Business

- Professional application due Nov 19
  - Please try to turn this in ASAP!
  - This will make the secretaries very happy!
  - You will get the letter with the add code by email within 1-2 days after you submit the application (even if it is early)

1

Business

- Case Study
  - Posted on Learning Suite
  - Don't use the 4^{th} Ed book problem statement!
  - 21 problems, all connected
    - One extra problem to satisfy accreditation requirements
  - Don't be afraid to start early

- **You are doing great! Keep up the good work!**

2

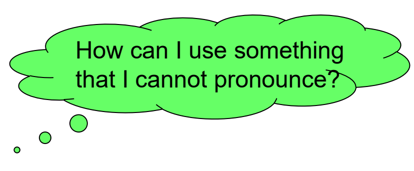
Class 28

Heat and Humidity

3

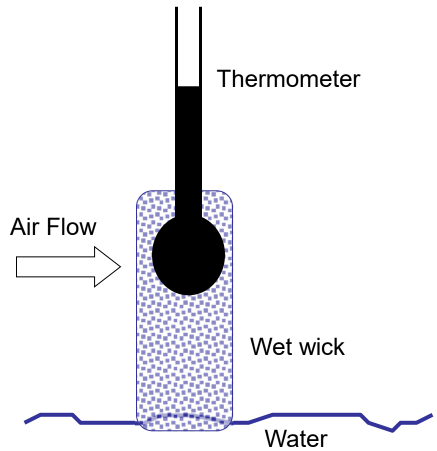
How Do You Measure Humidity?

- Cool the air and weigh the moisture
- Chemically absorb the moisture
- Correlate some other property, such as thermal conductivity
  - – show **Kestrel instrument**
- Use IR spectra
- **Sling psychrometer**



4

Wet Bulb Temperature



- Thermometer has a wet cloth around bulb
- Air blows past cloth
- As water evaporates, the bulb is cooled
  - Like when you get cold when you get out of a swimming pool
- The difference between dry and wet bulb temperatures is related to relative humidity (RH)
  - No water will evaporate at 100% RH, so $T_{dry} = T_{wet\ bulb}$
  - Biggest ΔT with driest air

5

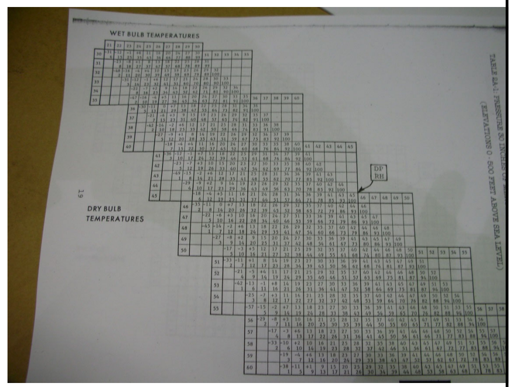
Sling Psychrometer

- Two thermometers
  - One dry
  - One kept in wet cloth
- Twirl the wet thermometer
  - High velocity air through cloth
- Measures:
  - Dry bulb T
  - Wet bulb T

https://www.youtube.com/watch?v=mB9VTmQ5V4o

6

Other Psychrometers

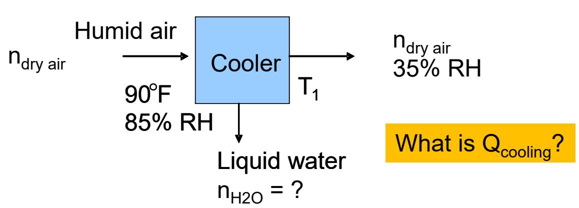


- Wind speed
- $T_{dry\ bulb}$, $T_{wet\ bulb}$
- Relative humidity
- $T_{dew\ point}$

7

Air-Water Systems

- Extremely common
- Chart developed for ease of use
- LOTS of data on chart!
- Based on “dry air” balance
  – Like on the HW and exam!!



8

Psychrometric Chart

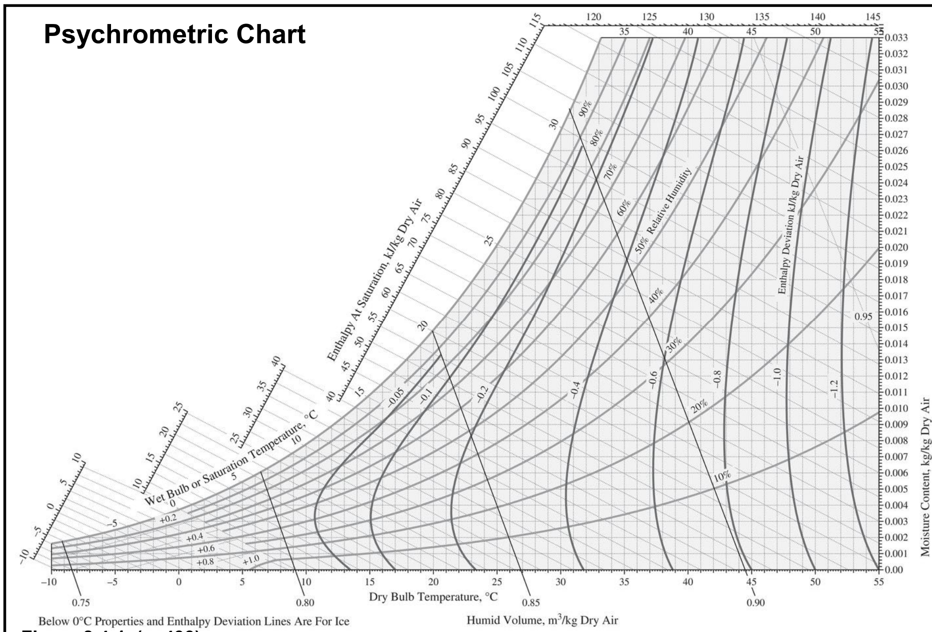


Figure 8.4-1 (p. 433)
Psychrometric chart—SI units. Reference states: H_2O (liquid, 0°C, 1 atm), dry air (0°C, 1 atm). (Data obtained from Carrier Corporation.)

Elementary Principles of Chemical Processes, 4/E by Richard M. Felder, Ronald W. Rousseau, and Lisa G. Bullard

9

American Units

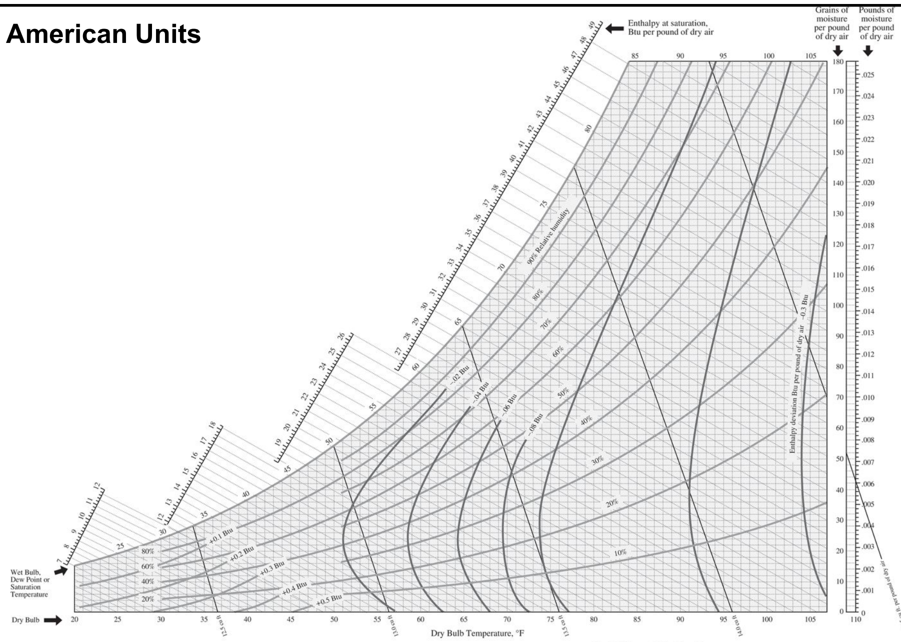


Figure 8.4-2 (p. 434)
Psychrometric chart—U.S. customary units. Reference states: H_2O (liquid, 32°F, 1 atm), dry air (0°F, 1 atm). (Data obtained from Carrier Corporation.)

Elementary Principles of Chemical Processes, 4/E by Richard M. Felder, Ronald W. Rousseau, and Lisa G. Bullard

10

Psychrometric Chart

(yes, I know the obvious nickname)

Air-Water systems at 1 atm

$$\hat{H}_{H_2O,L\,at\,0^\circ C,1\,atm} = 0$$

$$\hat{H}_{air,gas\,at\,0^\circ C,1\,atm} = 0$$

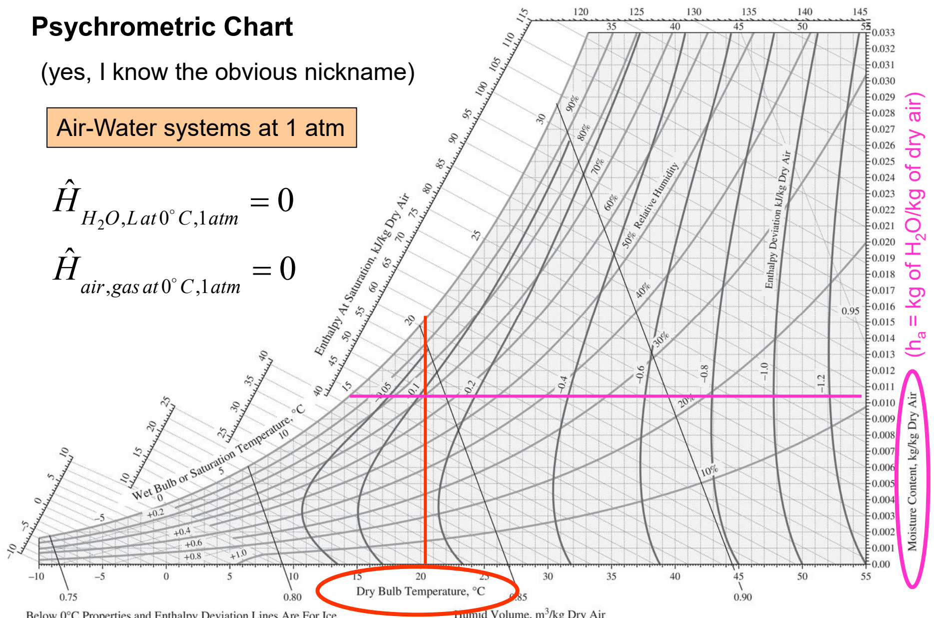


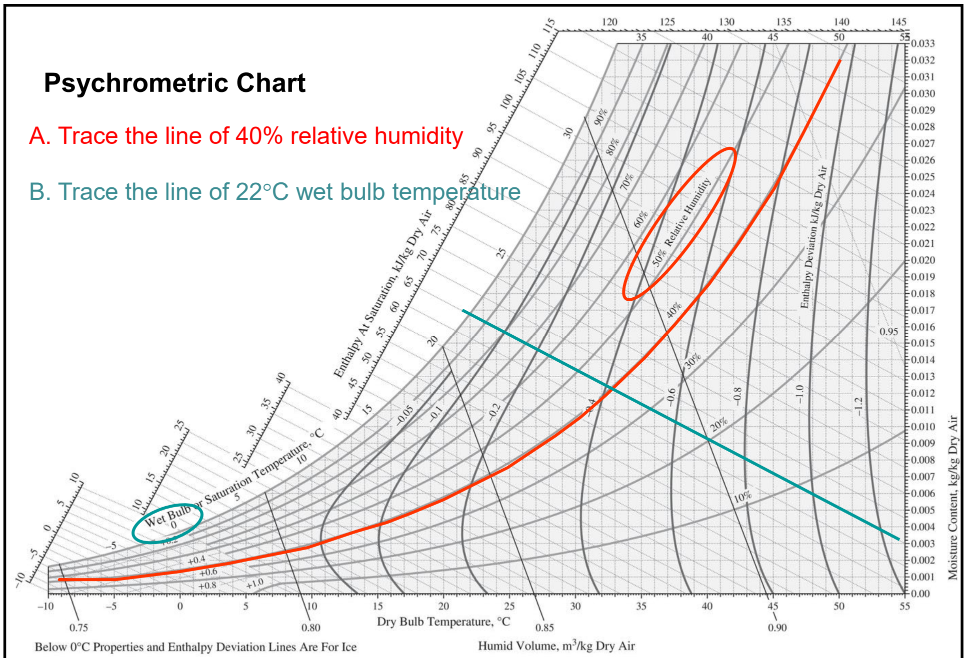
Figure 8.4-1 (p. 433)
Psychrometric chart—SI units. Reference states: H_2O (liquid, 0°C, 1 atm), dry air (0°C, 1 atm). (Data obtained from Carrier Corporation.)

11

Psychrometric Chart

A. Trace the line of 40% relative humidity

B. Trace the line of 22°C wet bulb temperature



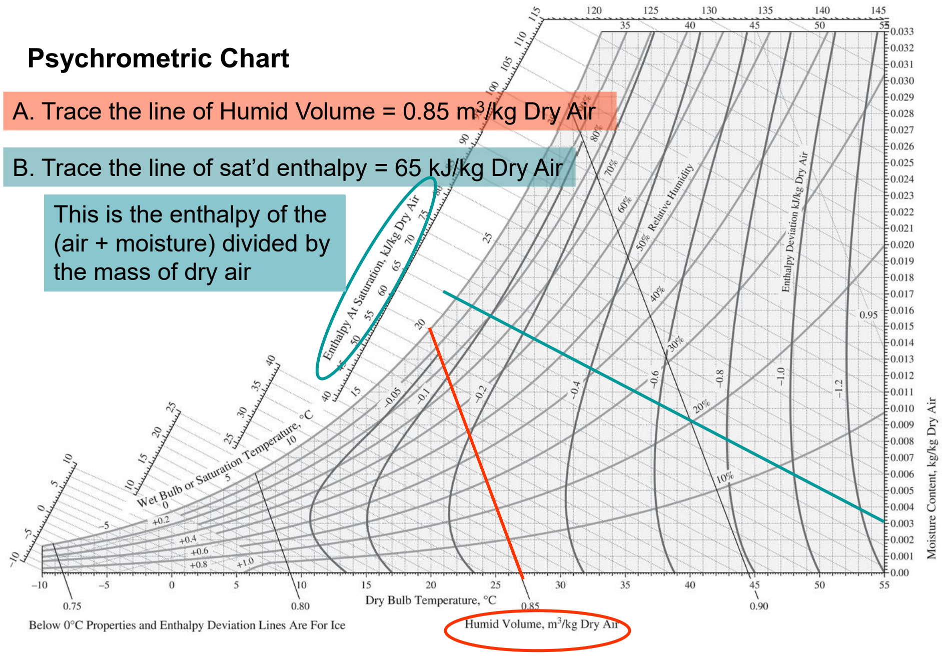
12

Psychrometric Chart

A. Trace the line of Humid Volume = 0.85 m^3/kg Dry Air

B. Trace the line of sat'd enthalpy = 65 kJ/kg Dry Air

This is the enthalpy of the (air + moisture) divided by the mass of dry air



(m³ of air + water vapor)/(kg of dry air)

13

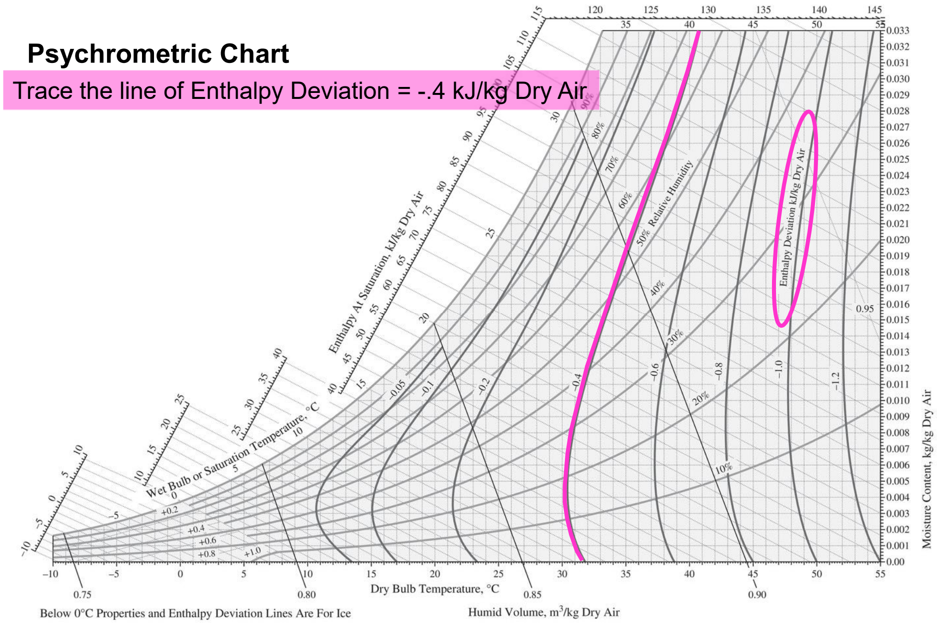
What if I want an enthalpy that is not saturated? (e.g., at 50% RH?)

- ΔH_{dev} given on chart
- $H_{true} = H_{sat'd} + \Delta H_{dev}$

14

Psychrometric Chart

Trace the line of Enthalpy Deviation = -.4 kJ/kg Dry Air



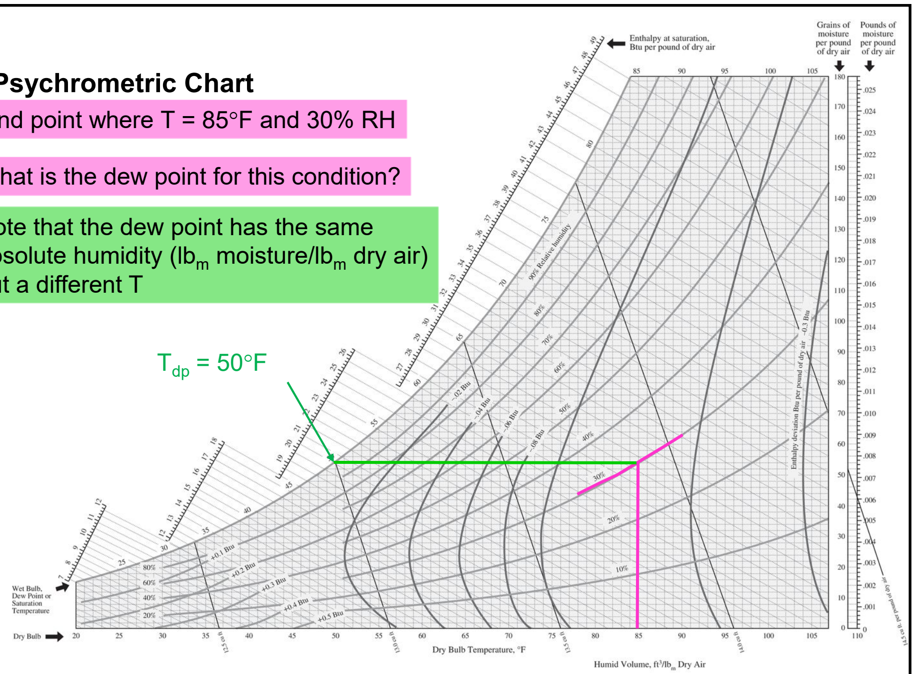
15

Psychrometric Chart

Find point where T = 85°F and 30% RH

What is the dew point for this condition?

Note that the dew point has the same absolute humidity (lb_m moisture/lb_m dry air) but a different T



16

When working with these charts, what is the enthalpy of liquid water?

- Reference enthalpy is liquid water at 0°C or 32°F

$$\hat{H}_{H_2O,L\,at\,T,1atm} = \hat{H}_{H_2O,L\,at\,0^\circ C,1atm} + \int_{0^\circ C}^{T} C_{p,H_2O,L}\,dT = C_{p,H_2O,L}\left(T - T_{ref}\right)$$

- $C_{p,H2O,L}$ = 1 Btu/lb_m·°F = 4.184 J/g ·°C
- Example: $\hat{H}_{H_2O,L\,at\,45^o F,1atm} = C_{p,H_2O,L}\left(45-32\right) = 13\,Btu/lb_m$

17

In-Class Assignment

18

Psychrometric Chart
Chemical Engineering 273, Class 29
In-Class Assignment

The psychrometric chart for air and moisture (i.e., H_2O) at 1 atm total pressure is shown on the next page. Please complete the following:

A. Air at 1 atm, 28°C, 70% relative humidity. Label this point A. Find the following from the psychrometric chart (and show your work on the graph, and don't forget units):
   1. absolute humidity (h_a) __________
   2. Wet bulb temperature (T_{wb}) __________
   3. Dew point temperature (T_{dp}) __________
   4. Saturated enthalpy ($\hat{H}_{sat}$) __________
   5. Specific enthalpy ($\hat{H}$) __________
   6. Humid volume (V_h) __________

B. Air at 1 atm, 80°F, T_{wb} = 70°F. Label this point B. Find the following from the psychrometric chart (and show your work on the graph, and don't forget units):
   1. absolute humidity (h_a) __________
   2. Relative humidity (h_r or RH) __________
   3. Dew point temperature (T_{dp}) __________
   4. Saturated enthalpy ($\hat{H}_{sat}$) __________
   5. Specific enthalpy ($\hat{H}$) __________
   6. Humid volume (V_h) __________

C. Air at 90°F, 80% RH, 100 ft^3/min is cooled to 60°F, 20% RH. Assume that the liquid water leaves at 60°F as well. Find the following:
   1. The mass flow rate of condensed water (lb_m H_2O (liq)/min)
   2. Cooling requirement (in tons of cooling, where 1 ton = 12,000 Btu/hr).

	Air stream in	Air stream out	Condensed water out
h_a (lb_m H_2O/lb_m dry air)			Not applicable
V_h (ft^3/lb_m dry air)			Not applicable
$\hat{H}$ (Btu/lb_m dry air)			

$\dot{m}_{dry\ air}$ =

$\dot{m}_{H2O,in}$ =

$\dot{m}_{H2O,vapor\ out}$ =

$\dot{m}_{H2O,liquid\ out}$ =

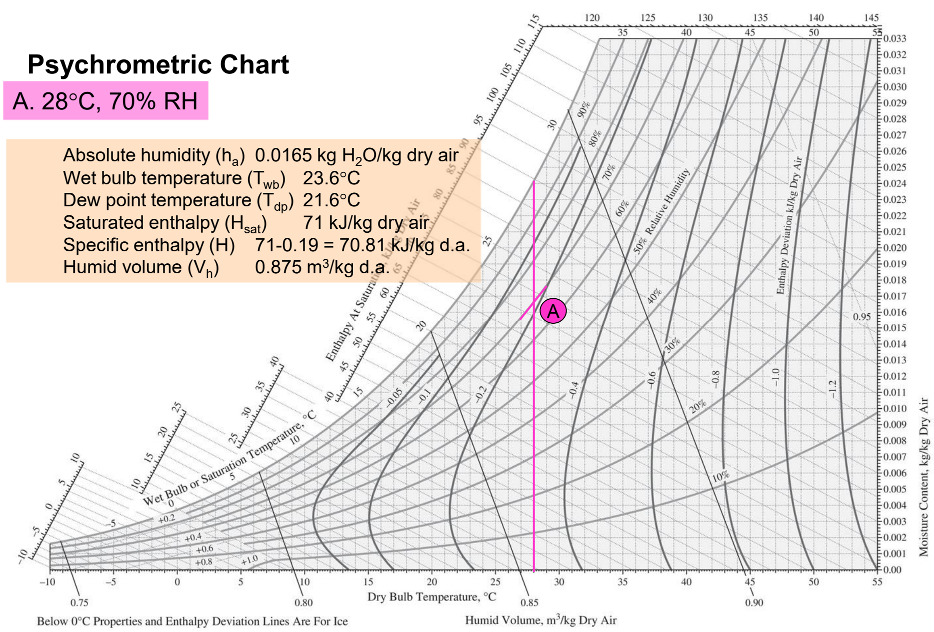
$\dot{Q}$ =

19

Psychrometric Chart

A. 28°C, 70% RH

Absolute humidity (h_a) 0.0165 kg H_2O/kg dry air
Wet bulb temperature (T_{wb}) 23.6°C
Dew point temperature (T_{dp}) 21.6°C
Saturated enthalpy (H_{sat}) 71 kJ/kg dry air
Specific enthalpy (H) 71-0.19 = 70.81 kJ/kg d.a.
Humid volume (V_h) 0.875 m^3/kg d.a.

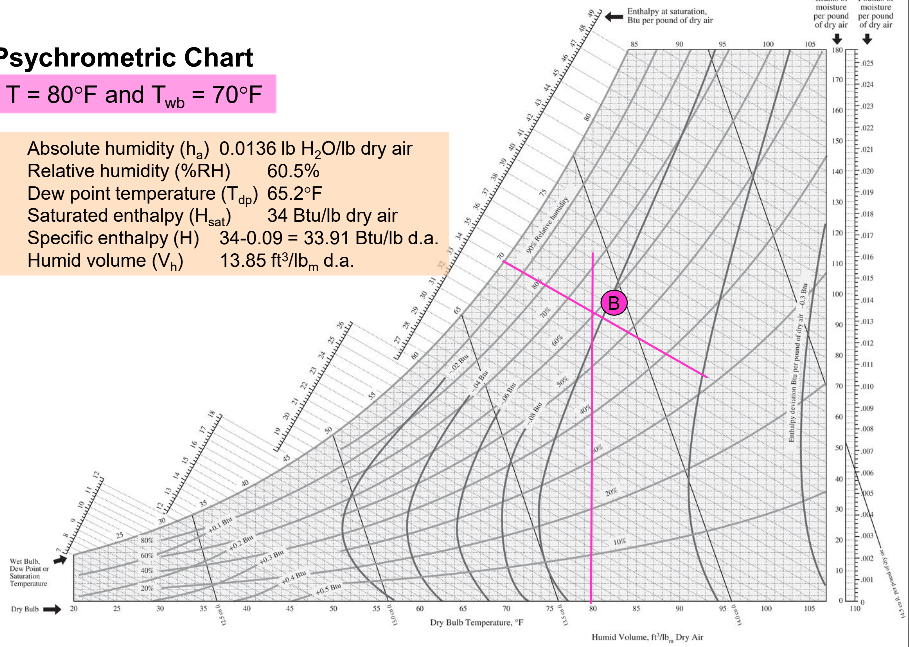


20

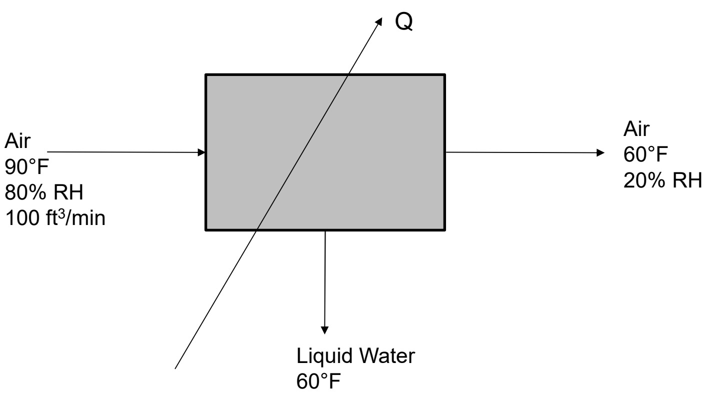
Psychrometric Chart

B. T = 80°F and T_{wb} = 70°F

Absolute humidity (h_a) 0.0136 lb H_2O/lb dry air
Relative humidity (%RH) 60.5%
Dew point temperature (T_{dp}) 65.2°F
Saturated enthalpy (H_{sat}) 34 Btu/lb dry air
Specific enthalpy (H) 34-0.09 = 33.91 Btu/lb d.a.
Humid volume (V_h) 13.85 ft^3/lb_m d.a.



21

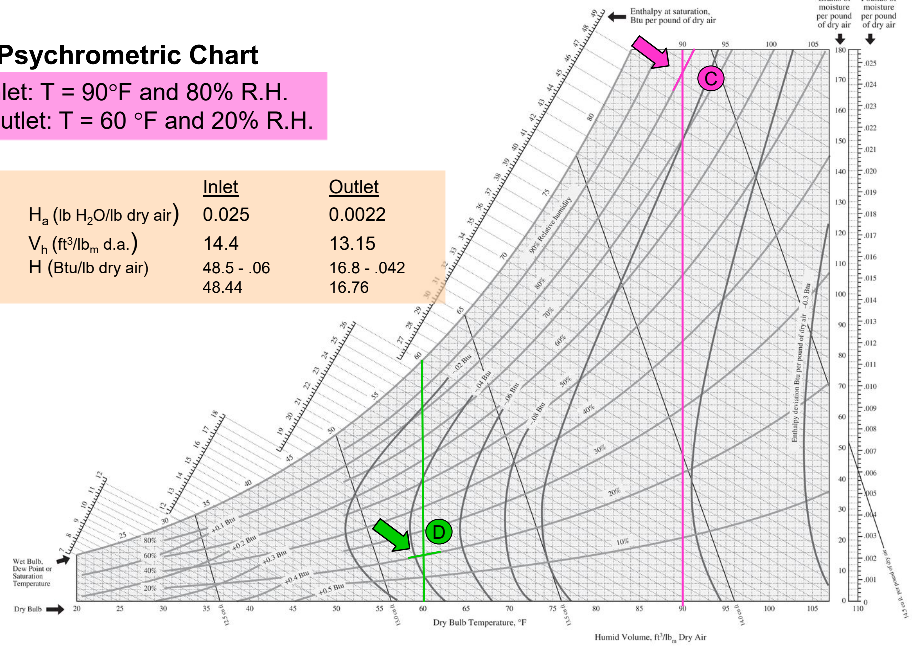


22

Psychrometric Chart

Inlet: T = 90°F and 80% R.H.
Outlet: T = 60 °F and 20% R.H.

	Inlet	Outlet
H_a (lb H_2O/lb dry air)	0.025	0.0022
V_h (ft^3/lb_m d.a.)	14.4	13.15
H (Btu/lb dry air)	48.5 - .06 48.44	16.8 - .042 16.76



23

Enthalpy of liquid water out?

$$H = H_{ref} + c_p\Delta T$$
$$= 0 + (1\ Btu/lb_m\text{-}°F)(60 - 32°F)$$
$$= 28\ Btu/lb_m(liq)$$

24

$$\dot{m}_{dry\ air} = (100\ ft^3/\min)\left(\frac{1}{14.4\ ft^3/lb\,dry\,air}\right) = 6.94\,lb_m dry\,air/\min$$

$$\dot{m}_{H2O,in} = \left(6.94\,lb_m\frac{dry\,air}{\min}\right)\left(0.025\frac{lb_m\,H_2O}{lb_m\,dry\,air}\right) = 0.1736\frac{lb_m\,H_2O_{in}}{\min}$$

$$\dot{m}_{H2O,vapor\ out} = \left(6.94\,lb_m\frac{dry\,air}{\min}\right)\left(0.0022\frac{lb_m\,H_2O}{lb_m\,dry\,air}\right) = 0.0153\frac{lb_m\,H_2O_{out}}{\min}$$

$$\dot{m}_{H2O,liquid\ out} = 0.1736\frac{lb_m\,H_2O_{in}}{\min} - 0.0153\frac{lb_m\,H_2O_{out}}{\min} = 0.1583\frac{lb_m\,H_2O_{liquid,out}}{\min}$$

$$\dot{Q} = \left(\sum\dot{m}\hat{H}\right)_{out} - \left(\sum\dot{m}\hat{H}\right)_{in}$$

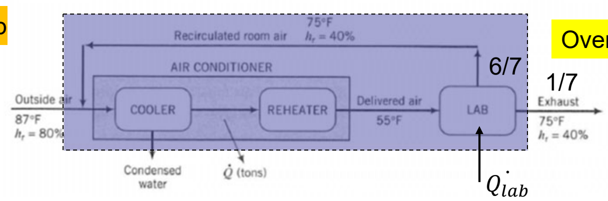
$$= \left(0.1583\frac{lb_m\,H_2O_{liq,out}}{\min}\right)\left(28\frac{Btu}{lb_m(liq)}\right) + \left(6.94\frac{lb_m\,dry\,air_{out}}{\min}\right)\left(16.76\frac{Btu}{lb_m dry\,air}\right)$$

$$-\left(6.94\frac{lb_m\,dry\,air_{out}}{\min}\right)\left(48.44\frac{Btu}{lb_m dry\,air}\right)$$

$$= -215\frac{Btu}{\min} = -12{,}925\frac{Btu}{hr} = 1.08\ ton\ cooling$$

Prob 25-3b

Overall mass balance

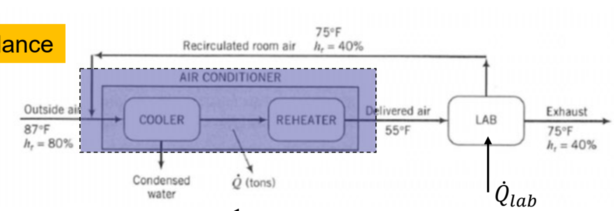


- "Delivered air" flow rate stays the same, but 6/7 is recycled

$$\dot{m}_{in,recycle} = \frac{1}{7}\dot{m}_{in,no\,recycle}$$

$$\dot{m}_{out,recycle} = \frac{1}{7}\dot{m}_{out,no\,recycle}$$

Heat balance



$$Q_{recycle} \neq \frac{1}{7} Q_{no\,recycle}$$

$$\dot{Q}_{recycle} = \Delta \dot{H} = \left(\sum \dot{m}_i \hat{H}_i\right)_{out} - \left(\sum \dot{m}_i \hat{H}_i\right)_{in}$$

$$\dot{Q}_{recycle} = \dot{m}_{H_2O,liq} \hat{H}_{H_2O,liq} + \dot{m}_{delivered\ air} \hat{H}_{delivered\ air} - \dot{m}_{inlet\ air} \hat{H}_{inlet\ air} - \dot{m}_{recycled\ air} \hat{H}_{recycled\ air}$$

We could also get $\dot{Q}_{lab}$

27