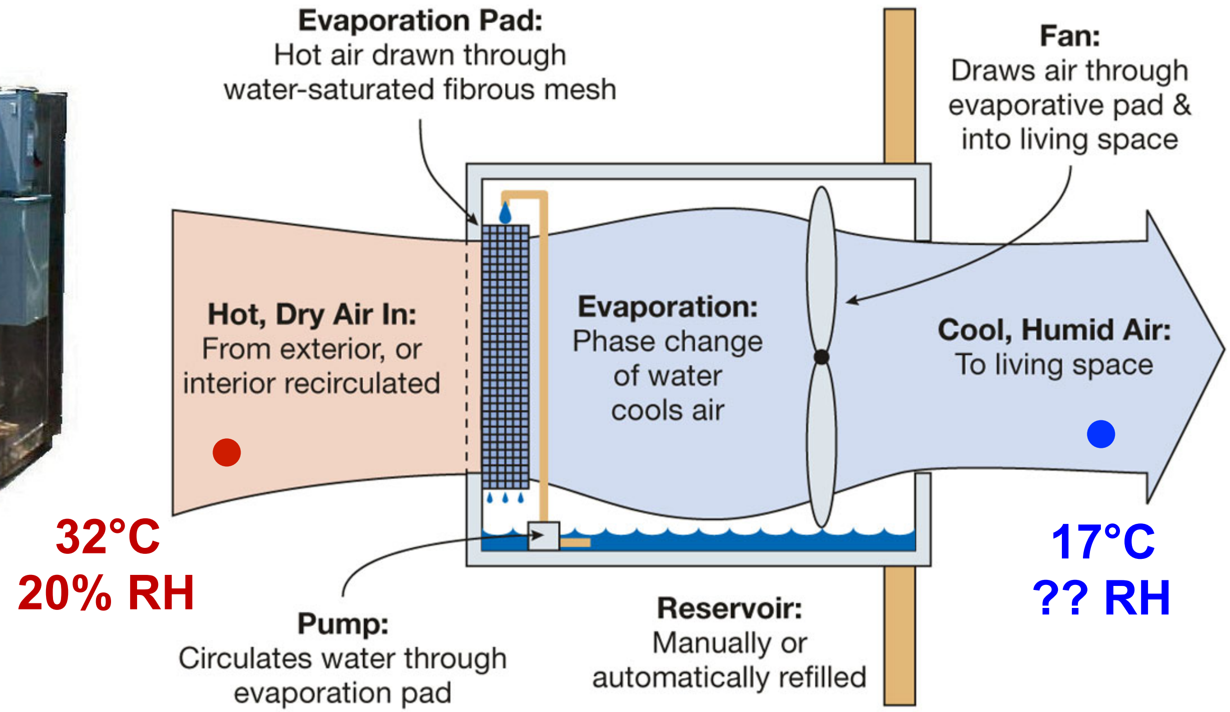
$$T_3 = \frac{\dot{m}_{da1}T_1 + \dot{m}_{da2}T_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

$$W_3 = \frac{\dot{m}_{da1}W_1 + \dot{m}_{da2}W_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

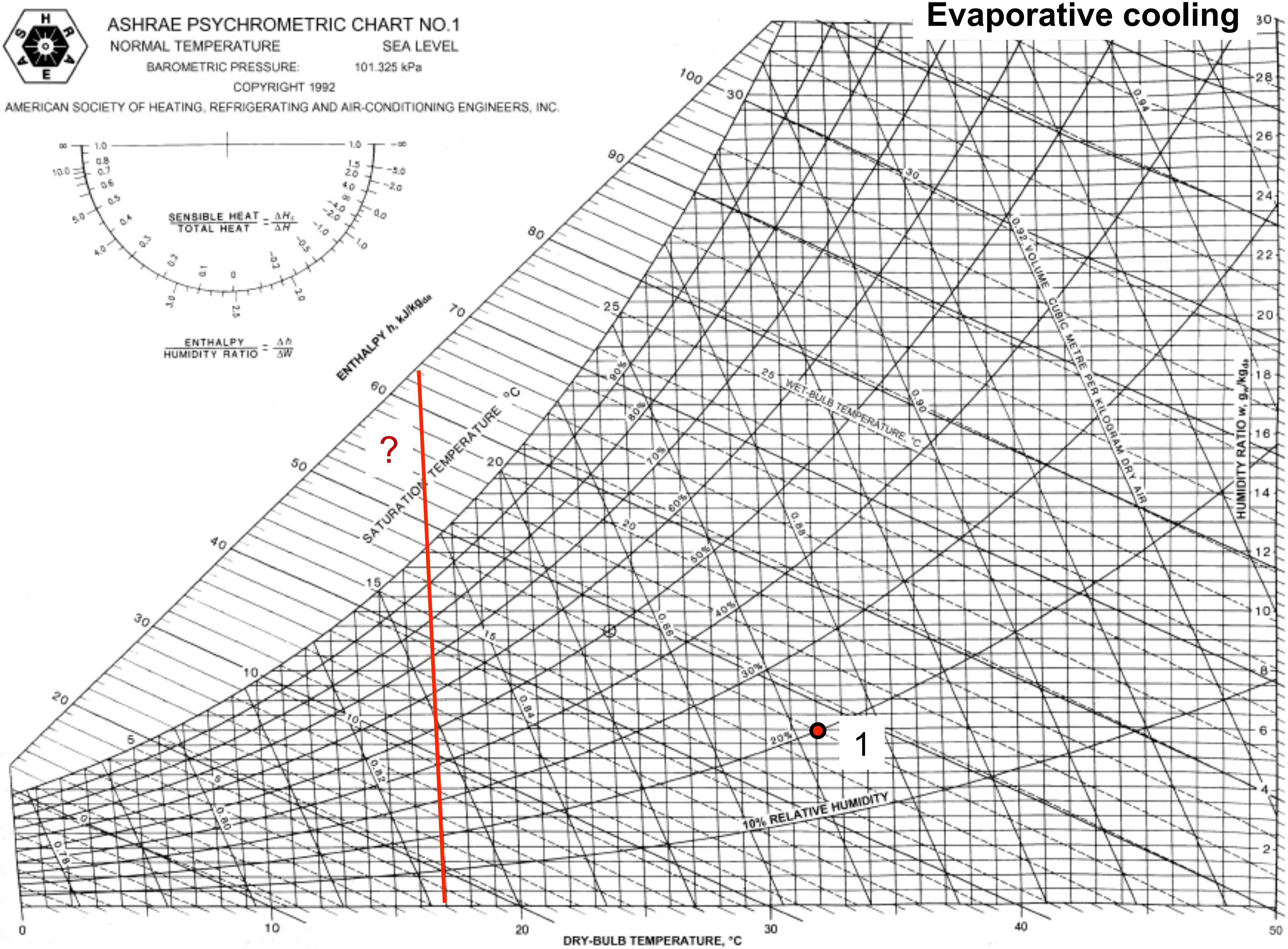
$$h_3 = \frac{\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

Evaporative cooling example

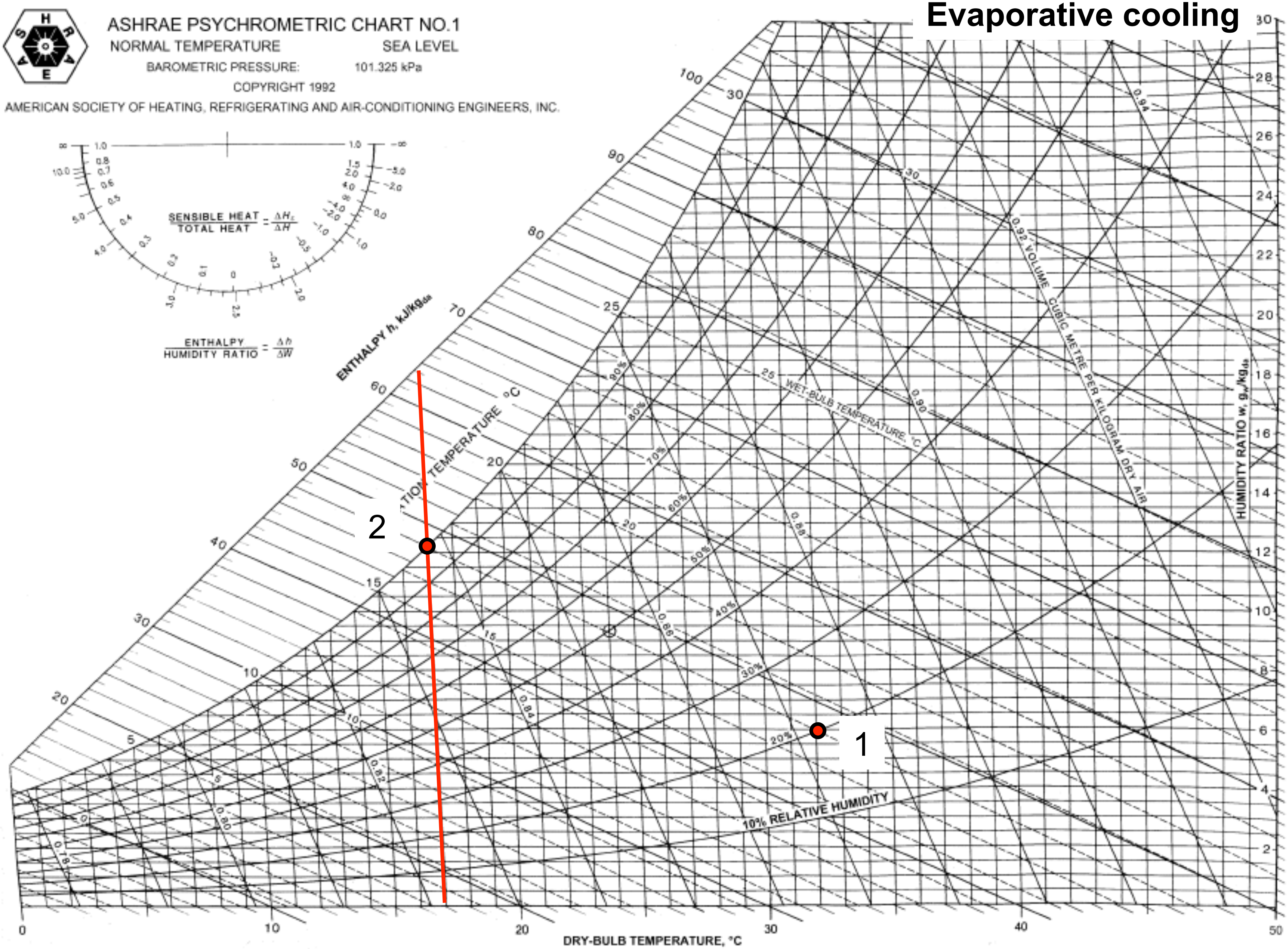
- Hot, dry outdoor air is cooled with an evaporative cooler, or “swamp cooler”
  - Q1: What is RH and W of the supply air?
  - Q2: Why would we choose this system?



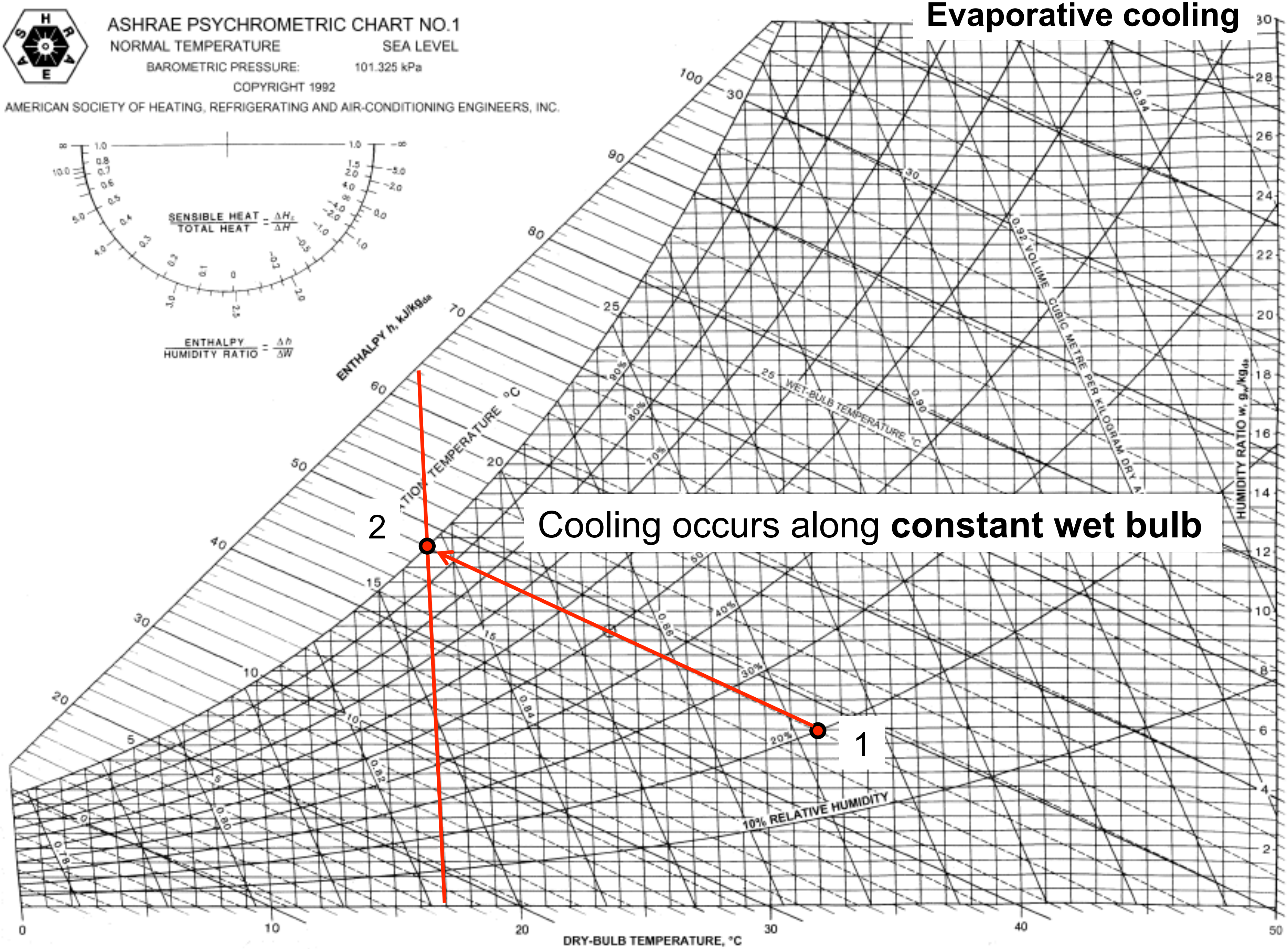
Evaporative cooling



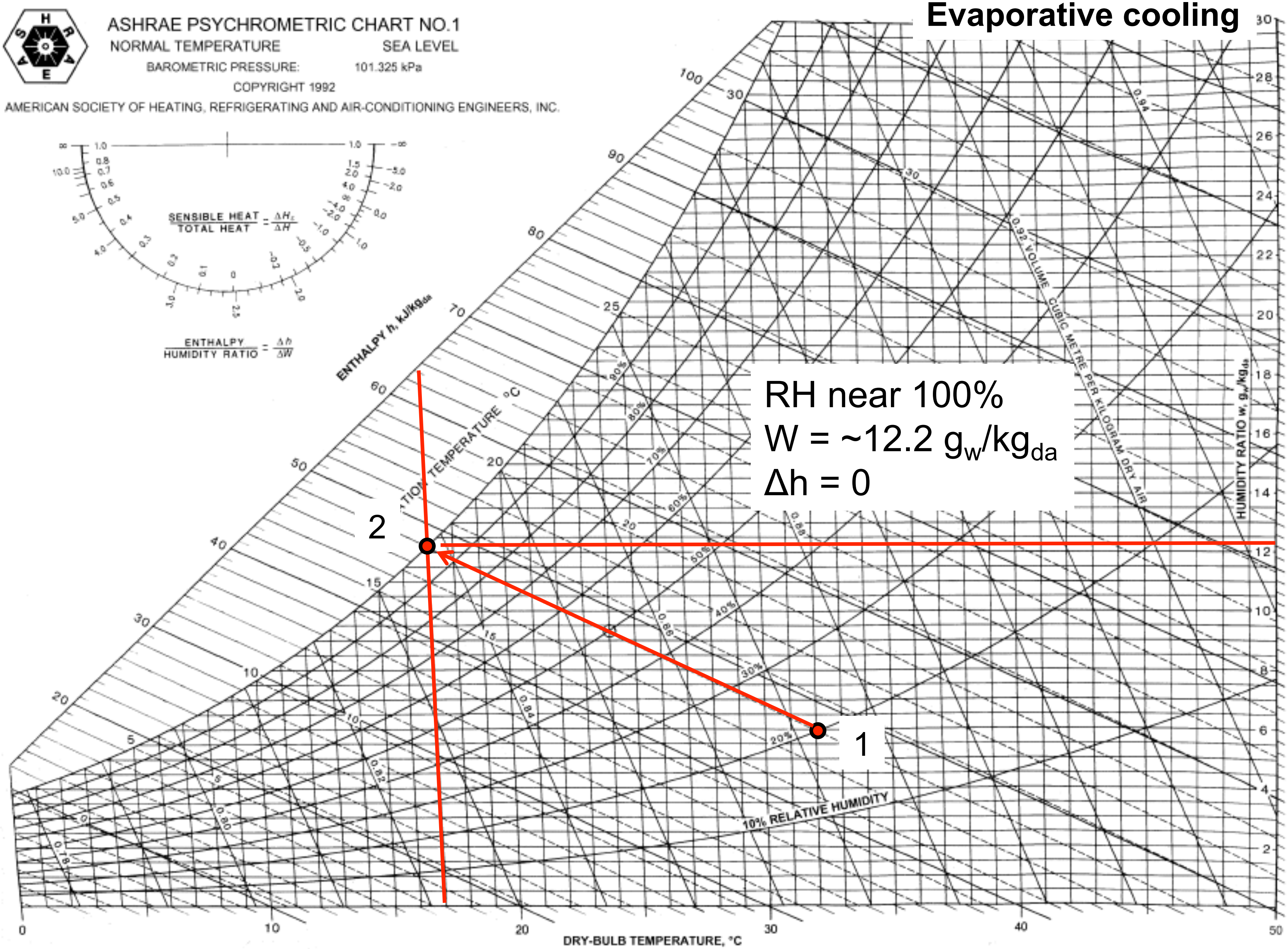
Evaporative cooling



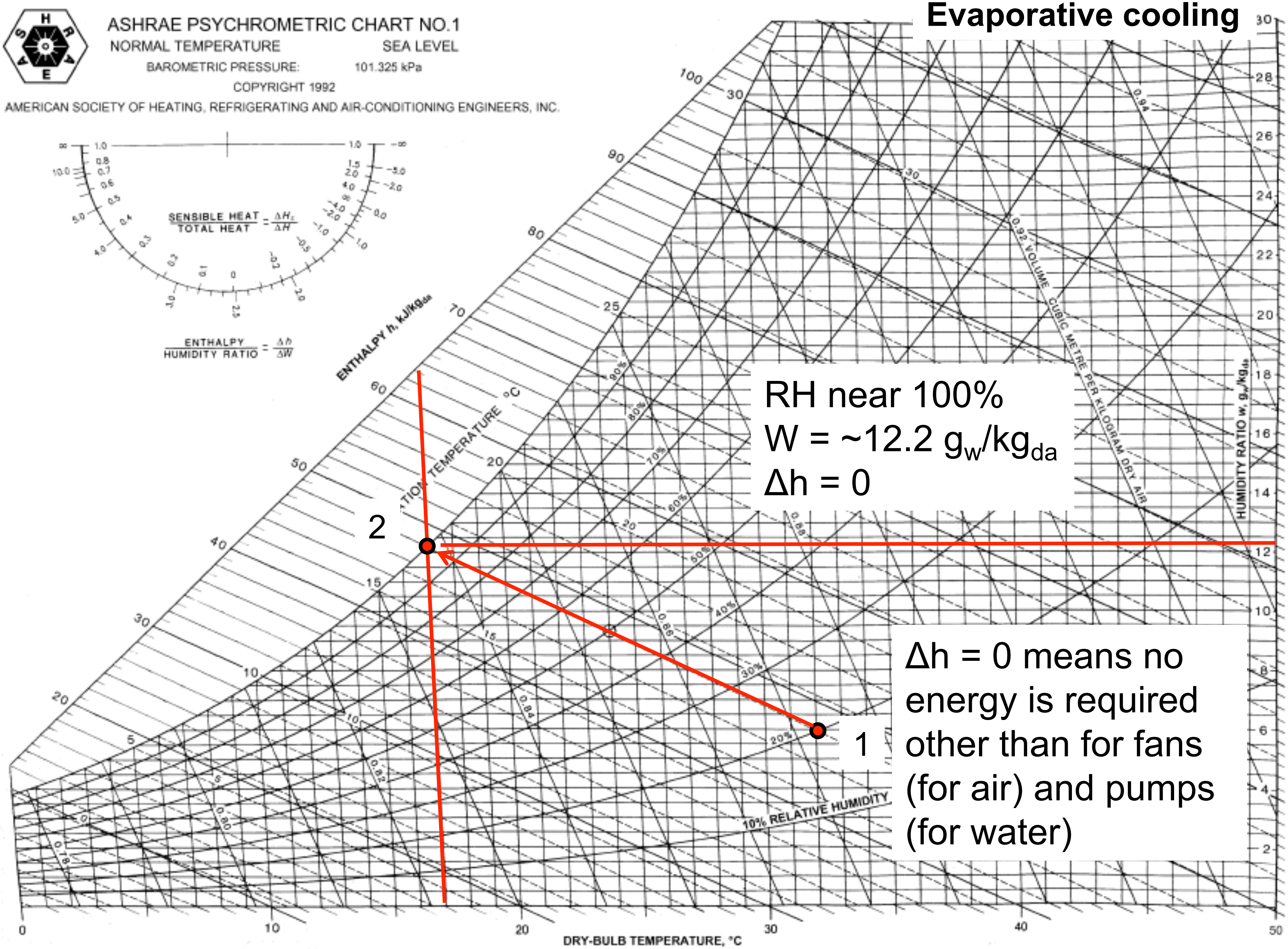
Evaporative cooling

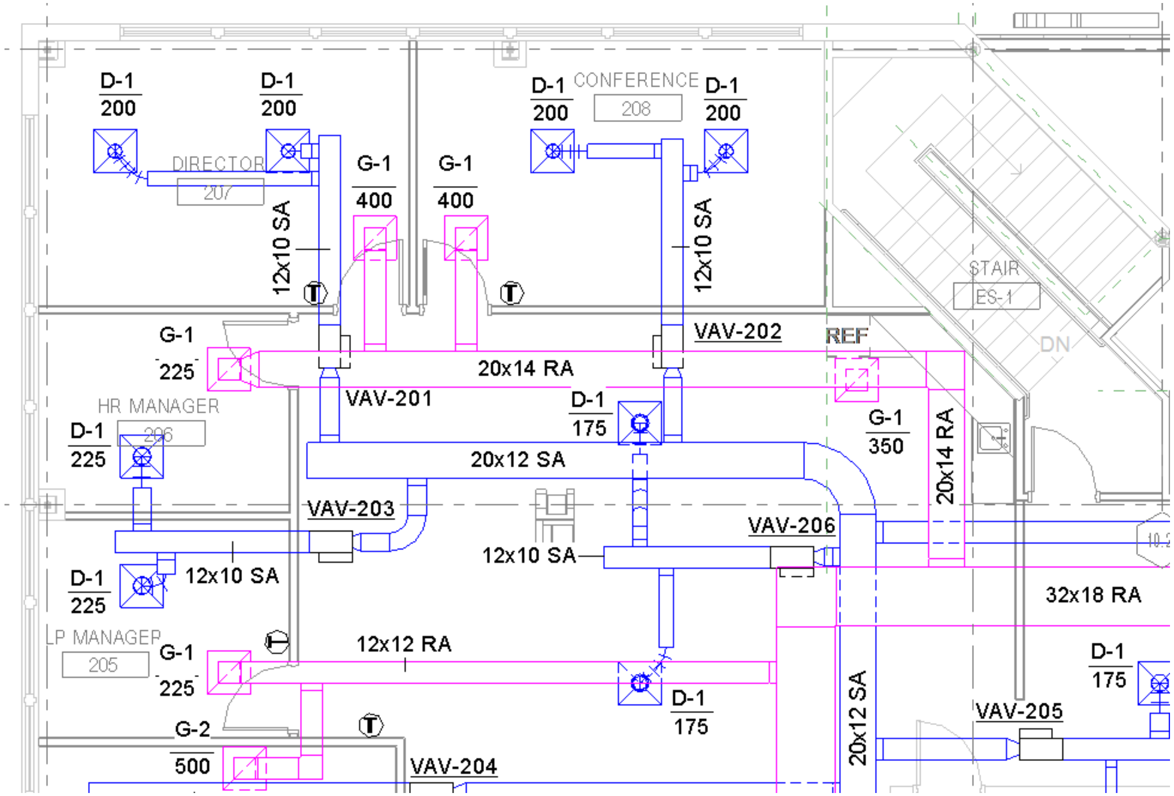


Evaporative cooling



Evaporative cooling





OVERVIEW OF HVAC SYSTEMS

What do they look like?

HVAC systems overview

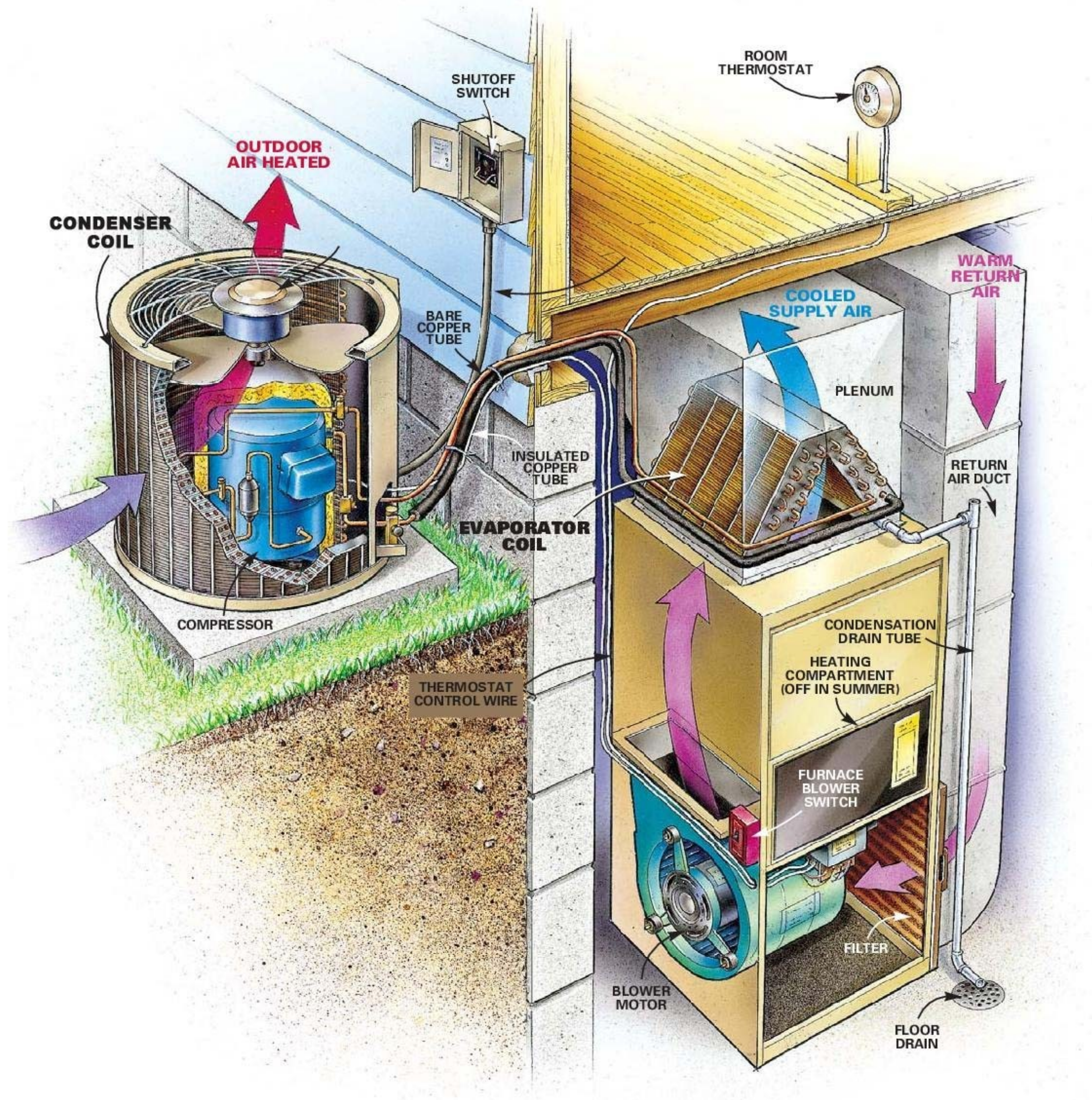
- Now that we understand psychrometric processes involved in HVAC systems in buildings, we will eventually need to select equipment
  - HVAC = Heating, Ventilating, and Air-Conditioning
  - We will also need to understand how to properly size HVAC systems
    - Later in the semester
- Primary mechanical systems
  - Vapor compression systems (i.e., chillers and condenser units)
    - Electrically driven
    - Thermally driven
  - Cooling towers
- Secondary mechanical systems
  - Distribution systems (air and water)

HVAC system design options

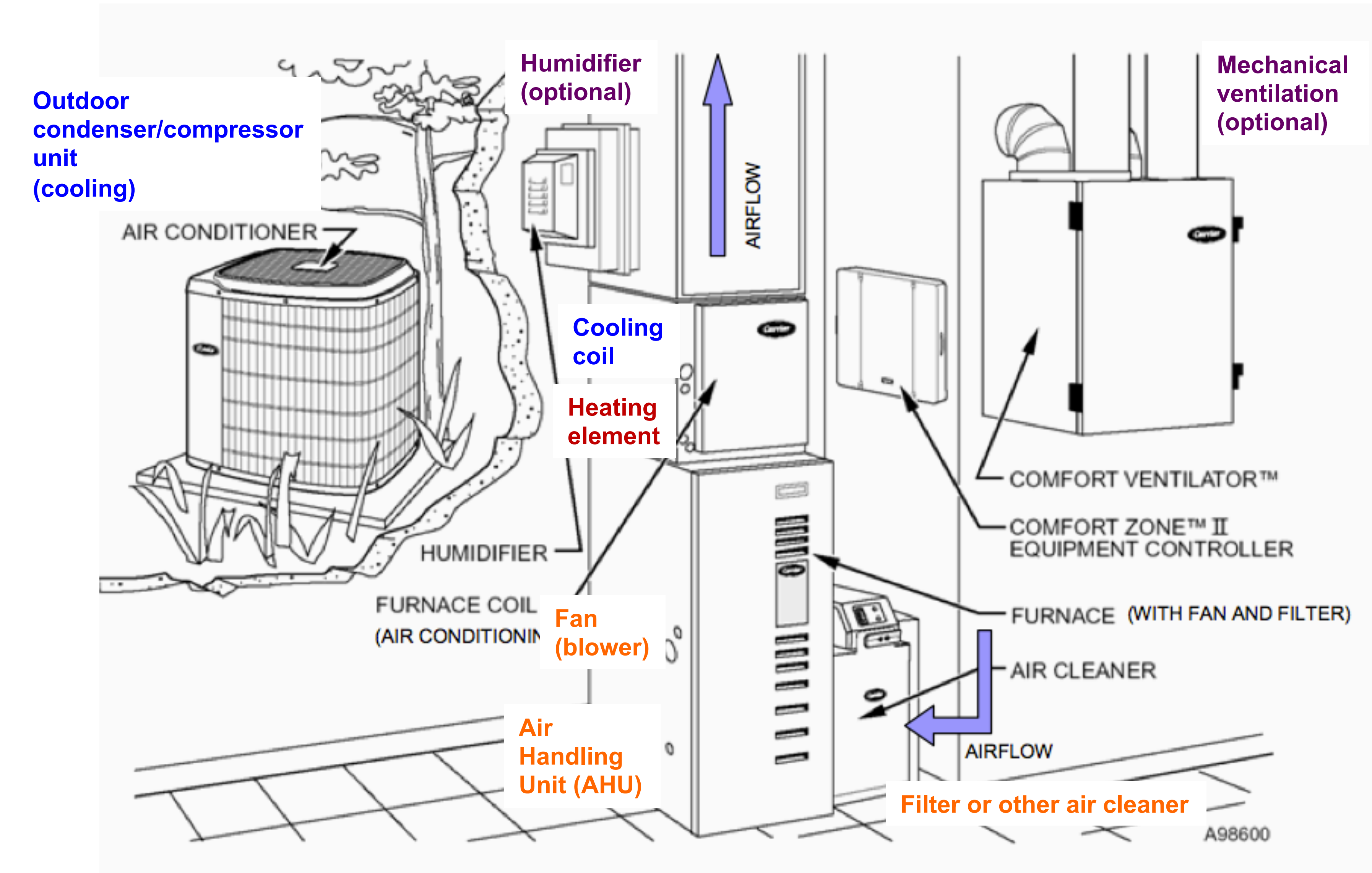
- We can rely on **central** HVAC systems
  - One system per building
  - May control all zones similarly or different zones differently
    - Depends on system type
- Or we can rely on **distributed** HVAC systems for every zone
  - Motels, strip malls, apartment buildings
- Need to figure out what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

Typical central residential system

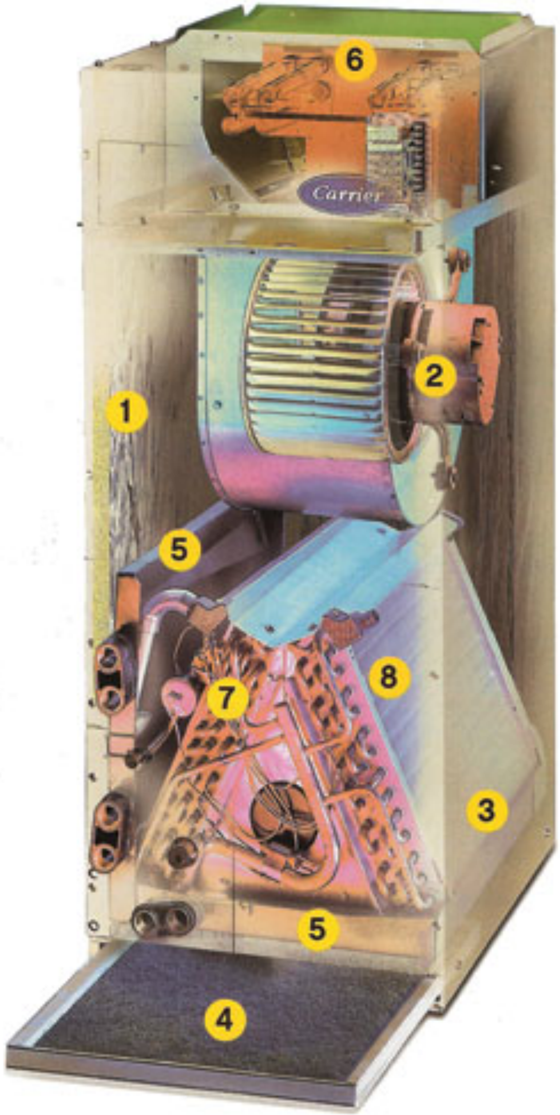
What modes of heat transfer are involved?

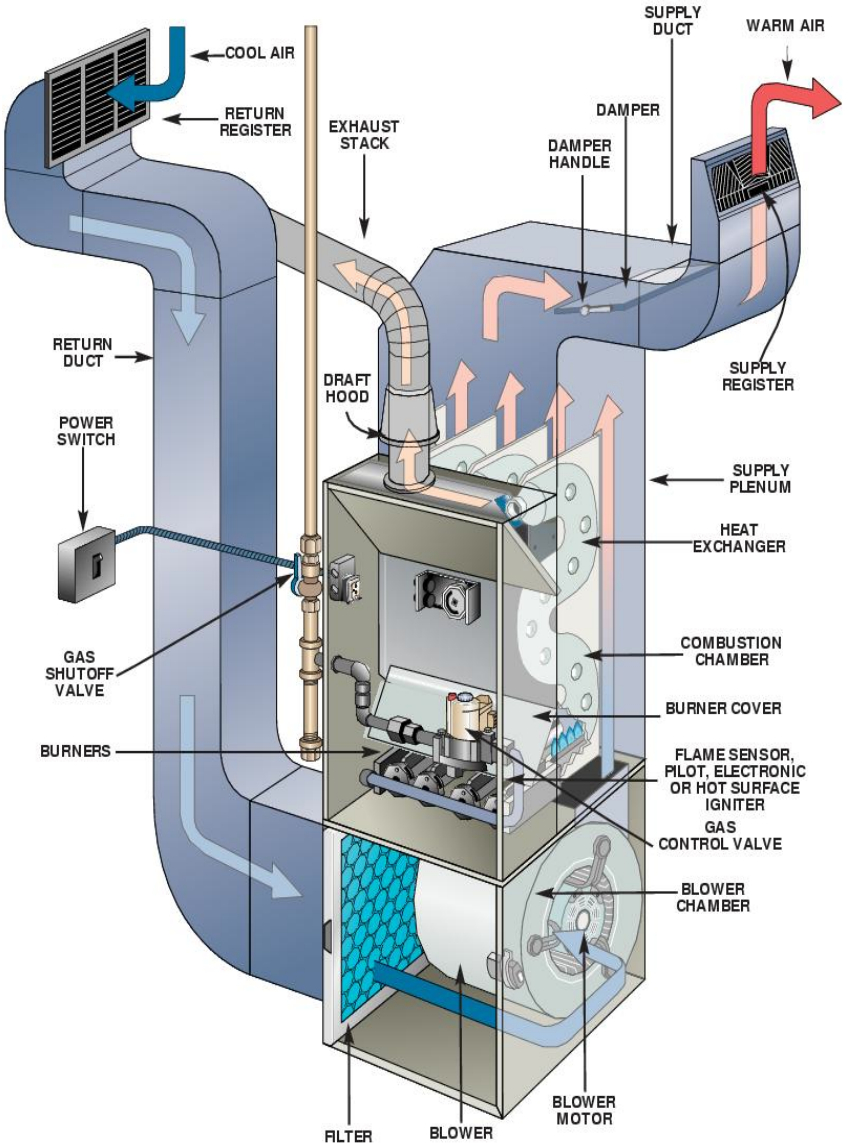


Typical central residential system w/ upgrades



Inside a typical central residential air handler



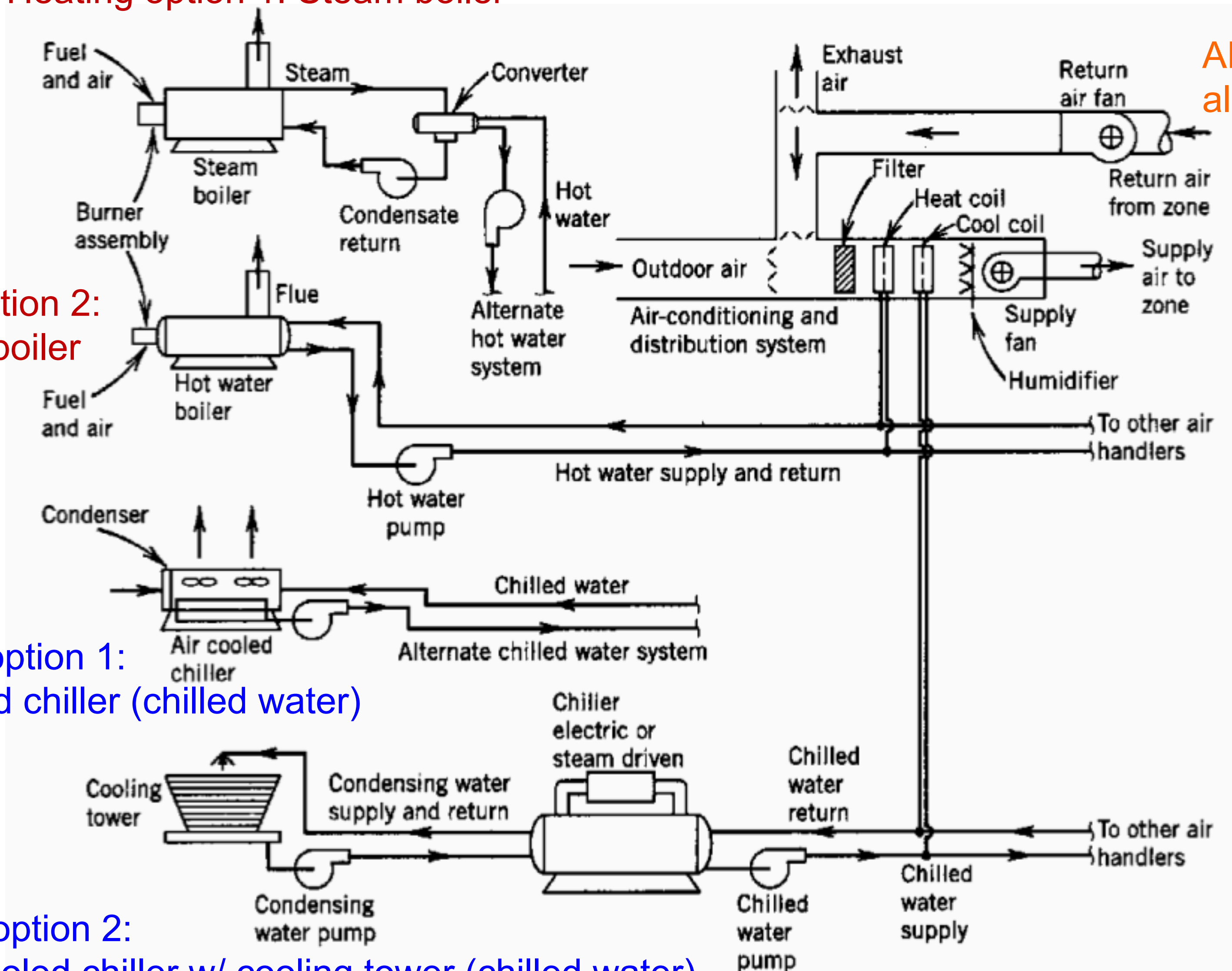


Typical large central commercial systems

Heating option 1: Steam boiler

AHU serves all rooms

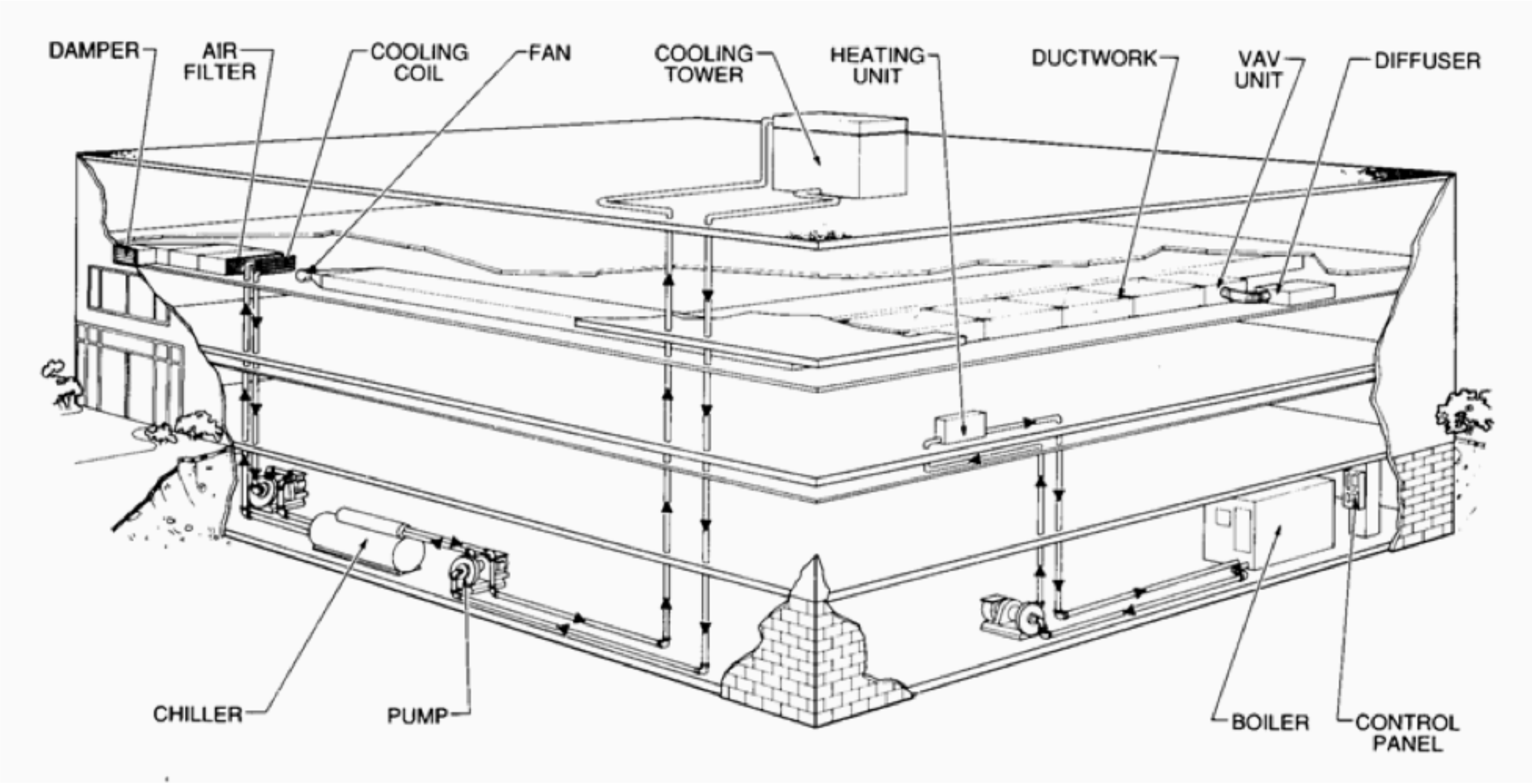
Heating option 2: Hot water boiler



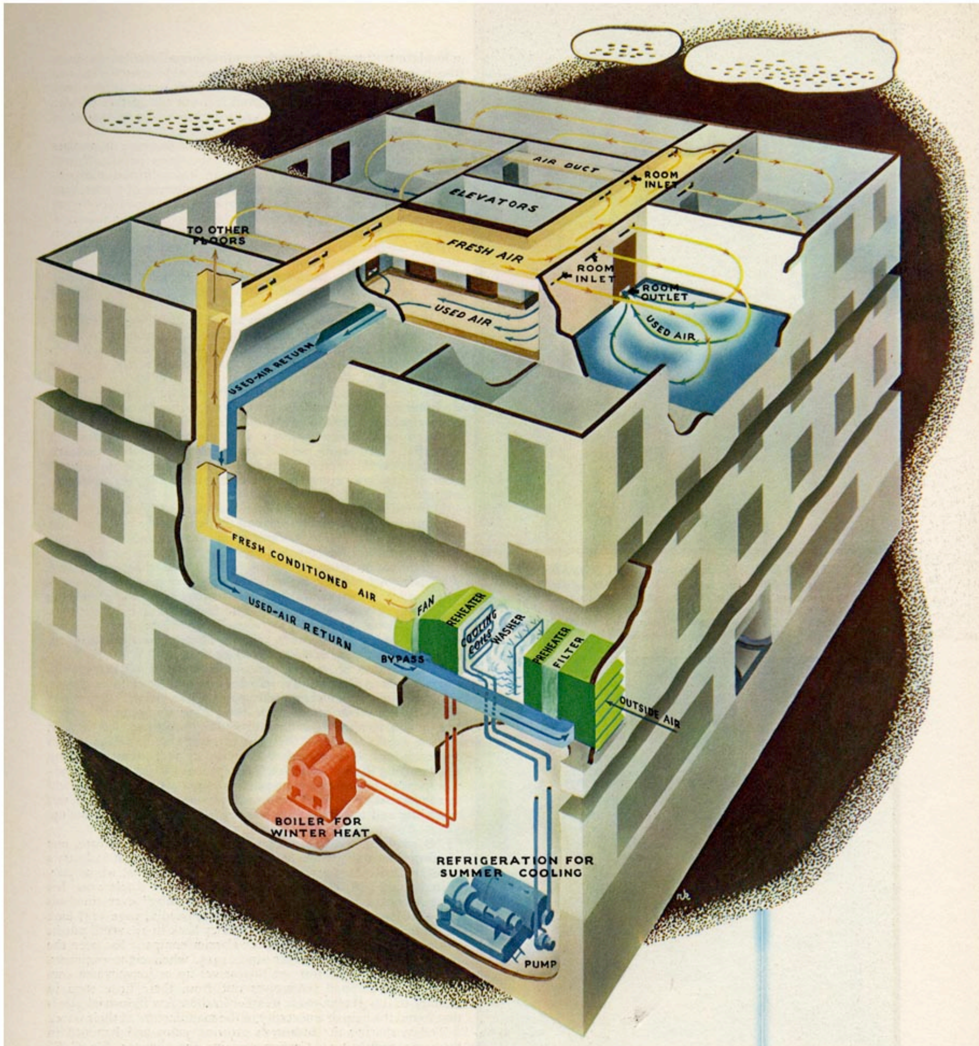
Cooling option 1: Air cooled chiller (chilled water)

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

Typical large commercial systems: Central

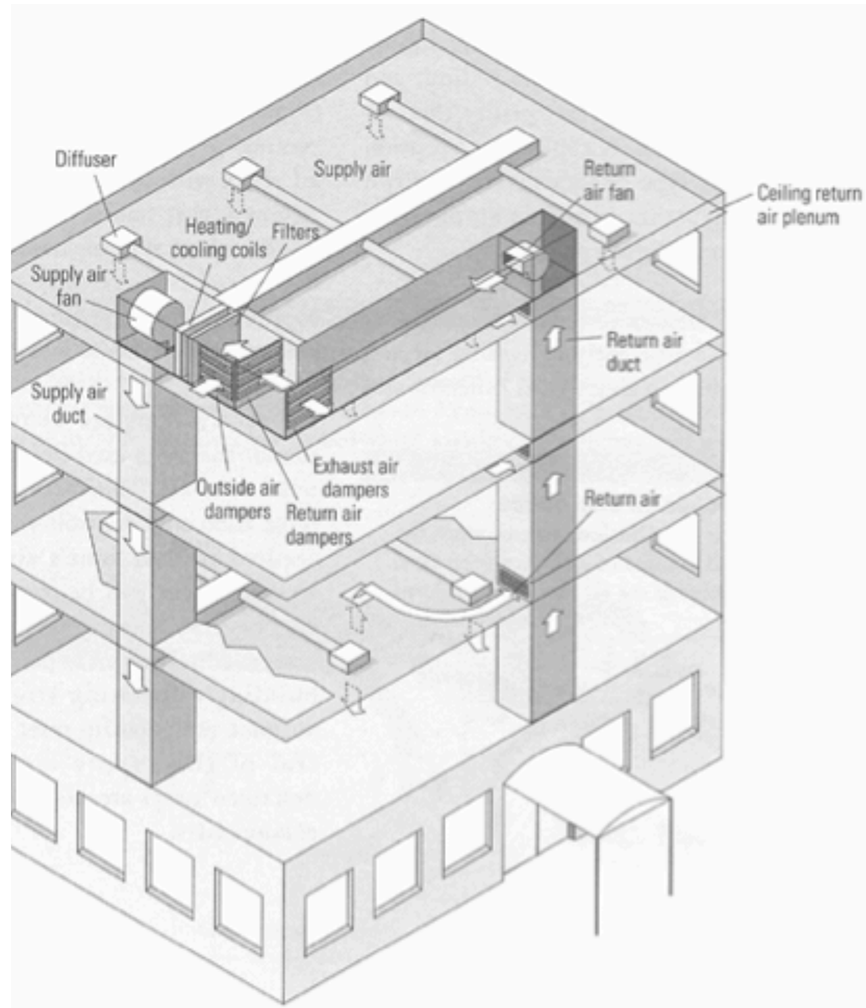


Typical large **central** **commercial** systems



AN X-RAY VIEW OF AN AIR-CONDITIONED OFFICE BUILDING WOULD NOT LOOK SO SIMPLE AS THIS

. . . but the diagram gives a good idea of the way a big year-round installation works. In winter, the boiler sends steam up through the red pipe to coils in the conditioning apparatus; in summer, the refrigerating unit sends cold water up through the blue pipe. Air drawn from the building mixed with outside air is filtered, washed, heated and humidified (in winter), cooled and dehumidified (in summer), and then led into each office.



Typical large central commercial systems

Typical large central commercial systems

Typical large central commercial systems

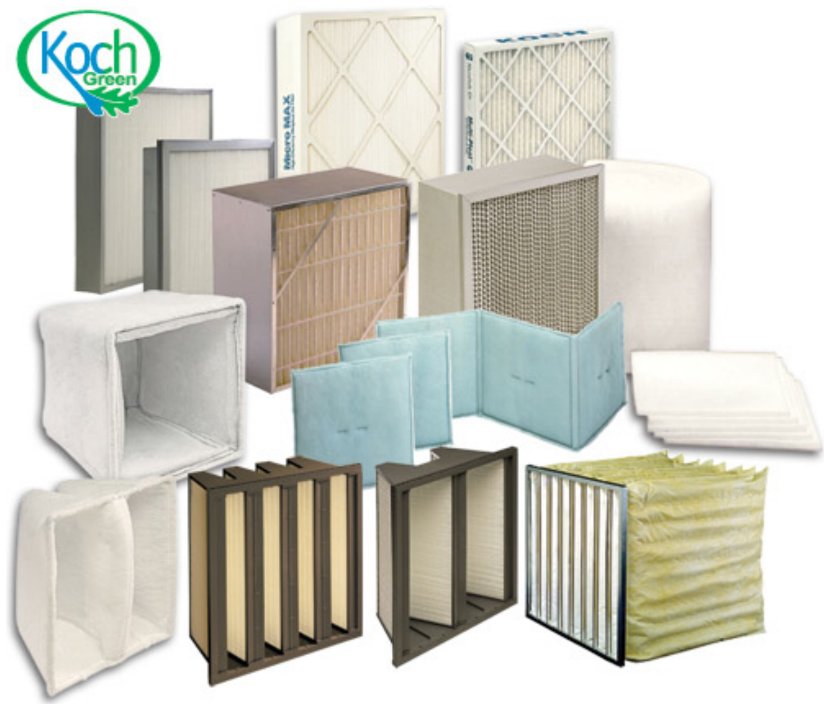
Typical large central commercial systems

Typical large central commercial AHUs

Air Handling Unit (AHU)

Typical large central commercial AHU components

Filter bank



Typical large central commercial AHU components

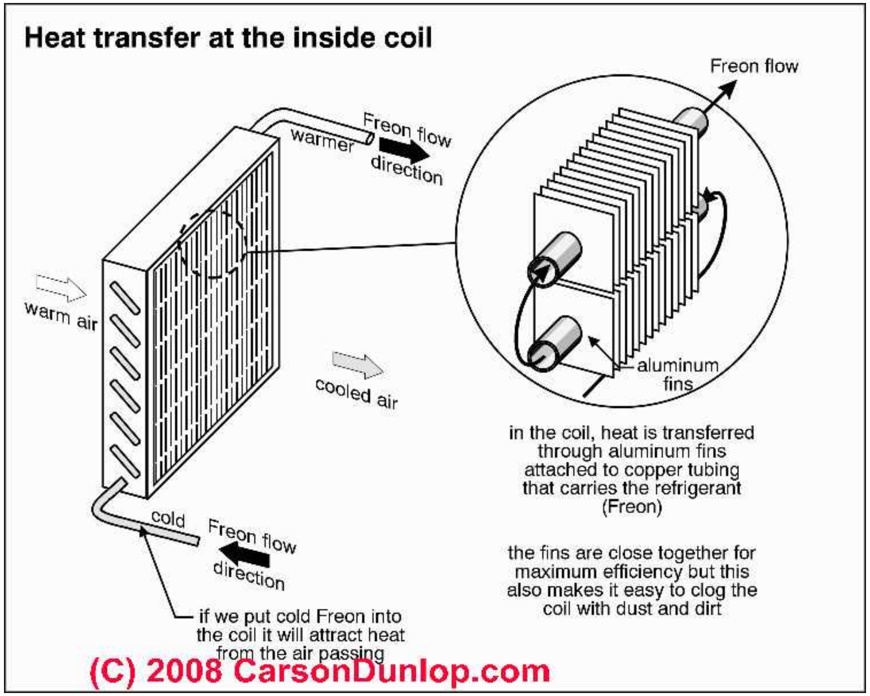
Fan (or blower)

Typical large central commercial AHU components

Mixing box

Typical large central commercial AHU components

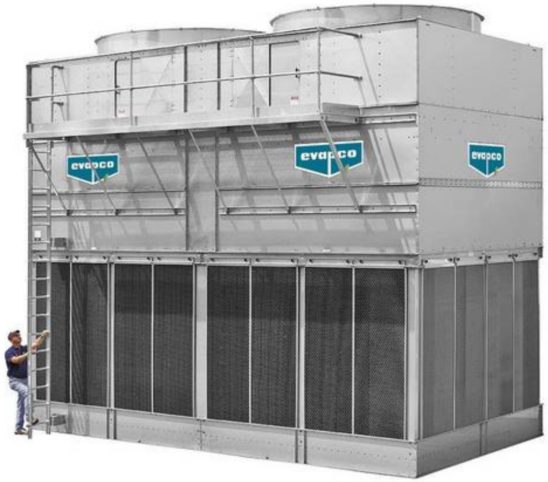
Heating and cooling coils



Typical large central commercial system components

Air cooled chiller

Smaller capacity



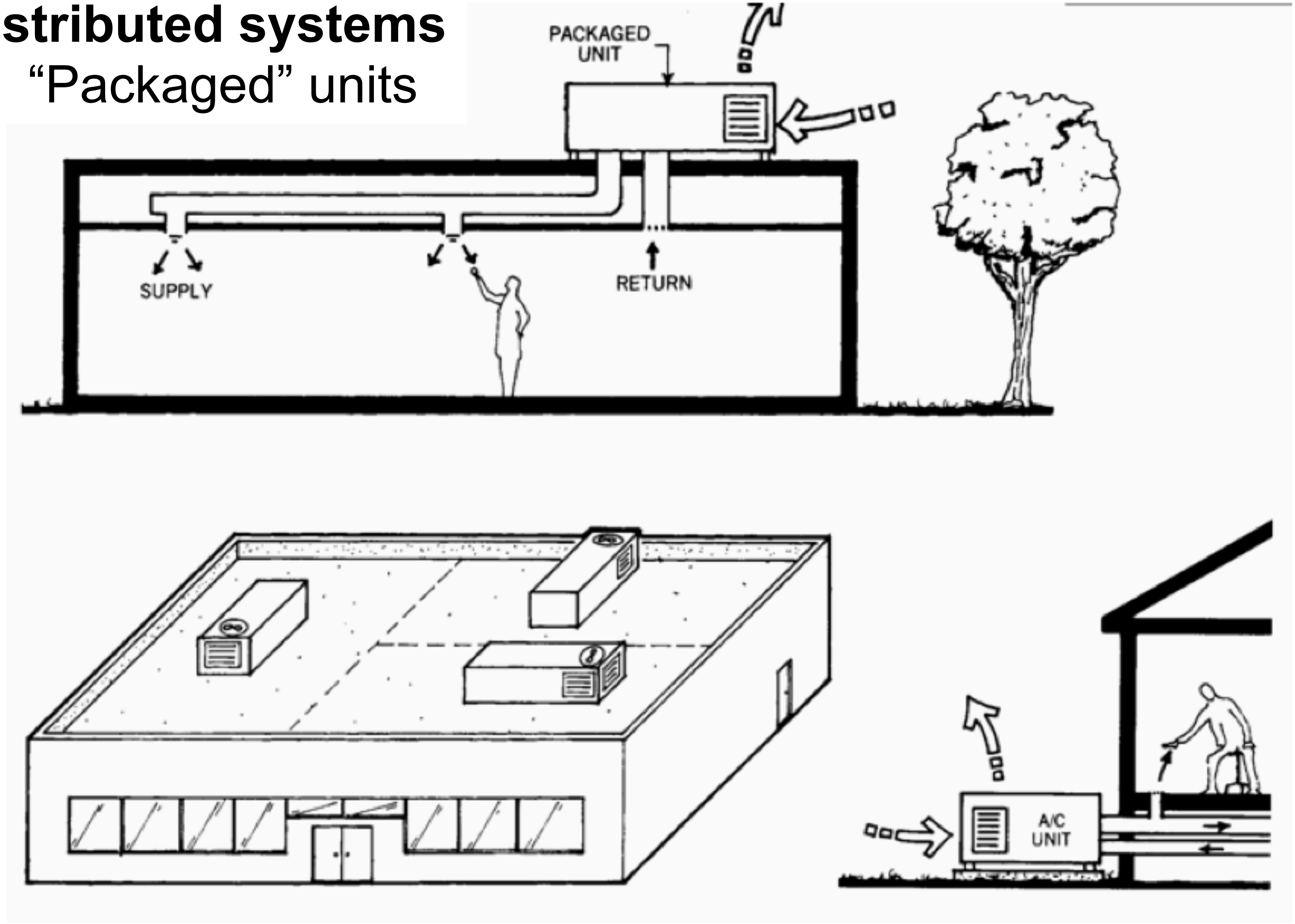
Water-cooled chiller
(w/ cooling tower)

Hot water or
steam boiler

Typical large distributed commercial systems

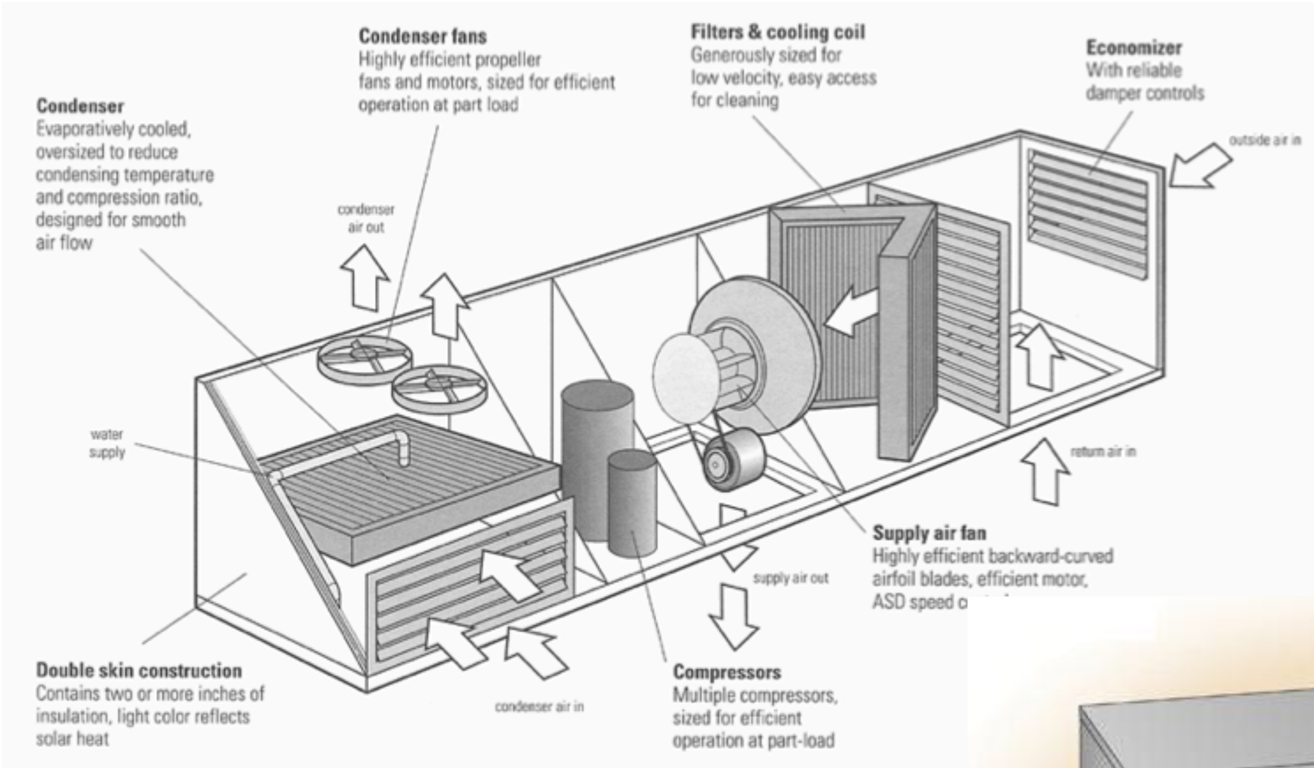
Distributed systems

"Packaged" units

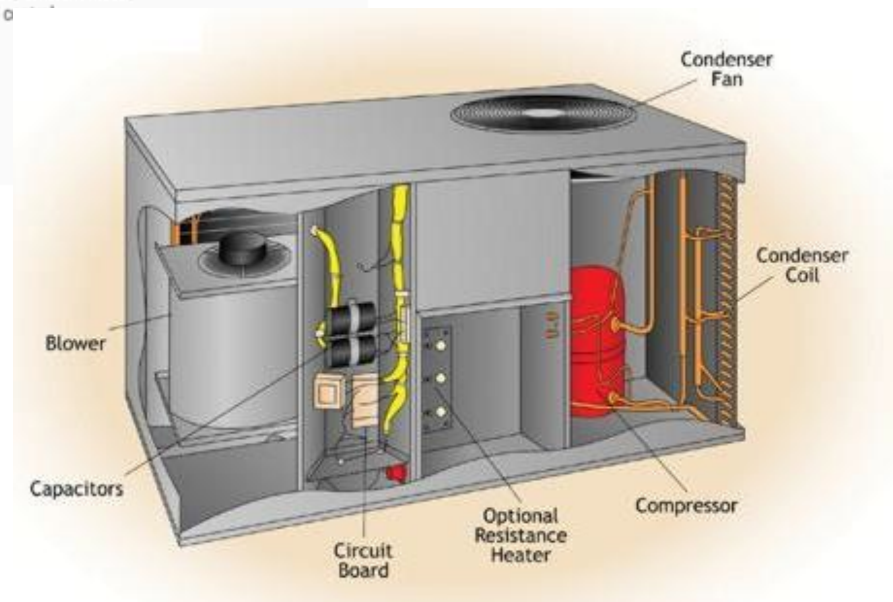


Typical large distributed commercial systems

Typical large distributed commercial systems

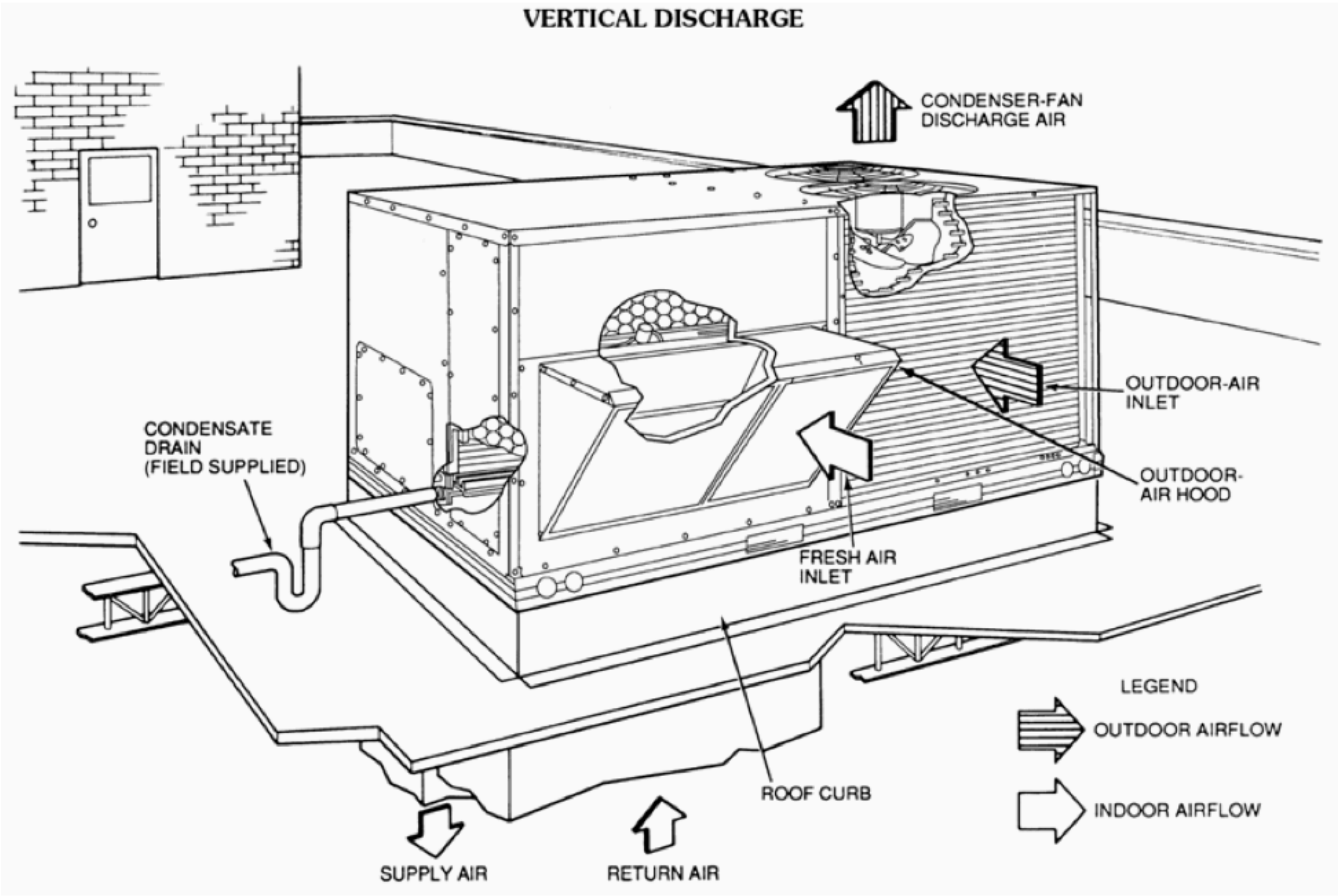


Packaged systems



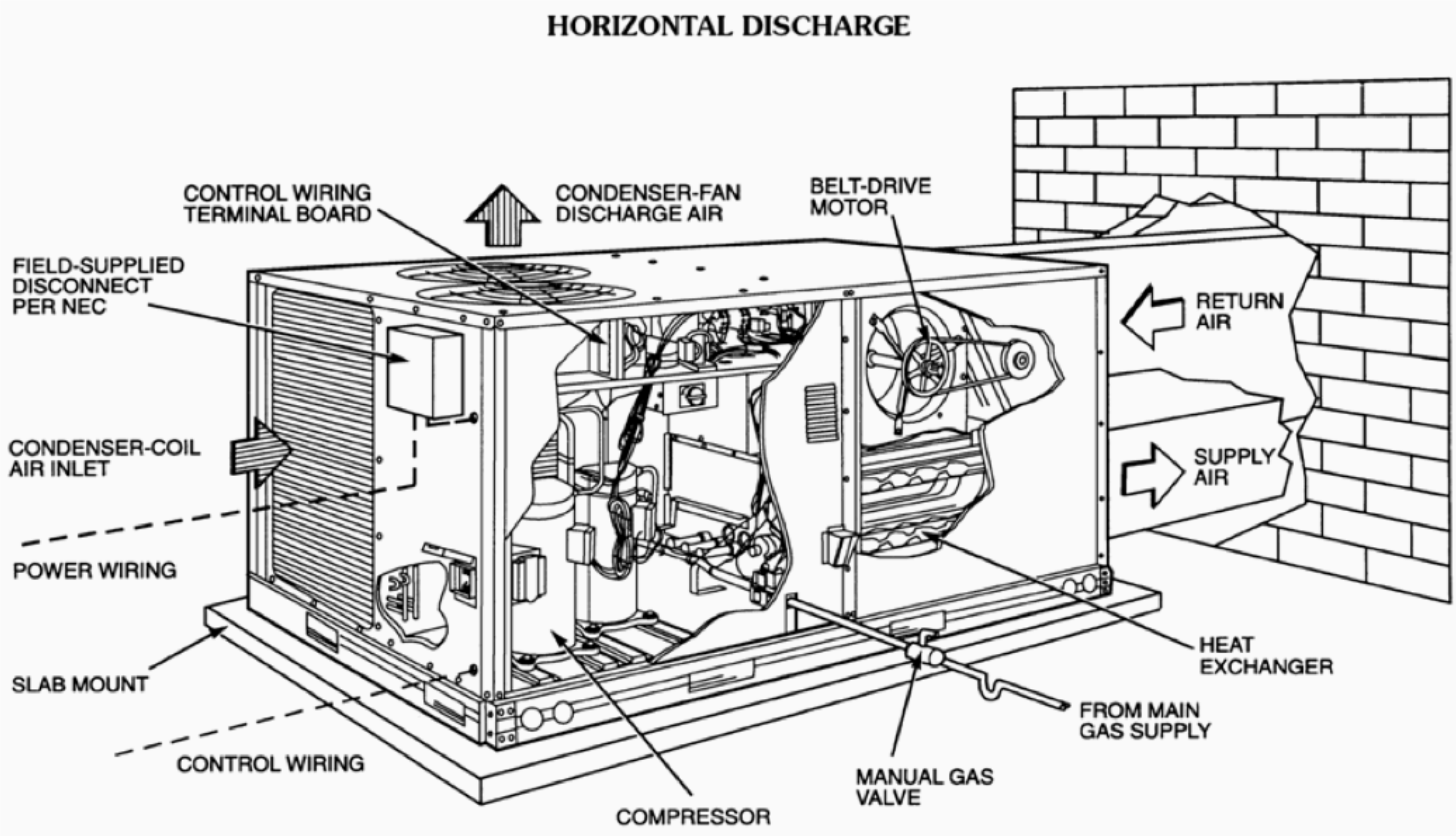
Typical large distributed commercial systems

Packaged roof-top units (RTUs)



Typical large distributed commercial systems

Packaged slab installations



Central vs. distributed systems

Central

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

Distributed

- 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)

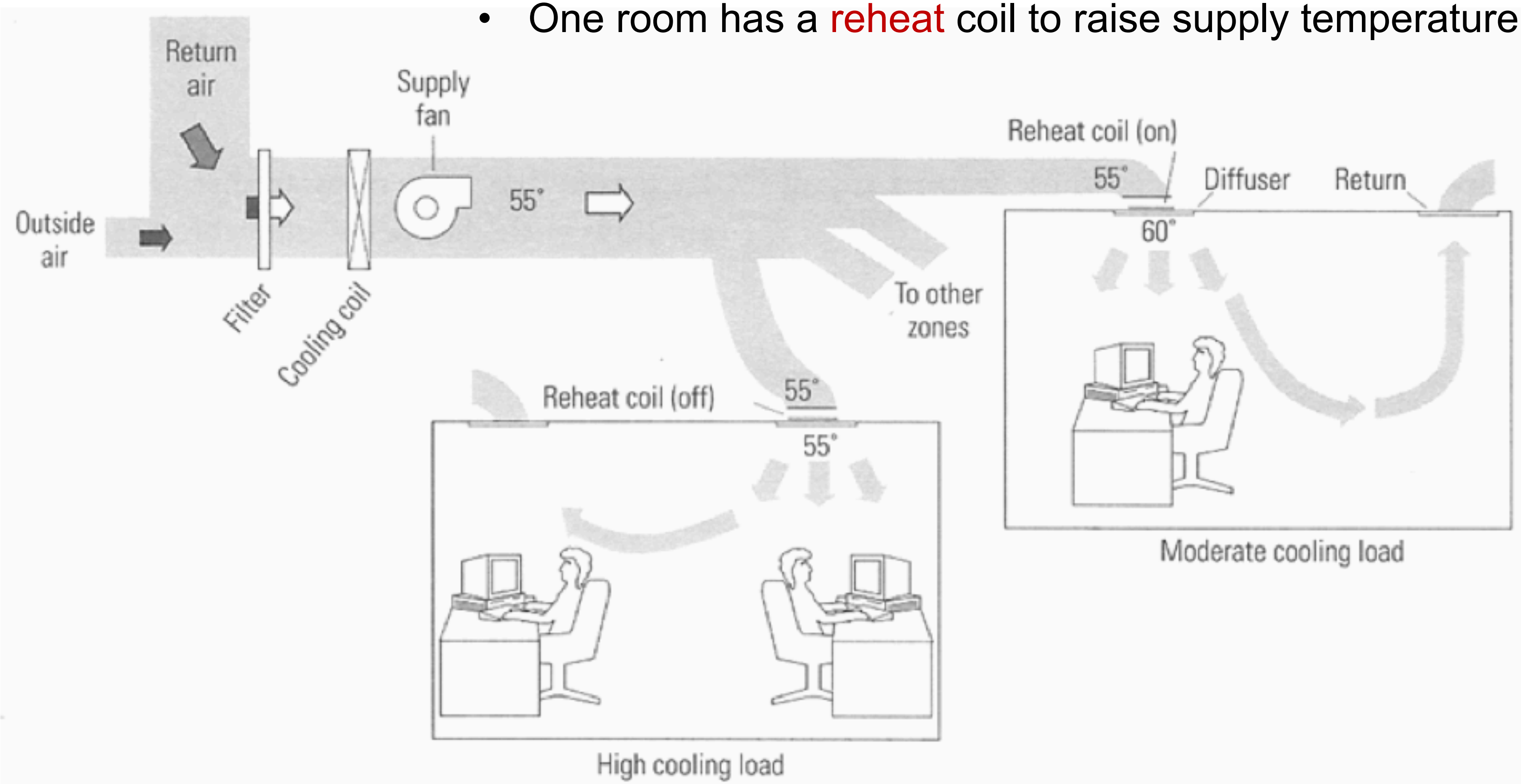
Air distribution: Air handling systems

- 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)

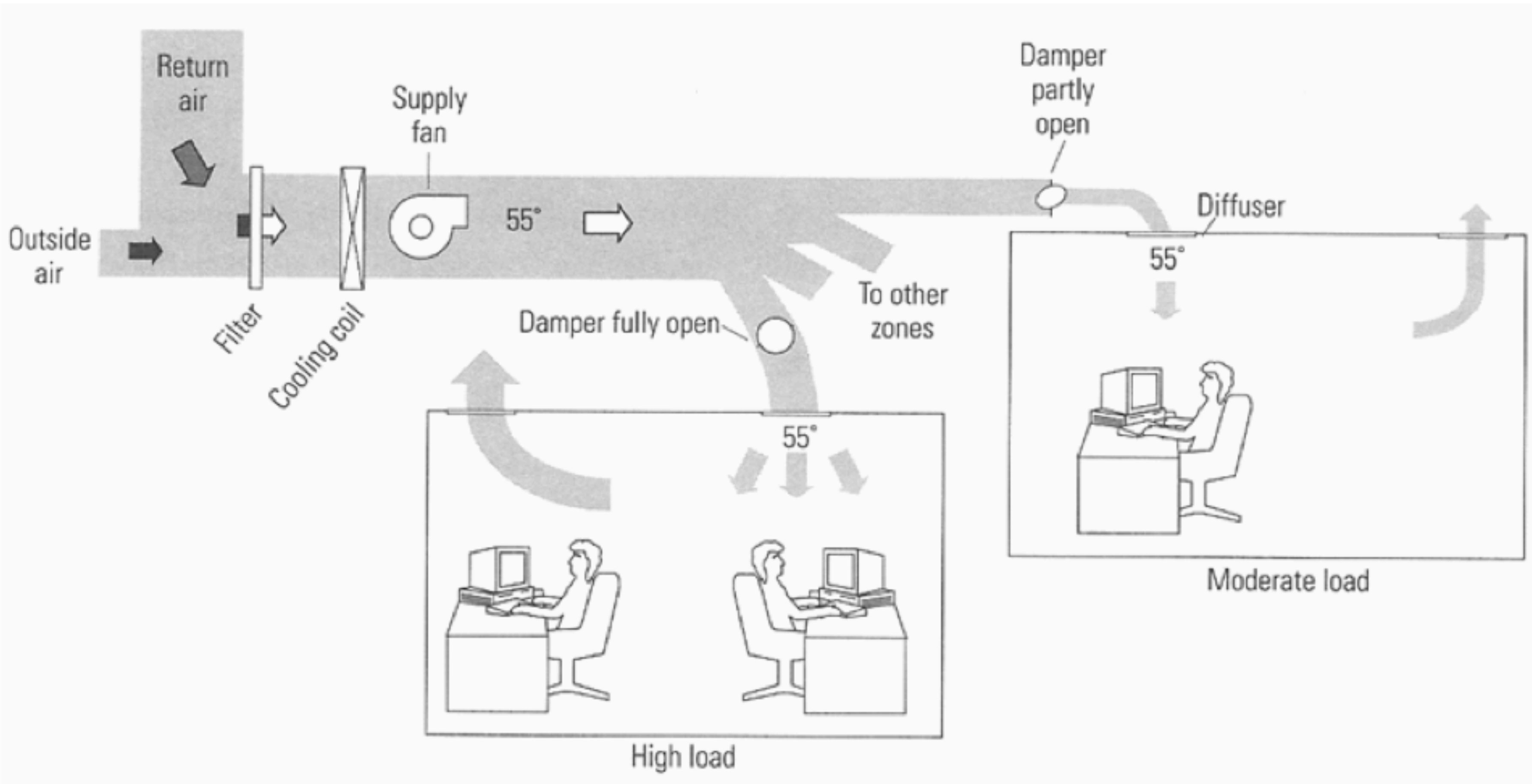
Same airflow rate to each room

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



Typical variable air volume (VAV)

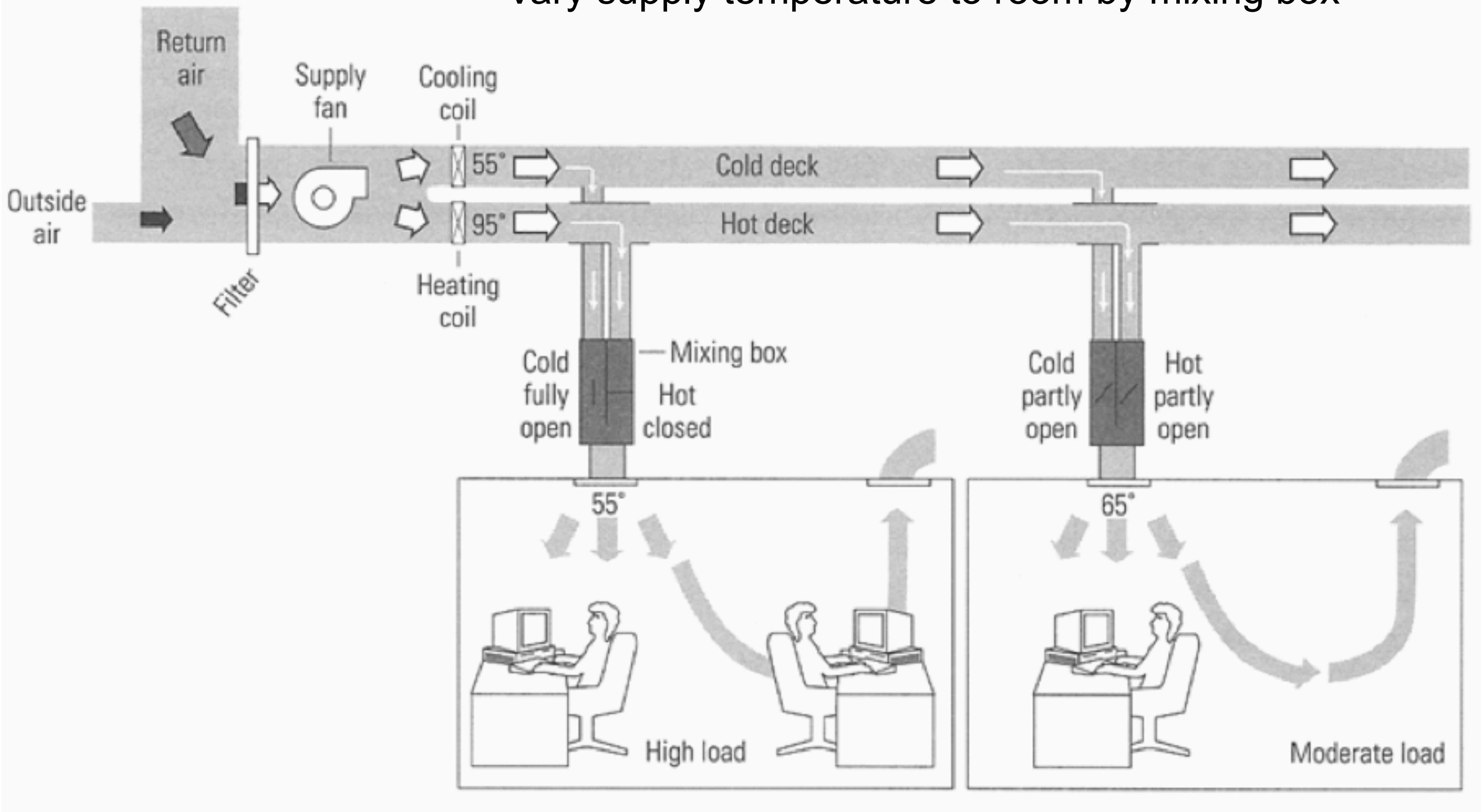
Different **airflow rate** to each room
- Same temperature air delivered



Typical dual duct (DD)

1 hot deck and 1 cold deck

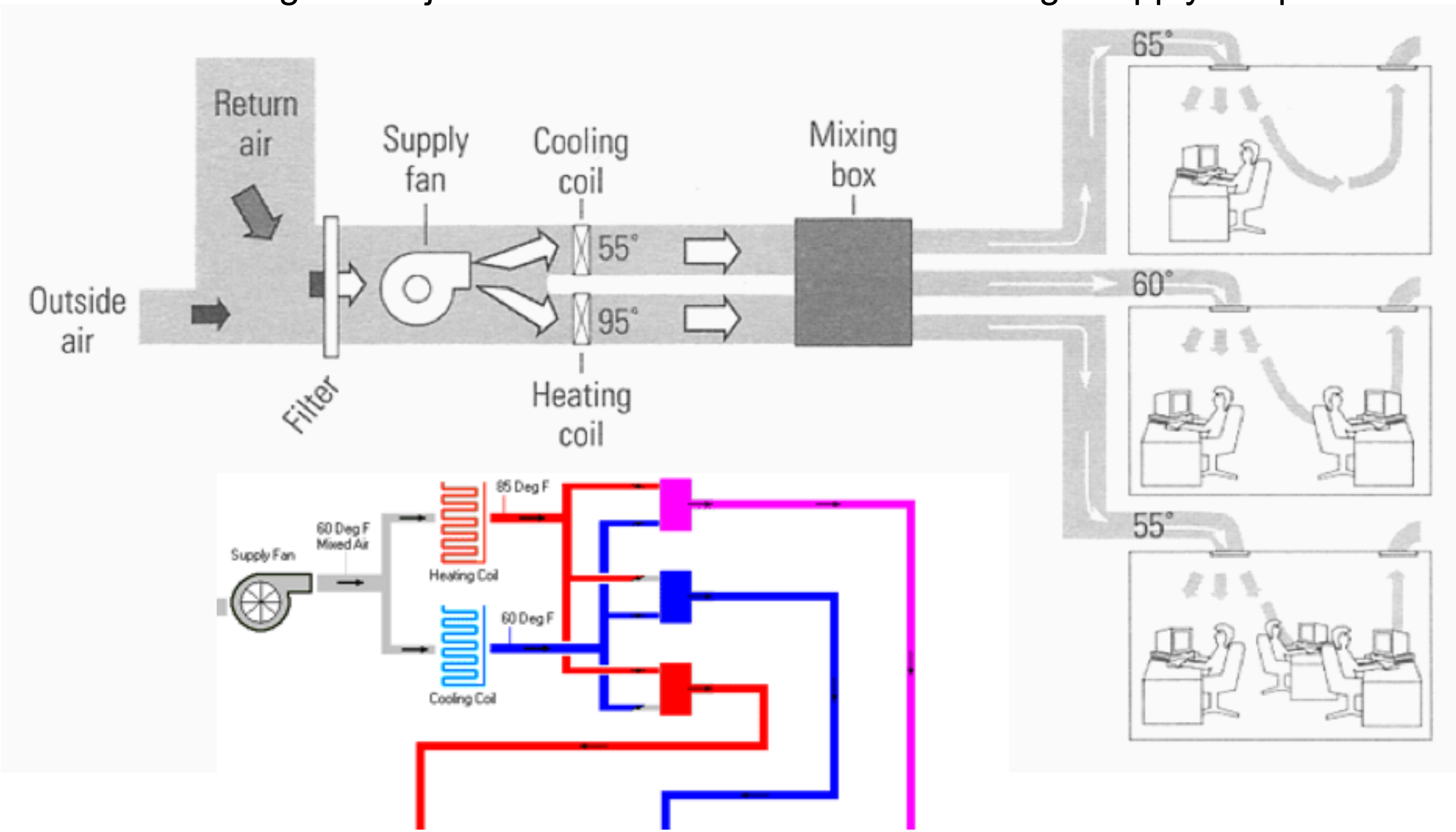
- Vary supply temperature to room by mixing box



Typical multi-zone (MZ)

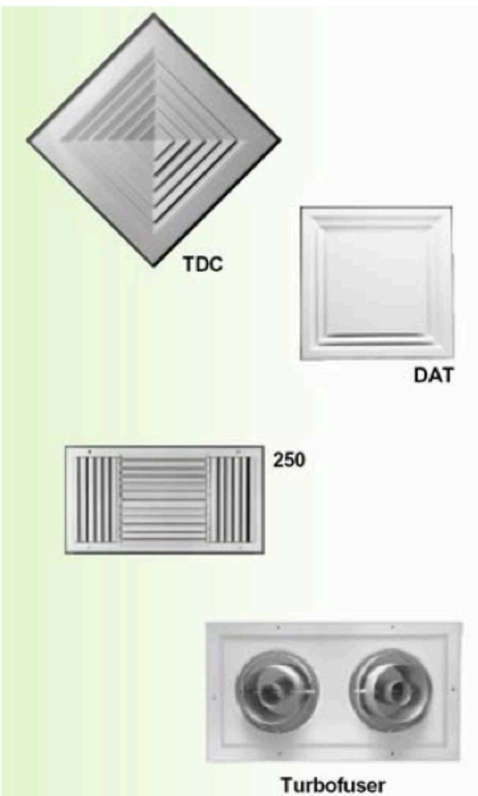
Same airflow rate to each room

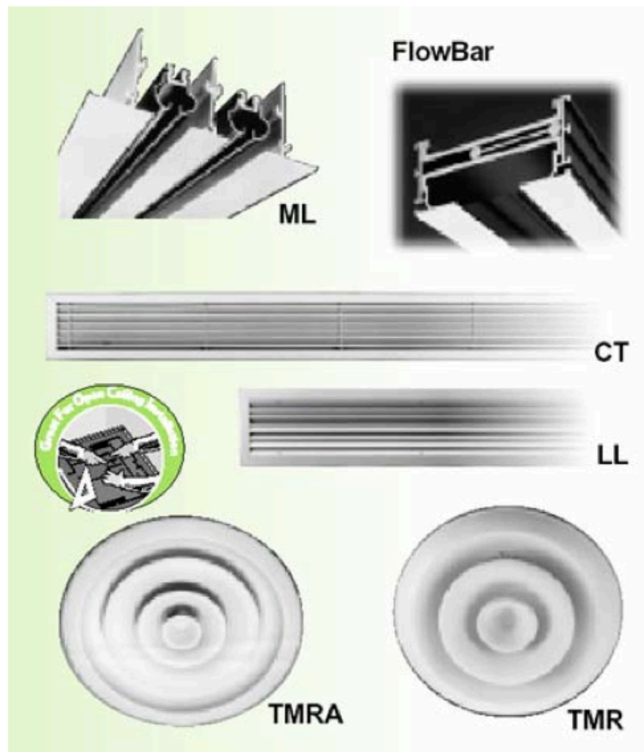
- Mixing box adjusts mixture of hot and cold to change supply temperature

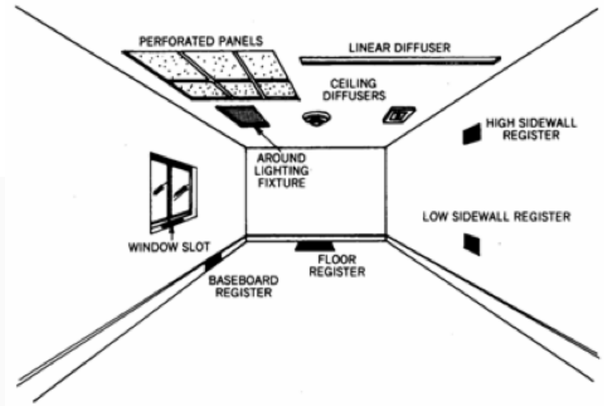


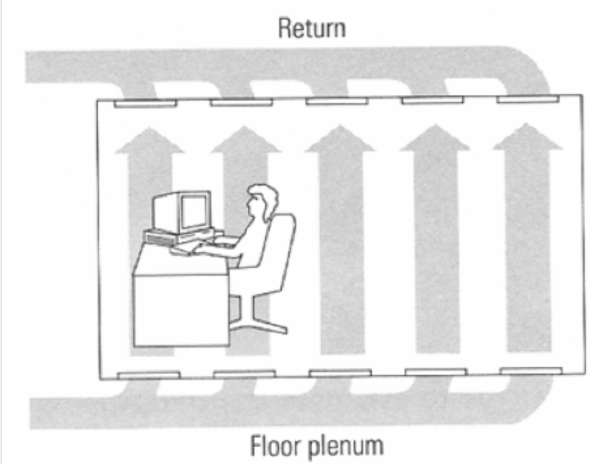
Air supply and diffusers

- Mixed versus displacement ventilation
- Diffuser selection









Air-water systems

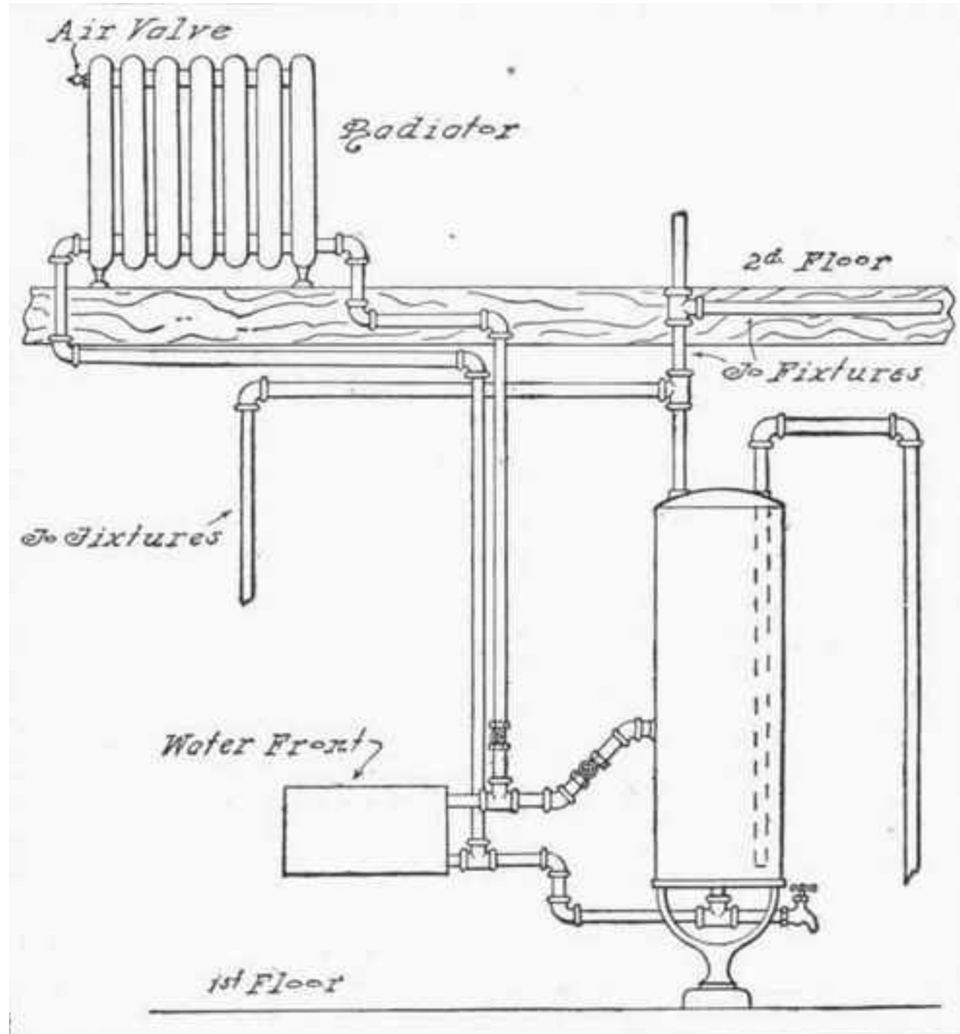
- Many commercial buildings use a combination of conditioned air and zone water coils

- Ventilation requires air movement

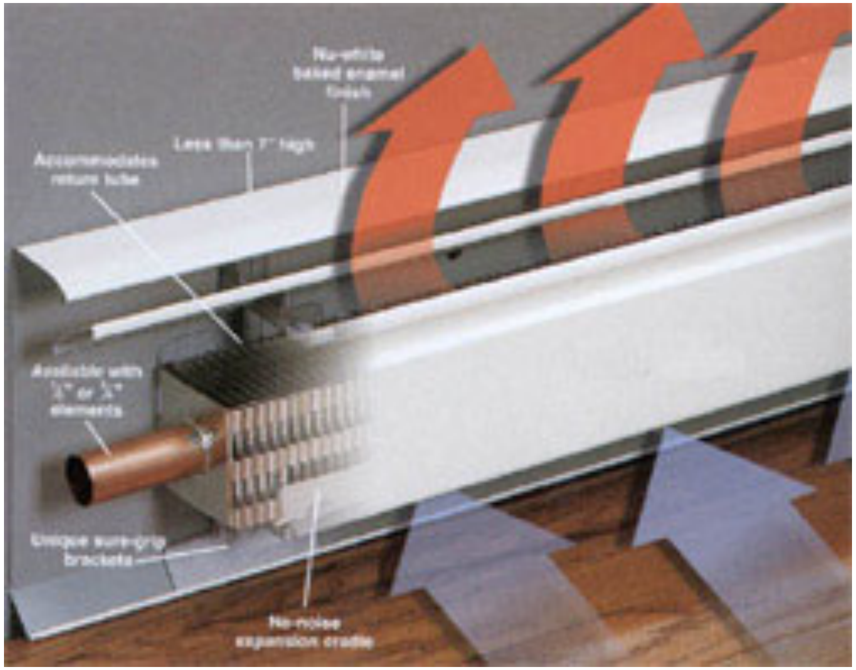
- But zone heating and cooling loads can be met with coils
  - We use fan coils now
  - We used to use radiators (like in Alumni)

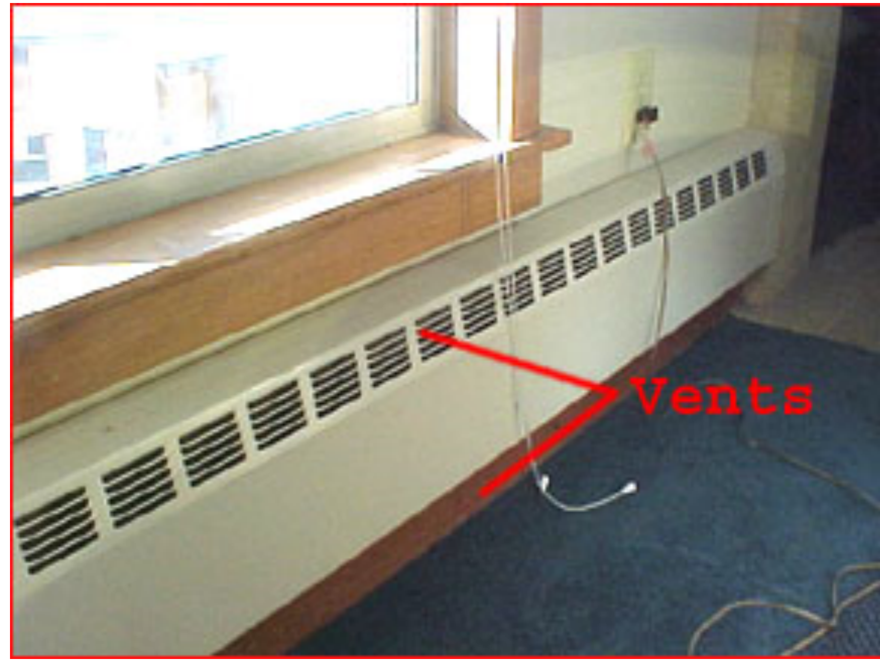
Radiator systems (for heating)

What modes of heat transfer are involved?

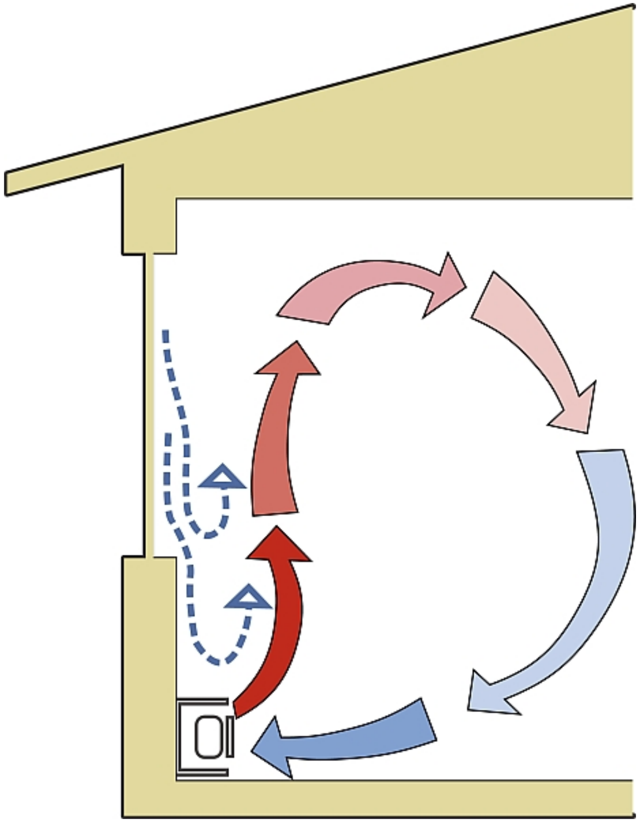


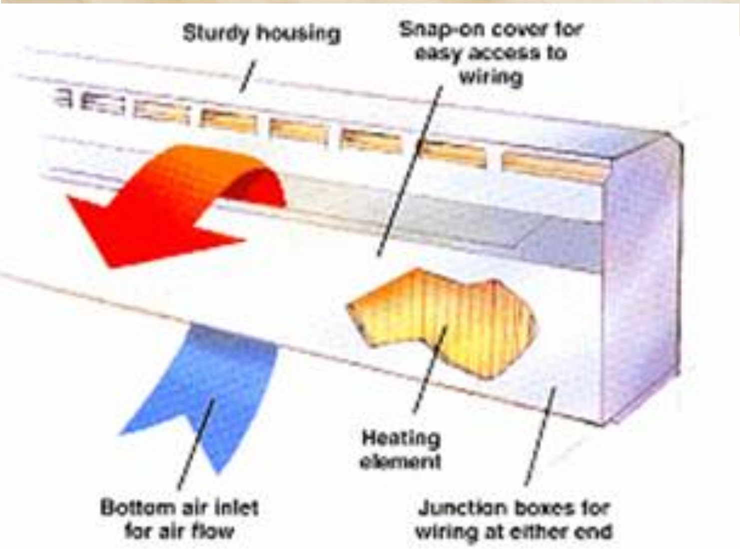
Water-based baseboard systems (heating)





Electric baseboard systems (for heating)





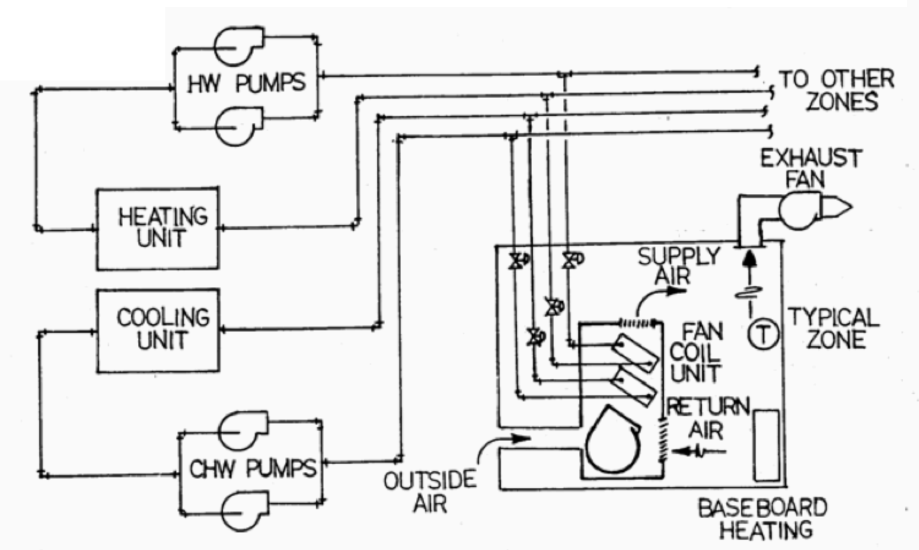
Fan coils: Modern radiator replacement w/ fan

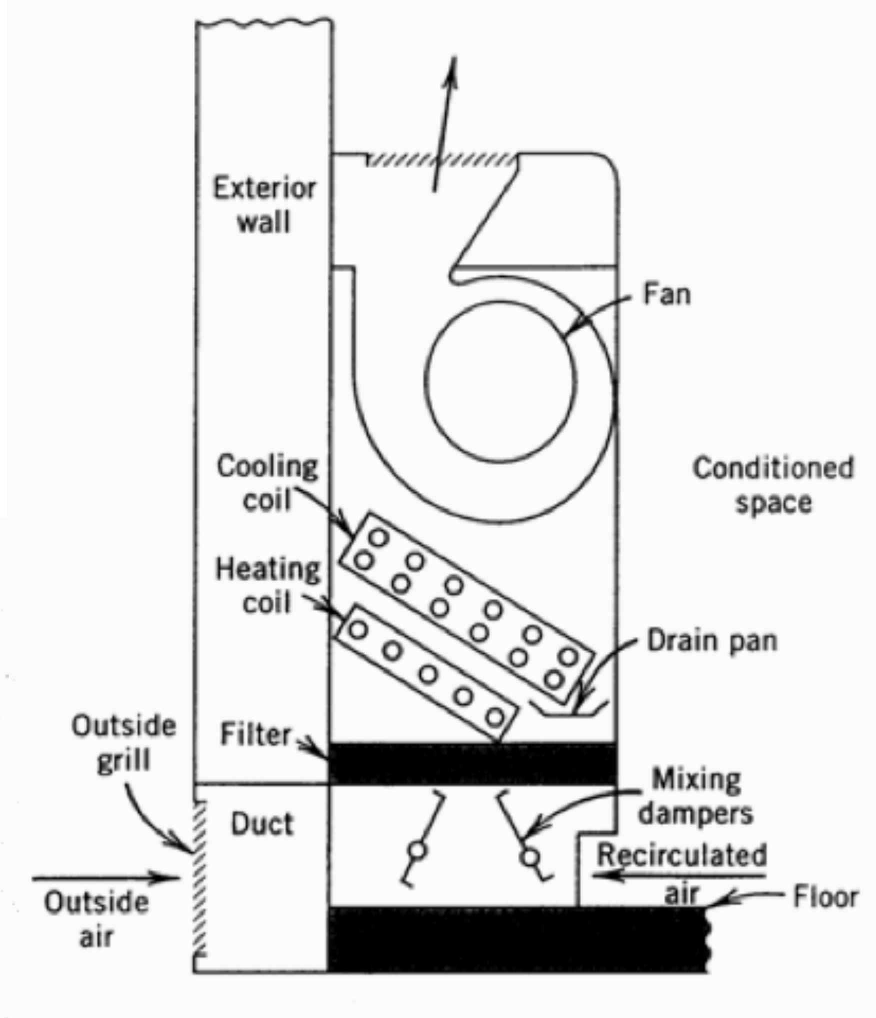
Wall installation

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

Next time

- Mechanical properties of HVAC systems