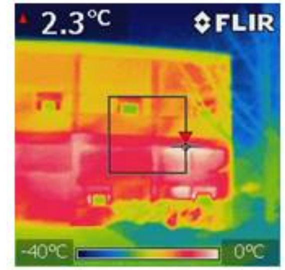
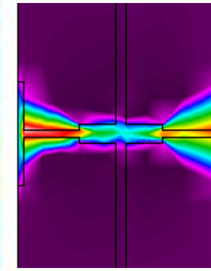
CAE 331/513
Building Science
Fall 2018



October 16, 2018
Psychrometric processes (part 3)

Built
Environment
Research
@ IIT

Advancing energy, environmental, and sustainability research within the built environment

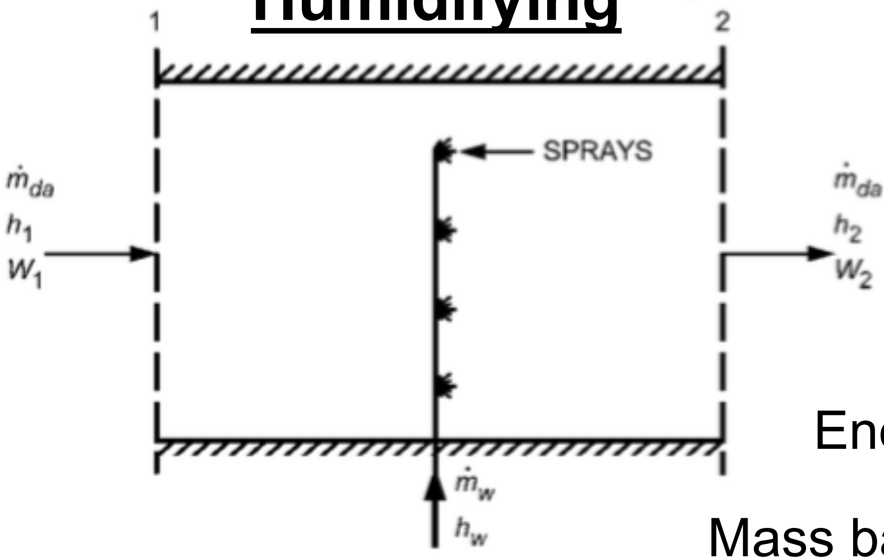
www.built-envi.com

Twitter: @built_envi

Dr. Brent Stephens, Ph.D.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu

Energy/mass balances for psychrometric processes

Humidifying



Energy balance: $\dot{m}_{da,1}h_1 + \dot{m}_w h_w = \dot{m}_{da,2}h_2$

Mass balance on air: $\dot{m}_{da,1} = \dot{m}_{da,2} = \dot{m}_{da}$

Mass balance on water vapor: $\dot{m}_{da,1}W_1 + \dot{m}_w = \dot{m}_{da,2}W_2$

Therefore: $\dot{m}_w = \dot{m}_{da}(W_2 - W_1)$

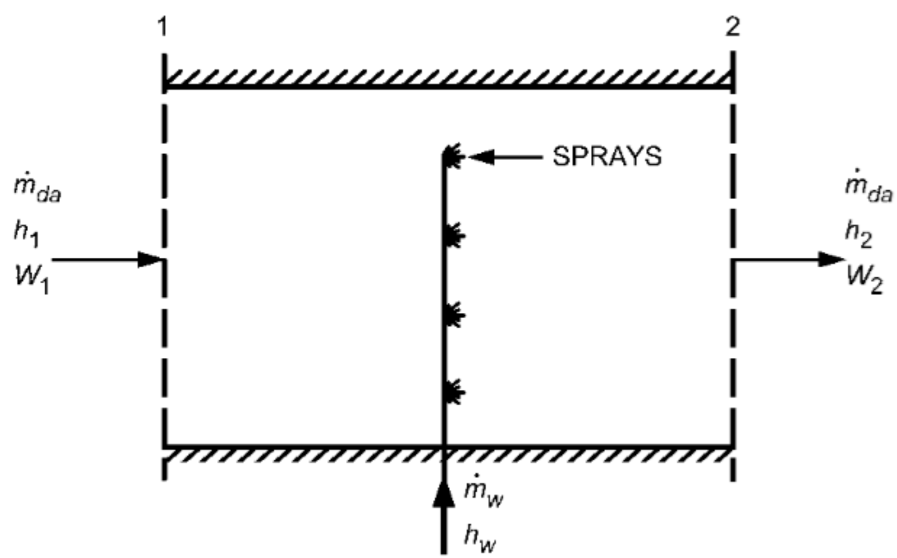
And: $\dot{m}_w h_w = \dot{m}_{da}(h_2 - h_1)$

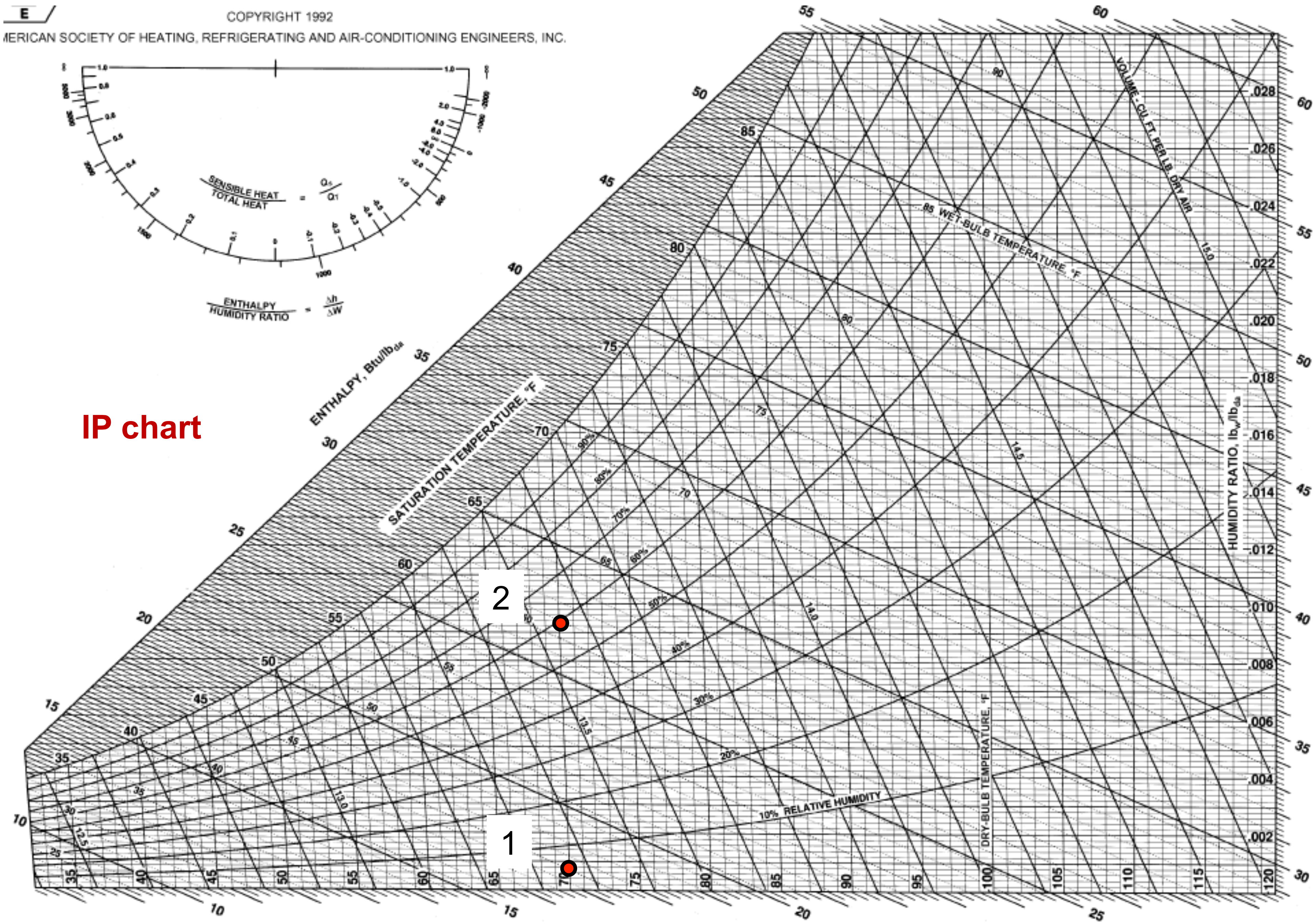
And: $$\frac{h_2 - h_1}{W_2 - W_1} = \frac{\Delta h}{\Delta W} = h_w$$

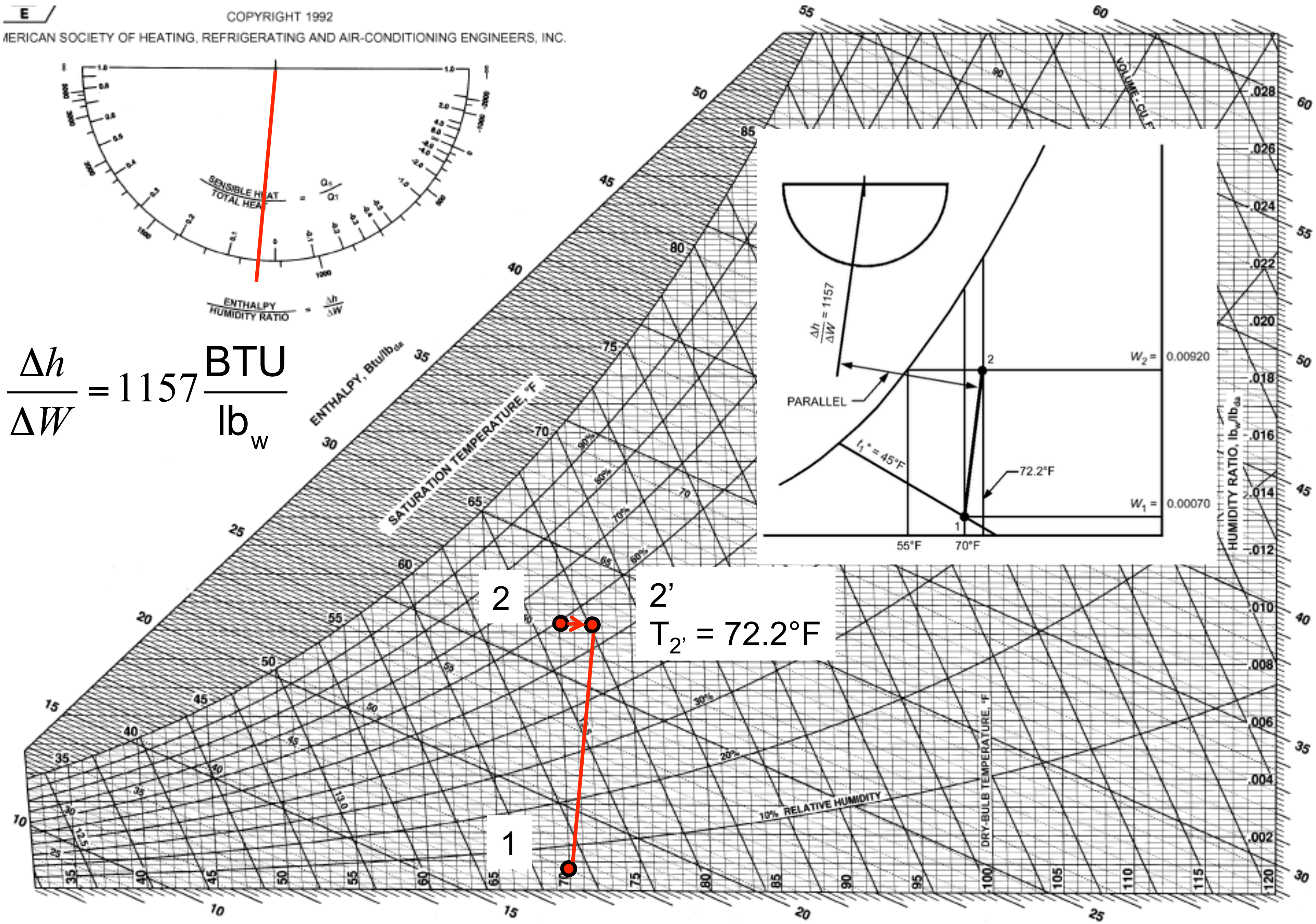
*Note that $h_w = h_g$ for steam/vapor and $h_w = h_f$ for water

Example 5: Humidification (IP)

- Moist air at 70°F dry bulb temperature and 45°F wet bulb temperature is to be processed to a final dew point of 55°F by adiabatic injection of saturated steam at 230°F
- The air flow rate is 10,000 CFM
  - Find the rate of steam flow required



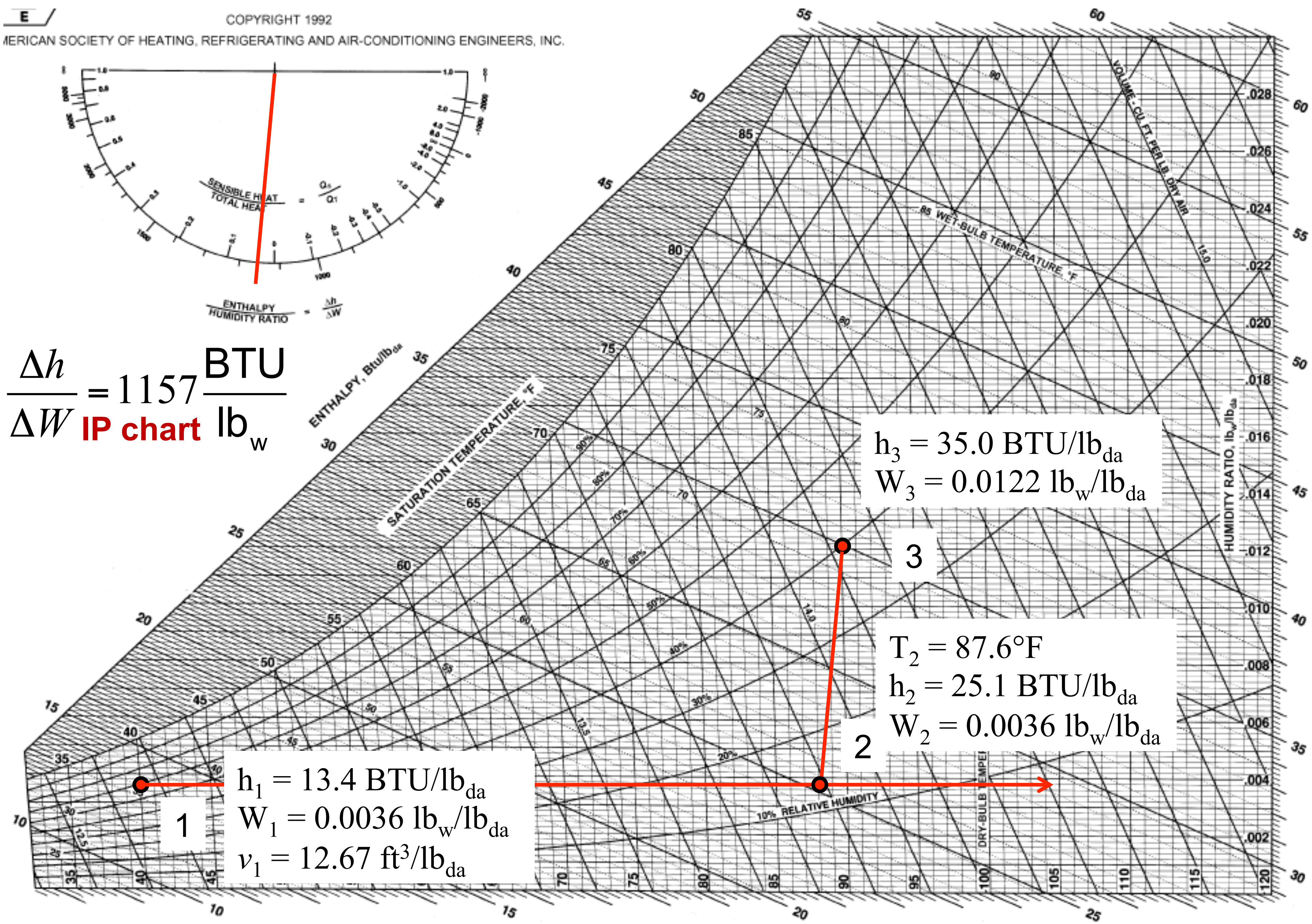

COPYRIGHT 1992
MERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
IP chart
ENTHALPY, Btu/lb
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME - CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb/lb
DRY-BULB TEMPERATURE, °F
10% RELATIVE HUMIDITY
2
1


COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Δh / ΔW = 1157 BTU / lbw
ENTHALPY, Btu/lbda
SATURATION TEMPERATURE, °F
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °F
HUMIDITY RATIO, lbw/lbda
VOLUME, CU.FT
1
2
2'
T2' = 72.2°F
Δh / ΔW = 1157
PARALLEL
t1* = 45°F
72.2°F
W2 = 0.00920
W1 = 0.00070
55°F
70°F

Example 6: Heating and humidification (IP)

- Moist air is heated and humidified by passing it first over a heating coil and then adding moisture. The moist air enters the system at 40°F dry bulb temperature and 36°F wet bulb temperature at a mass flow rate of 235 lb_{da}/min. The humidifier injects saturated steam at 230°F. The moist air exists the system at 90°F dry bulb temperature and 40% RH.

- Locate state 2 on a psychrometric chart and determine the rate of heat addition by the heating coil and the rate of mass addition by the humidifier.



$$\frac{\Delta h}{\Delta W} = 1157 \frac{\text{BTU}}{\text{lb}_w}$$

IP chart

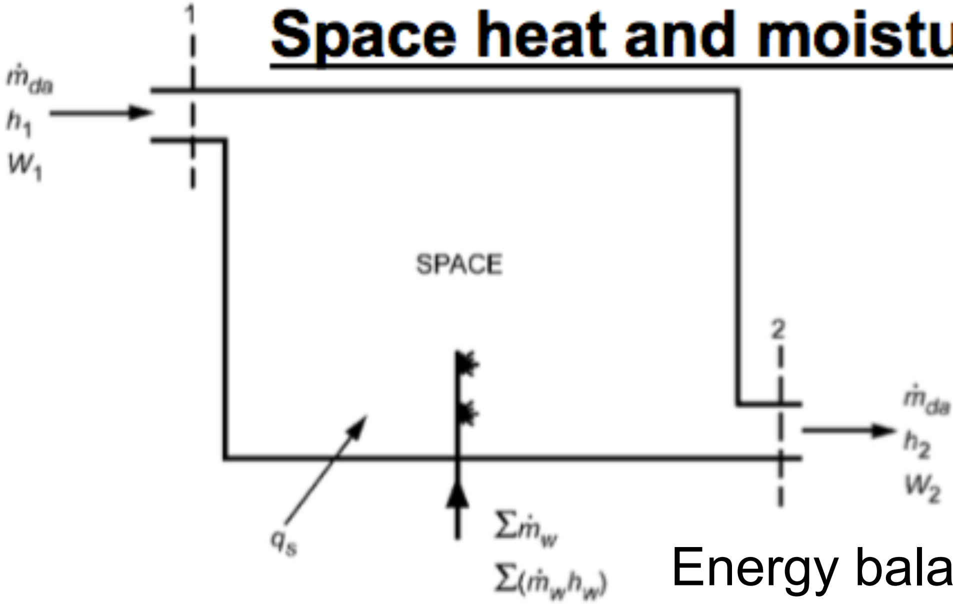
$h_3 = 35.0\ \text{BTU/lb}_{da}$, $W_3 = 0.0122\ \text{lb}_w/\text{lb}_{da}$

$T_2 = 87.6°\text{F}$, $h_2 = 25.1\ \text{BTU/lb}_{da}$, $W_2 = 0.0036\ \text{lb}_w/\text{lb}_{da}$

$h_1 = 13.4\ \text{BTU/lb}_{da}$, $W_1 = 0.0036\ \text{lb}_w/\text{lb}_{da}$, $v_1 = 12.67\ \text{ft}^3/\text{lb}_{da}$

Energy/mass balances for psychrometric processes

Space heat and moisture gains



Energy balance: $\dot{m}_{da}h_1 + Q_{gains} + \sum \dot{m}_w h_w = \dot{m}_{da}h_2$

Mass balance on water vapor: $\dot{m}_{da}W_1 + \sum \dot{m}_w = \dot{m}_{da}W_2$

Therefore: $\sum \dot{m}_w = \dot{m}_{da}(W_2 - W_1)$

Therefore: $\sum \dot{m}_w h_w + Q_{gains} = \dot{m}_{da}(h_2 - h_1)$

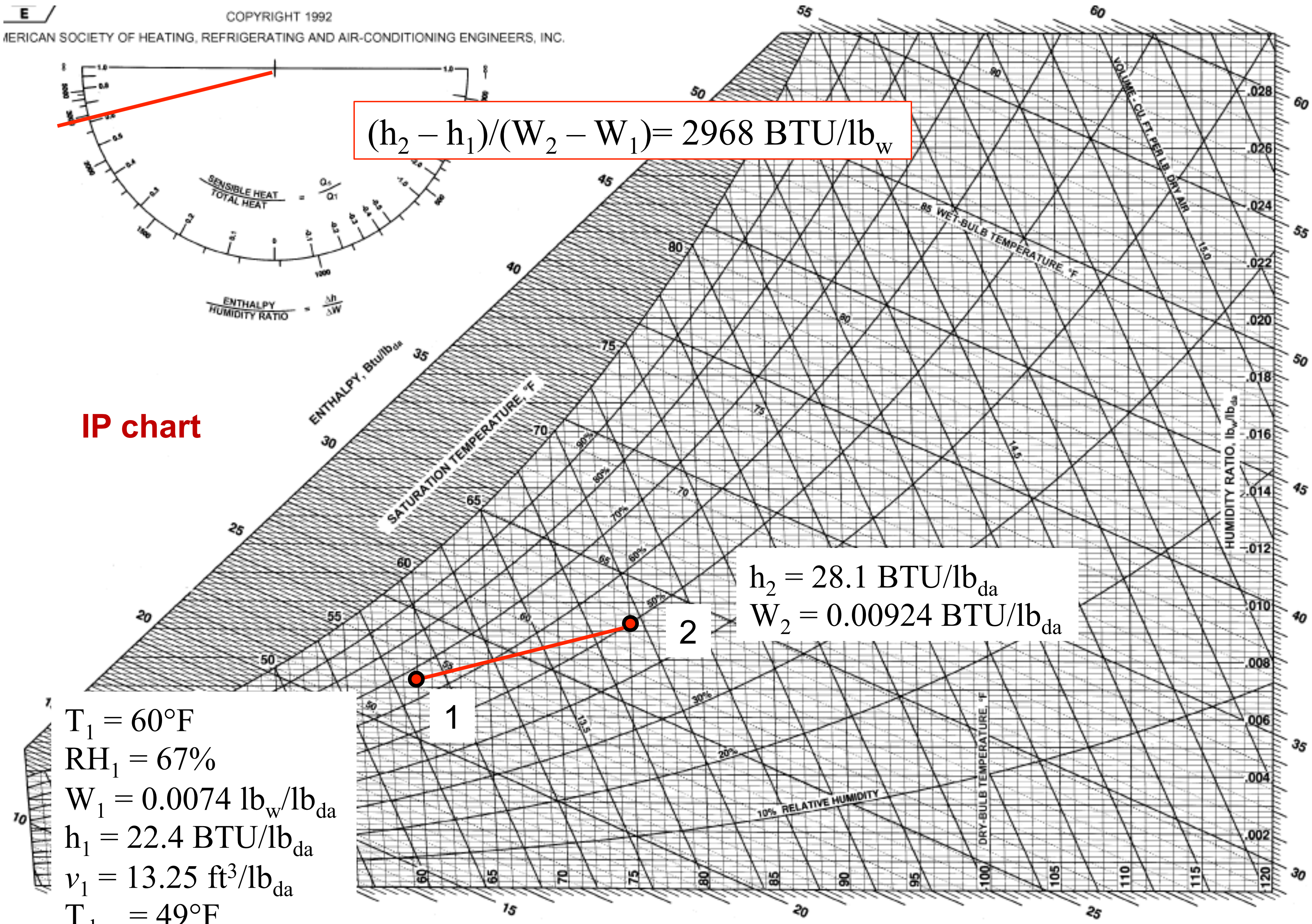
And: $$\frac{\Delta h}{\Delta W} = \frac{\sum \dot{m}_w h_w + Q_{gains}}{\sum \dot{m}_w}$$

*Note that h_w = h_g for steam/vapor and h_w = h_f for water

Example 7: Space conditioning – cooling (IP)

- The air in a restaurant is to be maintained at 75°F dry-bulb temperature and 50% RH. The load calculations for the restaurant estimate the rate of sensible heat gain to be 178,000 BTU/h. The rate of moisture gain is estimated to be 95 lb_w/h with an average enthalpy of moisture (h_w) of 1095 BTU/lb_w. The supply air temperature is to be 60°F. Assume standard atmospheric pressure.

- Determine the following:
  a) The required dew-point temperature of the supply air
  b) The required volumetric flow rate of supply air (in CFM)



IP chart

$(h_2 - h_1)/(W_2 - W_1) = 2968$ BTU/lb_w

$T_1 = 60°F$

$RH_1 = 67\%$

$W_1 = 0.0074\ lb_w/lb_{da}$

$h_1 = 22.4$ BTU/lb_{da}

$v_1 = 13.25\ ft^3/lb_{da}$

$T_{dew} = 49°F$

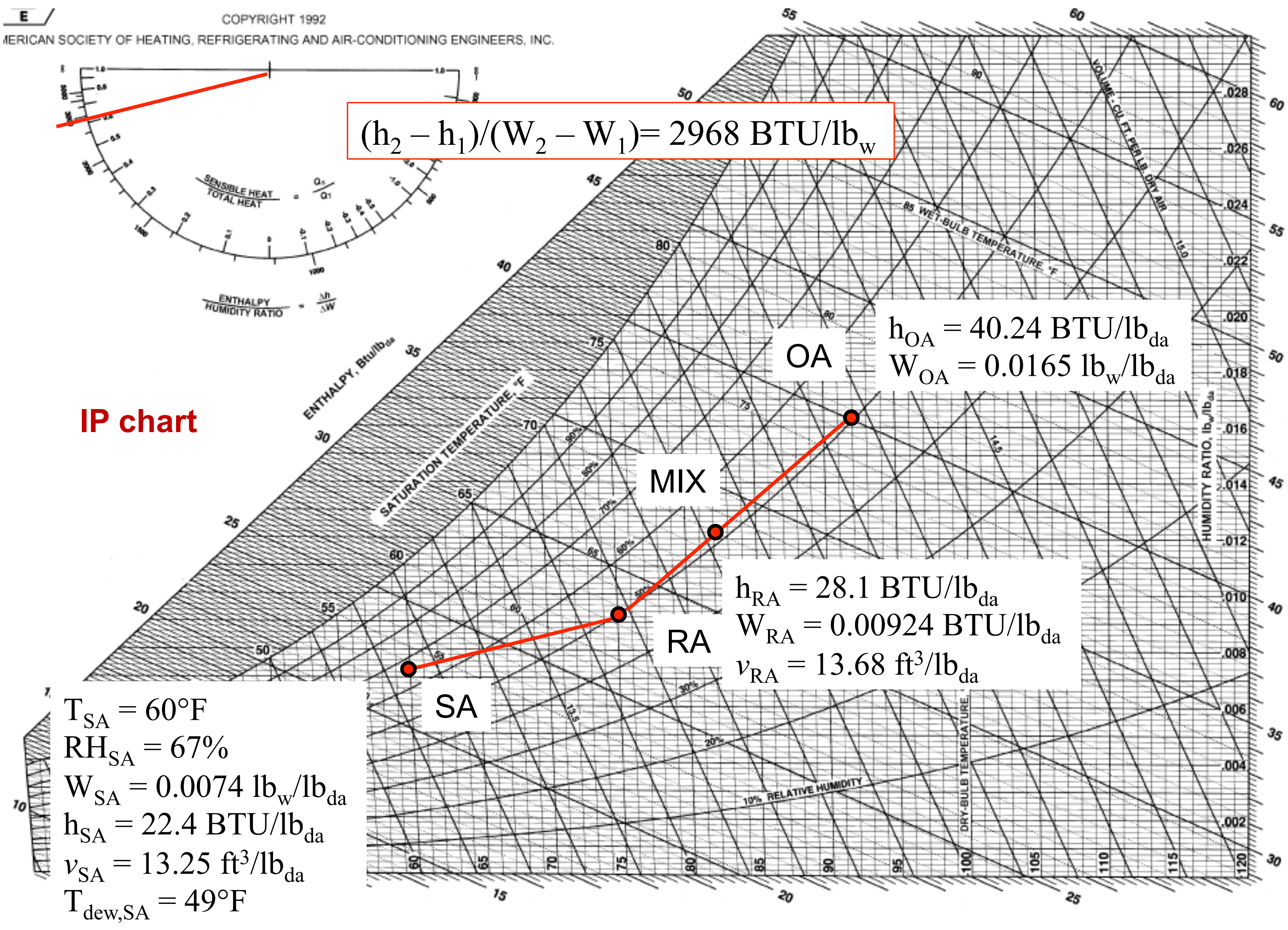
$h_2 = 28.1$ BTU/lb_{da}

$W_2 = 0.00924$ BTU/lb_{da}

Example 8: Single-zone space conditioning (IP)

- Assume the restaurant from the previous example is to be served by an air handling unit that mixes outdoor air with recirculated air, then passes the air over a cooling coil to the space. Outside air conditions are 92°F dry bulb and 77°F wet bulb temperatures. The rate of exhaust from the restaurant is 4500 CFM.

- Determine the following:
  a) The mass flow rate of recirculated air
  b) The thermodynamic state of the moist air entering the cooling coil
  c) The refrigeration capacity required


COPYRIGHT 1992
MERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
$(h_2 - h_1)/(W_2 - W_1) = 2968$ BTU/lb_w
SENSIBLE HEAT / TOTAL HEAT = Q_s / Q_t
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
IP chart
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
DRY-BULB TEMPERATURE, °F
10% RELATIVE HUMIDITY
OA
$h_{OA} = 40.24$ BTU/lb_{da}
$W_{OA} = 0.0165$ lb_w/lb_{da}
MIX
RA
$h_{RA} = 28.1$ BTU/lb_{da}
$W_{RA} = 0.00924$ BTU/lb_{da}
$v_{RA} = 13.68$ ft^3/lb_{da}
SA
$T_{SA} = 60°F$
$RH_{SA} = 67\%$
$W_{SA} = 0.0074$ lb_w/lb_{da}
$h_{SA} = 22.4$ BTU/lb_{da}
$v_{SA} = 13.25$ ft^3/lb_{da}
$T_{dew,SA} = 49°F$