Psychrometrics

Psychrometrics

- It involves determination of thermodynamic properties of gas-vapor mixtures.
- The most common applications are associated with the air-water vapor system.

Properties of dry air

- Composition of air

composition	% by volume
Nitrogen	78.08400
Oxygen	20.94760
Argon	0.934000
Carbon dioxide	0.031400
Neon	0.001818
Helium	0.000524
Others (methane, sulfur dioxide, hydrogen, krypton และ xenon)	0.000658

Properties of dry air

- Molecular weight = 28.9645
- Gas constant for dry air = 287.055 $m^3Pa/kg.K$
- Specific volume $V'_a = \frac{R_a T_A}{P_a}$
- Specific heat (average) = 1.005 kJ/kg.K
- Enthalpy = $H_a = 1.005 (T_a - T_o)$ kJ/kg
- Dry bulb temperature = temperature indicated by unmodified sensor

Properties of water vapor

- Molecular weight = 18.01534
- Gas constant for dry air = 461.52 m^3Pa/kg.K
- Specific volume $V'_w = \frac{R_w T_A}{P_w}$
- Specific heat (average) = 1.88 kJ/kg.K
- Enthalpy = H_w = 2501.4 + 1.88 (T_a-T_o) kJ/kg

Properties of air-vapor mixtures

- Gibbs-Dalton Law

$$p_B = p_a + p_w$$

where

p_B = total pressure

p_a = partial pressure of dry air

p_w = partial pressure of water vapor

Dew-point temperature

- The water vapor in the air will be saturated when air is at a temperature equal to the saturation temperature corresponding to the partial pressure exerted by the water vapor.
- This temperature is called dew-point temperature.

Humidity ratio/ moisture content (W)

- $PV = mRT$ (ideal gas law)

$$W = \frac{m_w}{m_a} = \frac{\left(\frac{P_w V}{R_w T}\right)}{\left(\frac{P_a V}{R_a T}\right)} = \frac{P_w}{P_a}\frac{R_a}{R_w}$$

- $P = P_w + P_a$

$$W = 0.622\frac{P_w}{P - P_w}$$

R = gas constant
P = total pressure
V = volume
T = absolute temperature
W = humidity ratio

Subscripts: w is water vapor, a is dry air

Relative Humidity

- $\Phi = x_w/x_{w,s} = P_w/P_{ws} = \rho_w/\rho_{ws}$
- **Function of T**

$$\Phi = \mu \frac{0.622 + W_s}{0.622 + W}$$

x = mole fraction
P = pressure
μ = degree of saturation
W = humidity ratio

- Easy to measure and useful in some contexts, but often need to know temperature as well

Humid heat

- It is amount of heat (kJ) required to raise the temperature of 1 kg dry air plus water vapor present by 1 K.
- $C_s = 1.005 + 1.88W$

Specific volume

- It is the volume (m^3) of 1 kg dry air plus water vapor in the air.

$$V'_m = (0.082Ta + 22.4)\left(\frac{1}{29} + W/18\right)$$

Wet bulb temperature

$$p_w = P_{wb} - \frac{(P_B - P_{wb})(T_a - T_w)}{1555.56 - 0.722 T_w}$$

where p_w = partial pressure of water vapor

p_B = total pressure = barometric pressure

p_{wb} = saturation pressure of water vapor at wet bulb temp.

T_a = dry bulb temp.

T_w = wet bulb temp.

Example

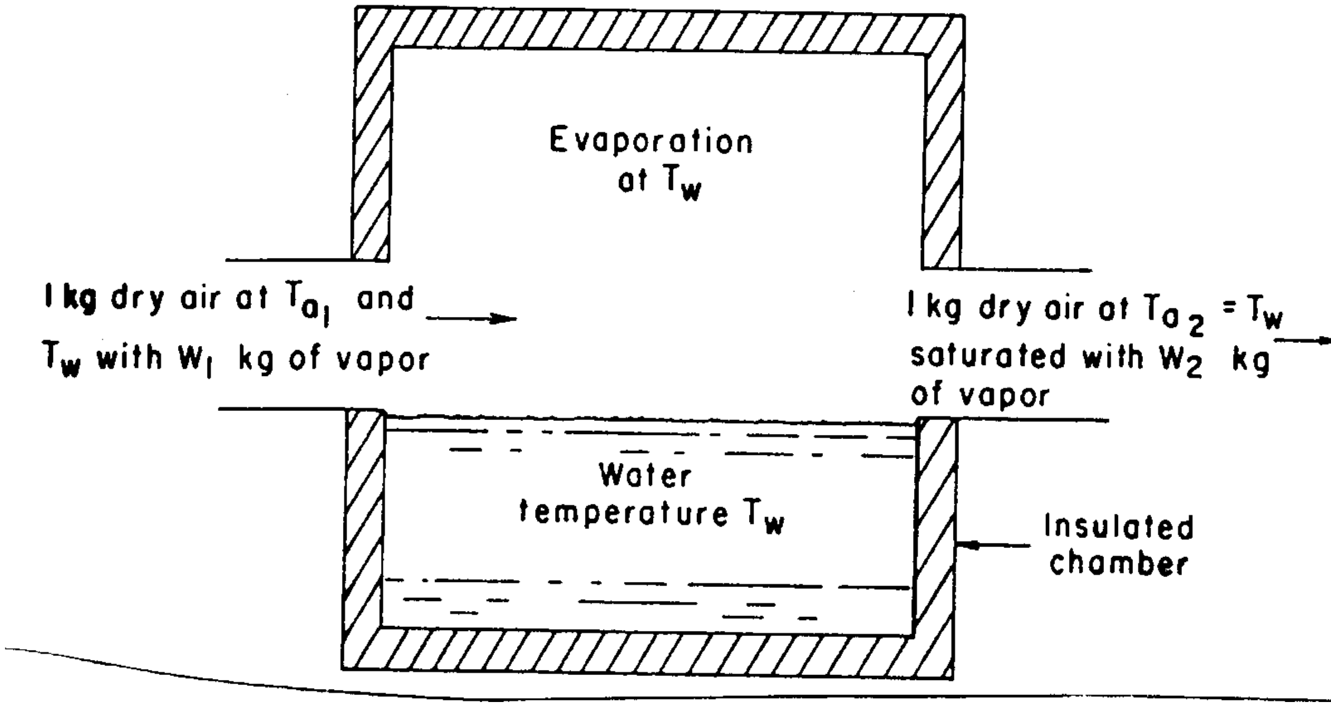
- Find dew-point temperature, humidity ratio, humid volume, and relative humidity of air having a dry bulb temperature of 40°C and a wet bulb temperature of 30°C.

Adiabatic saturation process

- Phenomenon of adiabatic saturation of air is applicable to convective drying of food materials.
- Adiabatic condition
  - Well insulated chamber: no heat gain and loss
  - Air is allowed to contact a large surface area of water
  - Part of sensible heat of entering air is transformed into latent heat

Adiabatic saturation process

- Process of evaporation water into the air results in saturation by converting part of sensible heat of the entering air into latent heat



$$T_{a1} = H_L \frac{(w_2 - w_1)}{(1.005 + 1.88\, w_1)} + T_{a2}$$

$$\frac{w_2 - w_1}{T_{a1} - T_{a2}} = \frac{\overline{C}_s}{H_L} \qquad \overline{C}_s = 1.005 + 1.88\left(w_1 + w_2 / 2\right)$$

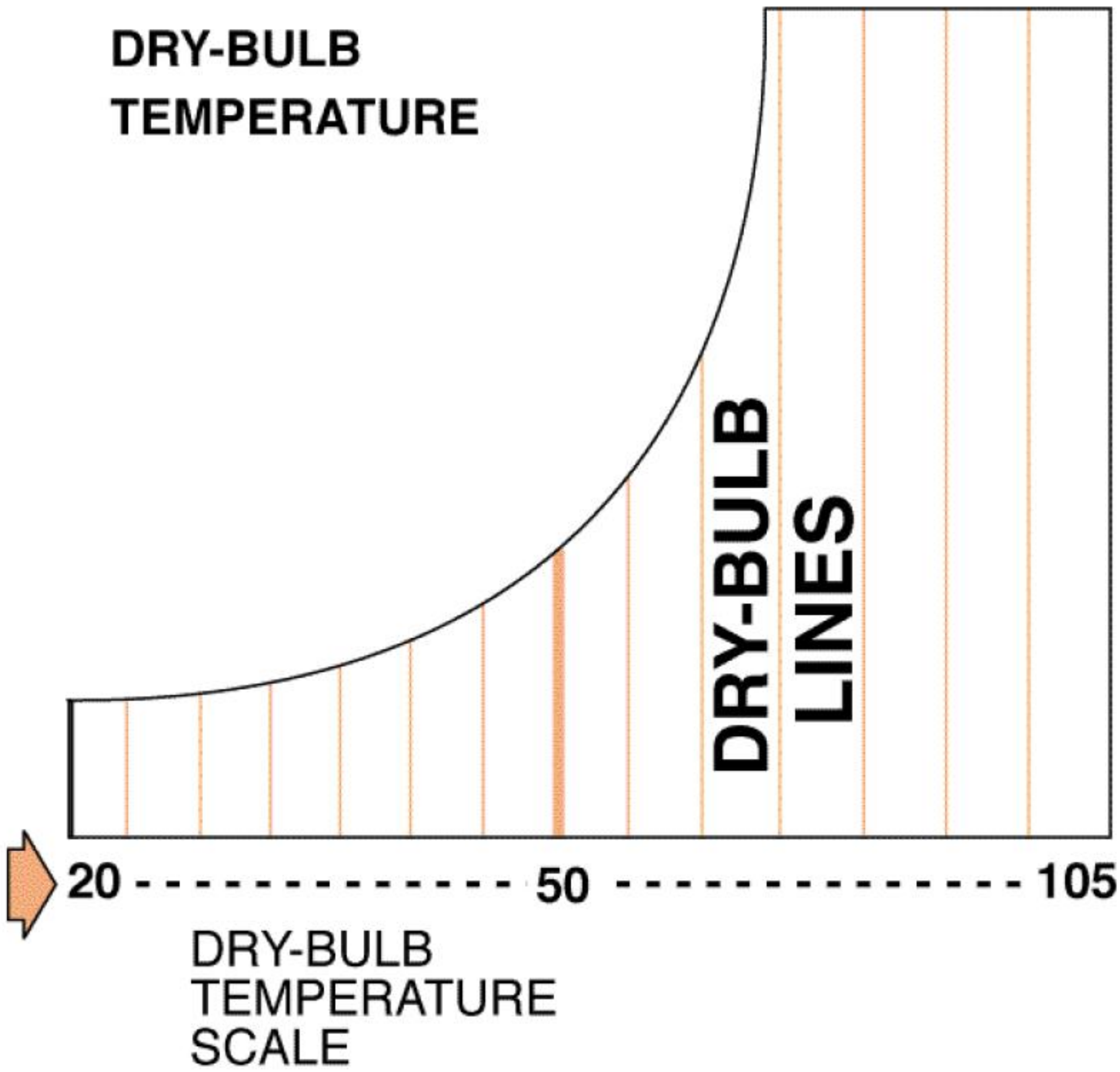
Psychrometric chart

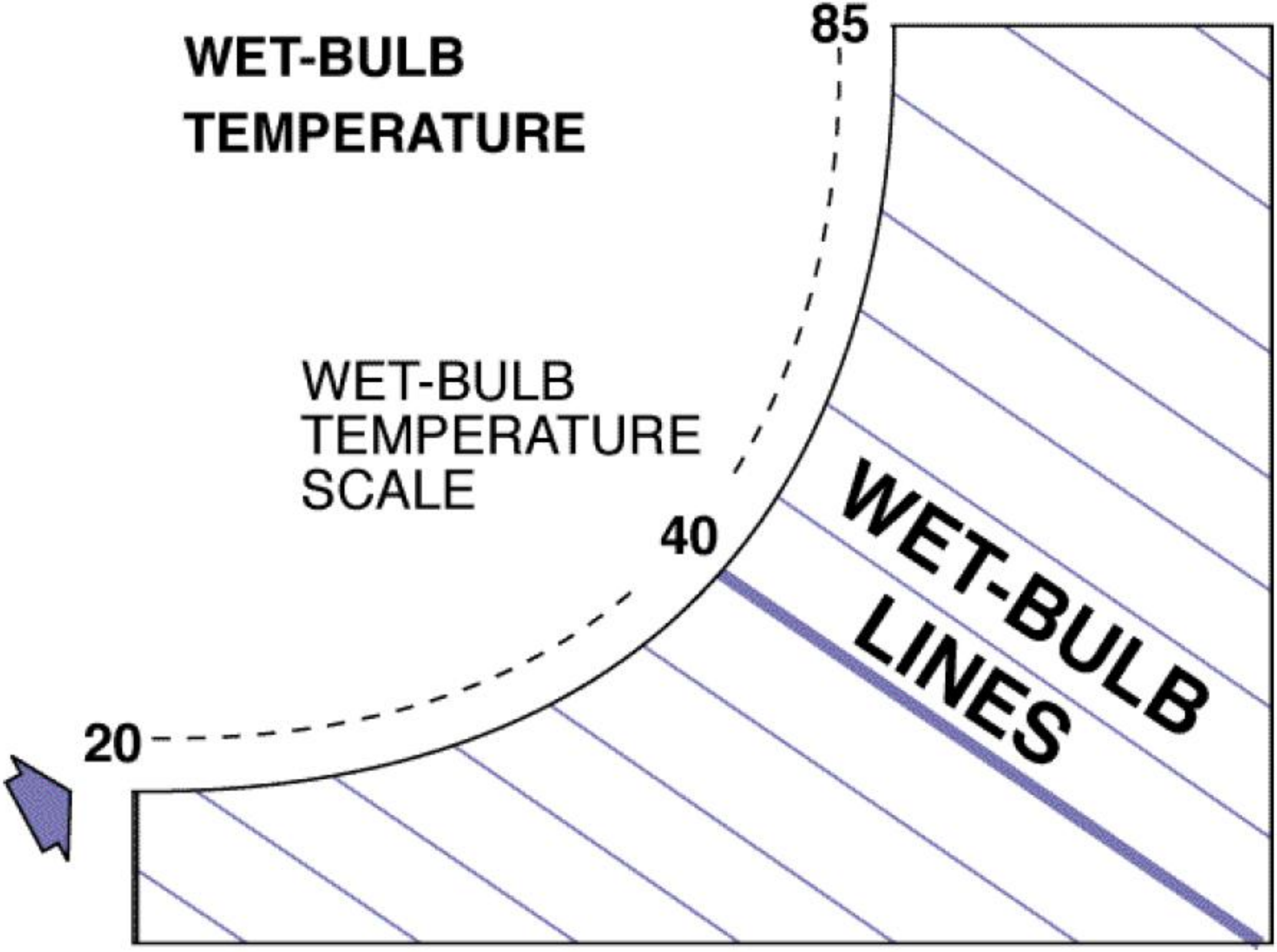
Psychrometric Chart

- Need two quantities for a state point
  - Can get all other quantities from a state point
- Can do all calculations without a chart
  - Often require iteration
  - Many “digital” psychrometric charts available
    - Can make your own

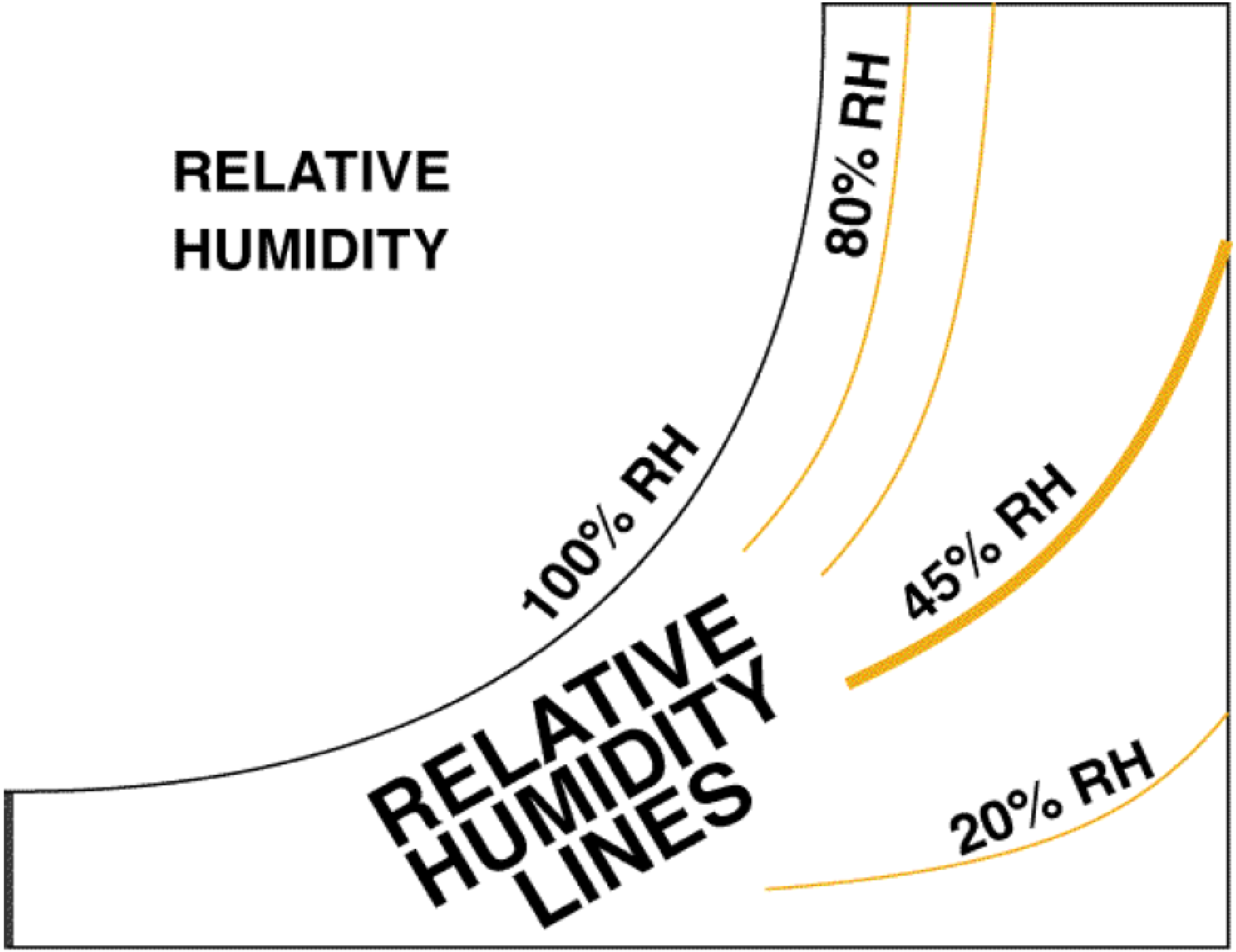
Temperature

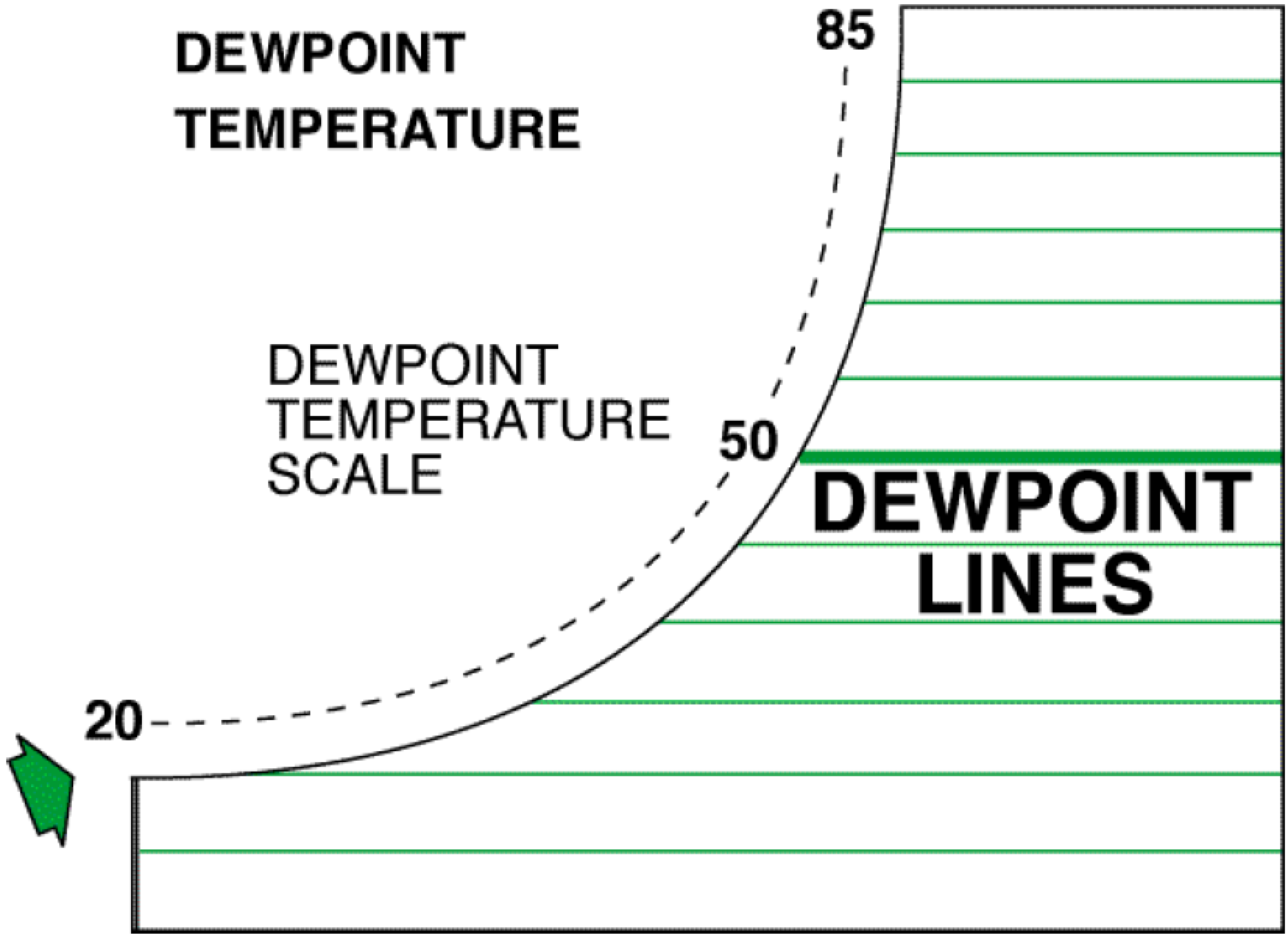
- Absolute Temperature
- Dry-bulb temperature
- Wet-bulb temperature
- Dew-point temperature


DRY-BULB
TEMPERATURE
DRY-BULB
LINES
20
50
105
DRY-BULB
TEMPERATURE
SCALE

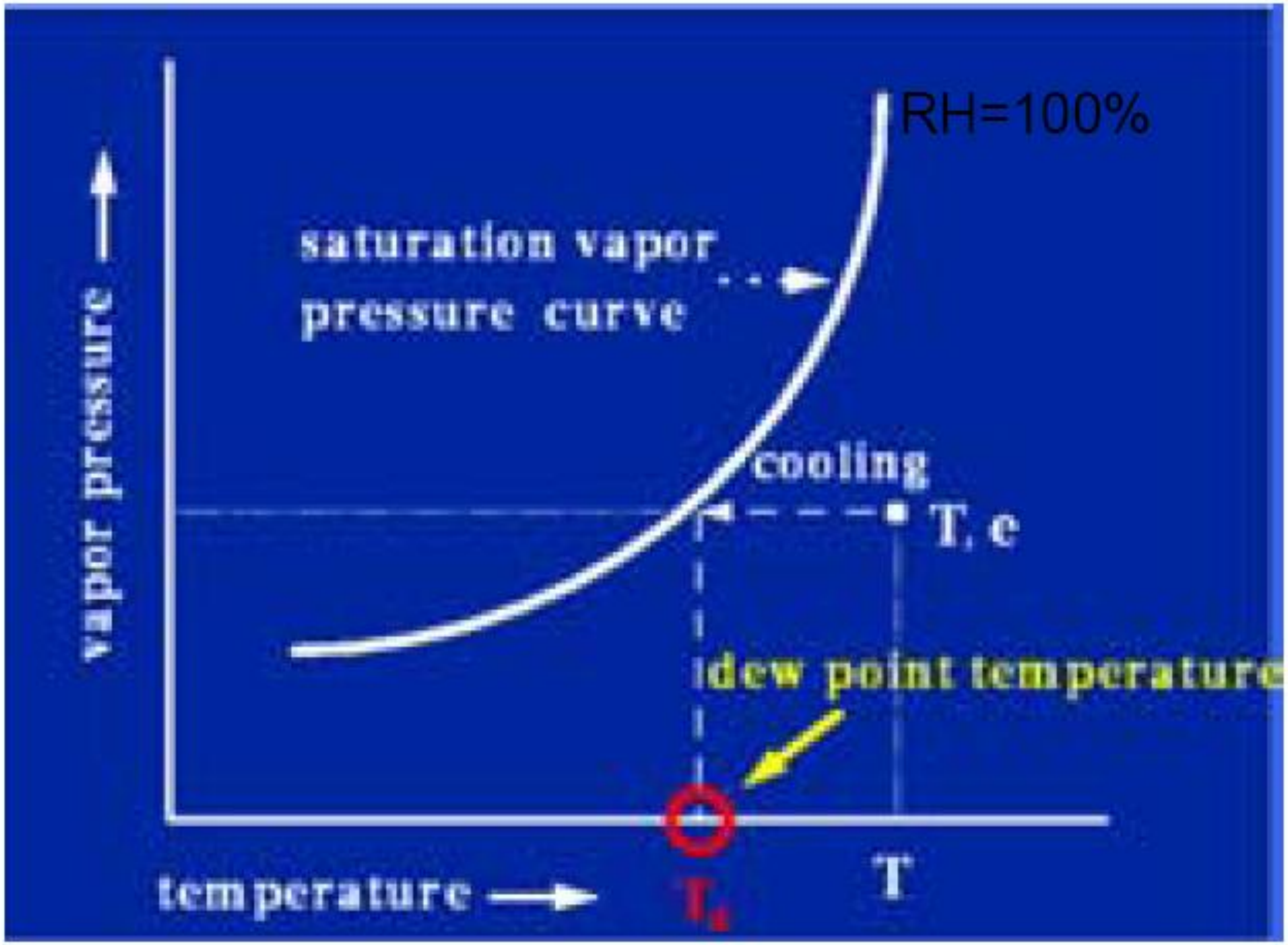


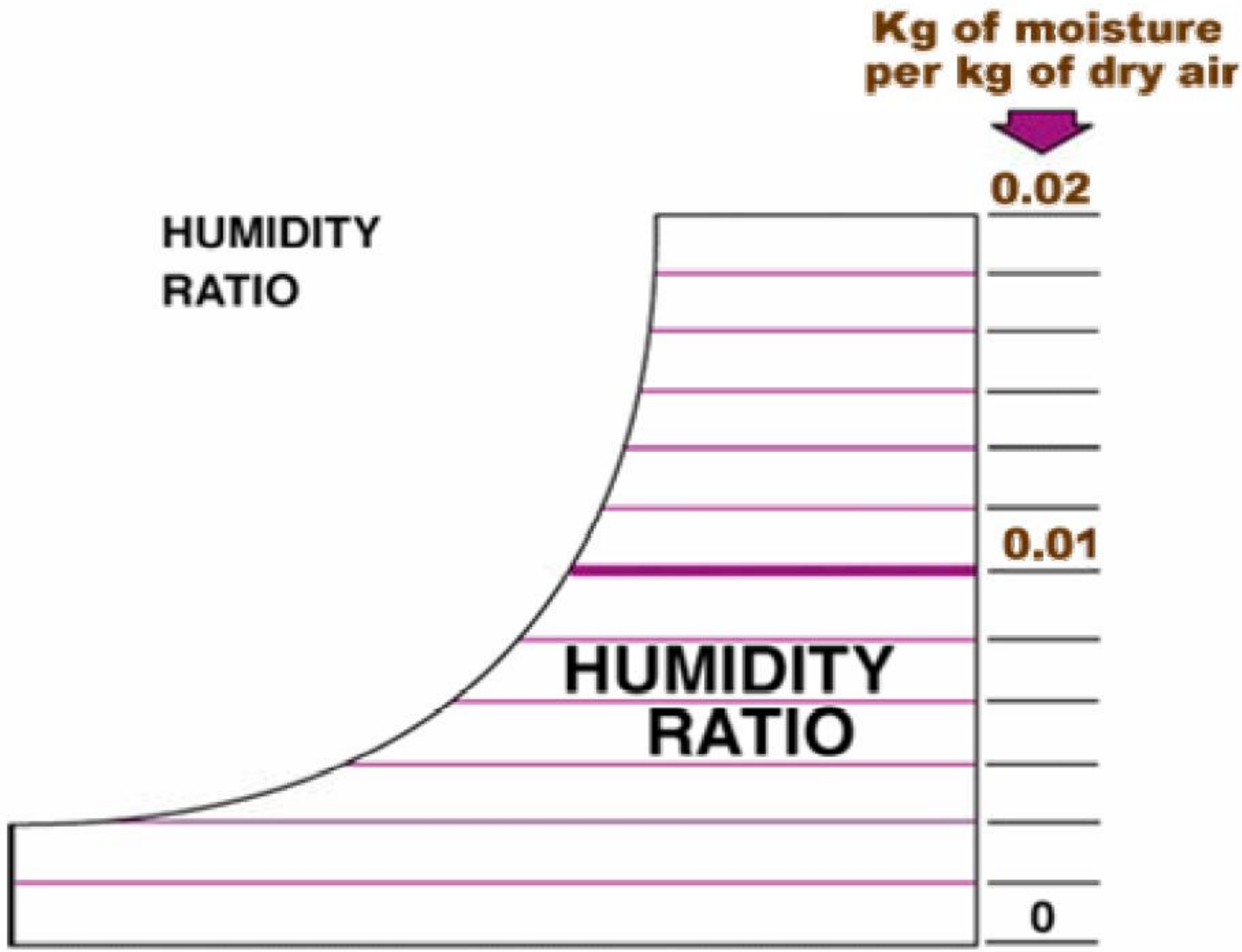
WET-BULB
TEMPERATURE
85
WET-BULB
TEMPERATURE
SCALE
40
20
WET-BULB
LINES


RELATIVE HUMIDITY
80% RH
100% RH
45% RH
RELATIVE HUMIDITY LINES
20% RH

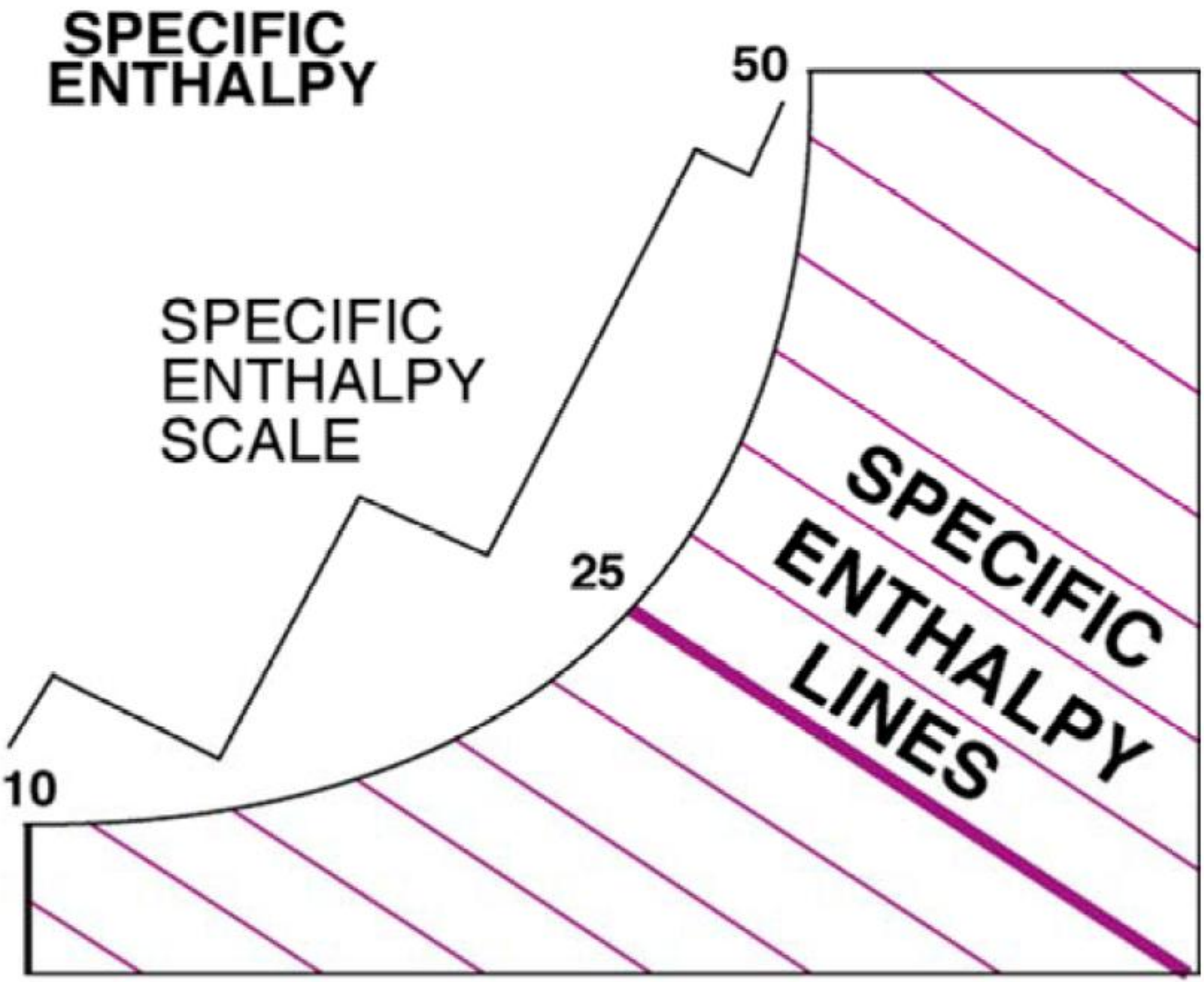

DEWPOINT
TEMPERATURE
85
DEWPOINT
TEMPERATURE
SCALE
50
DEWPOINT
LINES
20

RH and Dewpoint Temperature

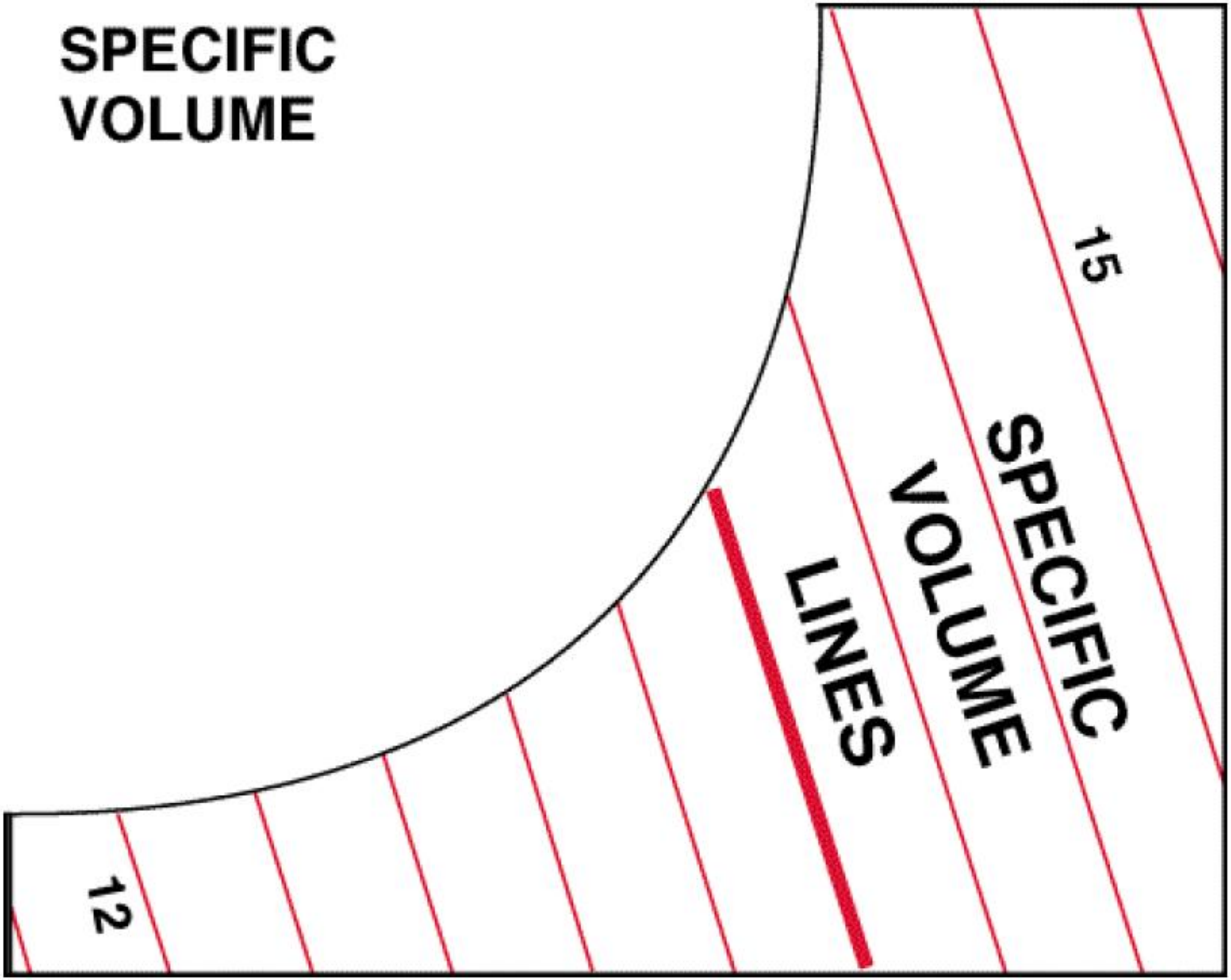




Kg of moisture
per kg of dry air
0.02
HUMIDITY
RATIO
0.01
HUMIDITY
RATIO
0


SPECIFIC
ENTHALPY
50
SPECIFIC
ENTHALPY
SCALE
25
10
SPECIFIC
ENTHALPY
LINES

SPECIFIC VOLUME



Psychrometric Charts

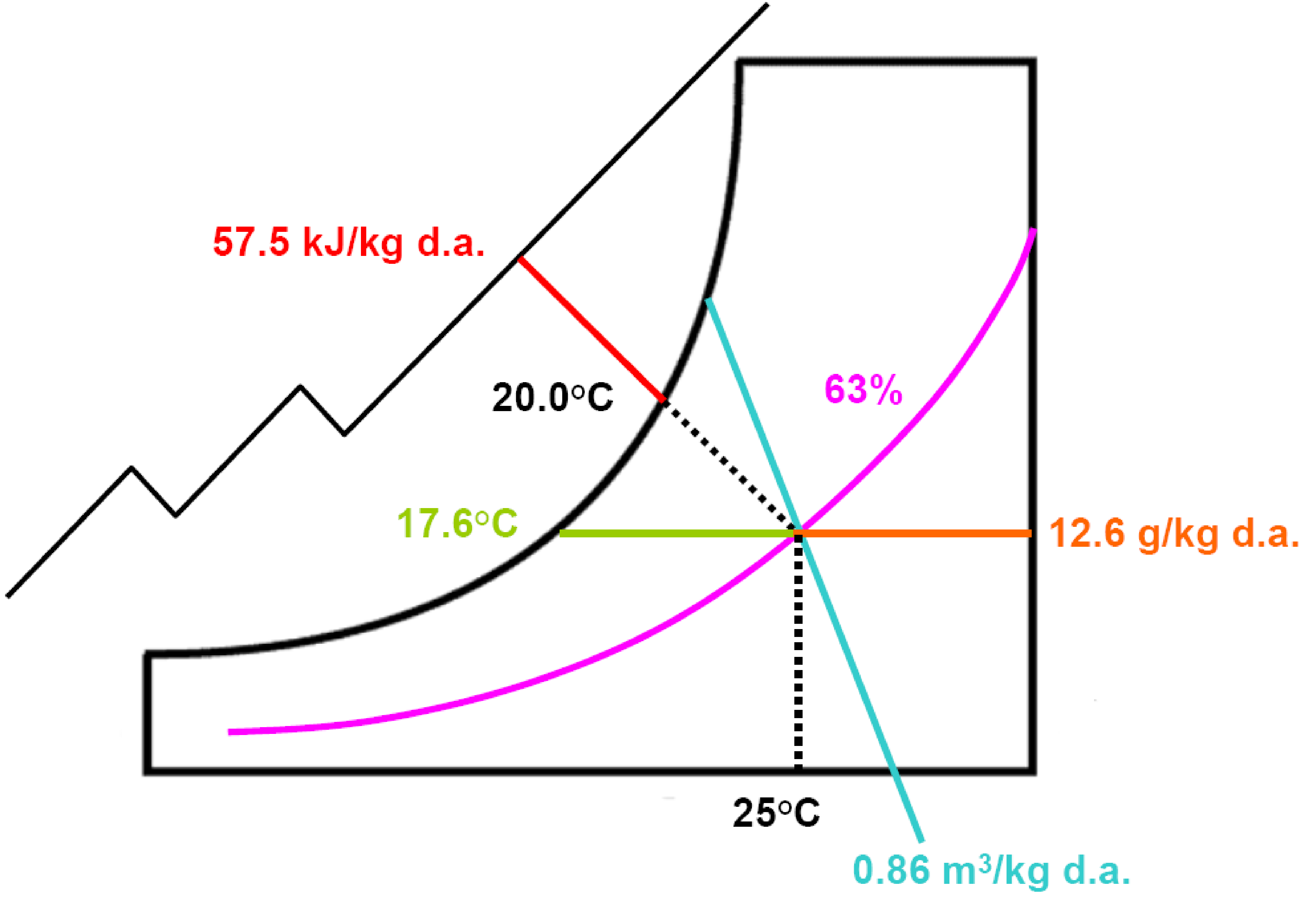
1. Make sure chart is appropriate for your environment
2. Figure out what two quantities you know
3. Understand their slopes on the chart
4. Find the intersection
   – Watch for saturation

Psychrometric chart: Example 1

Given: $T = 25°C$

$T_w = 20°C$

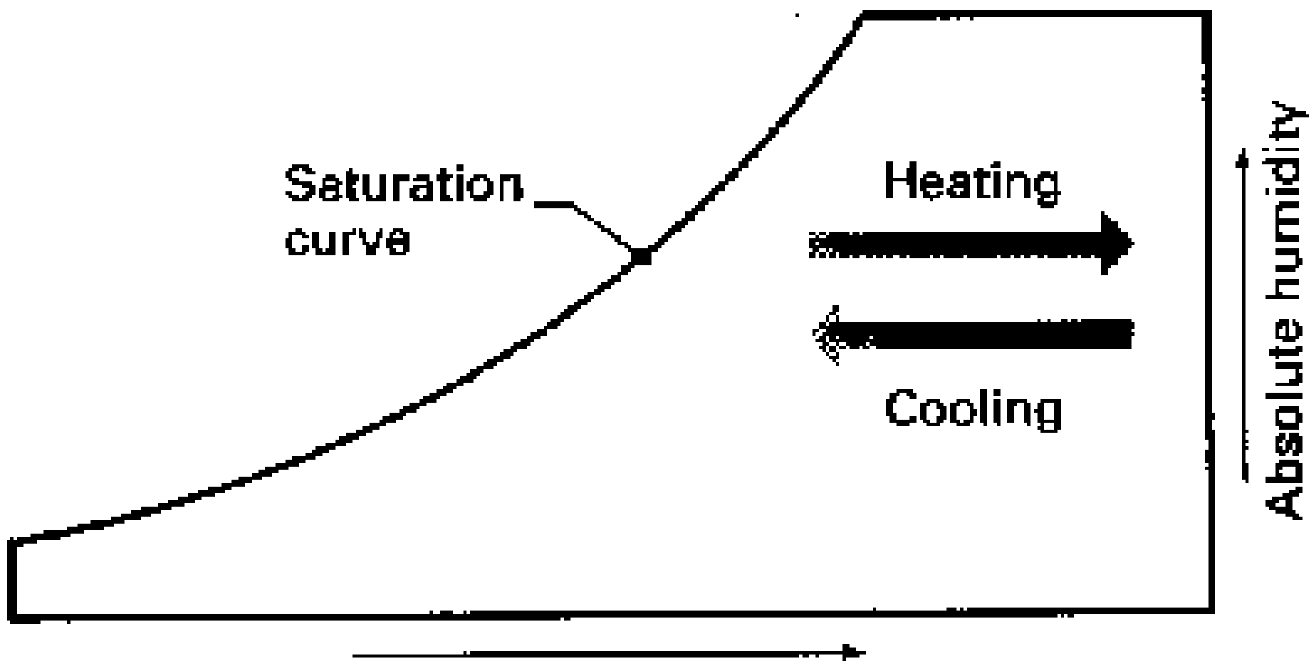
Required: (a) RH, (b) T_{dp}, (c) HR, (d) v, (e) h


57.5 kJ/kg d.a.
20.0°C
63%
17.6°C
12.6 g/kg d.a.
25°C
0.86 m3/kg d.a.

Psychrometric processes

Sensible Heating or Cooling

- a psychrometric process that involves the increase or decrease in the temperature of air without changing its humidity ratio
- Example: passing moist air over a room space heater and of kiln air over the heating coils



Sensible heating and cooling

Sensible heating

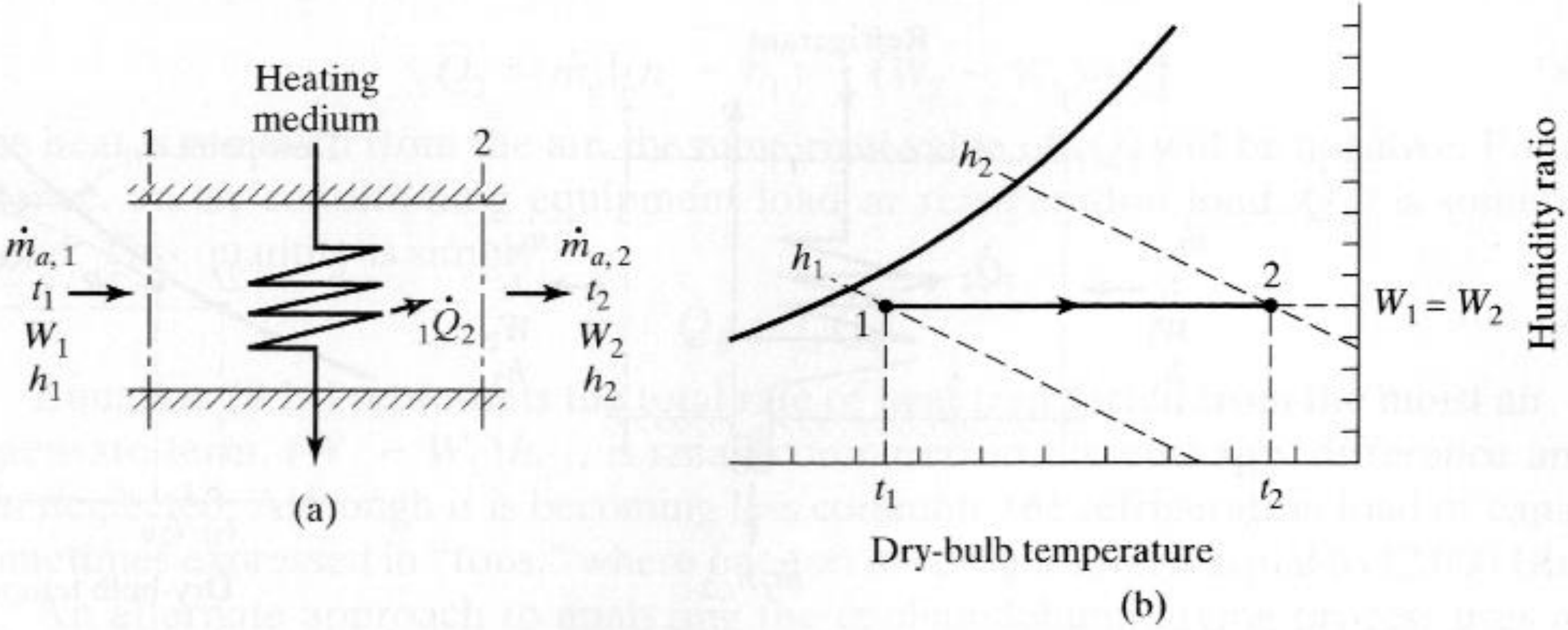
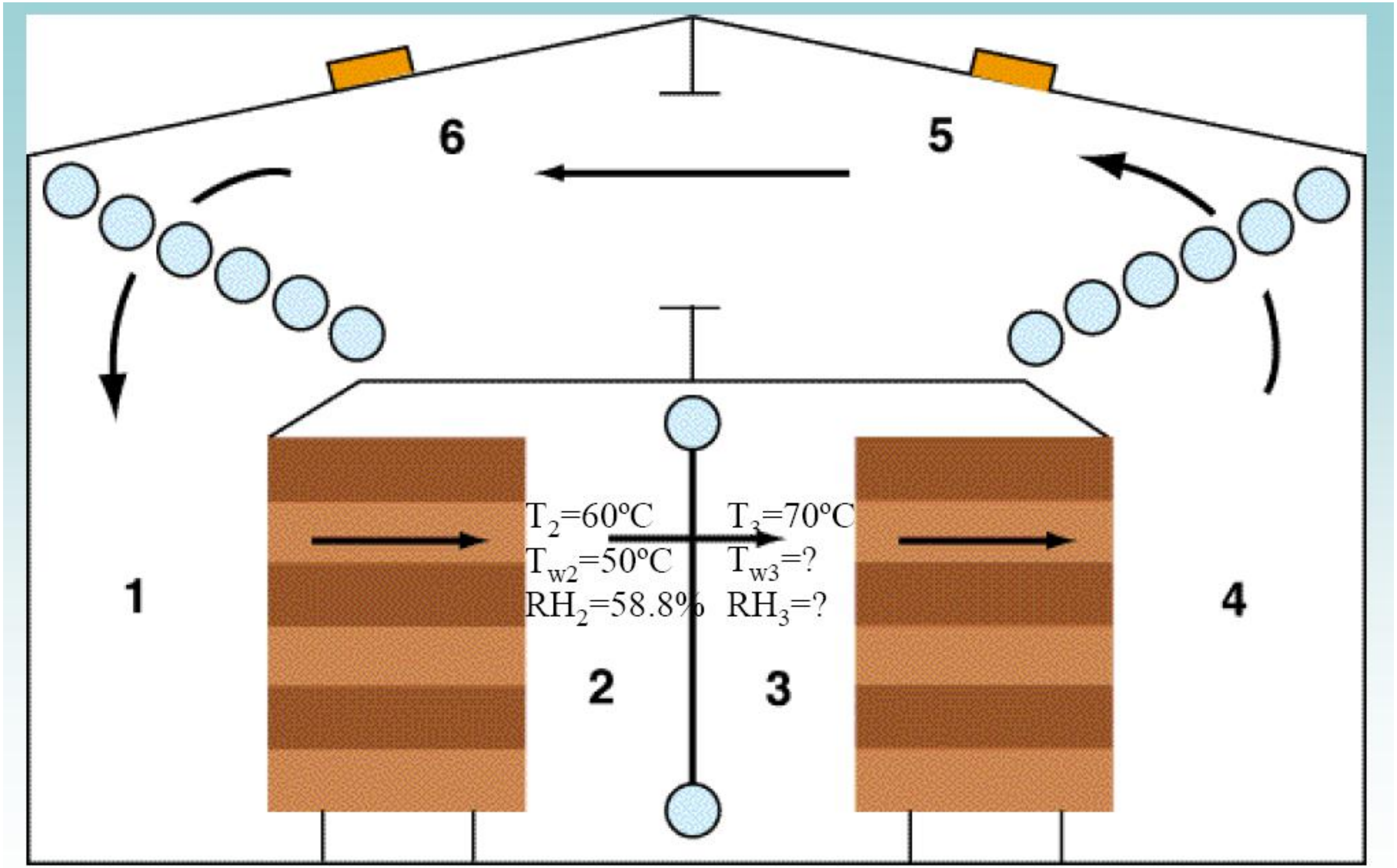
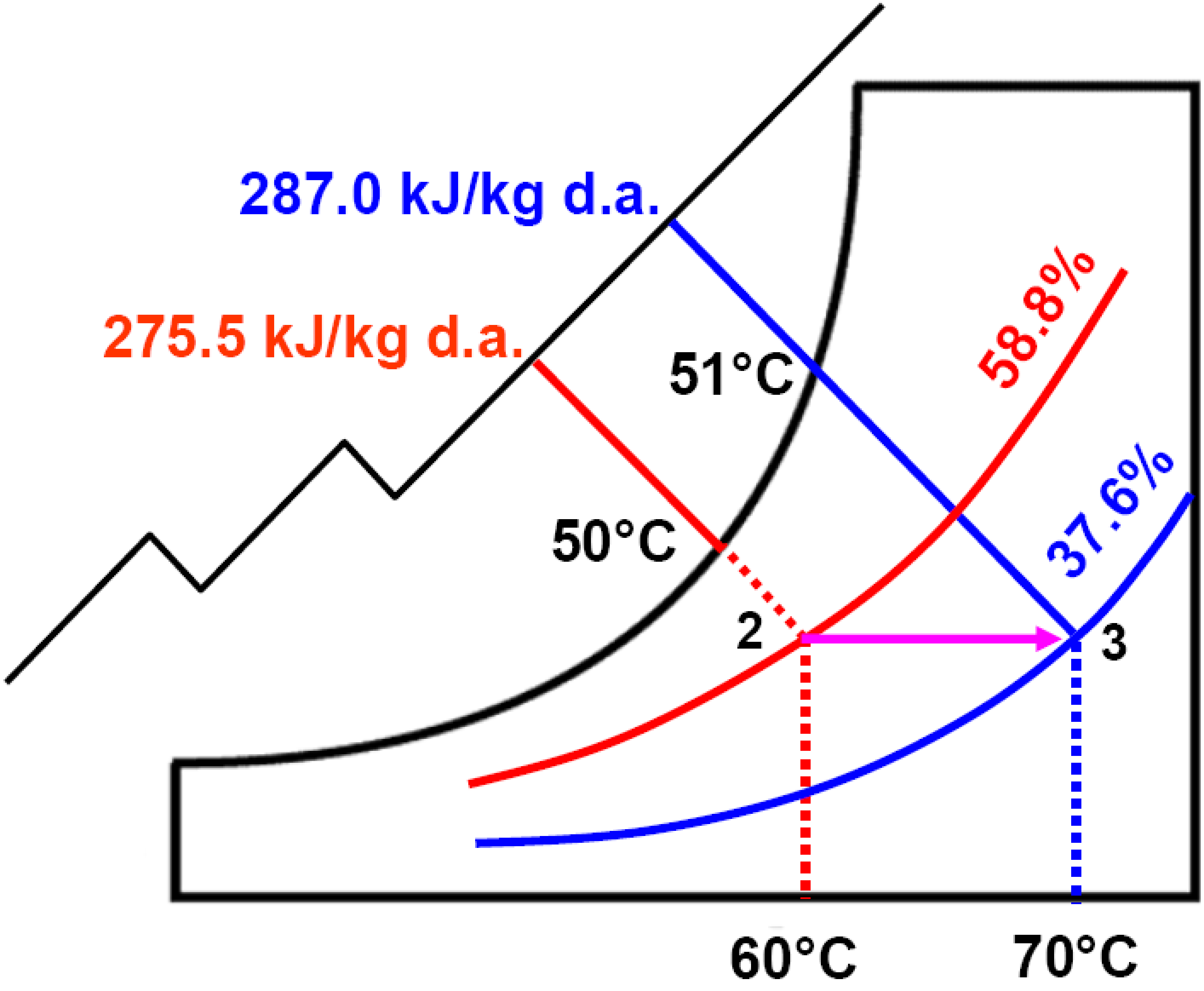


Figure 8.2 Schematic illustration of sensible heating of moist air.

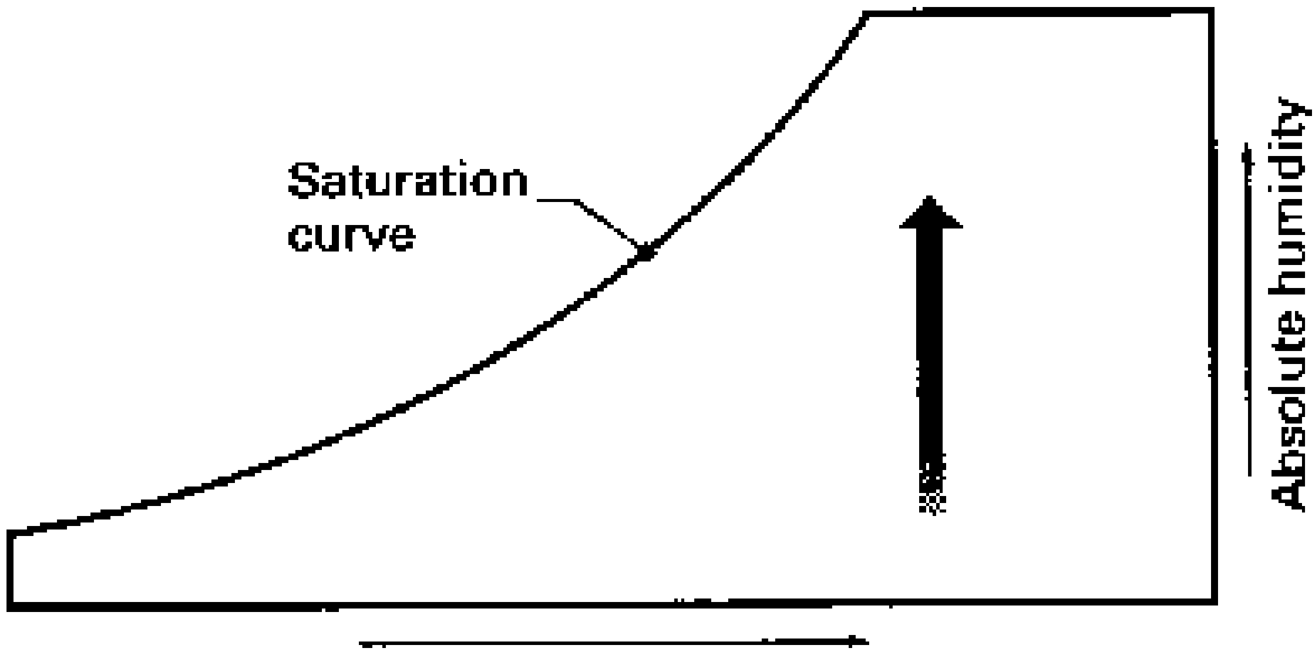
$$\dot{Q} = \dot{m} c_p \Delta t$$


6
5
T_2=60ºC
T_{w2}=50ºC
RH_2=58.8%
T_3=70ºC
T_{w3}=?
RH_3=?
1
2
3
4

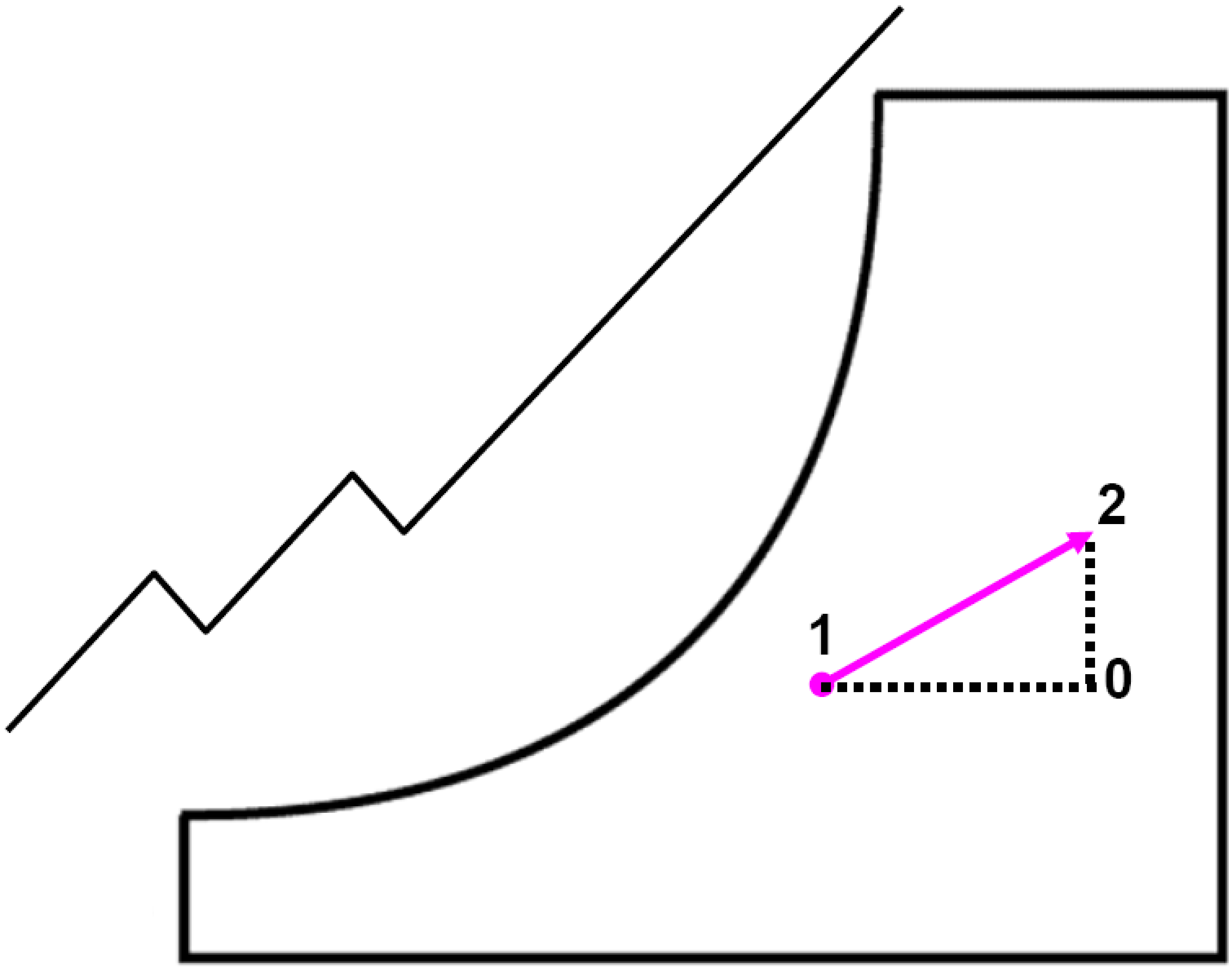

287.0 kJ/kg d.a.
275.5 kJ/kg d.a.
51°C
50°C
58.8%
37.6%
2
3
60°C
70°C

Heating and Humidifying

- a psychrometric process that involves the simultaneous increase in both the dry bulb temperature and humidity ratio of the air



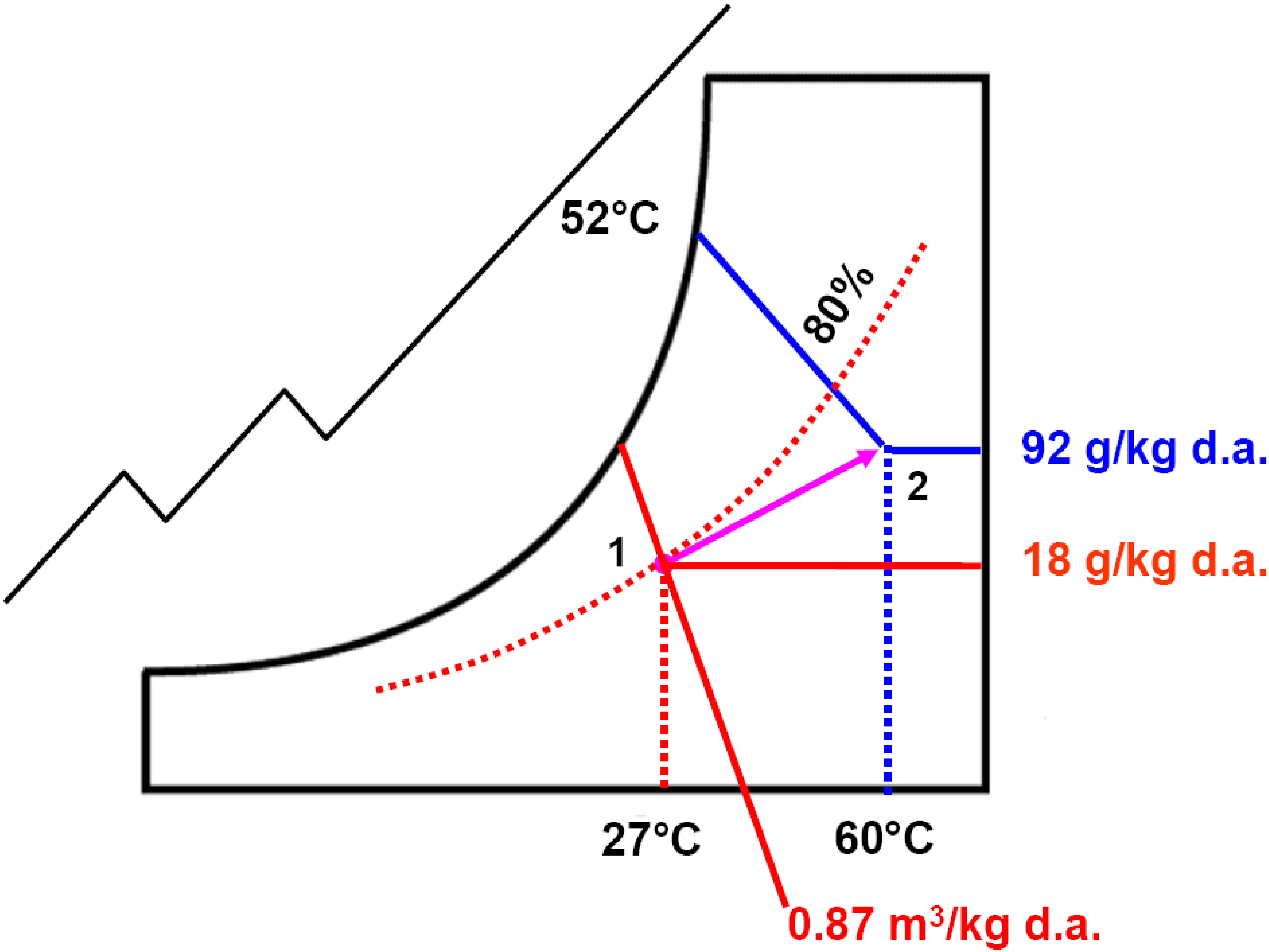
Humidification with steam



2
1
0

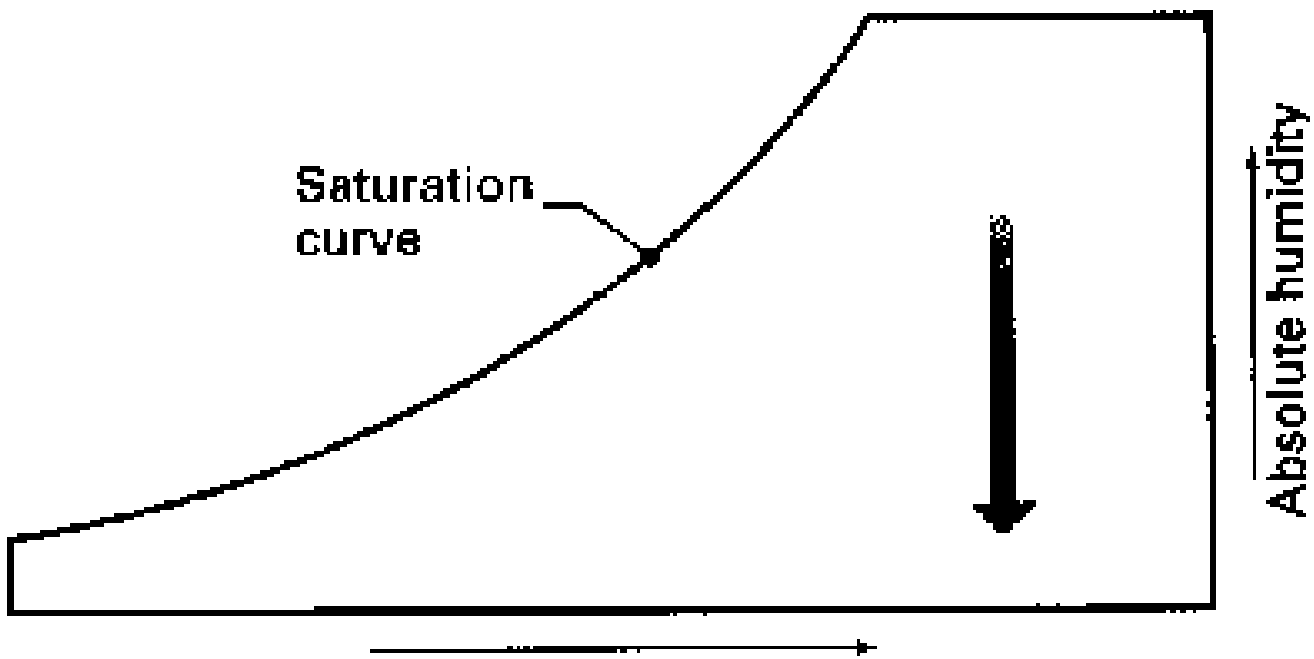
Example

Two and a half cubic meters of lumber is being dried at 60°C dry bulb temperature and 52°C wet bulb temperature. The drying rate of the lumber is 12.5 kg of water per hour. If outside air is at 27°C dry bulb temperature and 80% relative humidity, how much outside air is needed per minute to carry away the evaporated moisture?

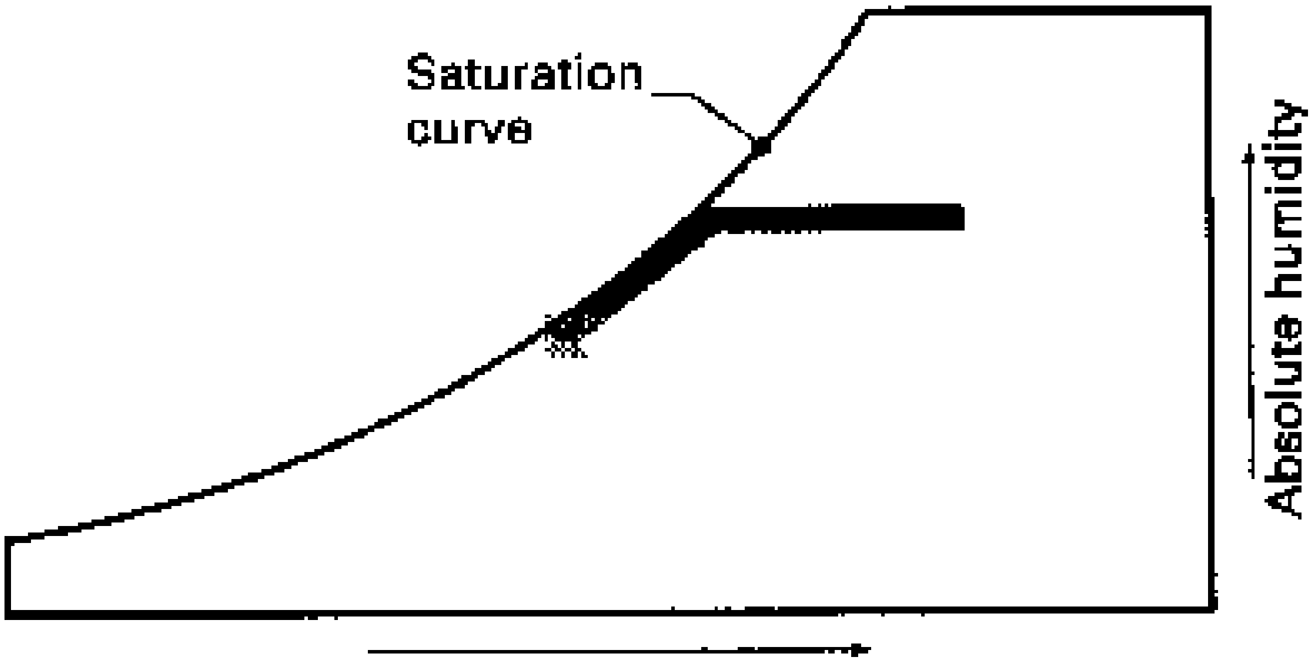

52°C
80%
92 g/kg d.a.
2
1
18 g/kg d.a.
27°C
60°C
0.87 m3/kg d.a.

Cooling and Dehumidifying

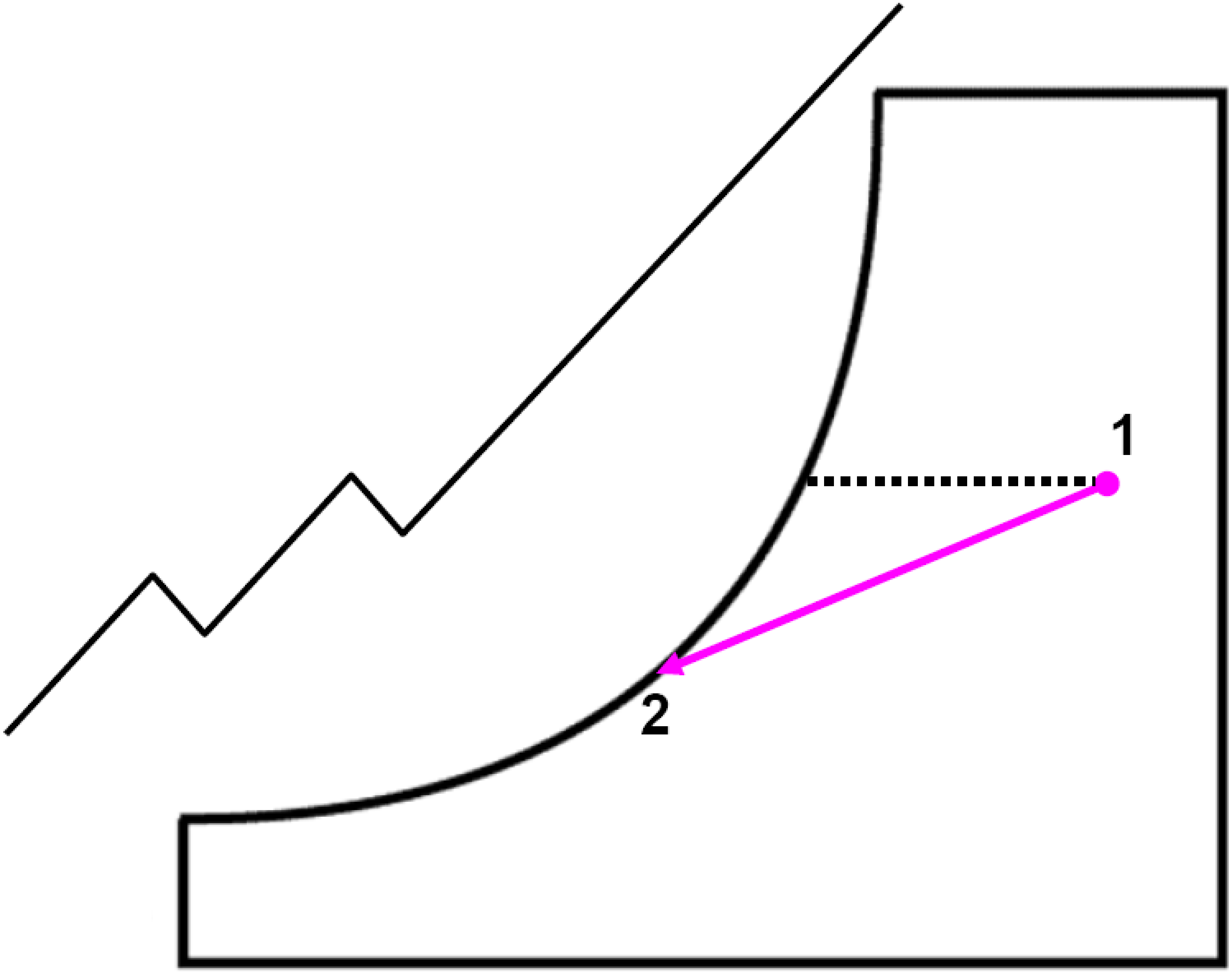
- a psychrometric process that involves the removal of water from the air as the air temperature falls below the dew-point temperature



Dehumidification by absorption



Dehumidification by cooling



1
2

Dehumidification by Cooling

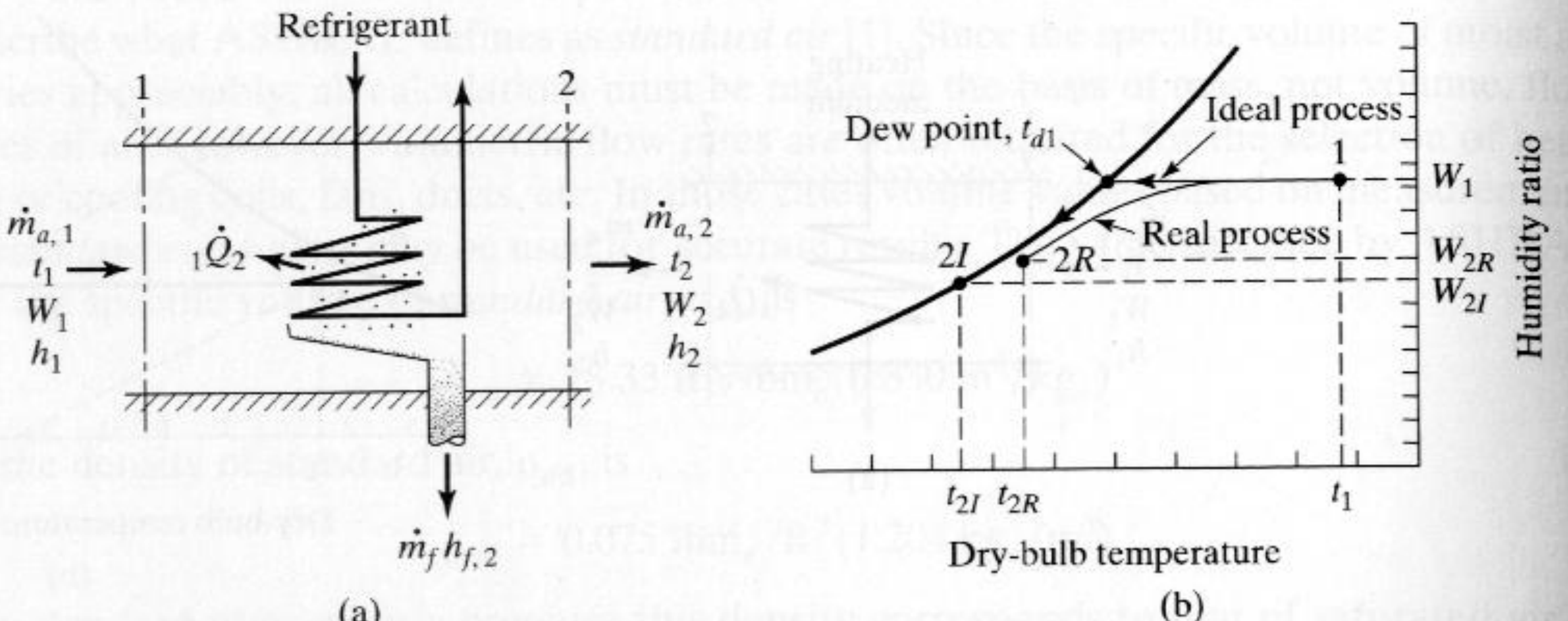
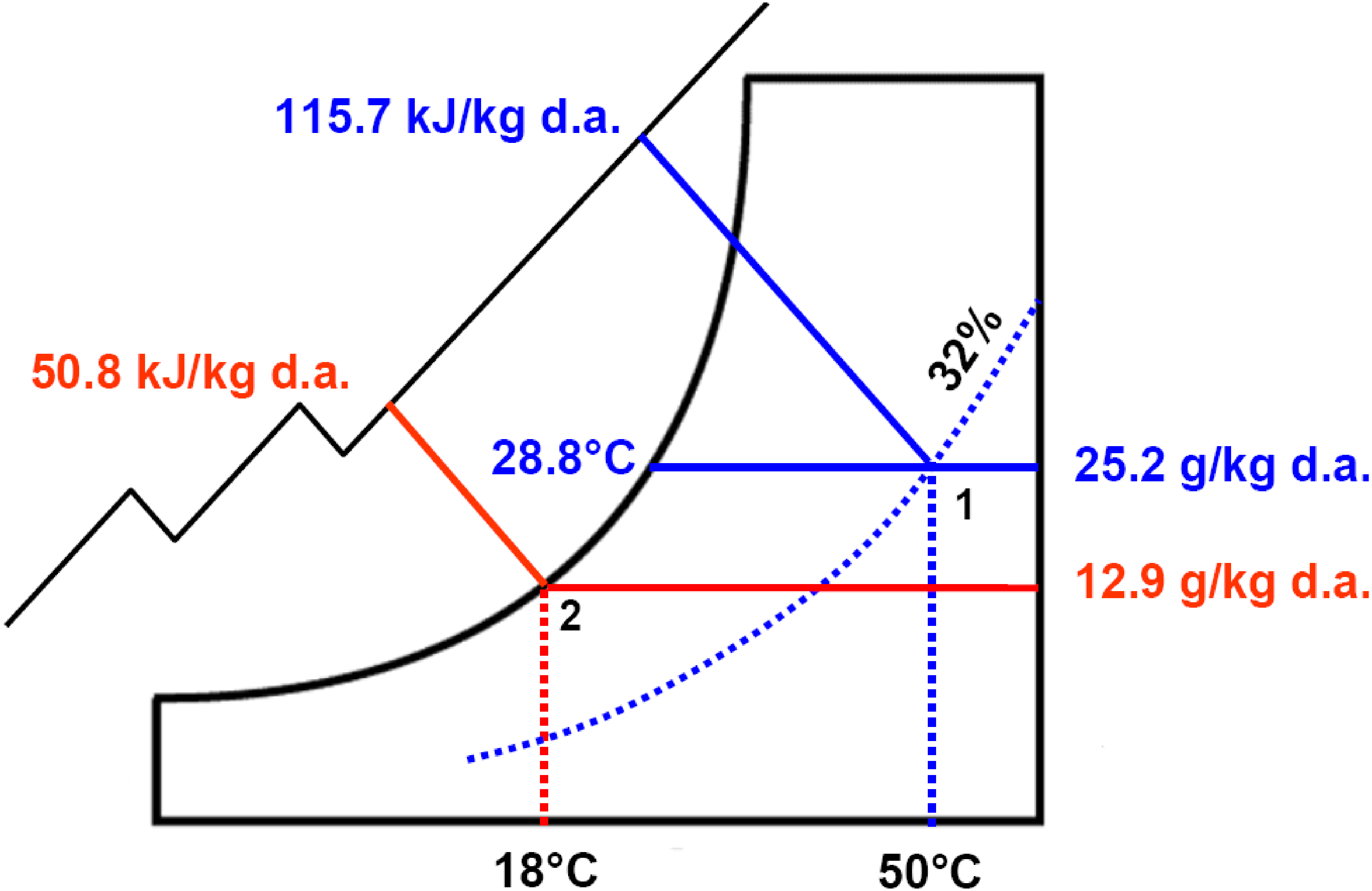


Figure 8.3 Schematic illustration of dehumidification by cooling.

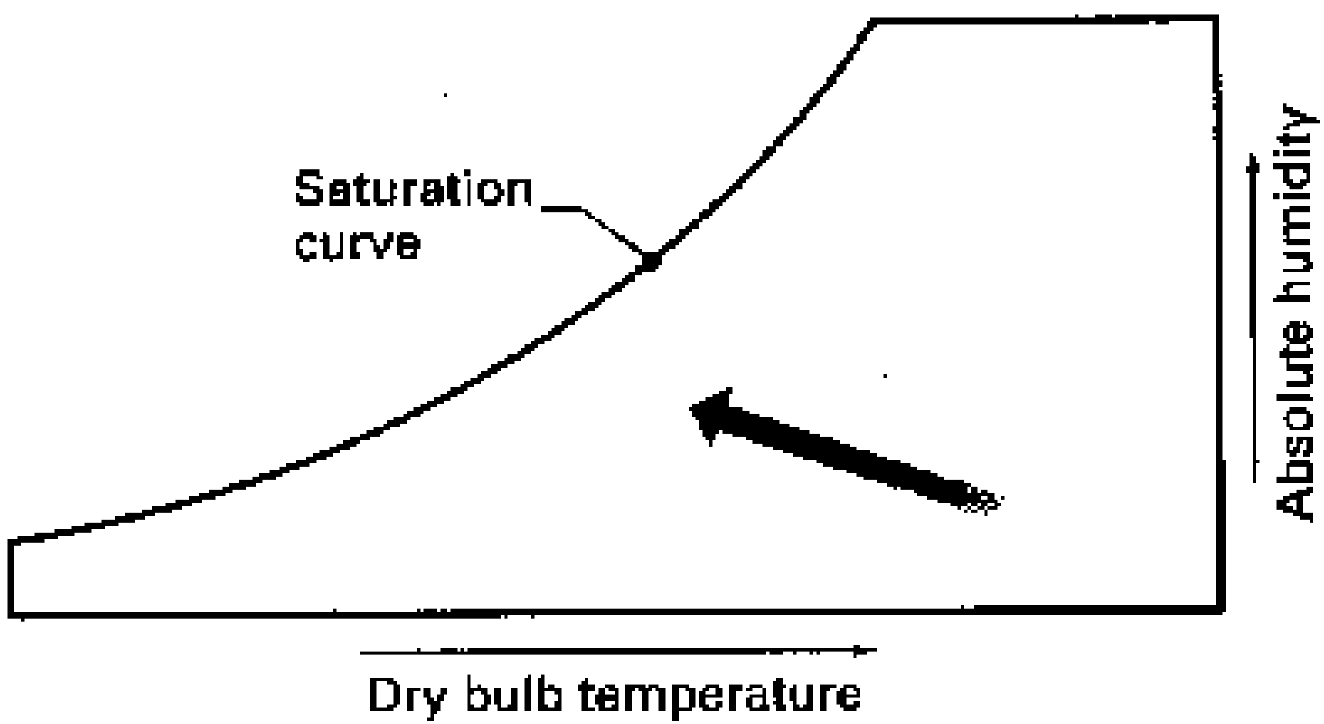
Example

Moist air at 50°C dry bulb temperature and 32% relative humidity enters the cooling coil of a dehumidification kiln heat pump system and is cooled to a temperature of 18°C. If the drying rate of 6 m^3 of red oak lumber is 4 kg/hour, determine the kW of refrigeration required.


115.7 kJ/kg d.a.
50.8 kJ/kg d.a.
32%
28.8°C
25.2 g/kg d.a.
1
12.9 g/kg d.a.
2
18°C
50°C

Adiabatic or Evaporative Cooling

- a psychrometric process that involves the cooling of air without heat loss or gain. Sensible heat lost by the air is converted to latent heat in the added water vapor



Humidification by evaporative cooling

Adiabatic Mixing of Moist Air Stream

- A psychrometric process that involves no net heat loss or gain during the mixing of two air streams

Adiabatic mixing

- Governing equation $\sum_{in} \dot{m}h + \dot{Q} = \sum_{out} \dot{m}h$

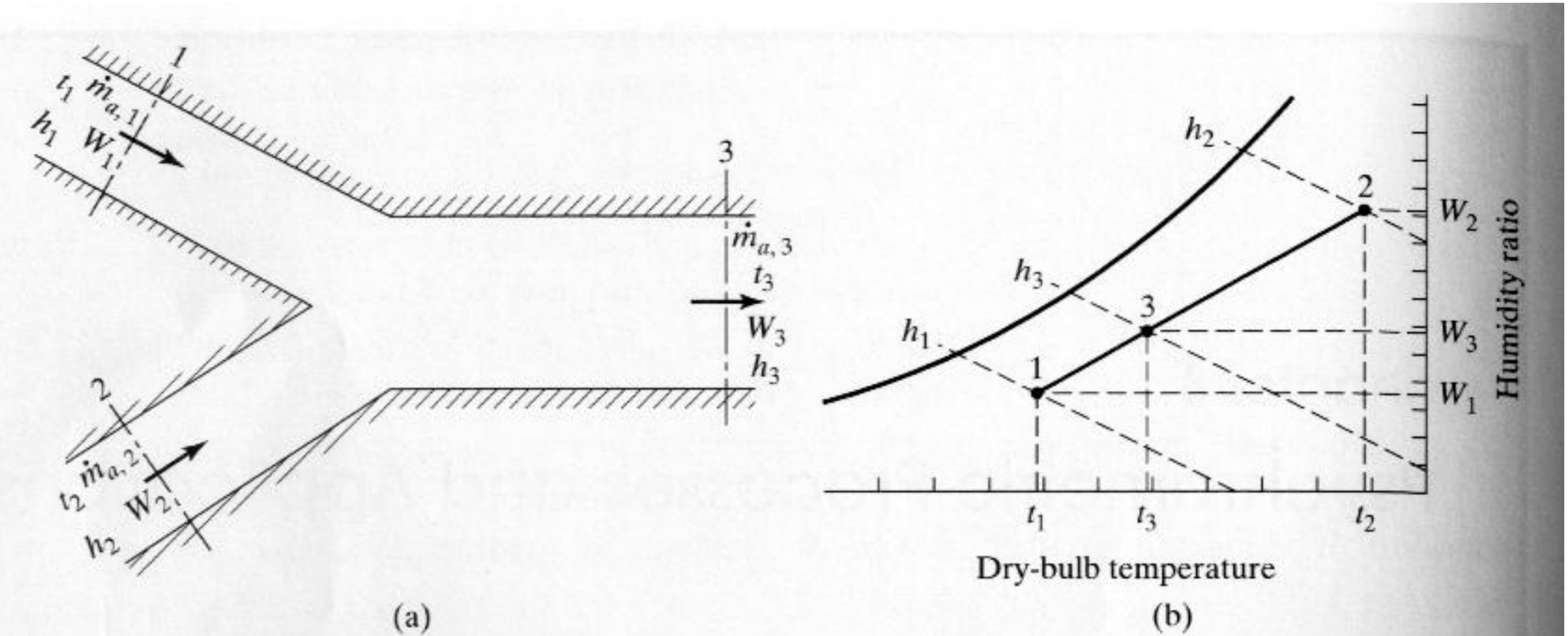
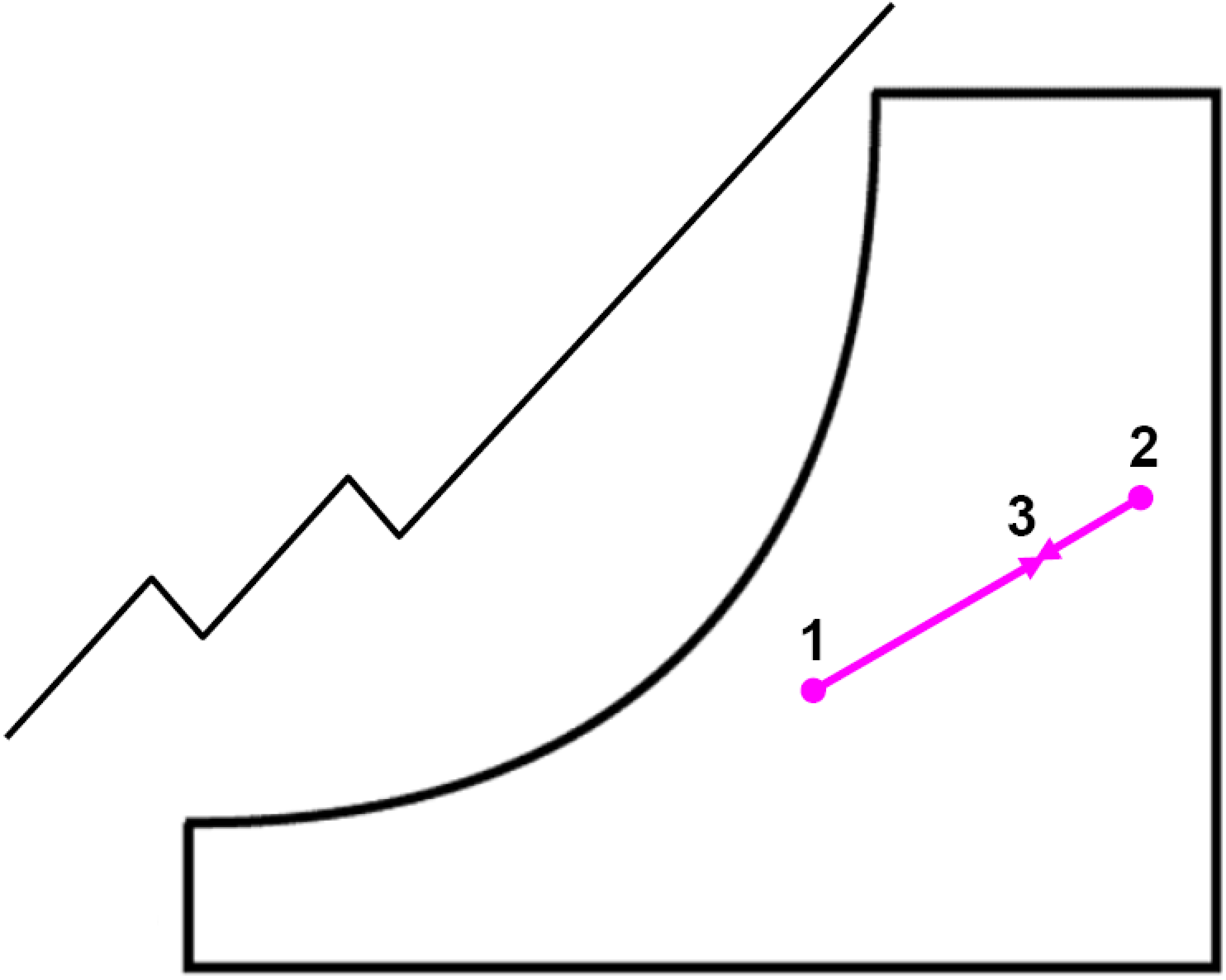
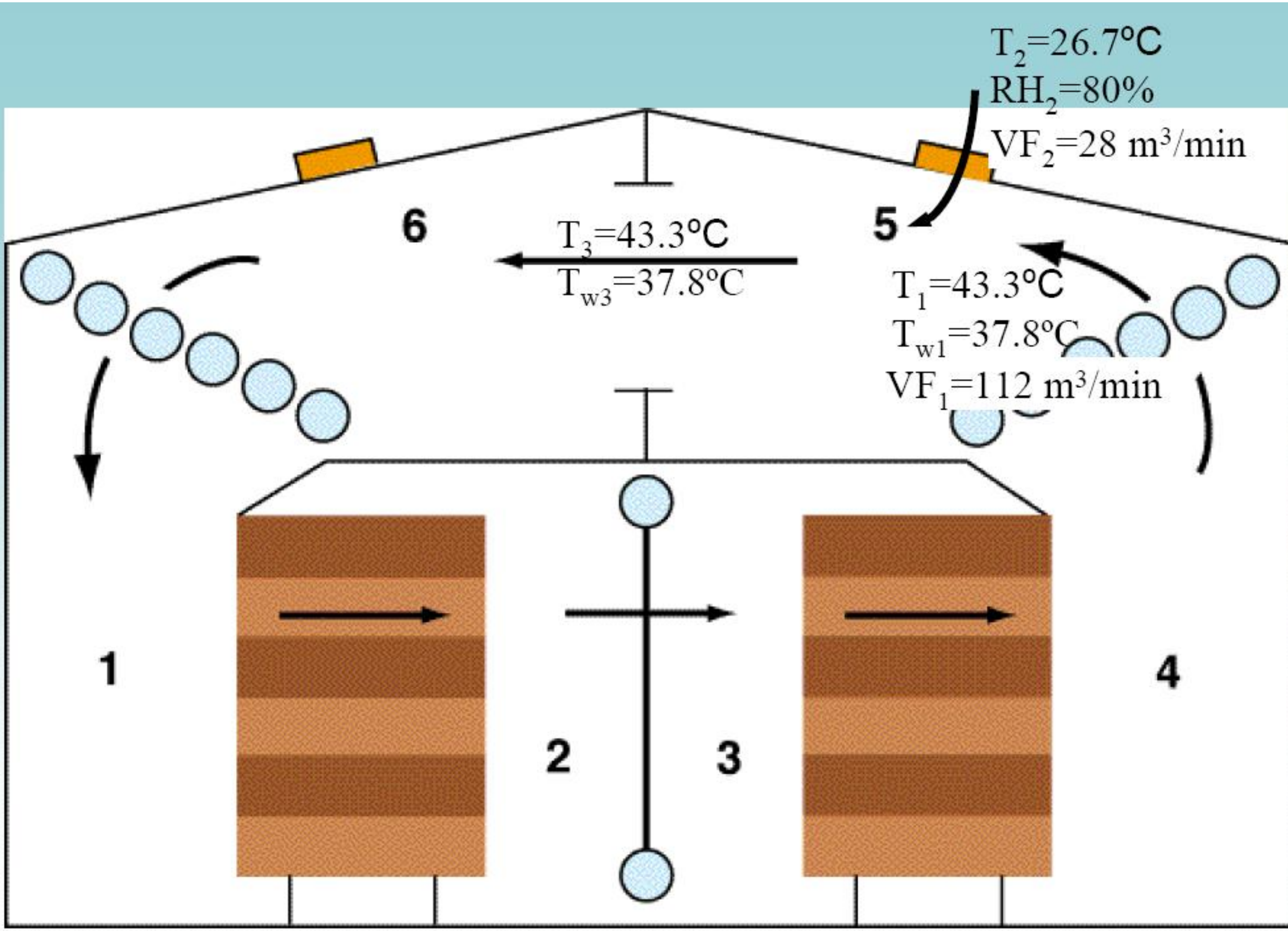
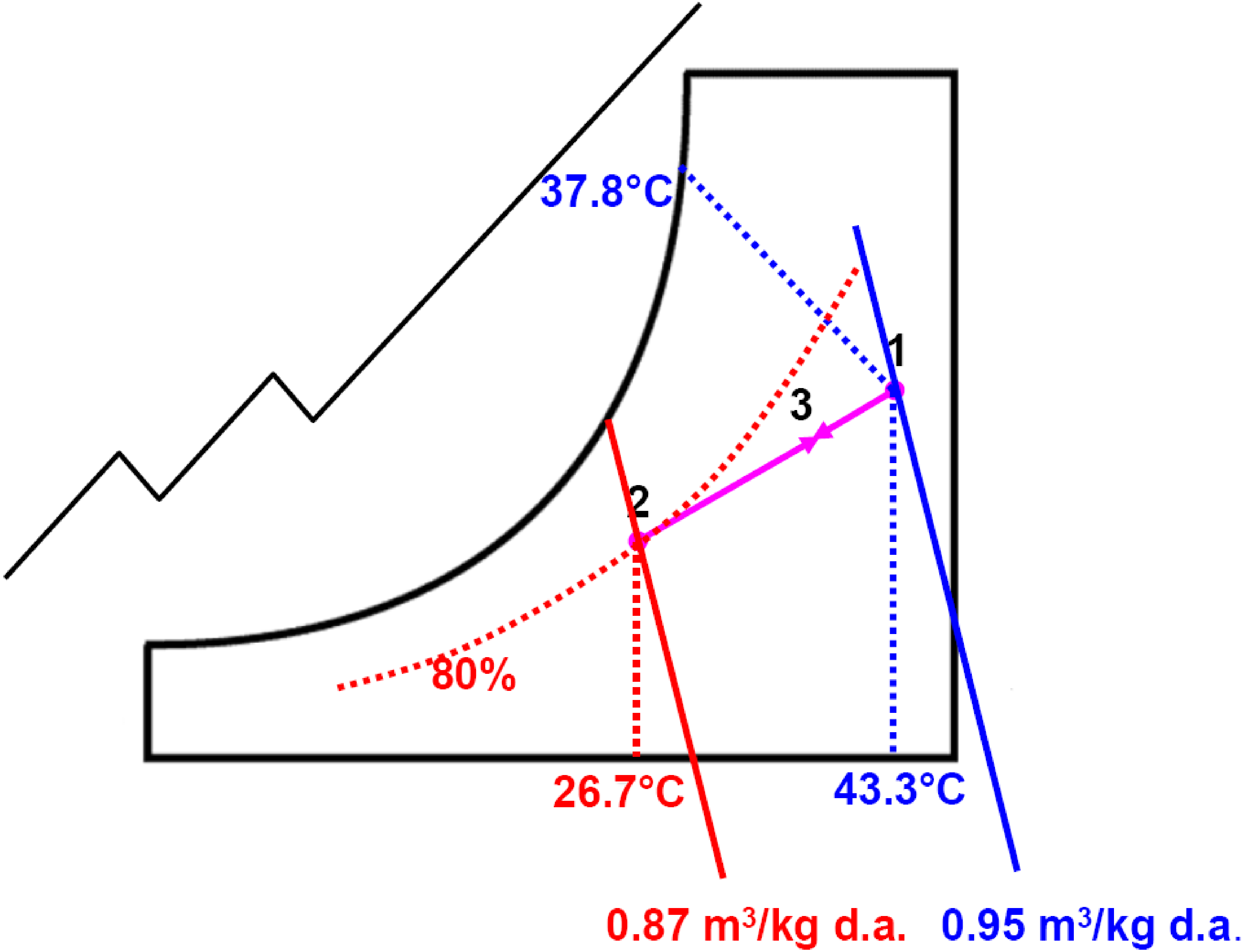


Figure 8.1 Schematic adiabatic mixing of two streams of moist air.


2
3
1



T2=26.7°C
RH2=80%
VF2=28 m3/min
6
5
T3=43.3°C
Tw3=37.8°C
T1=43.3°C
Tw1=37.8°C
VF1=112 m3/min
1
2
3
4


37.8°C
1
3
2
80%
26.7°C
43.3°C
0.87 m3/kg d.a.
0.95 m3/kg d.a.