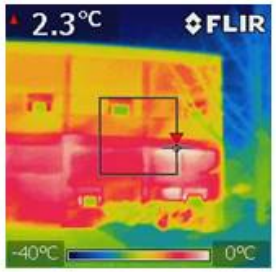
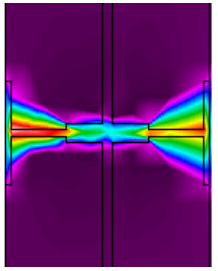
CAE 331/513 Building Science

Fall 2015





Week 6: October 1, 2015

Mechanical systems and psychrometric processes

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Scheduling update

- HW 3 due today
- Exam 1 is 2 weeks from today (Oct 15)
- I will not be here Tues Oct 13, Thurs Oct 15, or Tues Oct 20
  - Exam review with TA on Tues Oct 13
  - Guest lecture on Tues Oct 20

Wet-bulb temperature, T_{wb} (SI units)

- Wet-bulb temperature, T_{wb}
- Requires iterative solving… find the T_{wb} that satisfies the following equation (above freezing):

$$W = \frac{(2501 - 2.326T_{wb})W_{s@T_{wb}} - 1.006(T - T_{wb})}{2501 + 1.86T - 4.186T_{wb}} = \text{actual } W$$

- And for T below freezing:

$$W = \frac{(2830 - 0.24T_{wb})W_{s@T_{wb}} - 1.006(T - T_{wb})}{2830 + 1.86T - 2.1T_{wb}} = \text{actual } W$$

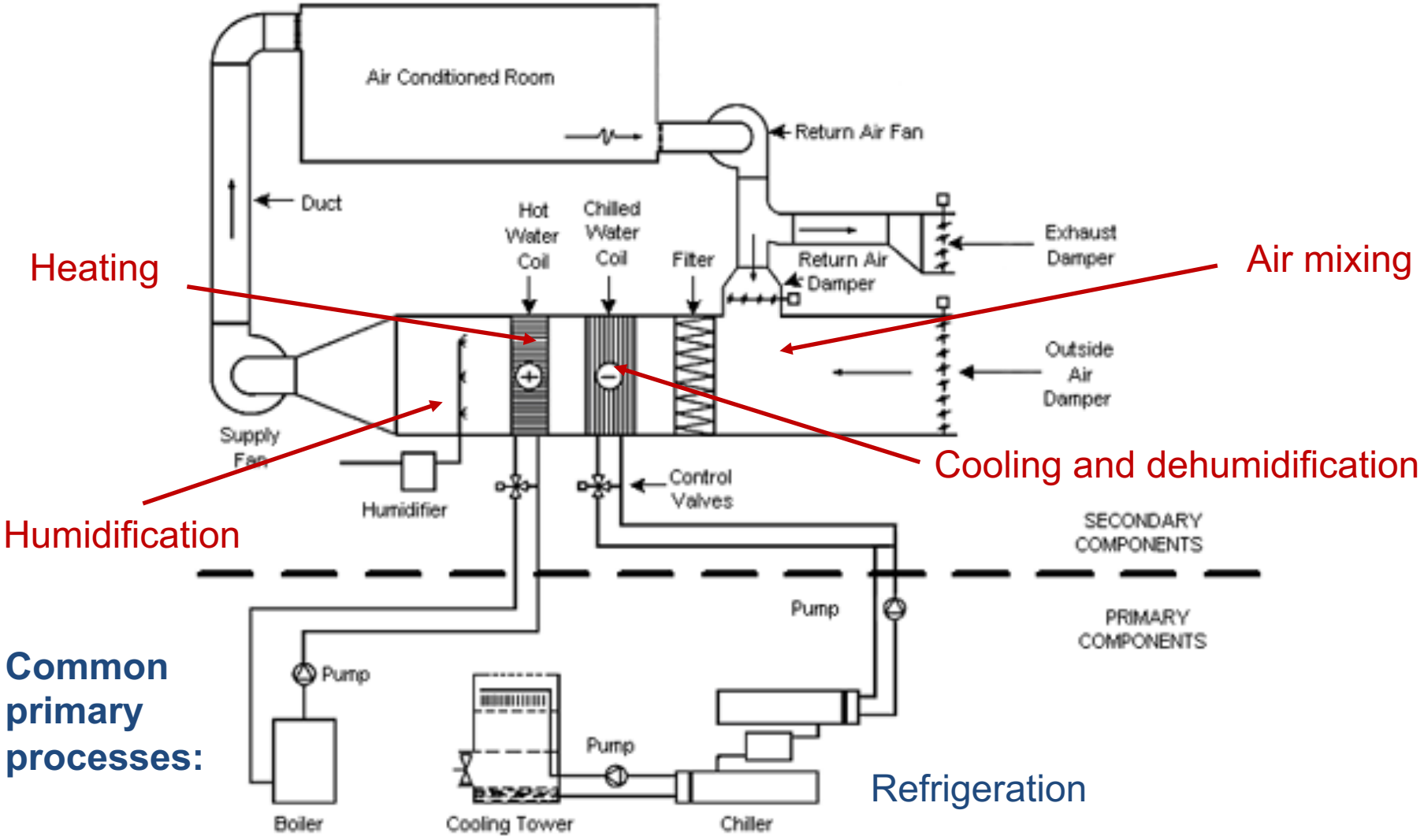
*Where T_{wb} and T are in **Celsius** ← **Correction from previous slides**

Review from last time

- Psychrometric equations examples (SI and IP units)
- Began an overview of HVAC systems and typical components and processes involved
- **Today:** continue HVAC overview and understand psychrometric processes

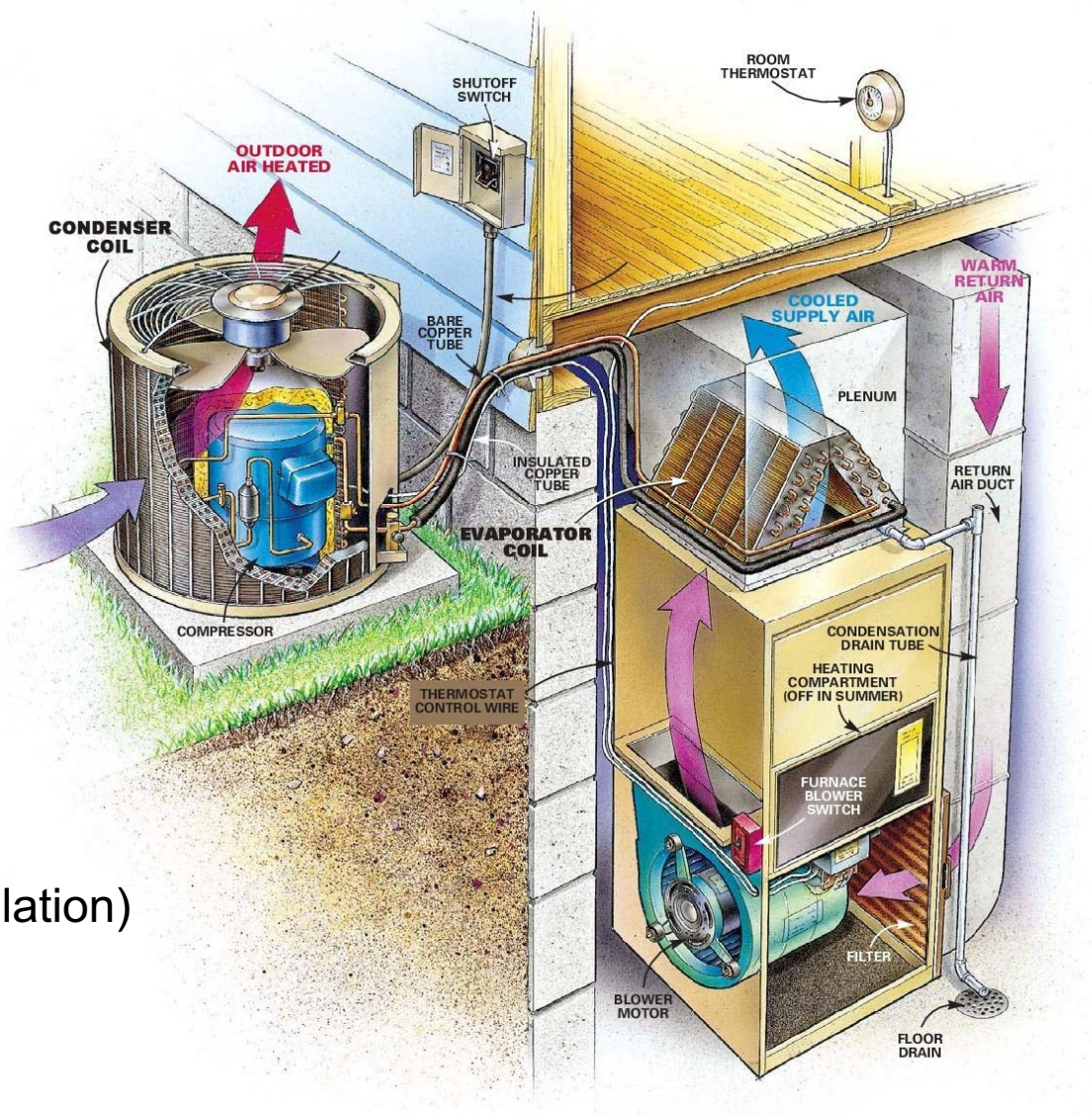
Primary and secondary components of HVAC

Some common psychrometric processes:

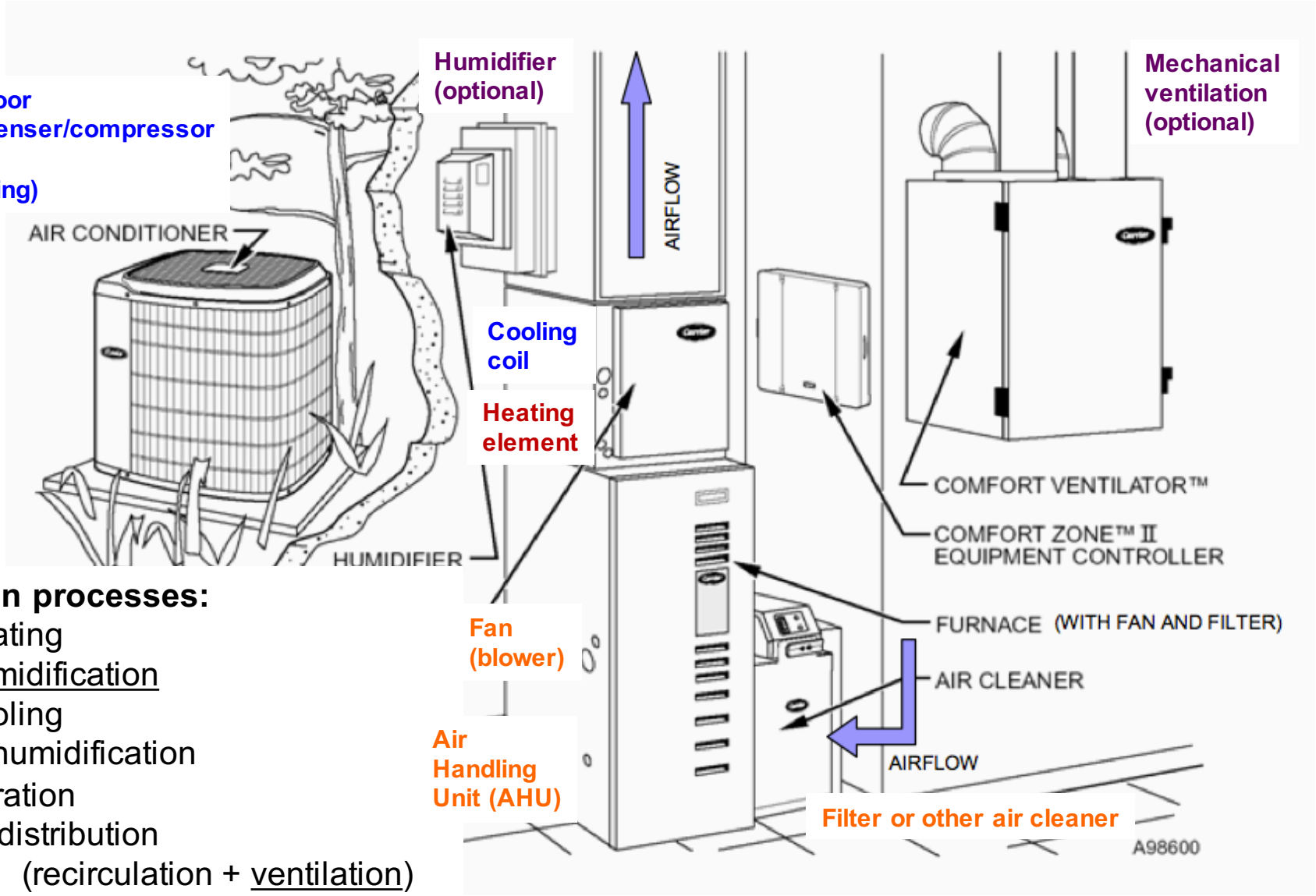


Typical central residential system

Main processes:
Heating
Cooling
Dehumidification
Filtration
Air distribution (recirculation)
On/off control



Typical central residential system w/ upgrades



Main processes:

Heating

Humidification

Cooling

Dehumidification

Filtration

Air distribution

(recirculation + ventilation)

On/off control (or variable control)

Typical large central commercial AHUs

Air Handling Unit (AHU)

Typical large central commercial systems

Center for Care and Discovery
University of Chicago Medicine

Typical large central commercial systems

Typical large central commercial systems

Typical large central commercial systems

PSYCHROMETRIC PROCESSES

Use of the psychrometric chart for *processes*

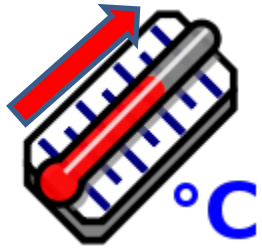
We can use the psychrometric chart (and equations) not only to describe states of moist air, but for a number of **processes** that are important for building science and HVAC applications

Examples:

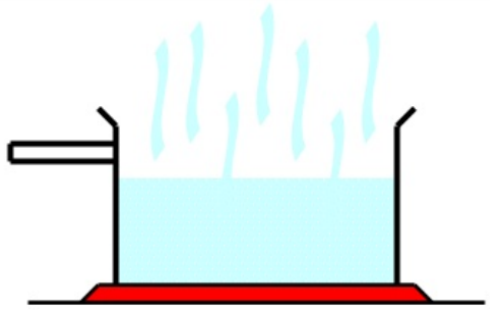
- Sensible cooling or heating
- Warming and humidification of cold, dry air
- Cooling and dehumidification of warm, humid air
  - Sensible + latent cooling
- Evaporative cooling
- Mixing of airstreams

Definitions: Sensible and latent heat

- **Sensible heat transfer**
  - Increase or decrease in temperature of a substance *without* undergoing a phase change



- **Latent heat transfer**
  - Heat transfer required to change the phase of a substance (e.g., heat required to change liquid to vapor)



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

Units of [W], [BTU/hr], or [ton]

Sensible and latent heat transfer equation

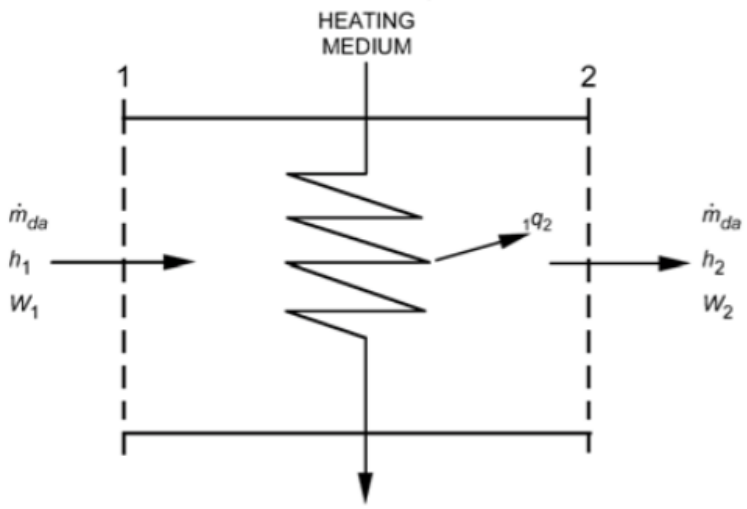


Fig. 2 Schematic of Device for Heating Moist Air

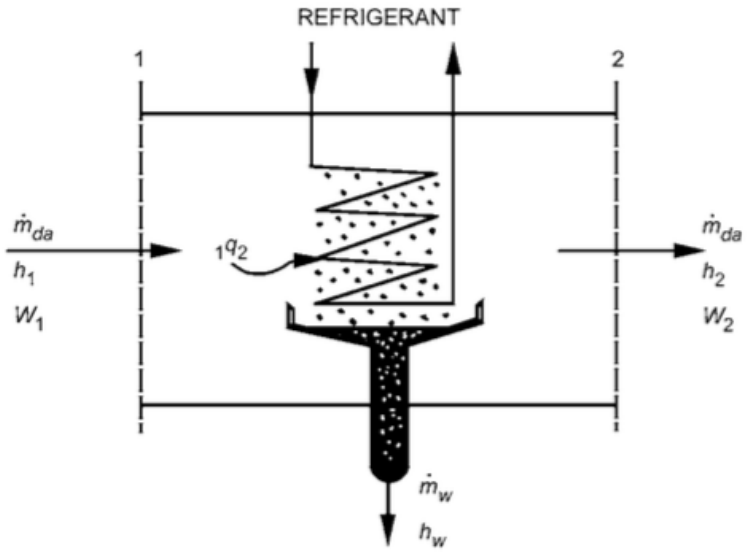


Fig. 3 Schematic of Device for Cooling Moist Air

Generic equations for both heating and cooling processes:

$$Q_{1\to2} = \dot{m}_{da}(h_2 - h_1) \qquad Q_{total} = \dot{m}\,(h_{exit} - h_{inlet})$$

$Q_{1\to2}$ = total rate of heat transfer from 1 to 2 (W or BTU/hr or ton)
$\dot{m}_{da}$ = mass flow rate of dry air (kg_{da}/s or lb_{da}/hr)
$h_{exit,2}$ = enthalpy at the exit (J/kg_{da} or BTU/lb_{da})
$h_{inlet,1}$ = enthalpy at the inlet (J/kg_{da} or BTU/lb_{da})

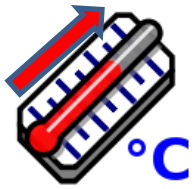
Sensible heat transfer equation

$$Q_{sensible} = \dot{m}_{da} C_p (T_{exit} - T_{inlet}) = \dot{V}_{da} \rho_{da} C_p (T_{exit} - T_{inlet})$$

$Q_{sensible}$ = rate of sensible heat transfer (W or BTU/hr or ton)
C_p = specific heat of air (J/kgK or BTU/lb°F)
ρ_{da} = dry air density (kg/m^3 or lb/ft^3)
T_{inlet} = inlet temperature (K or °F)
T_{exit} = exit temperature (K or °F)

For heating: $Q_{sensible} > 0$

For cooling: $Q_{sensible} < 0$



Latent heat transfer equation

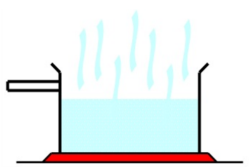
$$Q_{latent} = \dot{m}_w h_{fg}$$

$$Q_{latent} = \dot{m}_{da}(W_{exit} - W_{inlet})h_{fg} = \dot{V}_{da}\rho_{da}\,(W_{exit} - W_{inlet})\,h_{fg}$$

Q_{latent} = rate of latent heat transfer (W or BTU/hr or ton)
m_w = mass flow rate of water vapor (kg_w/s or lb_w/hr)
h_{fg} = enthalpy, or latent heat, of vaporization (J/kg or BTU/lb)
$* h_{fg}$ = 2260 kJ/kg or 970 BTU/lb for water
$\dot{W}_{inlet}$ = inlet humidity ratio (kg_w/kg_{da} or lb_w/lb_{da})
W_{exit} = exit humidity ratio (kg_w/kg_{da} or lb_w/lb_{da})

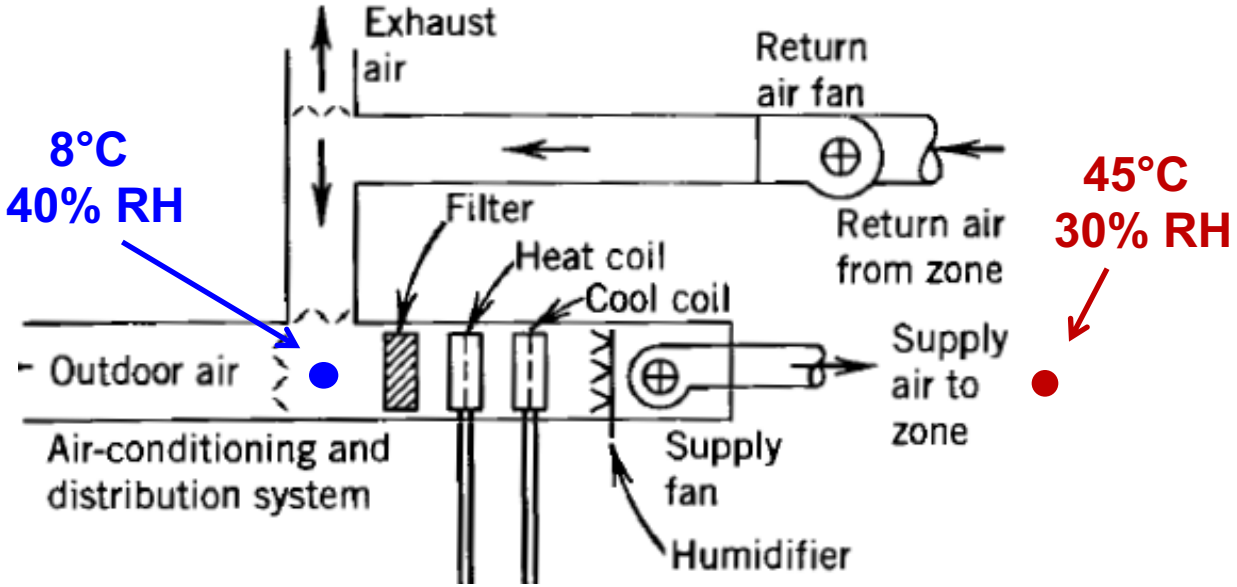
For humidification: $Q_{latent} > 0$

For dehumidification: $Q_{latent} < 0$



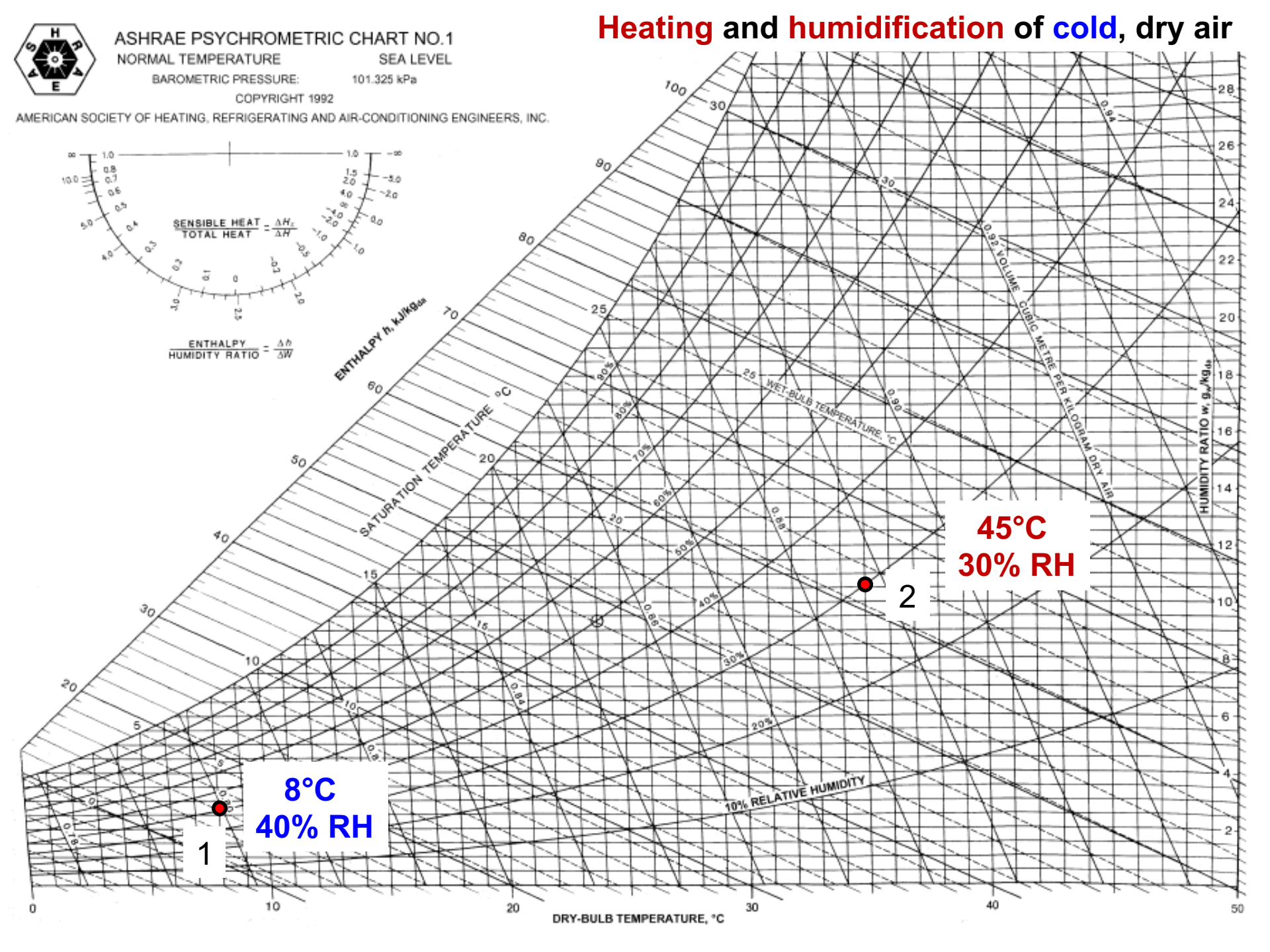
Heating and humidification of cold, dry air

- Example: Heating and humidification
  - Process: Adding moisture and heat (sensible + latent heating)

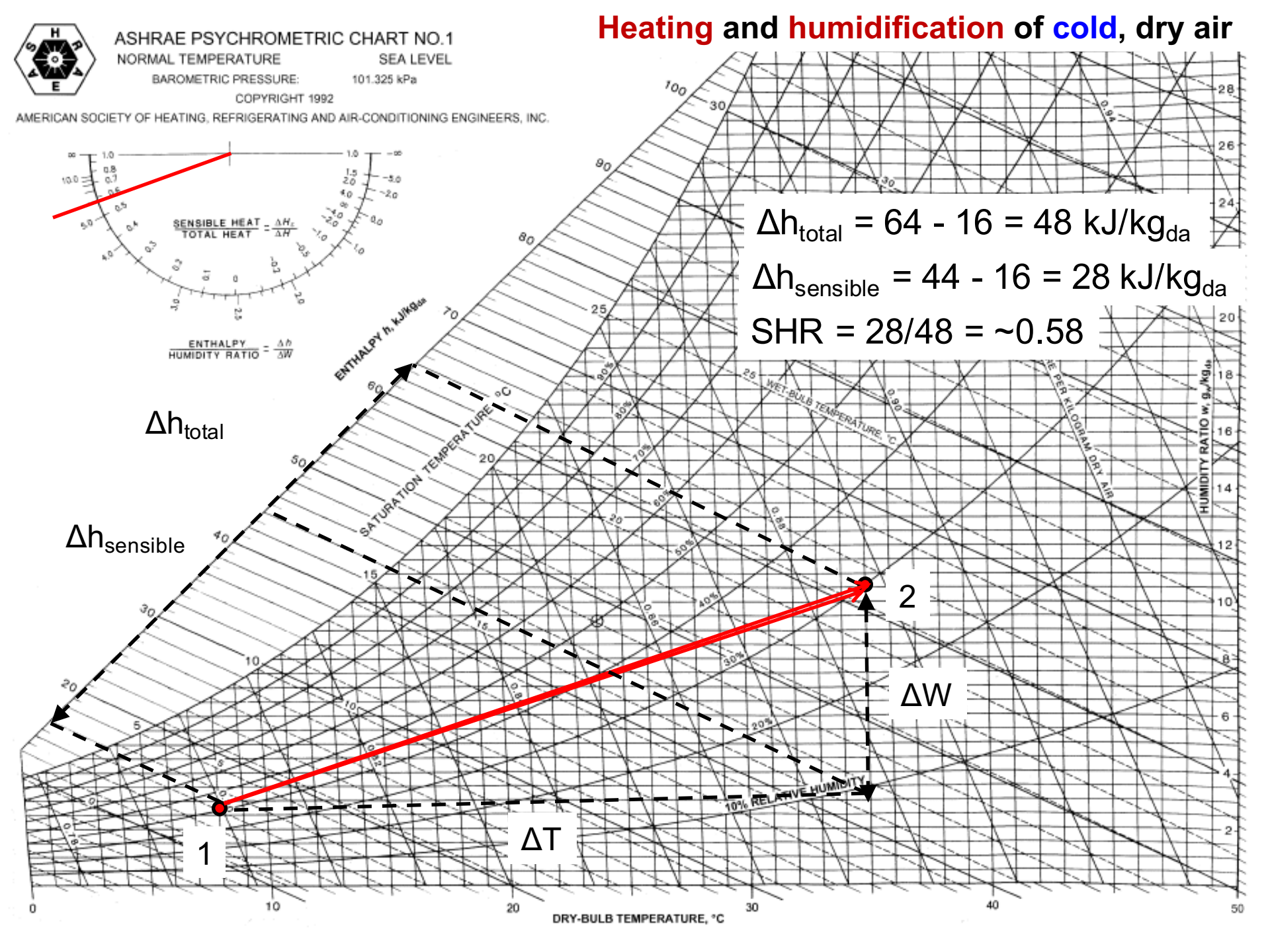


Q1: What is the enthalpy change required?
Q2: What is the total rate of heat transfer if the airflow rate is 10 m^3/s?
Q2: What is the split between sensible and latent transfer?

Heating and humidification of cold, dry air



Heating and humidification of cold, dry air

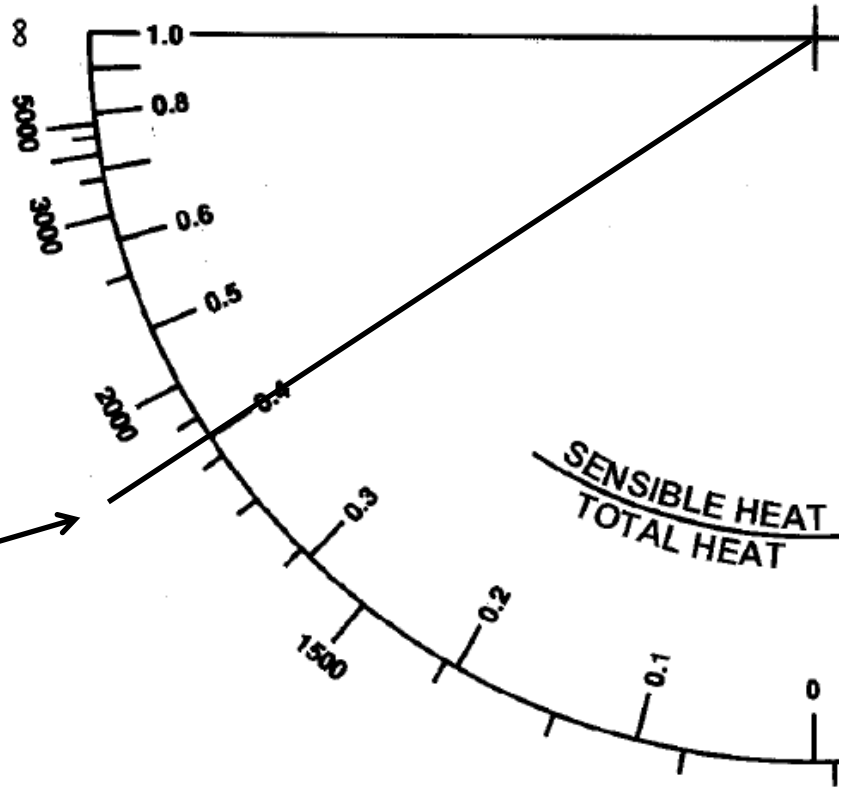


Sensible heat ratio (SHR)

- The **sensible heat ratio** is defined as:

$$SHR = \frac{\dot{q}_{sens}}{\dot{q}_{total}} = \frac{\dot{q}_{sens}}{\dot{q}_{sens} + \dot{q}_{latent}} = \frac{\Delta h_{sens}}{\Delta h_{total}}$$

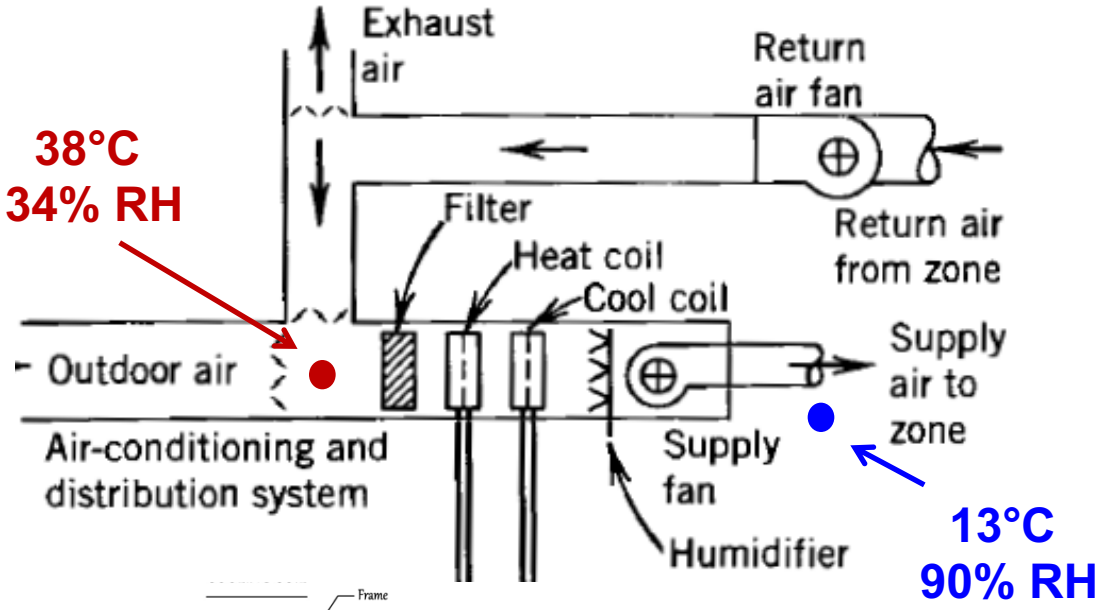
- Allows for understanding sensible load relative to latent load

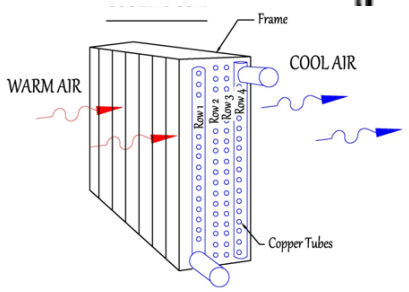


Here is a process with an SHR ≈ 0.4

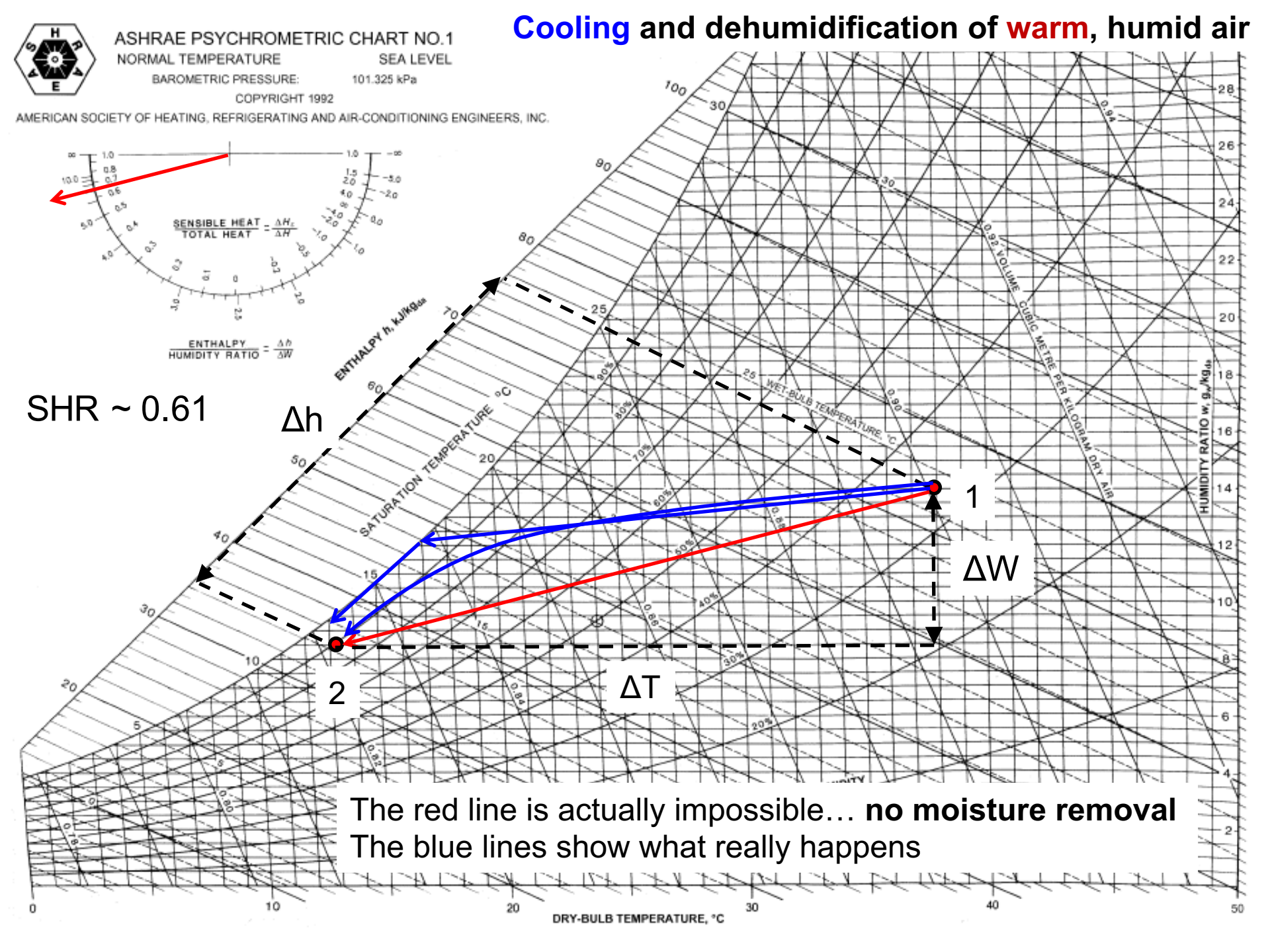
Cooling and dehumidification of warm, humid air

- Example: Cooling coil
- Removing both moisture and heat
  - Sensible + latent cooling





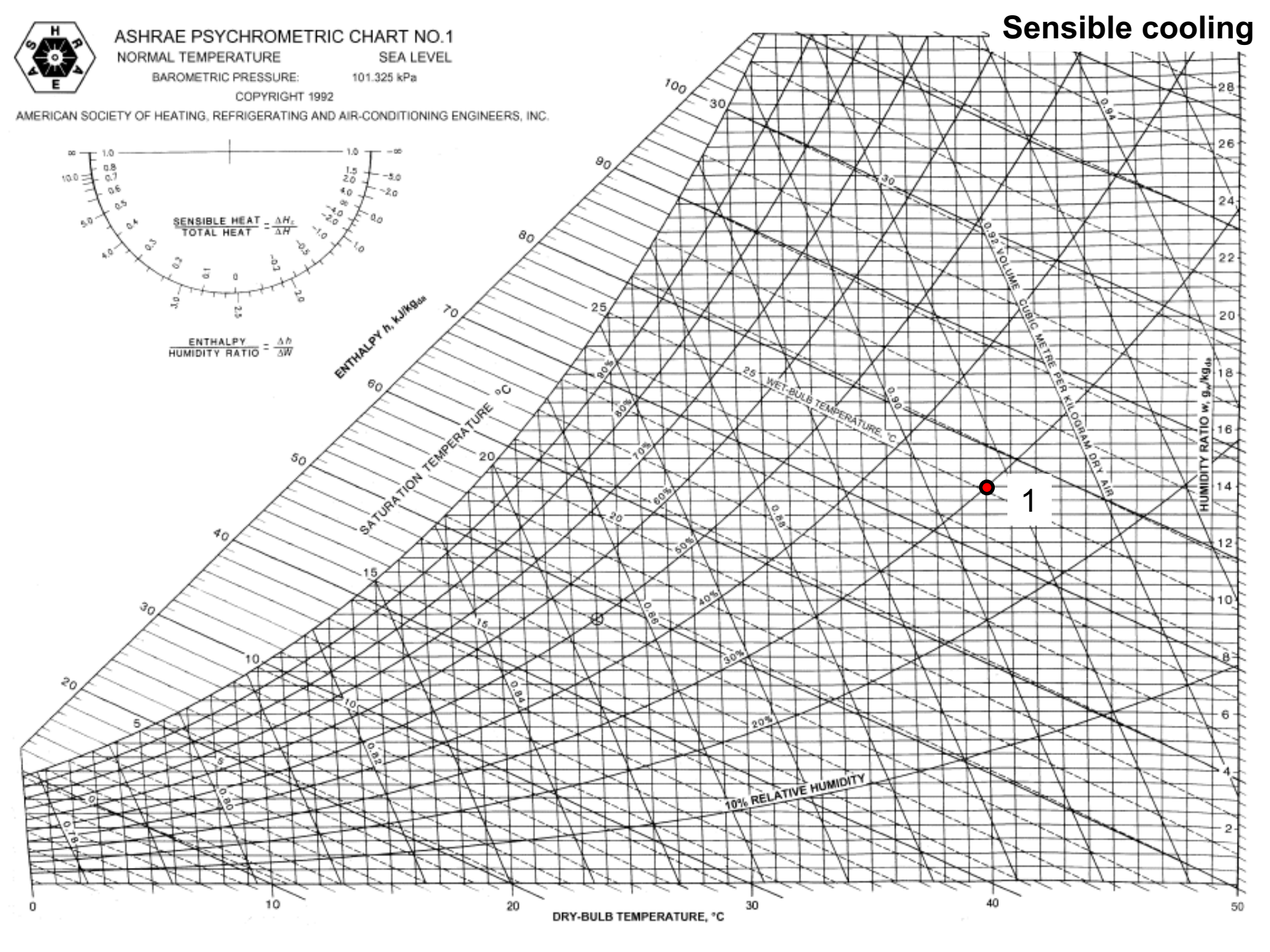
Cooling and dehumidification of warm, humid air



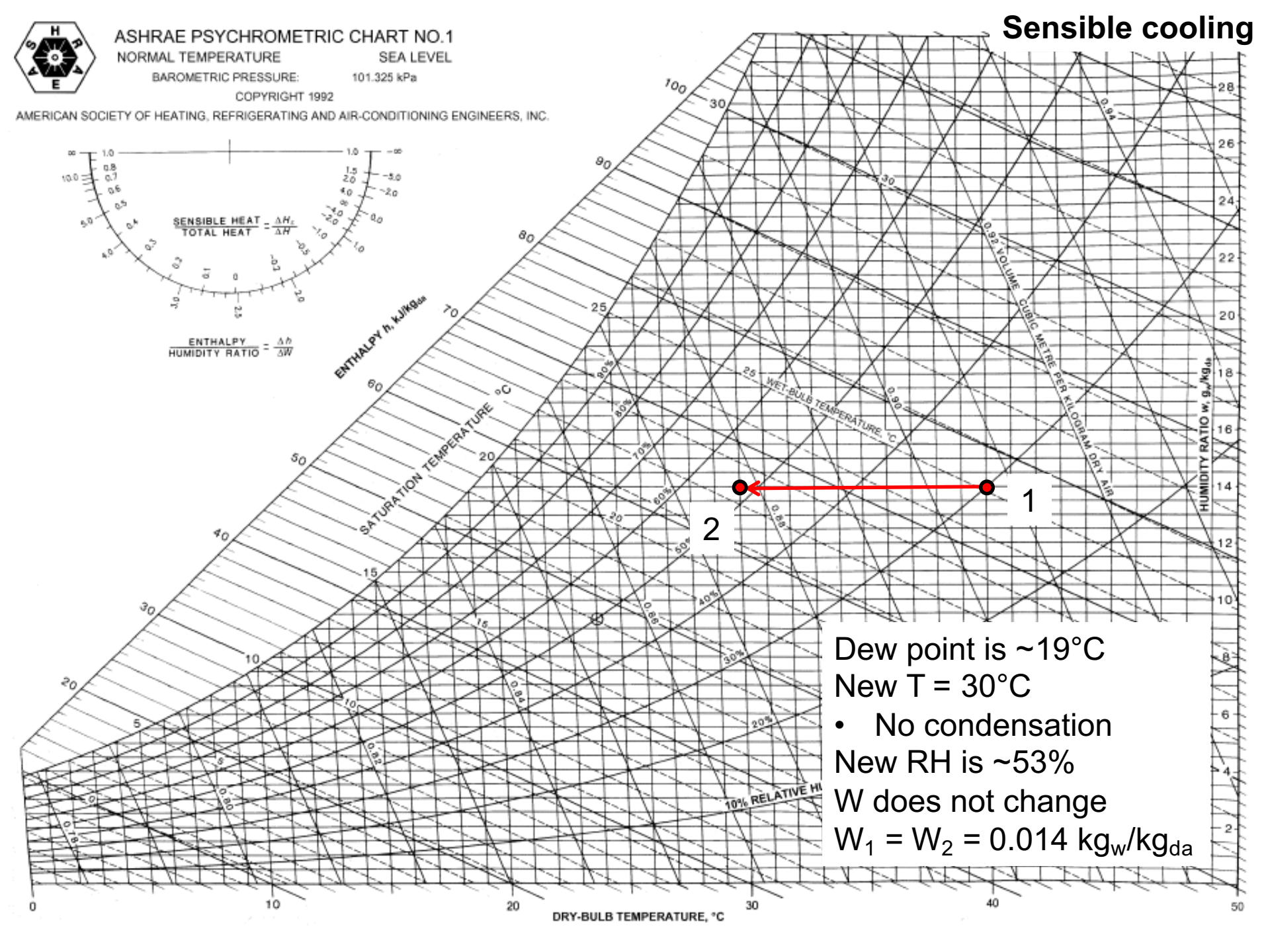
Example: *Sensible* cooling

- Moist air is cooled from 40°C and 30% RH to 30°C without condensation
  - What is the RH at W at the process end point?

Sensible cooling



Sensible cooling



Dew point is ~19°C

New T = 30°C

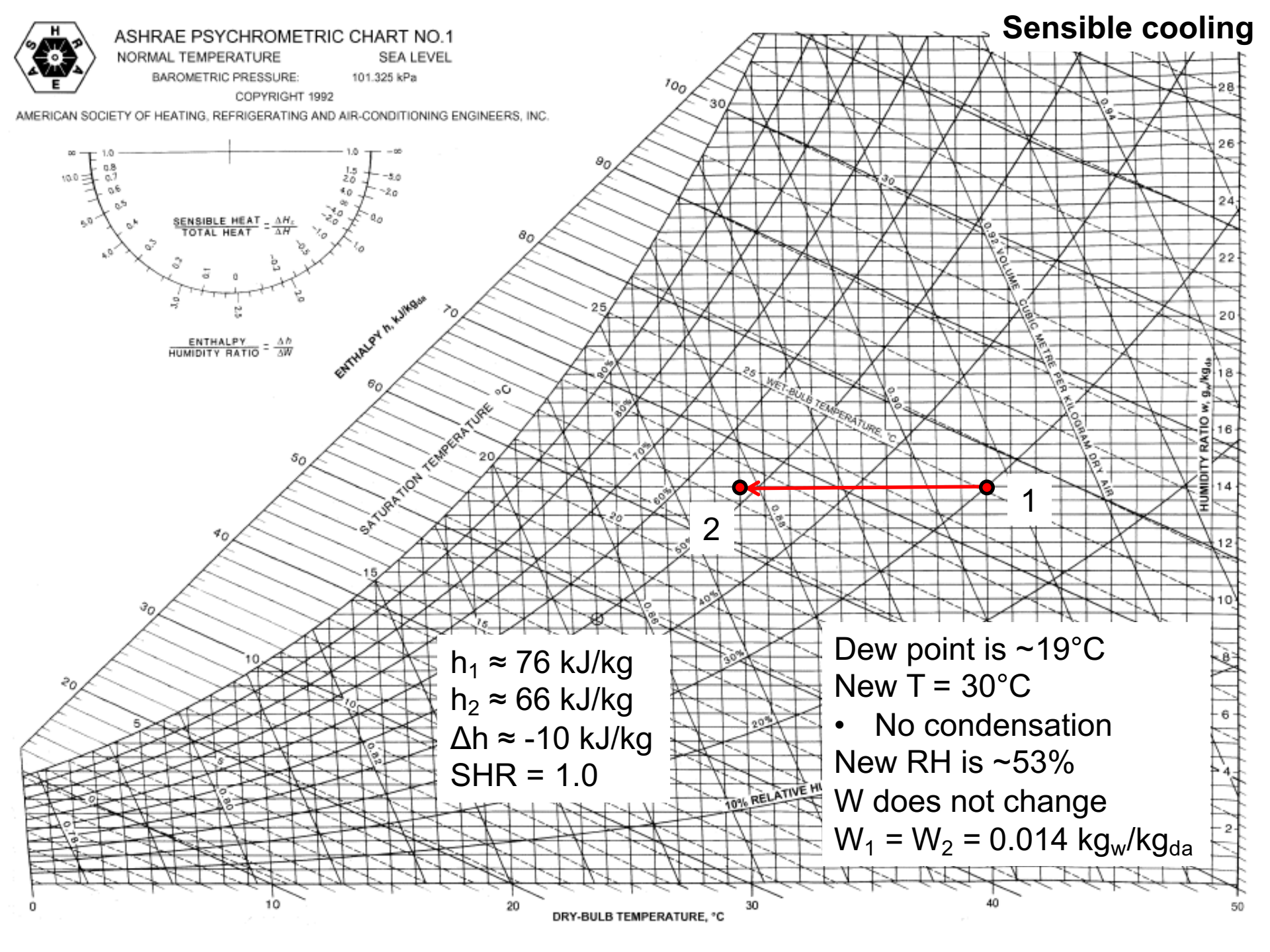
- No condensation

New RH is ~53%

W does not change

$W_1 = W_2 = 0.014\ kg_w/kg_{da}$

Sensible cooling



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

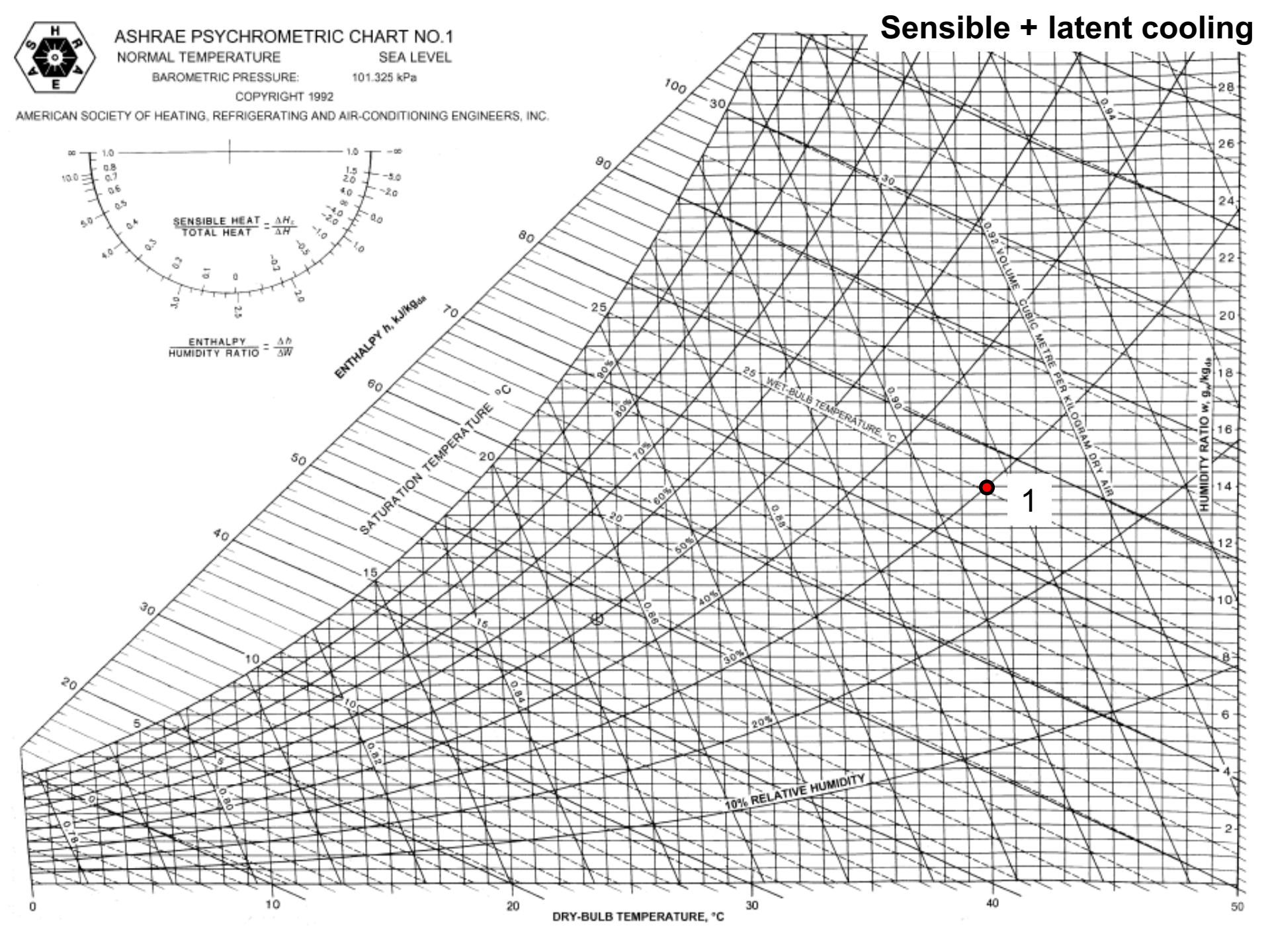
Dew point is ~19°C
New T = 30°C
- No condensation

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

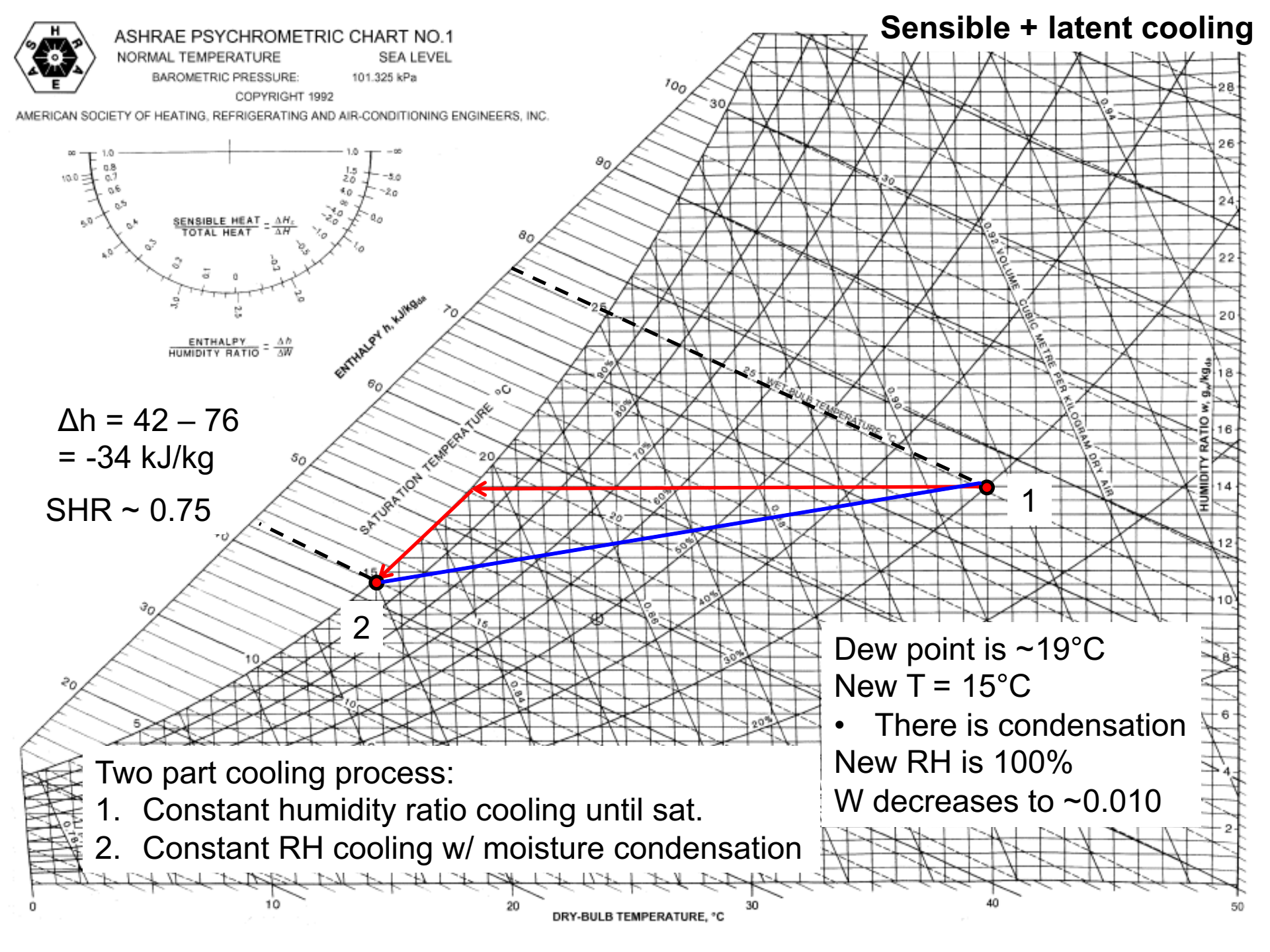
Example: *Sensible* + *latent* cooling

- Moist air is cooled from 40°C and 30% RH to 15°C
  - Q1: Does the moisture condense?
  - Q2: What is RH at W at the process end point?

Sensible + latent cooling



Sensible + latent cooling



$\Delta h = 42 - 76$
$= -34$ kJ/kg

SHR ~ 0.75

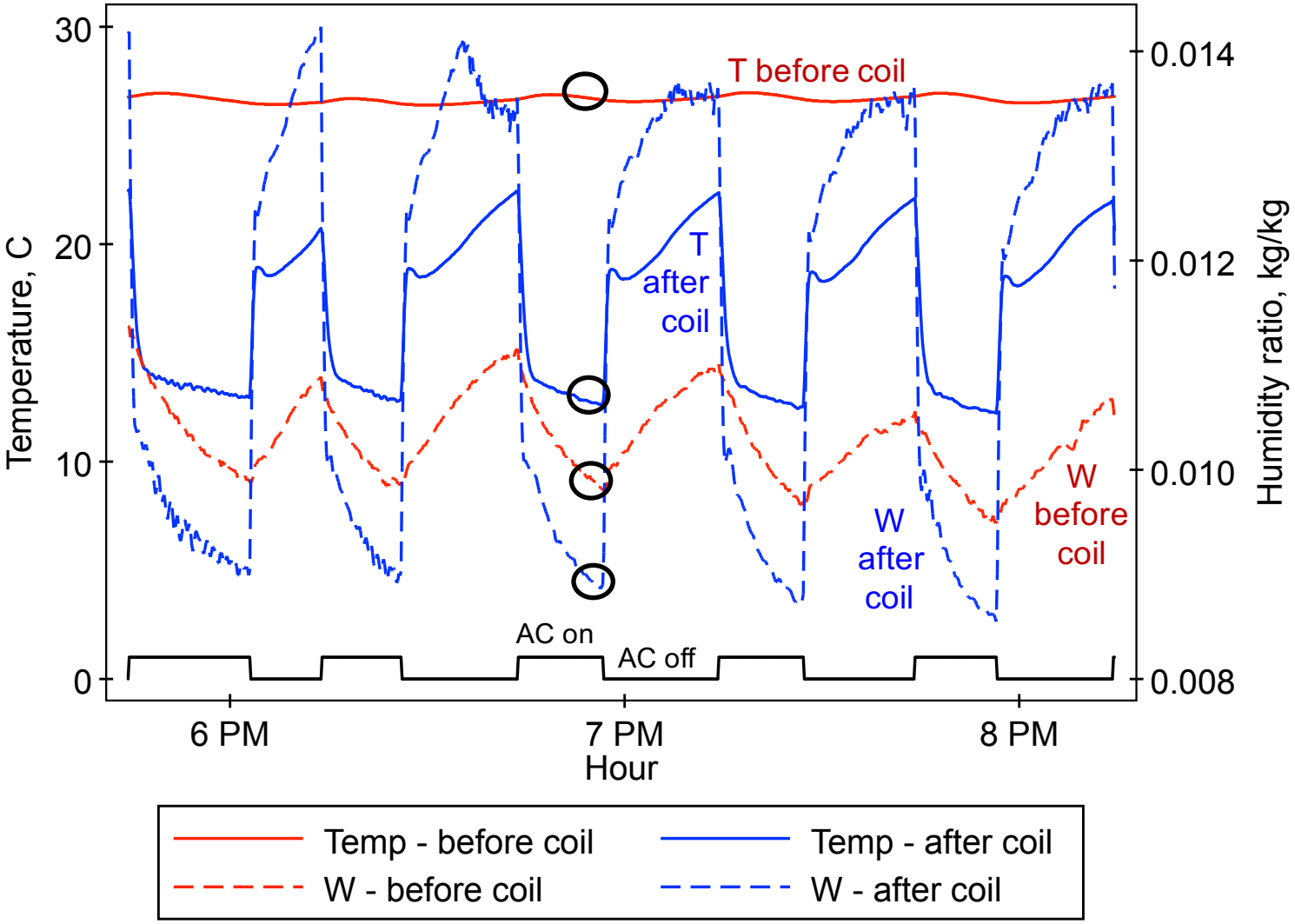
Dew point is ~19°C
New T = 15°C
- There is condensation

New RH is 100%
W decreases to ~0.010

Two part cooling process:
1. Constant humidity ratio cooling until sat.
2. Constant RH cooling w/ moisture condensation

Real data: ASHRAE RP-1299
Energy implications of filters

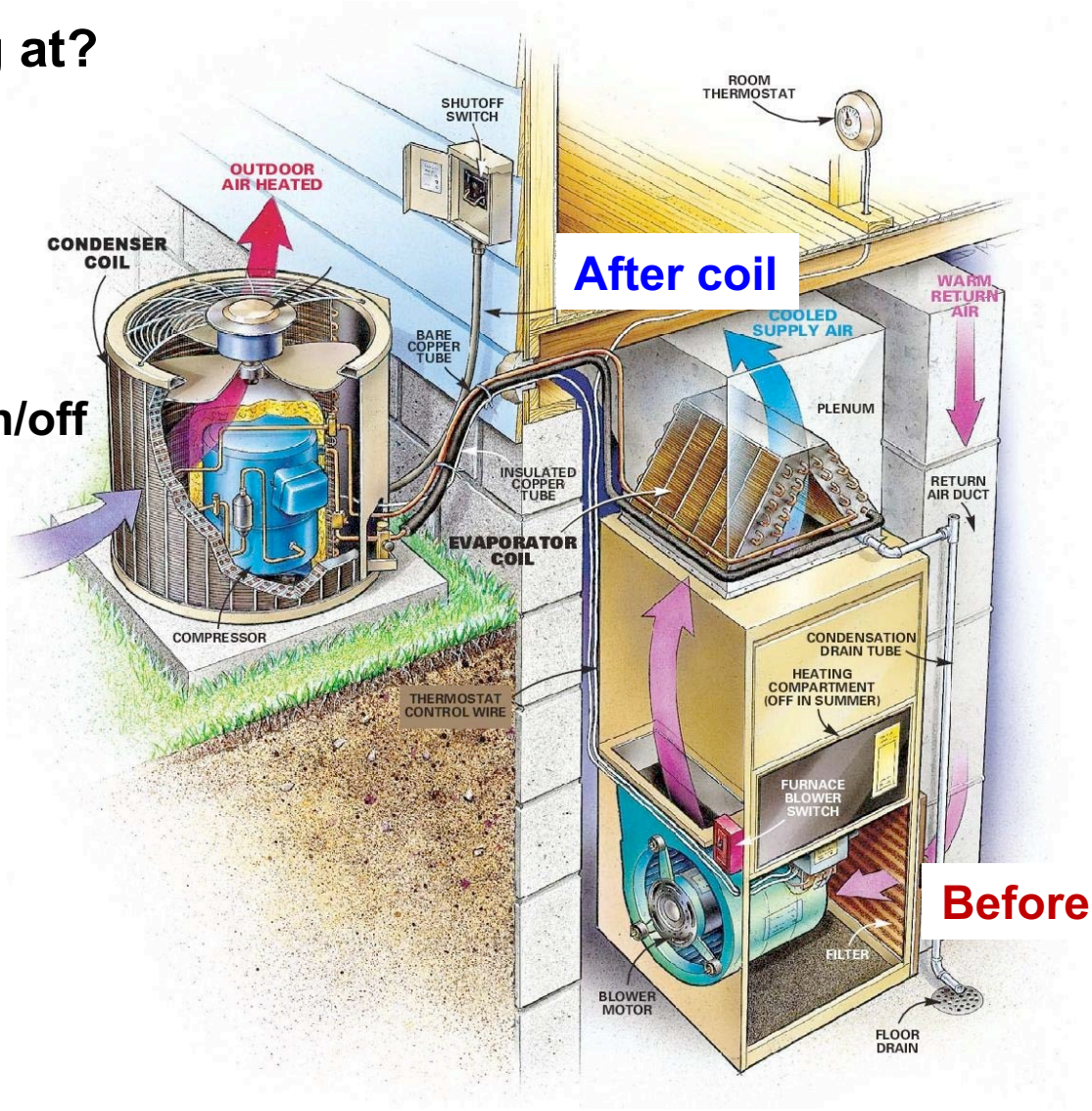
Temperature and humidity ratio differences across AC coils in homes



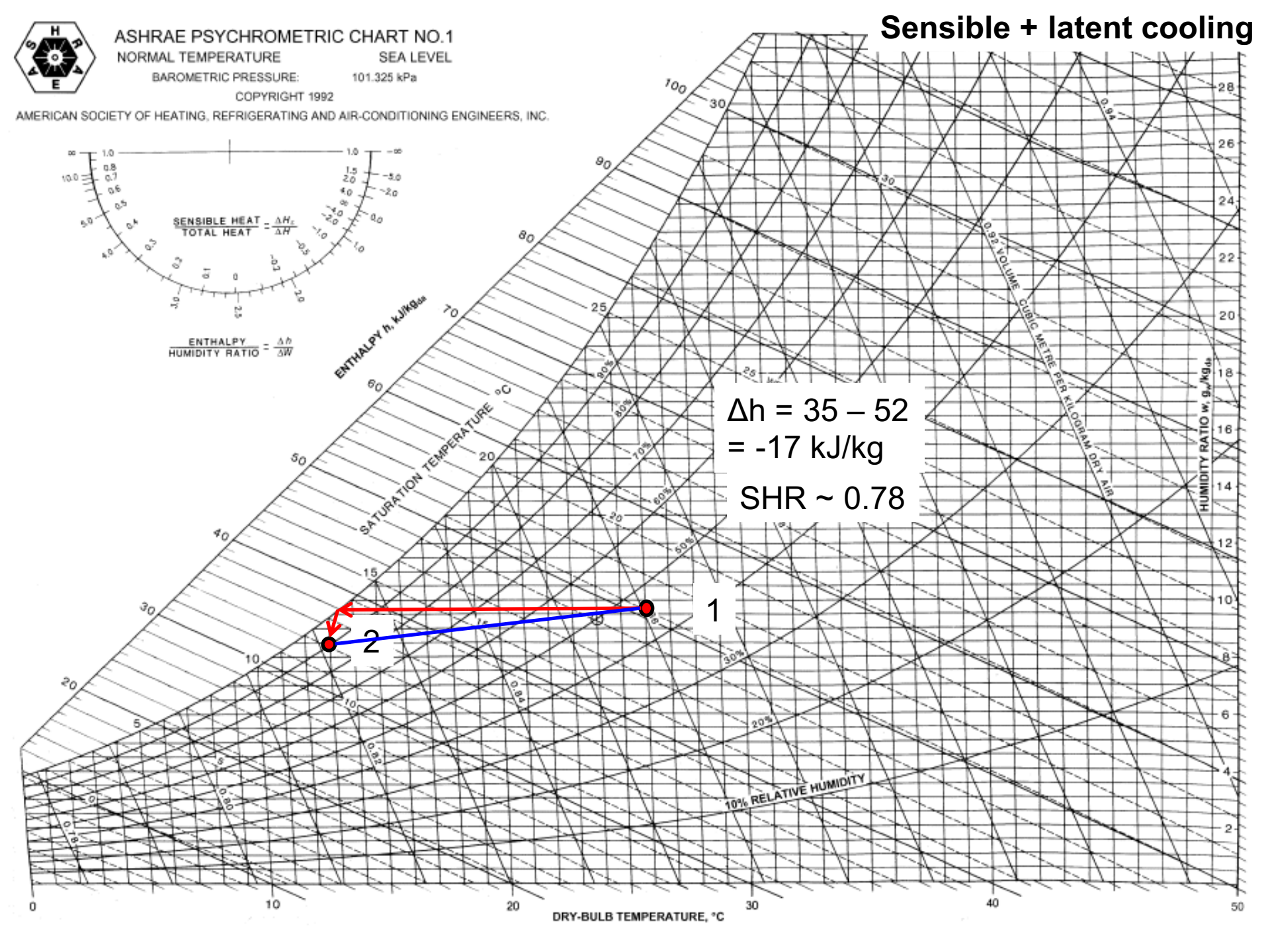
Real data: ASHRAE RP-1299
Energy implications of filters

What are we looking at?

AC on/off



Sensible + latent cooling



Mixing of air streams

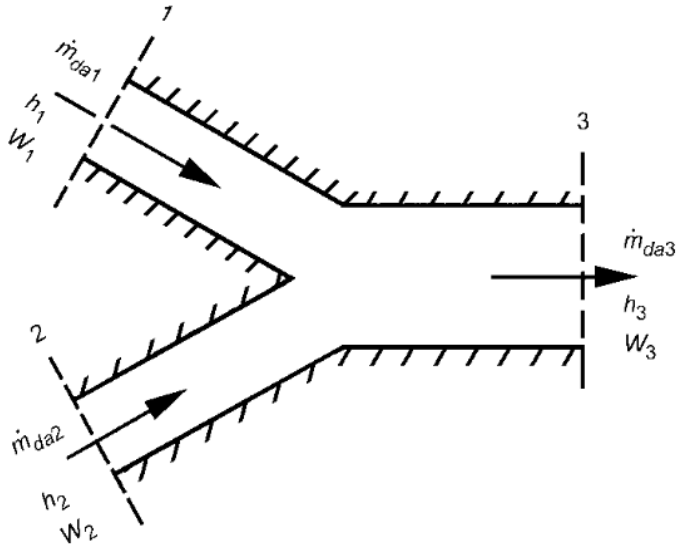
- Often in HVAC systems we mix airstreams adiabatically
  - **Adiabatically** = Without the addition or extraction of heat
  - e.g. outdoor air mixed with a portion of return/recirculated air

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

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

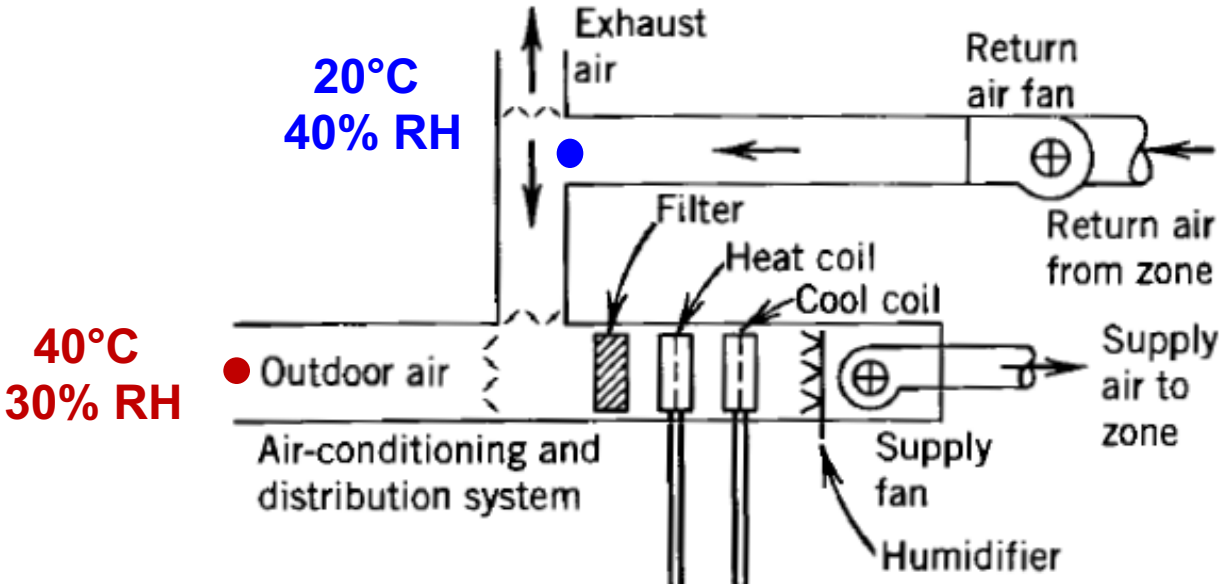
$$W_3 = \frac{\dot{m}_{da1} W_1 + \dot{m}_{da2} W_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

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

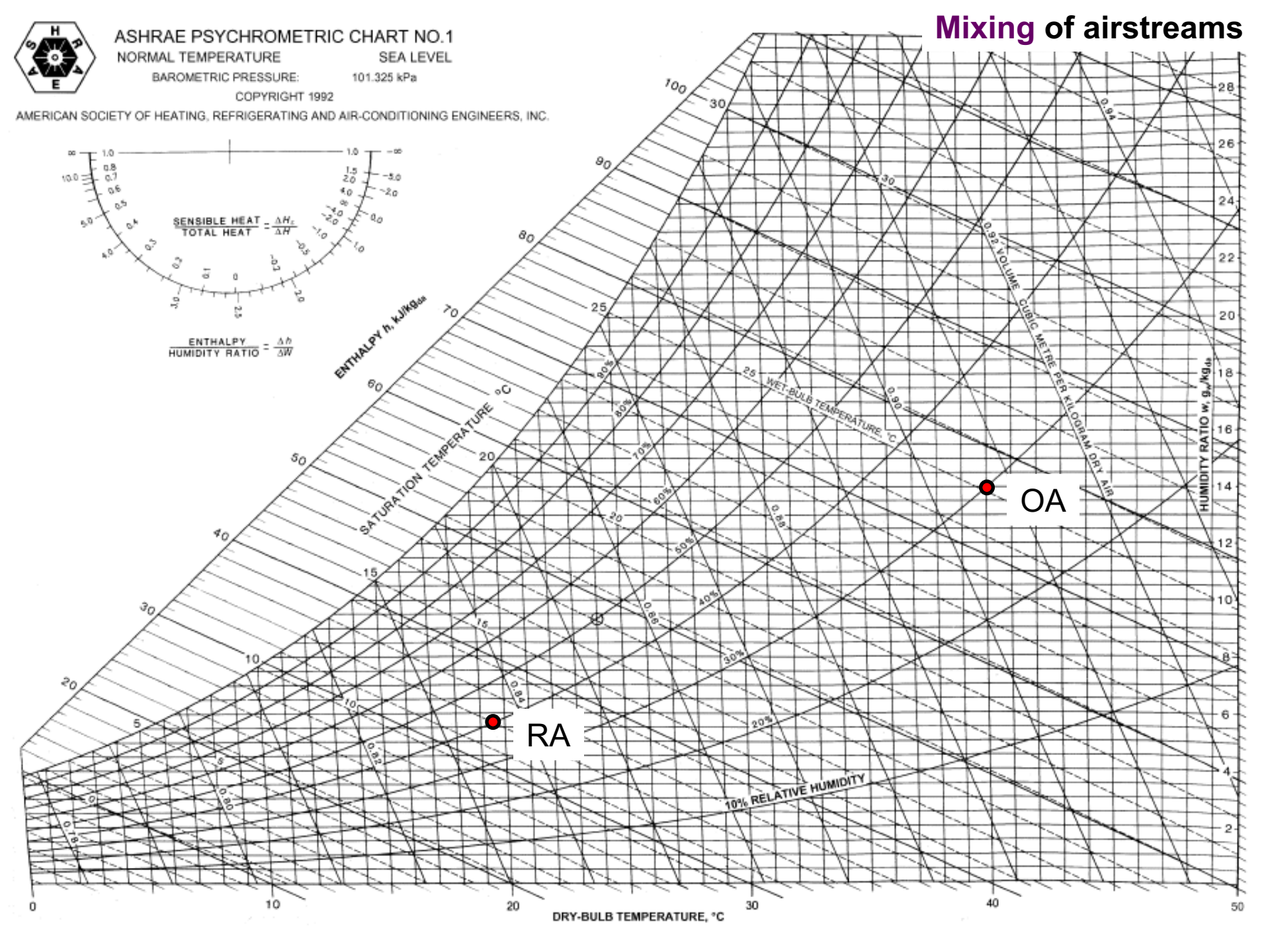


Mixing of airstreams example

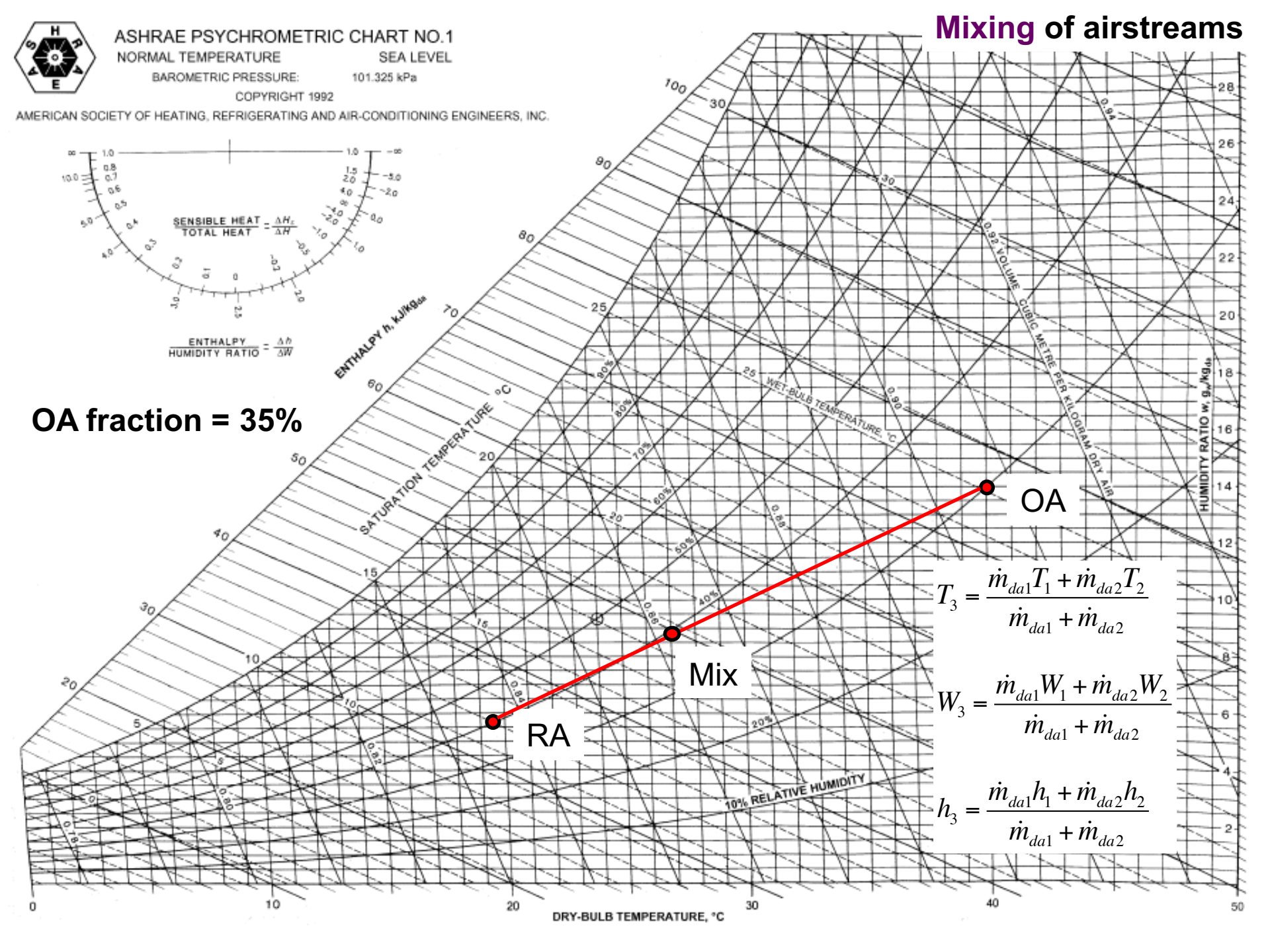
- Hot, humid outdoor air is mixed with recirculated indoor air at an outdoor air fraction of about 35%
  - Q1: What is T, W, RH, and h at the mixed condition?



Mixing of airstreams



Mixing of airstreams



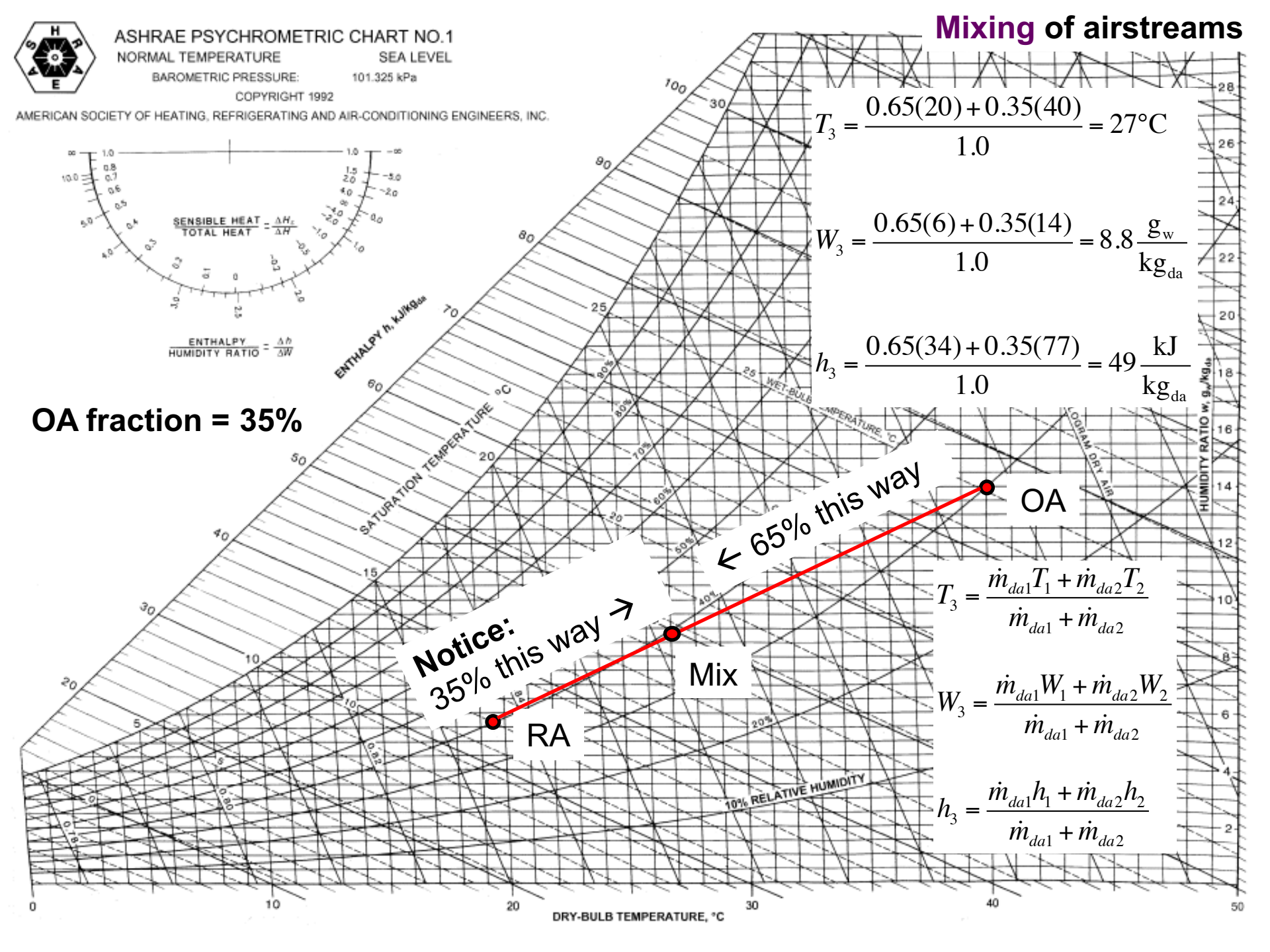
OA fraction = 35%

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

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

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

Mixing of airstreams



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

$$W_3 = \frac{0.65(6) + 0.35(14)}{1.0} = 8.8 \frac{\text{g}_\text{w}}{\text{kg}_\text{da}}$$

$$h_3 = \frac{0.65(34) + 0.35(77)}{1.0} = 49 \frac{\text{kJ}}{\text{kg}_\text{da}}$$

OA fraction = 35%

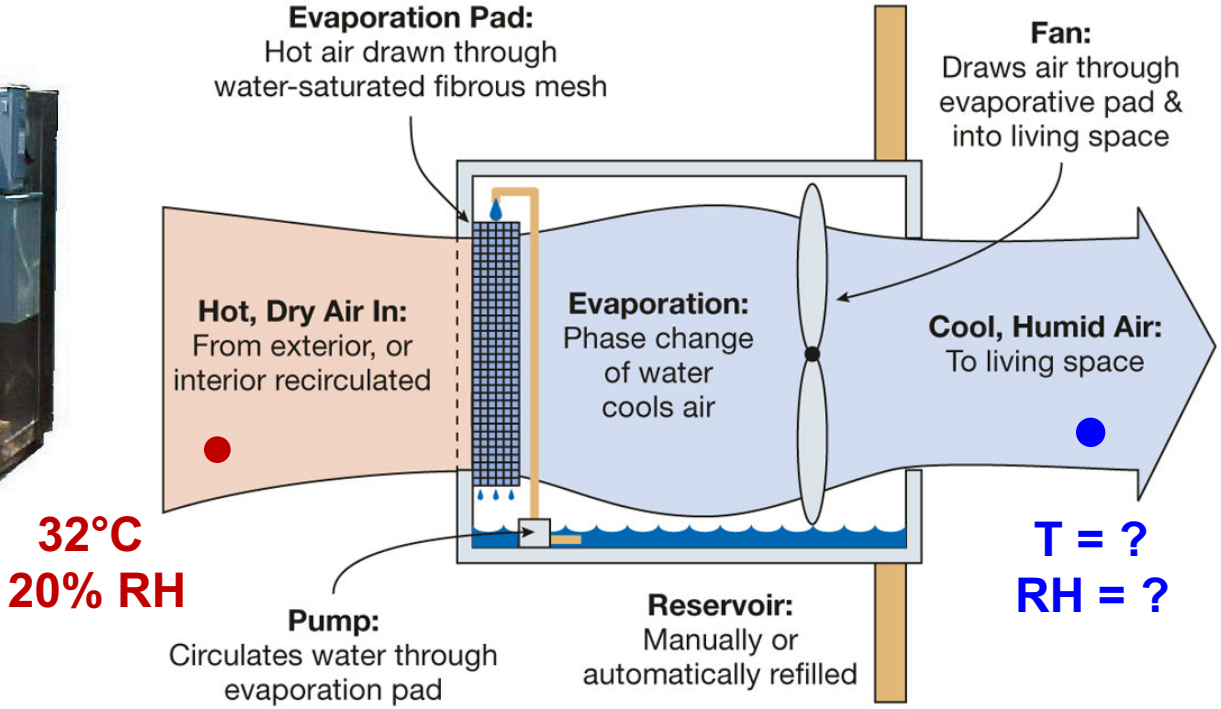
$$T_3 = \frac{\dot{m}_{da1} T_1 + \dot{m}_{da2} T_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

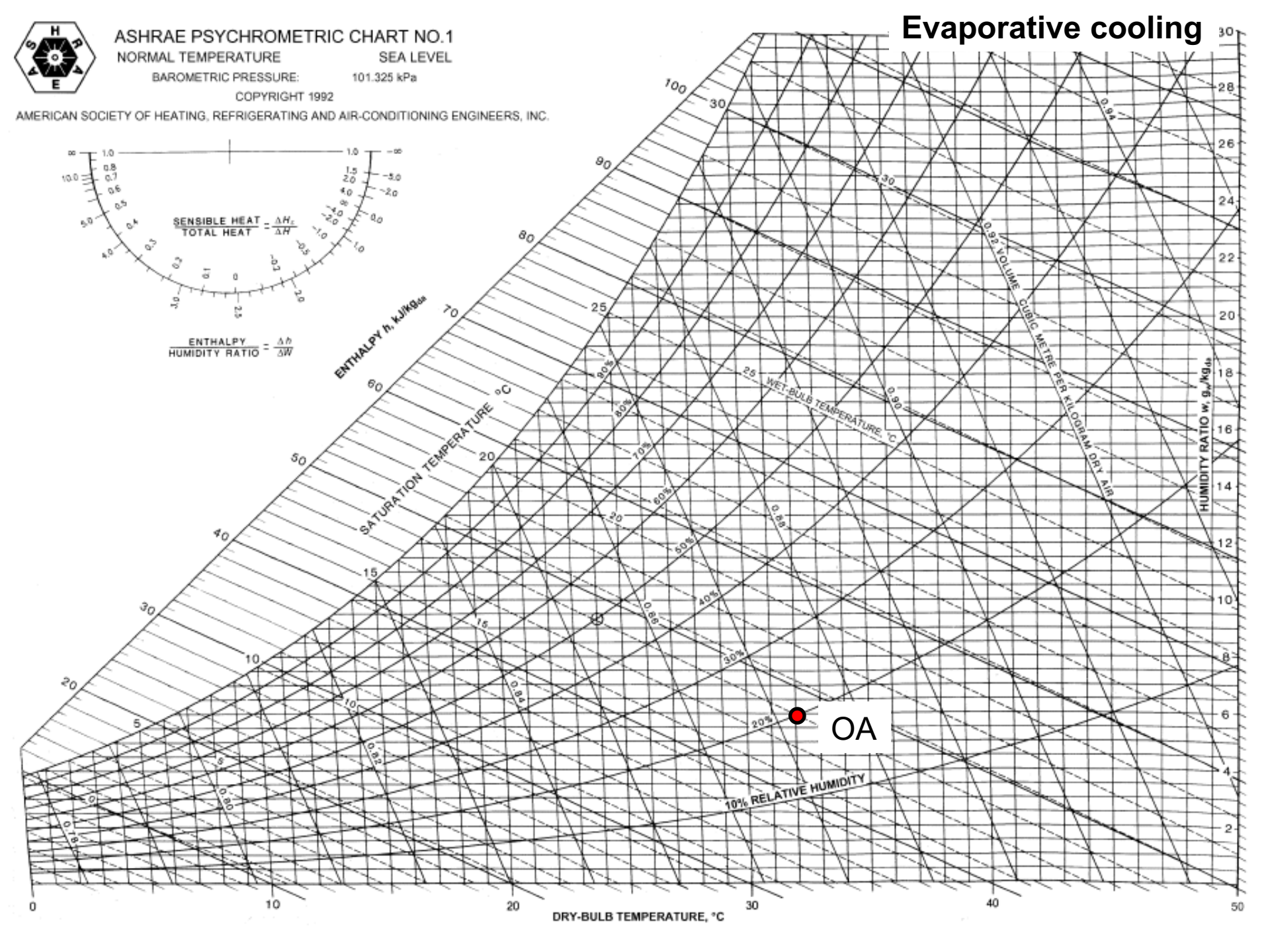
$$W_3 = \frac{\dot{m}_{da1} W_1 + \dot{m}_{da2} W_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

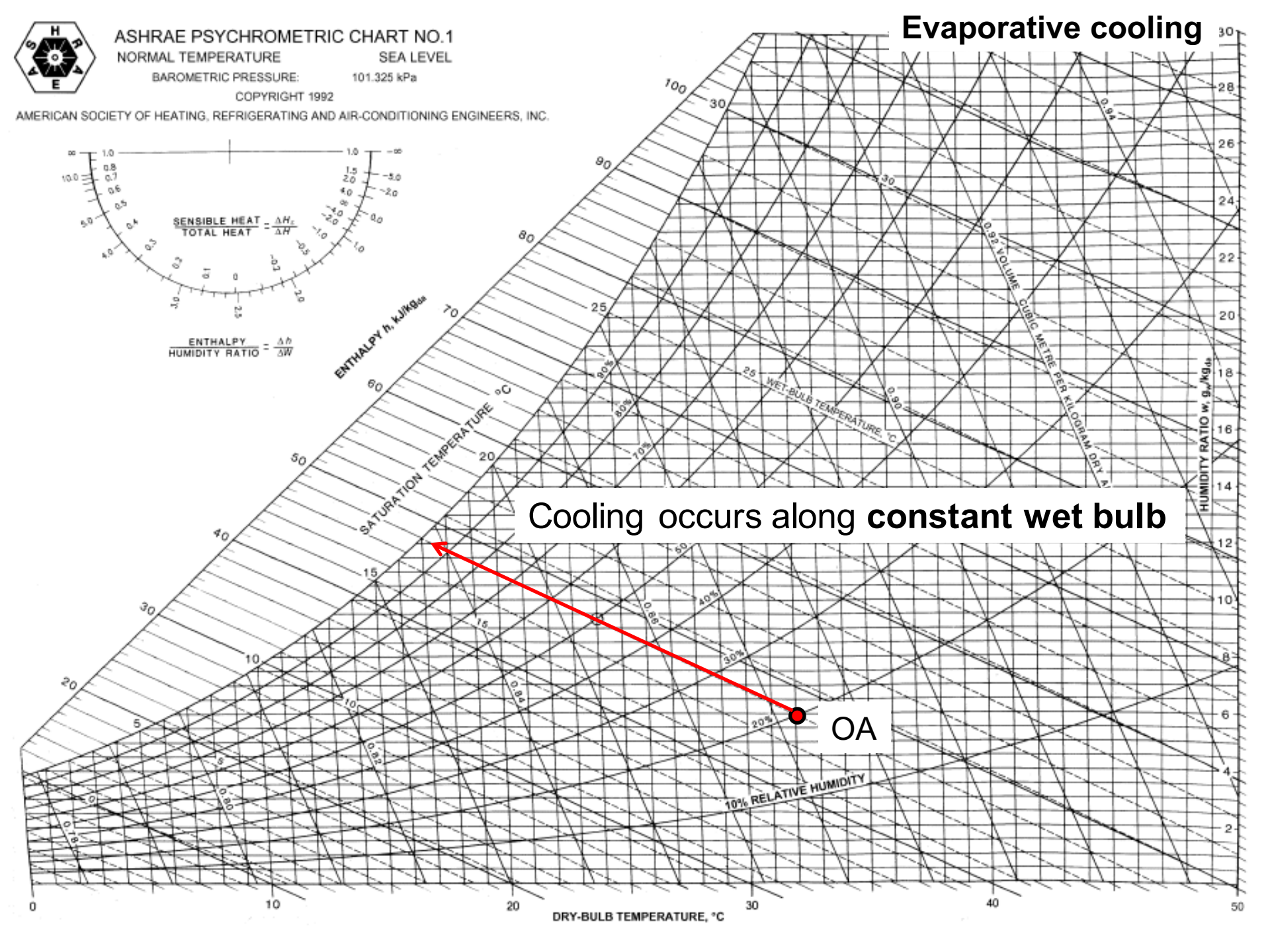
$$h_3 = \frac{\dot{m}_{da1} h_1 + \dot{m}_{da2} h_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

Evaporative cooling example

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




Evaporative cooling
ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔH_s / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg_da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
0.92 VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, g_w/kg_da
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
OA


Evaporative cooling
ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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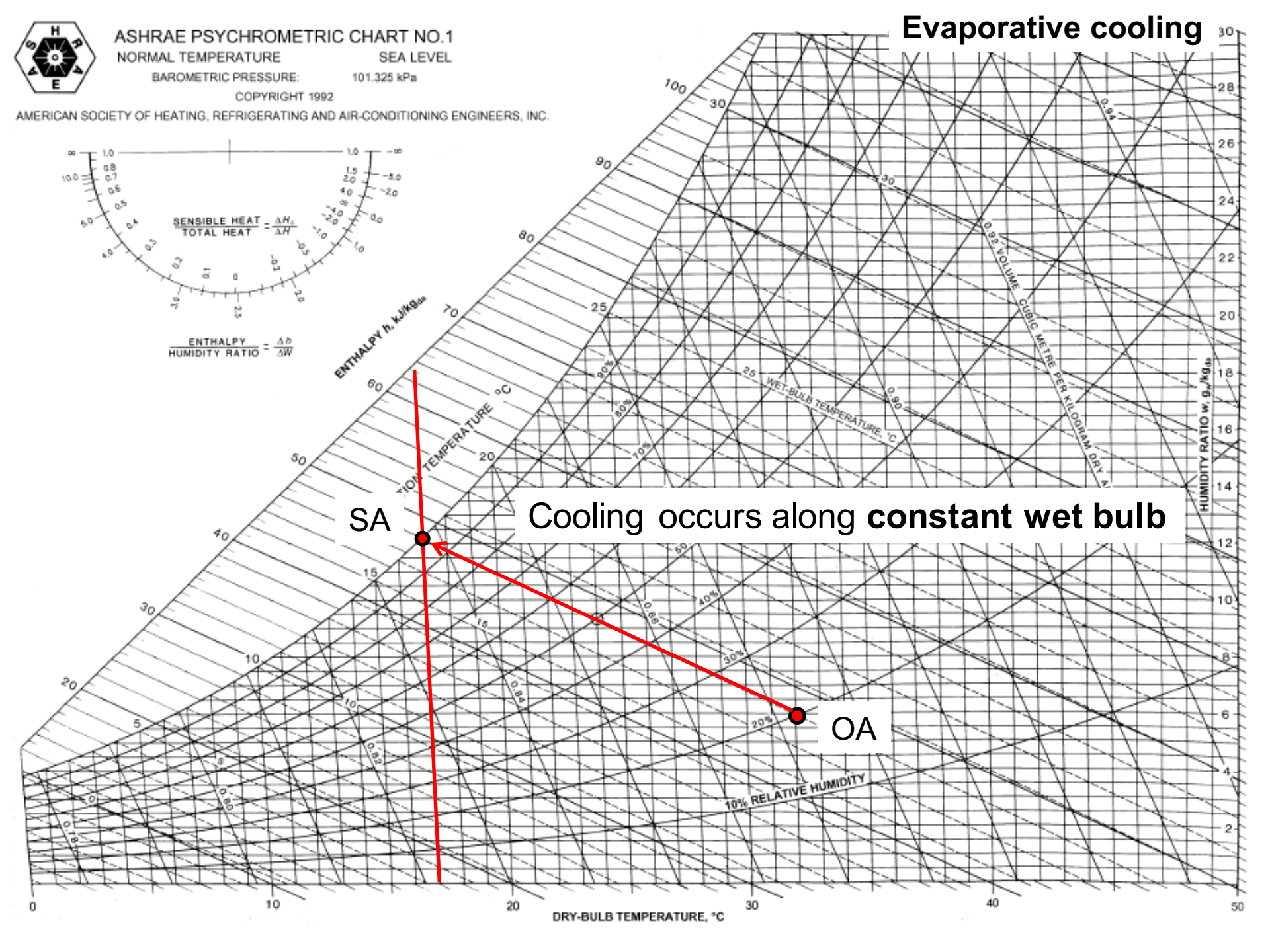
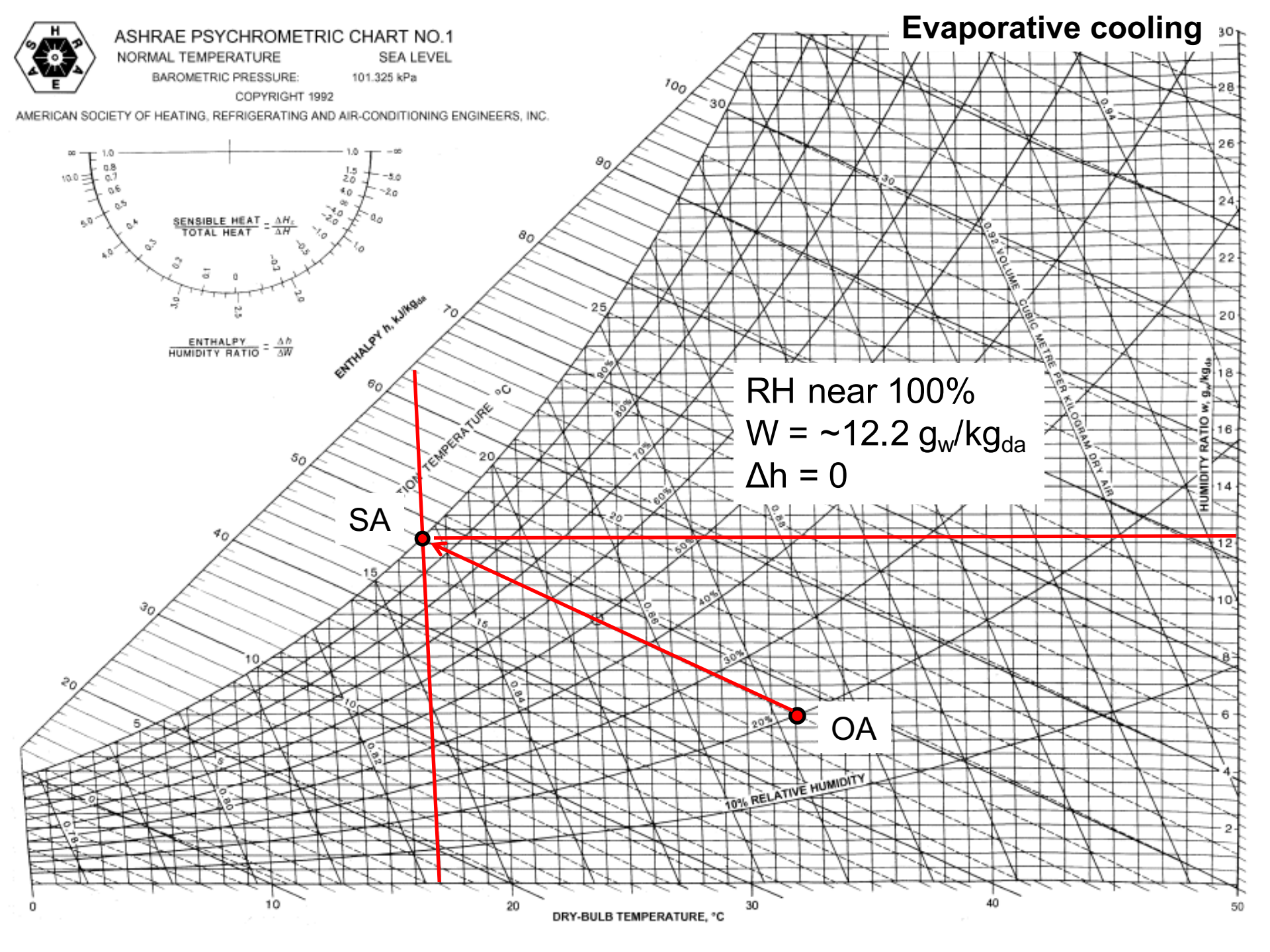
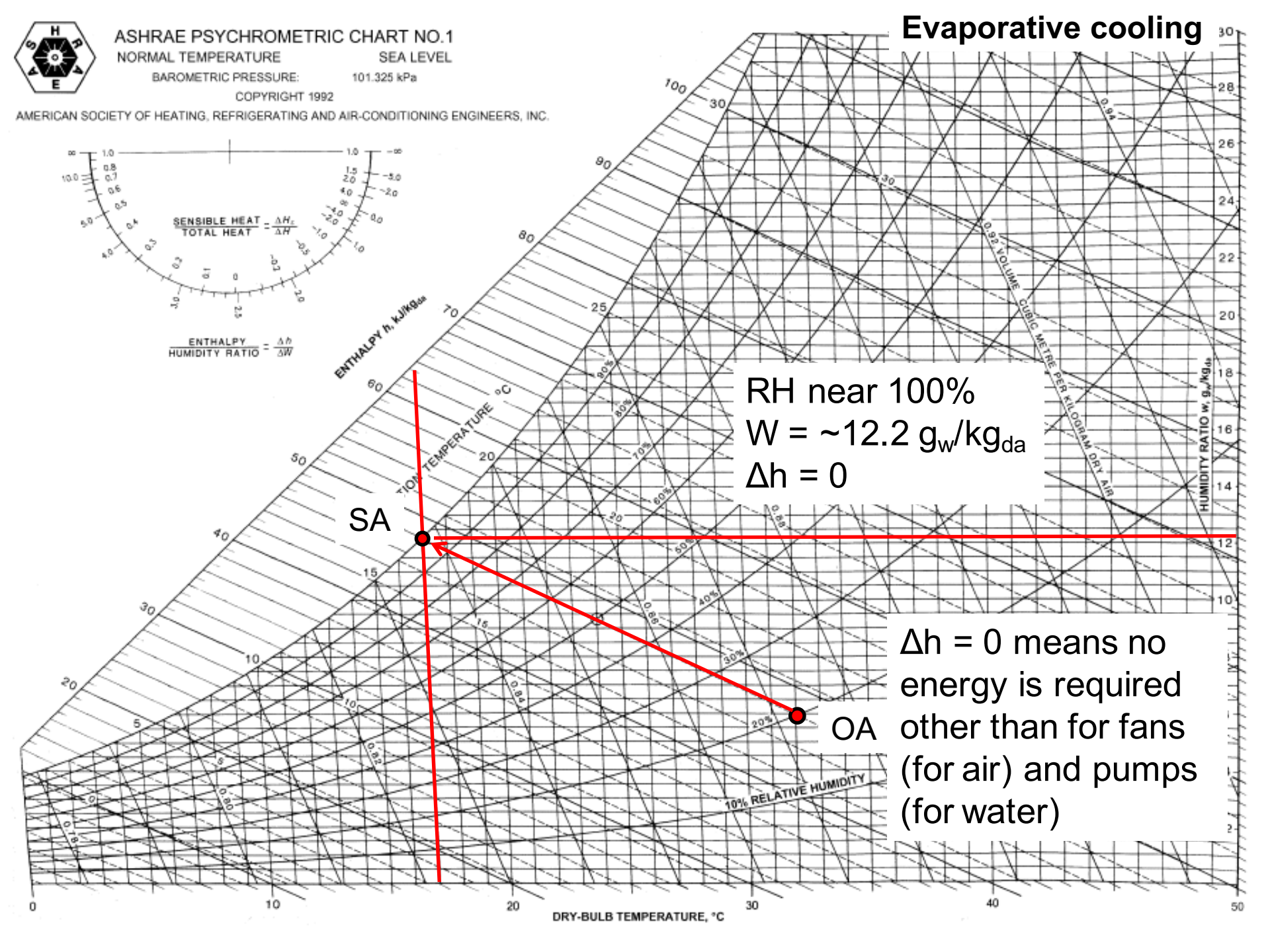
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔH_s / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg_da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
0.92 VOLUME CUBIC METRE PER KILOGRAM DRY A
HUMIDITY RATIO w, g_w/kg_da
Cooling occurs along constant wet bulb
OA
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C

Evaporative cooling



Evaporative cooling



Evaporative cooling