HVAC Fundamentals & Components

Course No. ENRG 55A

HVAC Fundamentals & Components Outline

- A – Introduction to physical principles of HVAC & systems
  - Conversion of units
  - Concept of work, power, and energy
  - Overview of psychrometric analysis of the air conditioning
  - Thermodynamic laws and heat transfer principles
  - Estimate of sensible and latent heat changes
  - Analysis of thermal comfort
- B – Load calculations
  - Heating loads
  - Cooling load
  - Use of psychrometric tables and various software packages for heating and cooling estimates
- C – Conveyance systems
  - Principles of conveyance systems
  - Types of conveyance equipment and components
  - Nameplate data interpretation
- D – Principles of heating systems
  - Types of heating equipment & components
  - Nameplate data interpretation
- E – Cooling systems
  - Principles of the refrigeration cycle
  - Types of equipment & components
  - Nameplate data interpretation
- F – Air-handling systems
  - Diffusers, and registers
  - Dampers, louvers, filters, fans

HVAC Fundamentals & Components

A. Introduction to physical principles of HVAC & systems
   1. Conversion of units
      a. **Temperature**
      b. Pressure
      c. Horse power
      d. Power (kWh)
      e. British Thermal Units/hr (BTU/hr)
      f. Tons
   2. Concept of work, power, and energy
   3. Overview of psychrometric analysis of the air conditioning system
      a. Psychrometric processes and calculations
         i. Sensible or latent processes
         ii. Air side equation
         iii. Air side mixing
         iv. Summary of process line calculations
      b. Room sensible heat ratio (RSHR) & room cubic feet per minutes (CFM)
         i. Room sensible heat ratio
         ii. Room sensible heat ratio line
         iii. Design CFM (CFM)
         iv. Multiple room sensible heat ratios
      c. The coil sensible heat ratio (CSHR)
         i. Coil sensible heat ratio without ventilation
         ii. Coil sensible heat ratio ventilation
         iii. Construction of the RSHR & CSHR
         iv. Coil By-pass factor
         v. Thermodynamic laws and heat transfer principles
         vi. Estimate of sensible and latent heat changes
         vii. Analysis of thermal comfort

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Conversion of Units

a. Temperature:

Definition: It is a thermodynamic property that indicates heat intensity or the amount of heat level in a substance or process. Heat intensity could be coldness or hotness.

Temperature scale: A thermometer is the instrument used to measure the temperature of a substance

Types of Thermometers: Celsius, Fahrenheit, Kelvin, and Rankine

System of International (SI) Units

Celsius scale: Measures ice point of water at 0^oC and boiling point of water at 100^oC

Kelvin scale: Measures ice point of water at 273^oK and boiling point of water at 373^oK. However, Kelvin scale measure absolute zero (0^oK) is (-273^oC) on the Celsius scale

English System Units (US Customary Units)

Fahrenheit scale: Measures ice point of water at 32^oF and boiling point of water at 212^oF

Rankine scale: Measures ice point of water at 492^oR and boiling point of water at 672^oR; In addition, Rankine scale absolute zero temperature at 0^oR is -460^oF on Fahrenheit scale

NB: Absolute zero temperature is the temperature set point when all molecules cease to move.

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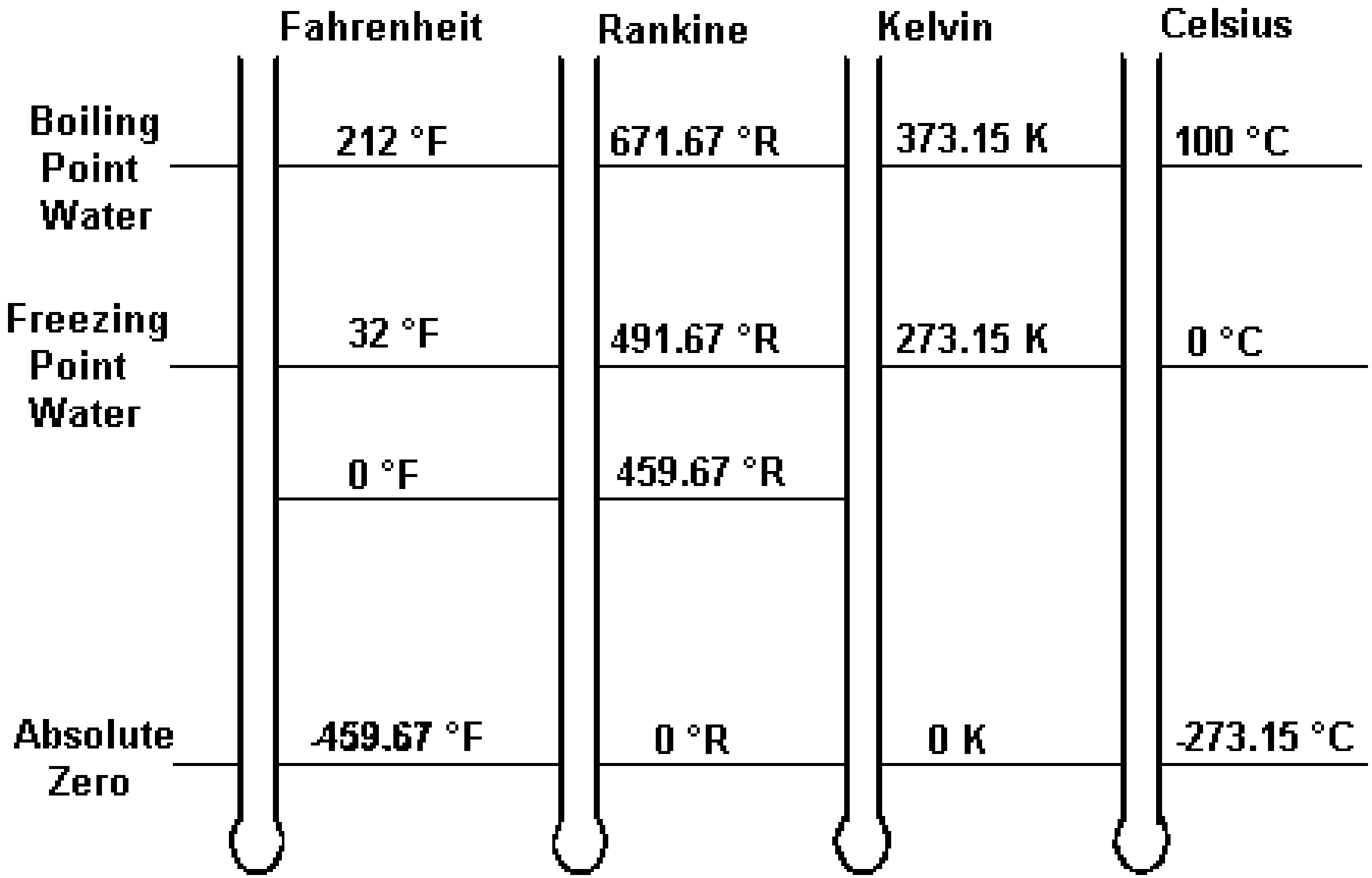
Temperature conversions



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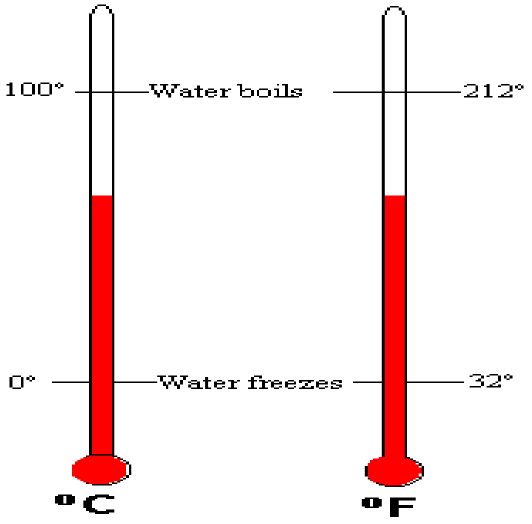
Temperature: Fahrenheit to Celsius conversion



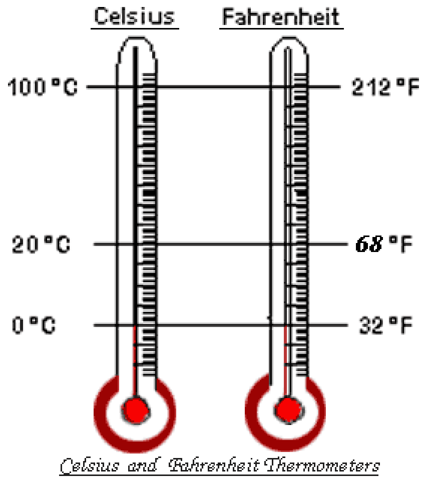
Equations for temperature conversions

$$^{o}C = \frac{5}{9}\left(^{o}F - 32\right) \longrightarrow (1)$$

$$^{o}F = \frac{9}{5}{}^{o}C + 32 \longrightarrow (2)$$

or

$$^{o}F = 1.8^{o}C + 32 \longrightarrow (3)$$



Example (1):

Convert 20°C to Fahrenheit degrees (°F)

Solution

Using equation 2 or 3

$$F = 1.8C + 32$$

$$\Rightarrow F = (1.8 \times 20) + 32$$

$$\therefore \underline{F = 68^{o}F}$$

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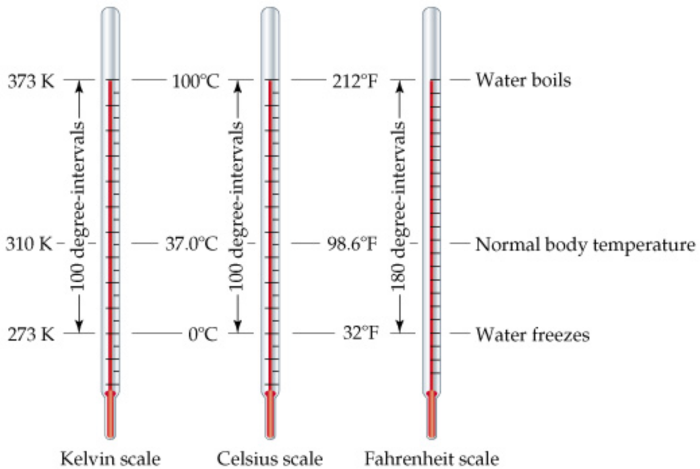
Equations for Celsius to Kelvin conversion and Fahrenheit to Rankine



$$^oK = ^oC + 273 \longrightarrow \quad (4)$$

$$^oR = ^oF + 460 \longrightarrow \quad (5)$$

Example (2):

Convert 82°F to Rankine degrees

Solution:

From equation (5)

$$R = F + 460$$

$$\Rightarrow R = 82 + 460 = \underline{542^oR}$$

Example (3)

Convert 104°F to Kelvin degrees

Solution:

From equation (1)

$$C = \frac{5}{9}(^oF - 32) \longrightarrow (1)$$

$$\Rightarrow C = \frac{5}{9}(104 - 32) = \frac{5}{9}(72) = \frac{360}{9}$$

$$\therefore C = 40^o C$$

Also using Equation (4)

$$K = ^oC + 273$$

$$\Rightarrow K = 40 + 273$$

$$\therefore \underline{K = 313^o K}$$

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Exercises on temperature conversions

Problem 1:

Convert the following Celsius temperature readings to equivalent temperatures on the Fahrenheit scale:

A. -76^oC
B. 95^oC
C. -115^oC

Problem 2:

In a manufacturing process, the temperature passing across a heating coil is increased from 40^oF to 160^oF. Estimate the temperature rise in degrees Celsius.

Problem 3:

Convert the following temperatures in Kelvin to equivalent temperatures in degrees Rankine

A. 125^oK
B. 210^oK

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b. Pressure unit conversion

1. Definition: Pressure is defined as a measure of the intensity of a force at any given point on the contact surface or in short, we say pressure is force exerted on a substance per unit area. Units for pressure include: inches mercury, inHg; inches water column, inwc or inches water gauge, inwg; pound per square inches, lb_f/in^2, or lb_f/ft^2, Pascal, etc.

2. Mathematically, we've $$\Pr essue(P) = \frac{Force(F)}{Area(A)}$$

3. There are three types of pressures used to describe fluid (air, water etc.) in motion. These include: Static Pressure (SP), Velocity Pressure (VP) and Total Pressure (TP)

4. Mathematically, we've $$TP = SP + VP$$

Where: TP = the total pressure which is the sum of static and velocity pressures

SP = the static pressure is the pressure of the fluid at rest. It is calculated by using *"Bernoulli's Equation"* or measured by manometers, barometers, Bourdon tube gages etc.

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + H_p = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} + H_f$$ Where: SP = $\frac{p_1}{\gamma}, \frac{p_2}{\gamma}$

This flow energy equation applied to flow in a duct and pipe

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VP = the velocity pressure is used to measure velocities and flow rates in piping and ducts.

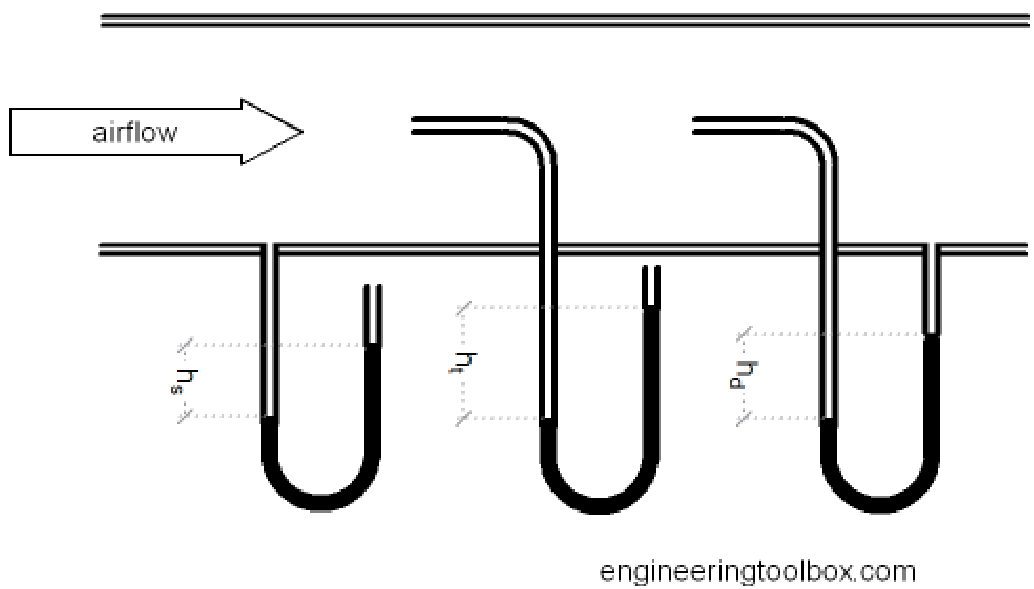
VP can be calculated using the equation $VP = \frac{V^2}{2g}$, from *Bernoulli's Equation*

$$\Rightarrow V = \sqrt{2gVP}$$

VP is measured using *pitot tube*

Pitot Tube

The pitot tube is a simple and convenient instrument to measure the difference between **static, total** and **dynamic pressure (or head)**.



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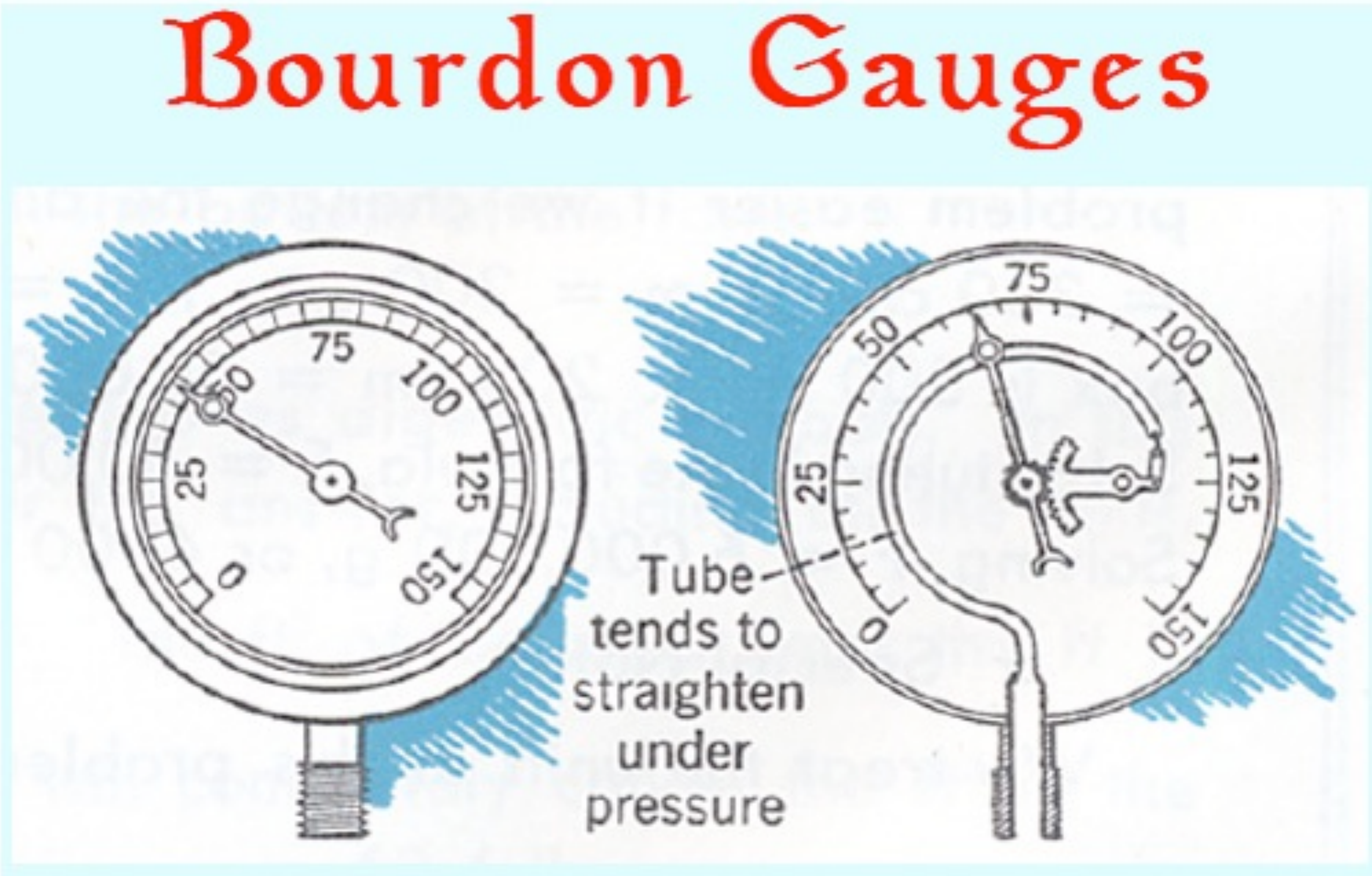

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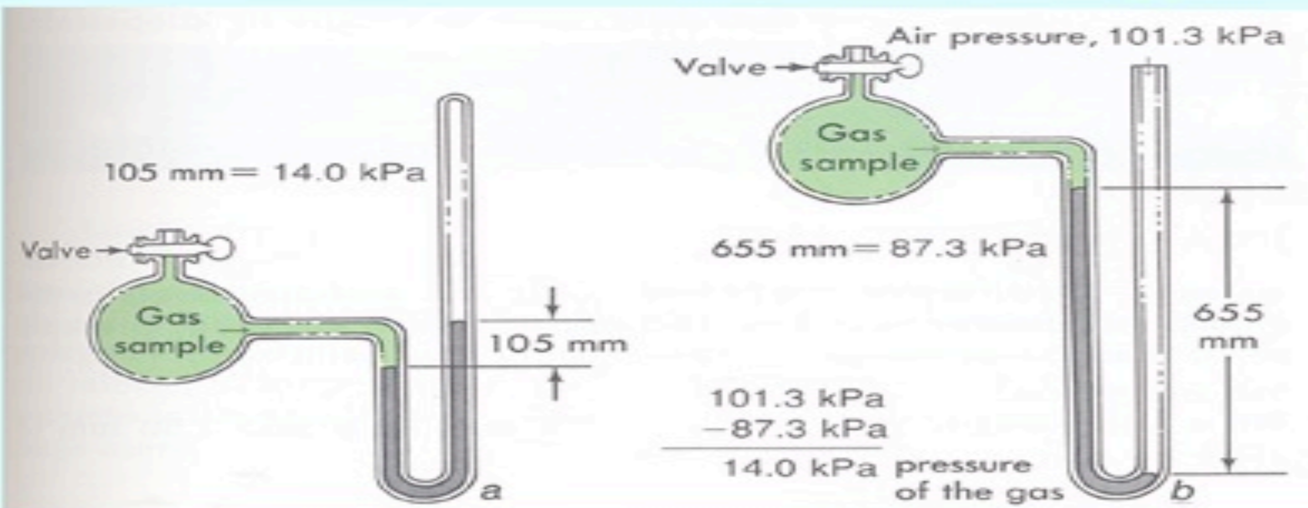
Total Force = (pressure)(area)

$$TF = pA$$

Manometers

Open & Closed tube manometers measure pressure.



One atmosphere = 760mm of Hg = 101 kPa.
So 1mm of Hg = 0.13 kPa.

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b. Pressure conversion cont'd

1. Convert 16.2 ft air to inches water gage (in wg)

Solution:

Using conversion factor: **1 *in.wg* = 69.6 *ft.air***

$$\therefore 16.2\,ft.air \times \frac{1 in.wg}{69.6\,ft.air} = 0.23 in.wg$$

2. Change the following quantities to the new units specified

A. 130 lb_f/in^2 (psi) to ft wg

B. 25 in. Hg to mm. Hg

Exercise:

Convert 20.5 in. Hg to lbf/in^2(psi)

Apply the following units conversion factors:

US Customary:

2.036 in. Hg = 1 lb_f/in^2 (psi)

1 psi = 2.3 ft. wg

Metric System/SI Systems:

1 Pa = 1 N/m^2

101.3 kN/m^2 = 1 atm

3386 Pa = in Hg

249.1 Pa = 1 mm Hg

Metric/SI systems – US Customary:

1 atm – 14.7 psia

1 atm – 760 mm Hg

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b. Pressure conversion cont'd

A. Given: 130 lb_f/in^2 to ft wg

$$1\frac{lb_f}{in^2} = 2.3\,ft.wg$$

$$\rightarrow \frac{130\,{}^{lb_f}\!/_{in^2}}{1\,{}^{lb_f}\!/_{in^2}} \times 2.3\,ft.wg = 299\,ft.wg$$

B. Convert 25 inHg to 1 mmHg

$$1inH_g = 3386P_a$$

$$\therefore 25inH_g \cong \frac{25inH_g}{1inH_g} \times 3386P_a = 84650P_a$$

$$249.1P_a = 1mmH_g$$

$$\therefore 84650P_a \cong \frac{84650P_a}{249.1P_a} \times 1mmH_g = 339.8mmH_g$$

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b. Pressure conversion continued

1. There are five types of pressure; namely: Pressure gage, vacuum pressure; atmospheric pressure and absolute pressure
   a. Pressure gage (P_{gage}): measures pressure in closed systems such as pipes, ducts, vessels etc.
   b. Vacuum pressure: (P_{vac}): It is the pressure that is measured below the atmospheric pressure
   c. Atmospheric pressure: P_{atm}: It is the pressure occupied by the weight of the atmosphere (universe). At the "Sea Level", the pressure is measured at approximately 14.696 psia (101,325 Pascal) and the value decreases as the "Altitude" atmosphere increases.
   d. Absolute pressure (P_{abs}) : It total of gage pressure and atmospheric pressure
   e. Zero Pressure also known as perfect vacuum is an area of space that has no pressure.

2. Mathematical Relationship Between: P_{abs}, P_{atm}, P_{gage} and P_{vac}

$$P_{abs} = P_{atm} + P_{gage} \rightarrow (1)$$

$$or$$

$$P_{abs} = P_{atm} - P_{vac} \rightarrow (2)$$

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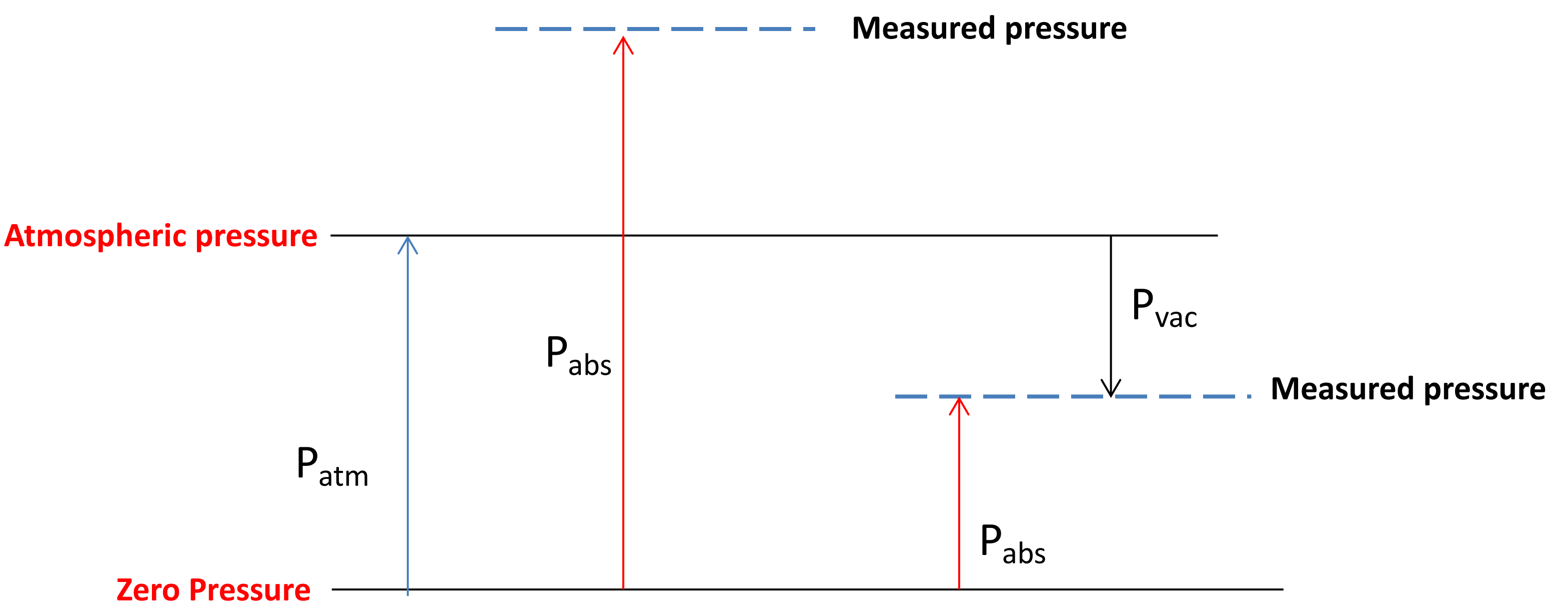
- Illustration



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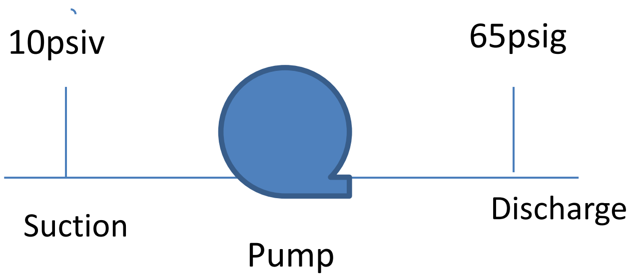
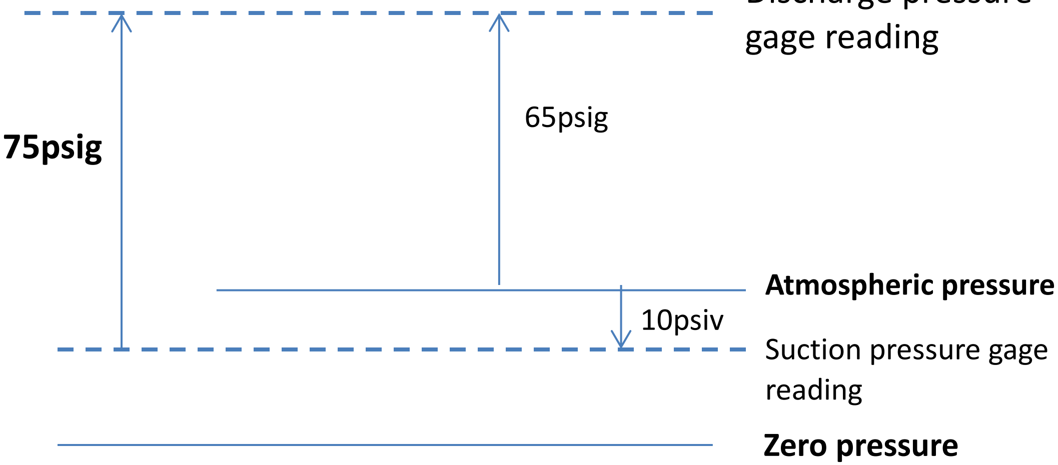
b. Pressure conversion continued

- **Example**
- The gages on suction gas and discharge gas lines of a pump is 10 psiv (lb/in^2 vac) and 65 psig, respectively. What is the pressure increase by the pump?
- **Solution:**



Illustration



- ***Mathematically***

$$Pressure\ Increase = 10 + 65 = 75\,psig$$

- **Exercise**

1. The pressure gage connected to the discharge of a cooling tower pump in Pharmaceutical Company in Emeryville, Oakland, California reads 28psig. Calculate the absolute water pressure at the pump discharge?
2. A 250 ft vertical pipe in a high-rise building is filled with chilled water. Estimate the pressure in psig that a valve in the bottom of the line will have to withstand.

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c. Horse power conversion

Definition: One horsepower is the work done at a rate of 550 pound$_{force}$-foot per second or 33000 pound$_{force}$ –foot per minute, which is equivalent to 745.7 watts

- **Mathematically**

$$1hp = 550\frac{lb_f - ft}{s}$$

$$or$$

$$1hp = 33000\frac{lb_f - ft}{\min}$$

- **Example:**
- Convert 11840 lb_f--ft/min to horsepower (hp)
- Solution:

$$33000\frac{lb_f - ft}{\min} = 1hp$$

$$\rightarrow 11840\,{}^{lb_f - ft}\!/_{\min} \cong \frac{11840\cancel{\frac{lb_f - ft}{\min}}}{33000\cancel{\frac{lb_f - ft}{\min}}} \times 1hp = 0.36hp$$

- Exercise: Covert 250 hp to lb_f-ft/s .

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c. Horse power conversion cont'd

1. There are two types of horsepower (hp). These include:

    (a) Water Horsepower (WHP)

    (b) Brake Horsepower (BHP)

2. Mathematical Formulae for WHP and BHP

a. Water horsepower is the power transmitted to a fluid or it is the power output

$$WHP = \frac{Q \times H \times s.g_{fluid}}{3960} \rightarrow (1)$$ or $$WHP = \frac{Q \times H \times \gamma_{fluid}}{33000 \frac{lb_f - ft}{\min}} \rightarrow (2)$$ or $$WHP = \frac{Q \times H \times \gamma_{fluid}}{550 \frac{lb_f - ft}{s - hp}} \rightarrow (3)$$

Where:

WHP	=	Water horsepower, *hp*
Q	=	Flow rate, Gallons per minute (*GPM) or cubic feet per sec (ft^3/s)*
H	=	Total pump head, *ft*
$s.g_{fluid}$	=	Specific gravity of the fluid, for water s.g = 1
γfluid	=	Specific weight, lb_f/ft^3; for water specific weight = $62.4 lb_f/ft^3$

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c. Horse power conversion cont'd

b. Brake horsepower is the power required to drive the pump or it is also known as power input.

Mathematically:

$$BHP = \frac{WHP}{efficiency(\varepsilon)} \rightarrow (a)$$

$$but,$$

$$\varepsilon = \frac{Poweroutput}{Powerinput} \times 100\% = \frac{WHP}{BHP} \times 100\% \rightarrow (b)$$

$$Where:$$

$$\varepsilon \rightarrow MechanicalEfficiency$$

Example:

A chilled water pump used for air conditioning system in the Financial District , San Francisco, CA is delivering 250 GPM at a total head 40 ft of water. The manufacturer's specifications for the pump efficiency is 60% at this operating condition. What is the minimum size motor that should be used to drive the pump?

Solution:

$$U\sin g \rightarrow (1)$$

$$WHP = \frac{Q \times H \times s.g}{3960} = \frac{250 \times 40 \times 1}{3960} = 2.53hp$$

$$U\sin g \rightarrow (a)$$

$$BHP = \frac{WHP}{E} \times 100\% = \frac{2.53hp}{60\%} \times 100\% = 4.2hp$$

The 4.2 hp would be the minimum power needed for the motor, but in a real world a larger size motor might be used to prevent possible overloading of the motor (You may choose 5hp).

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d. Power (W) conversion:

The units for power Metric or SI systems is the watts that is equivalent to

$$1.0\frac{N.m}{s} \rightarrow or \rightarrow 1.0\frac{Joule}{s} = Watt$$

To convert $\frac{lb_f - ft}{s}$ or hp to the SI or Metric system we apply the factors :

$$\frac{lb_f - ft}{s} = 1.356\,W$$

$$1hp = 745.7\,W = 0.7457\,kW$$

Example: Convert 30 hp to kW.

Solution:

$$1hp = 0.7457kW$$

$$\therefore 30hp \cong \frac{30hp}{1hp} \times 0.7457kW = 22.4kW$$

Exercise: Work done by motor is 260 lbf-ft/s on a particular day. What is kW for this motor.

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e. British Thermal Units (BTU) conversion

- A BTU is a unit of measurement of thermal or heat energy. The capacity of an electrical equipment is usually expressed in watts (W) or kilowatts (kW) rather than BTU/hr
- Conversion factors:
- **Power Units**
- 3.410 BTU/hr = 1000 W
- 3410 BTU/hr = 1kW
- 2545 BTU/hr = 1hp
- **Energy Units**
- 1 BTU = 778 lb_f-ft
- 1 BTU = 1055 J = 252 calories (cal)
- Example: Convert the following quantities to the new units specifies

a. 3000W to BTU/hr

b. 20, 000 BTU/hr to kW

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e. British Thermal Units (BTU) conversion

Solution:

$$(a)\ 1000W = 3.410\frac{Btu}{hr}$$

$$\rightarrow 3000W \cong \frac{3000W}{1000W}\times 3.410\frac{Btu}{hr} = 10.23\frac{Btu}{hr}$$

$$(b)\ \frac{20000\frac{Btu}{hr}}{3410\frac{Btu}{hr}}\times 1kW = 5.865kW$$

Exercise:

a. Estimate the size electric heater kW must be used to supply 250 BTU/hr.

b. How many BTU/hr will a 20 kW electric heater supply?

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f. Tons conversion

- It is a unit of weight of an object, which is approximately equal to 2000 lb_f

- Conversion factors:
- 1 ton = 2000 lb_f = 12000 Btu/hr
- Example: Convert 10 tons of refrigeration unit into BTU/hr
- Solution:

$$1ton = 12000\frac{Btu}{hr}$$

$$\rightarrow 10tons \cong \frac{10tons}{1ton} \times 12000\frac{Btu}{hr} = 120{,}000\frac{Btu}{hr}$$

- Exercise: Change 1000 Btu/hr to $pound_{force}$

HVAC Fundamentals & Components

2. Concept of Work, Power & Force

Work

Work is done mechanically when a force acting on an object moves the object through a distance.

Mathematically:

$$w = F \times d$$

$$Where:$$

$$w \rightarrow \text{Work done, lb}_\text{f}\text{ - ft}$$

$$\text{F} \rightarrow \text{Force, lb}_\text{f}$$

$$\text{d} \rightarrow \text{Distance, ft}$$

Example: A chilled water pump having a weight of 220 lbf is hoisted 185 ft from the ground to the top floor of a building. Calculate work done ignoring friction and other losses.

$$Solution:$$

$$w = F \times d = 220 lb_f \times 175 ft$$

$$\rightarrow 38{,}500 lb_f - ft$$

Power

Power

Mechanical power is defined as rate of doing work.

Mechanical power is measured in horsepower (hp); The conversion factors and equations for mechanical power is either

$$33000\,\frac{lb_f - ft}{\text{minutes}} \ \text{or} \ 550\,\frac{lb - ft}{\text{seconds}} \rightarrow (1)$$

Mathematical Equation :

$$Power = \frac{w}{33000 * time} \ \text{or} \ Power = \frac{w}{550 * time} \rightarrow (2)$$

Where :

Power $\rightarrow hp$

$w \rightarrow$ Work done, $lb_f - ft$

$Time \rightarrow$ Minutes, seconds

- Estimate the power required to pump 300 gallons per minute (gpm) of water up to a storage tank located a vertical distance of distance of230 ft above the ground. Assume water density to be 8.33 lbf/gal
- *Solution* :

$$P = \frac{(400gal) \times (8.33lb_f / gal) \times (230\,ft)}{(33000\,\frac{lb_f - ft}{\min - hp}) \times (1\min)} = 23.2hp$$

Energy

- **Energy:**
- Definition: Energy is the ability or capacity to work. The amount of energy required to do a given amount of work is always exactly equal to the amount of work done.
- On the other hand, the amount of energy in a body is always equal to the amount of work the body can do in passing the energy from one position or condition to another.
- Unit of Energy = lb_f-ft
- Types of Energy:
- There are two types of energies: (1) Kinetic Energy; (2) Potential Energy
- **Kinetic Energy** is the energy a body possesses by virtue of its motion or velocity
- Mathematically:

$$KE = \frac{mV^2}{2g_c}$$

Where

$KE \rightarrow$ *Kinetic Energy*, $lb_f - ft$

$m \rightarrow$ *Mass, pounds*, $\mathrm{lb_f}$

$V \rightarrow$ *Velocity*, *ft/s*

$g_c \rightarrow$ Universal gravitational constant, 32.2 ft/s^2

Energy Cont'd

- **Potential Energy:** It is the energy a body possesses due to its position or configuration.
- Potential Energy = Mass x Height
- Potential Energy, lb_f-ft
- Mass, lb_f
- Height, ft
- **Total External Energy:** It is the sum of its Kinetic Energy (KE) and Potential Energy (PE)
- **Total Energy = KE + PE**
- Example: Calculate the total external energy of 1lb_f of water flowing at a rate of 60 ft/s in a manufacturing company located 200 ft above a reference datum
- Solution:

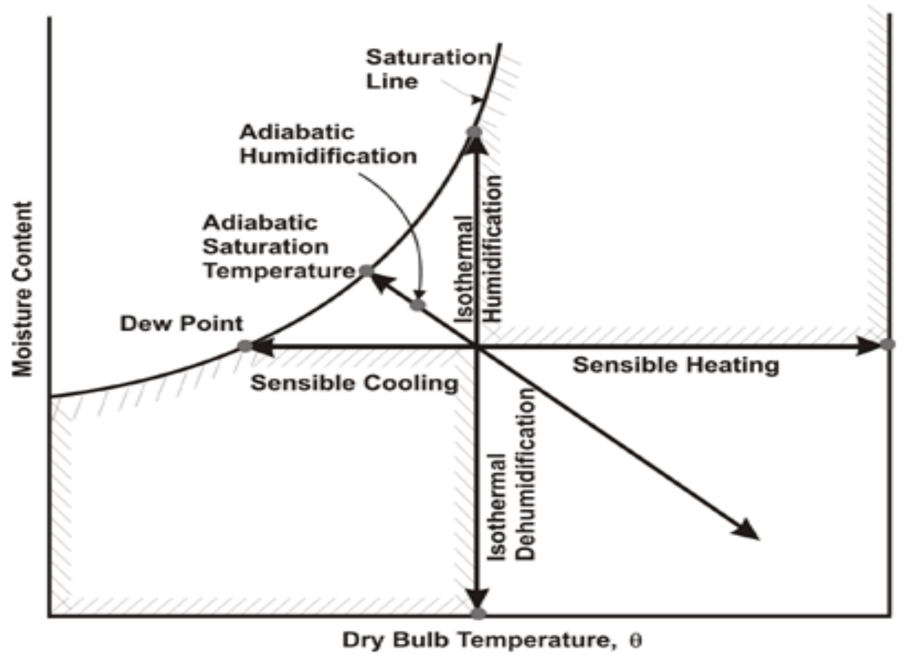
$$KE = \frac{(1lb_f)\times(60ft/s)^2}{(2\times 32.2ft/s^2)} = 55.90lb_f - ft$$

$$PE = 1lb_f \times 250ft = 250lb_f - ft$$

$$Total\ Energy = KE + PE = (55.90 + 250)lb_f - ft$$

Psychrometric Processes Overview

Air Conditioning Processes

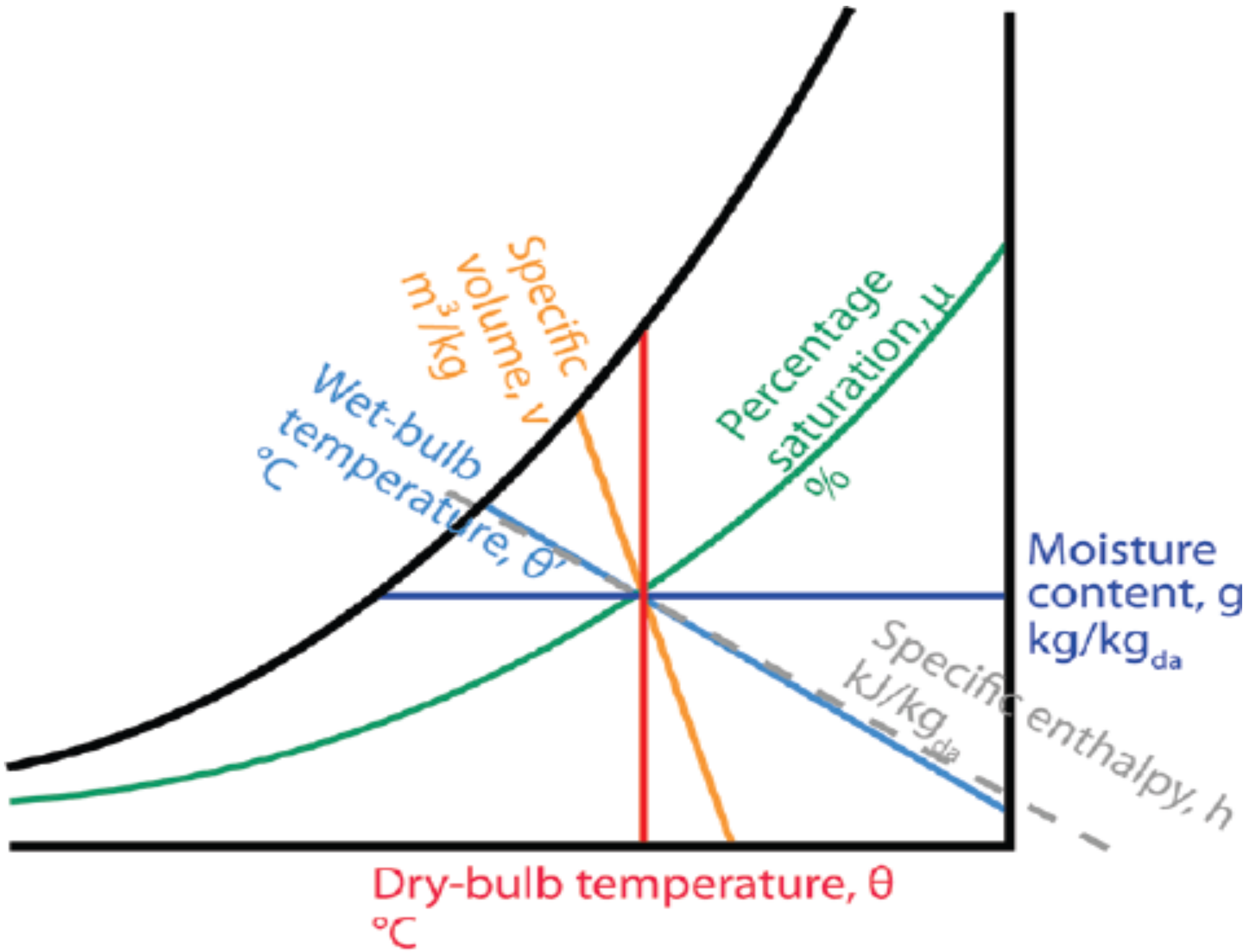


Air Conditioning Processes illustrated on a Psychrometric Chart

In air conditioning processes heat is added to or extracted from the air to produce heating or cooling. At any temperature, moist air will contain:

- Sensible heat for dry air.
- Sensible heat for water.
- Latent heat of evaporation.
- Sensible superheat for water vapor.

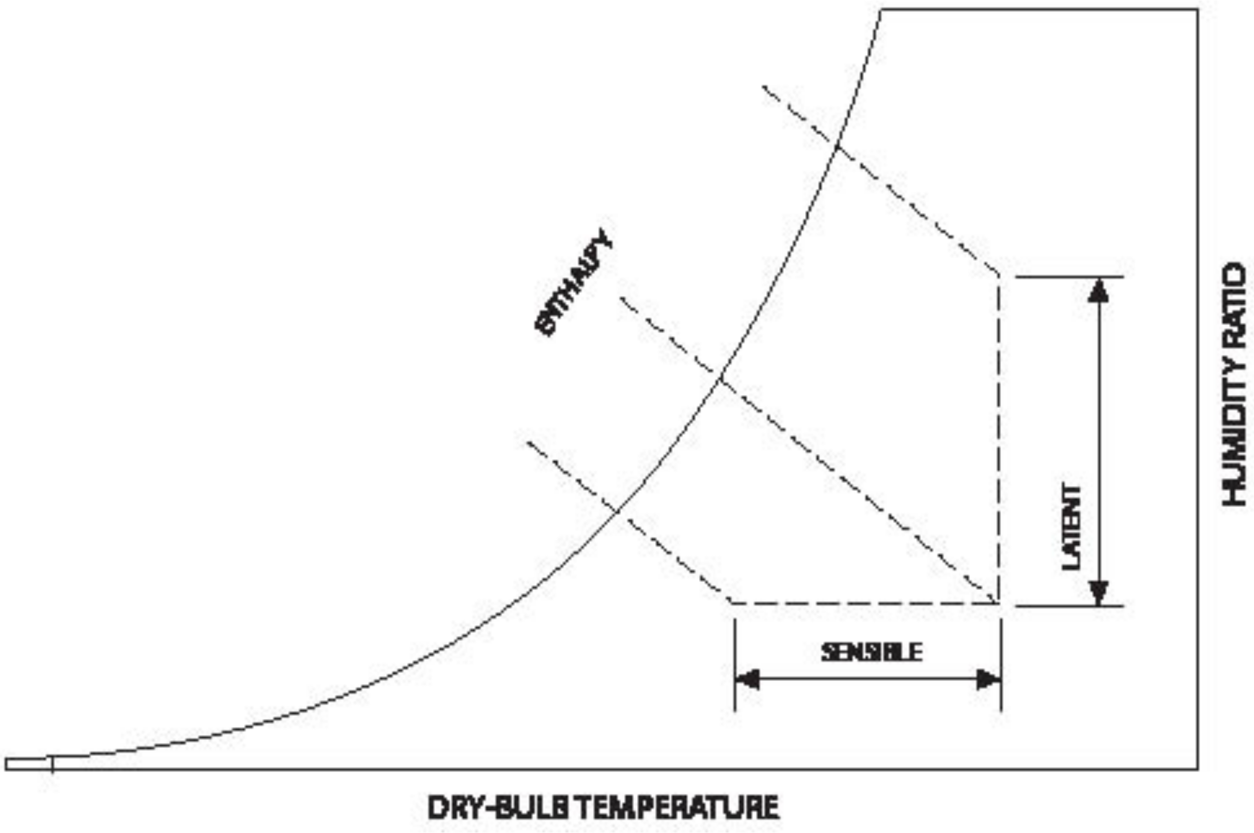
Outline of Psychrometric Chart



Overview of Psychometric Analysis of the Air Conditioning Systems

a. Psychrometric processes and calculations

- **1. Sensible or Latent Processes**



Sensible or Latent Process Cont'd

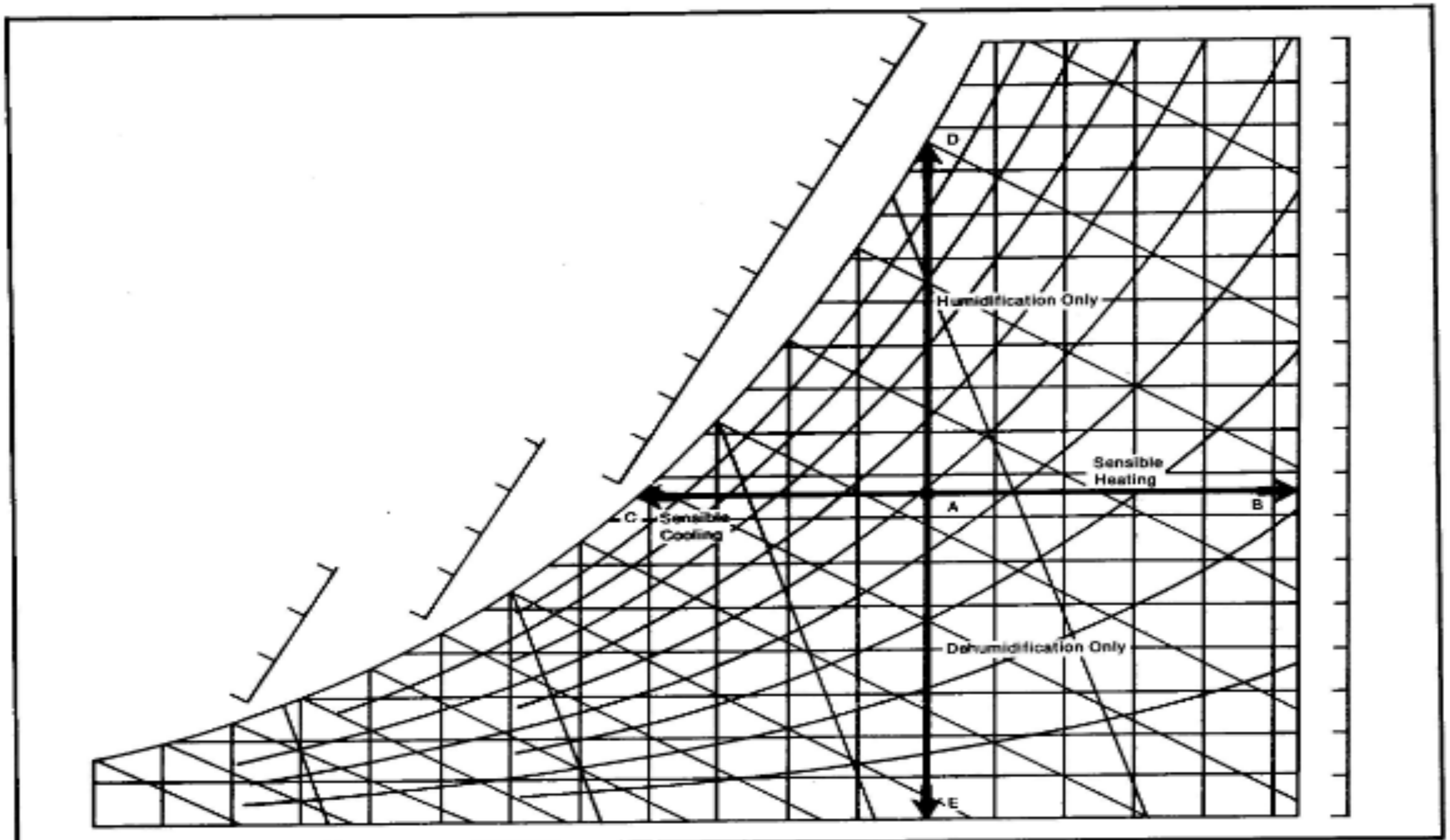
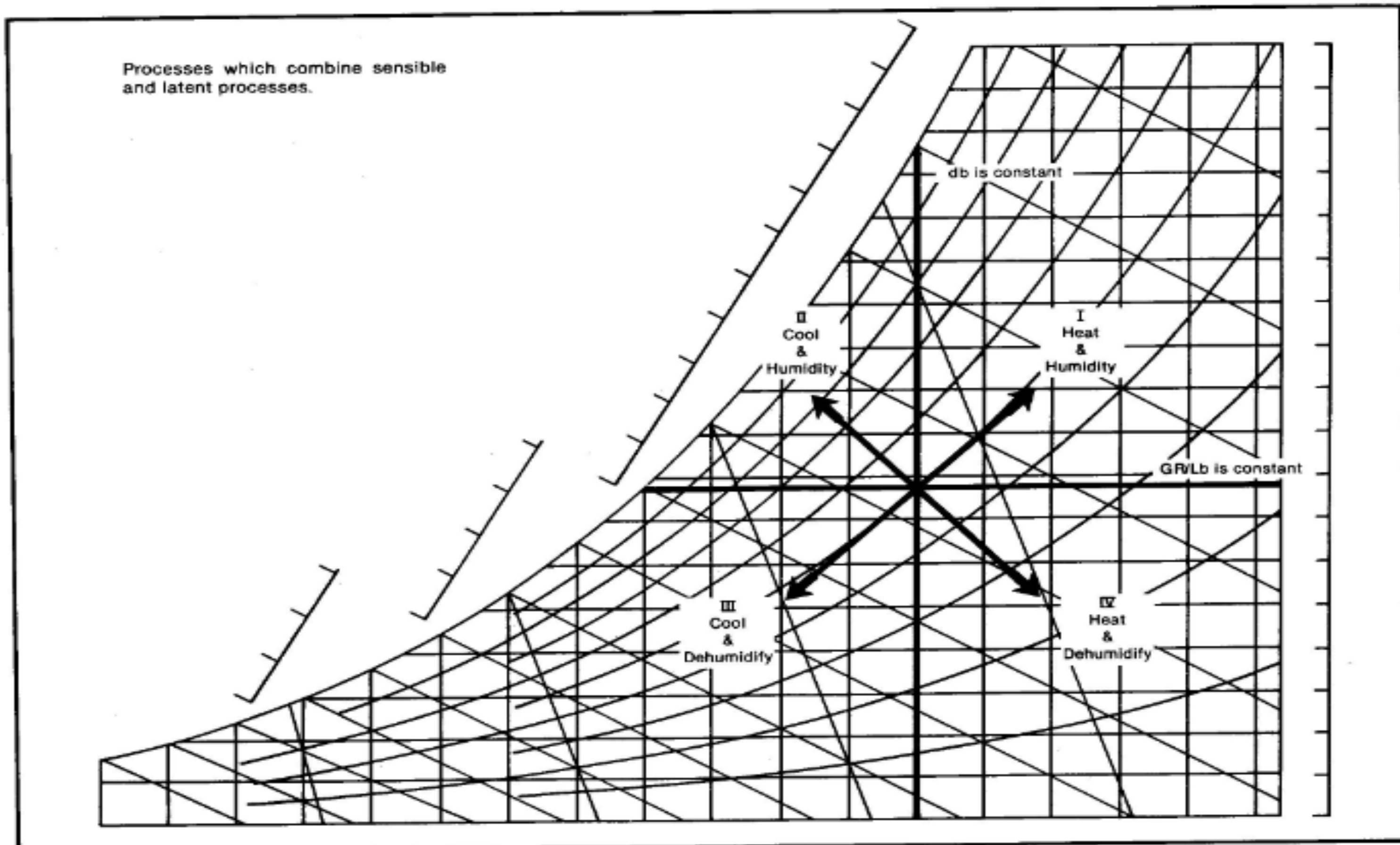


Figure 2.1 Sensible or Latent Processes

Combined Sensible and Latent Processes



Combined Sensible and Latent Processes

Air Side Equations

Once any process line is drawn on the psychrometric chart, the sensible, latent, and total loads associated with that process can be calculated by using the following air equations:

$$\text{Air Side Equations Are:}$$

$$\mathrm{Q_s} = 1.1 \times CFM \times \Delta Temperature \rightarrow (1a)$$

$$or$$

$$Q_s = 4.45 \times CFM \times \Delta \text{Sensible Change in Enthalpy} \rightarrow (1b)$$

$$Q_l = 0.68 \times CFM \times \Delta Grain \rightarrow (2a)$$

$$or$$

$$Q_l = 4.45 \times CFM \times \Delta \text{Latent Change in Enthalpy} \rightarrow (2b)$$

$$Q_T = 4.45 \times CFM \times \Delta \text{Total Enthalpy} \rightarrow (3)$$

$$Where:$$

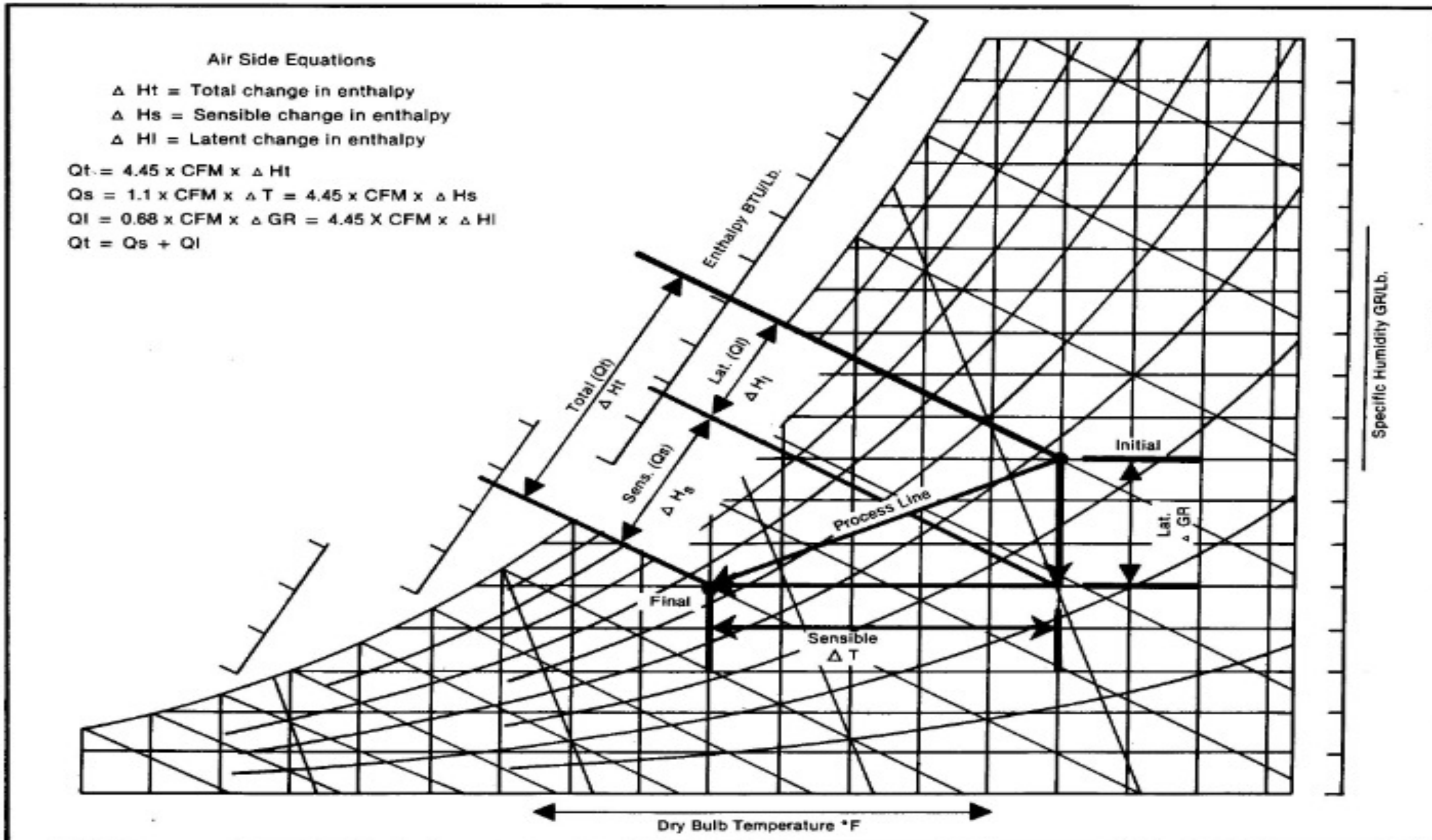
$$Q_s = \text{Sensible Load}$$

$$Q_l = \text{Latent Load}$$

$$Q_T = \text{Total Load}$$

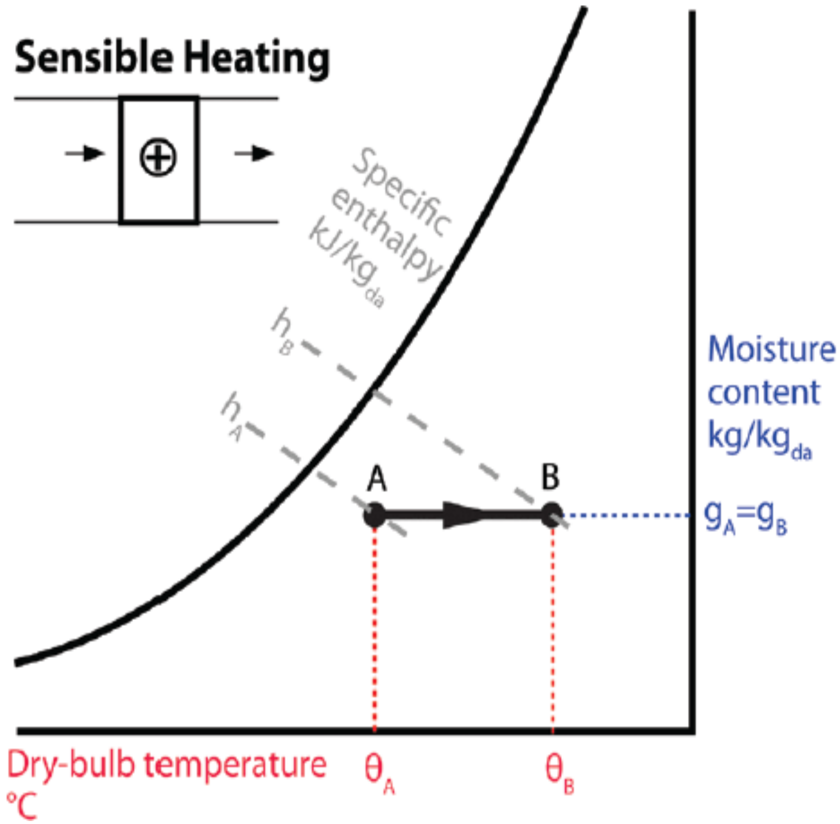
$$CFM = \text{Air Flow Rate}$$

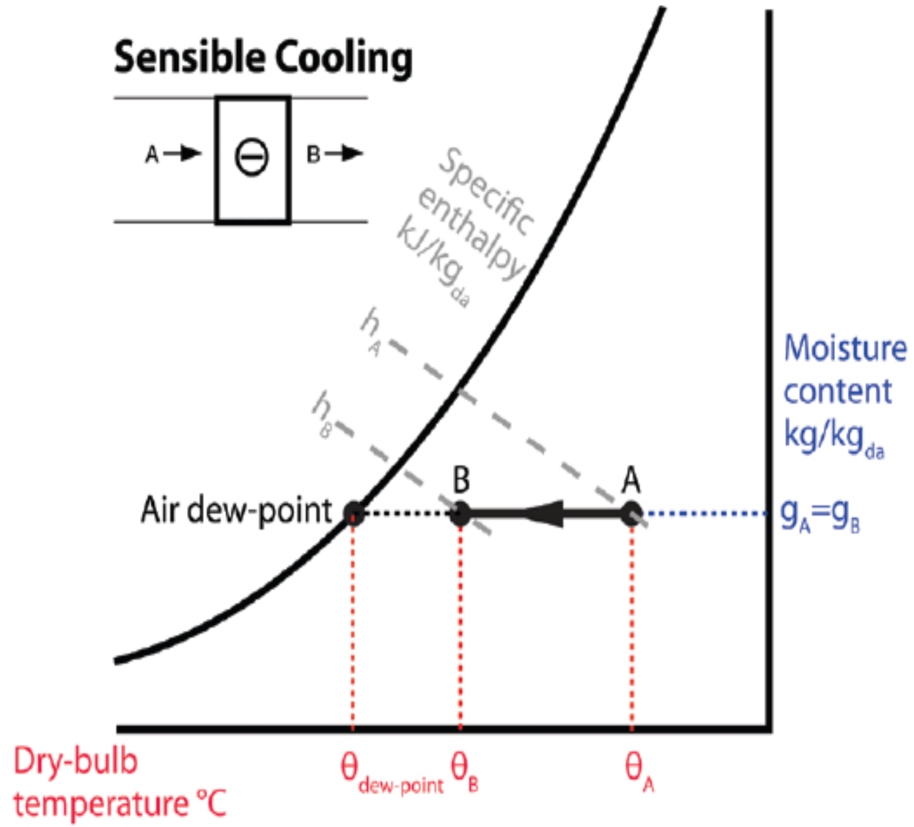
Air Side Equations Cont’d



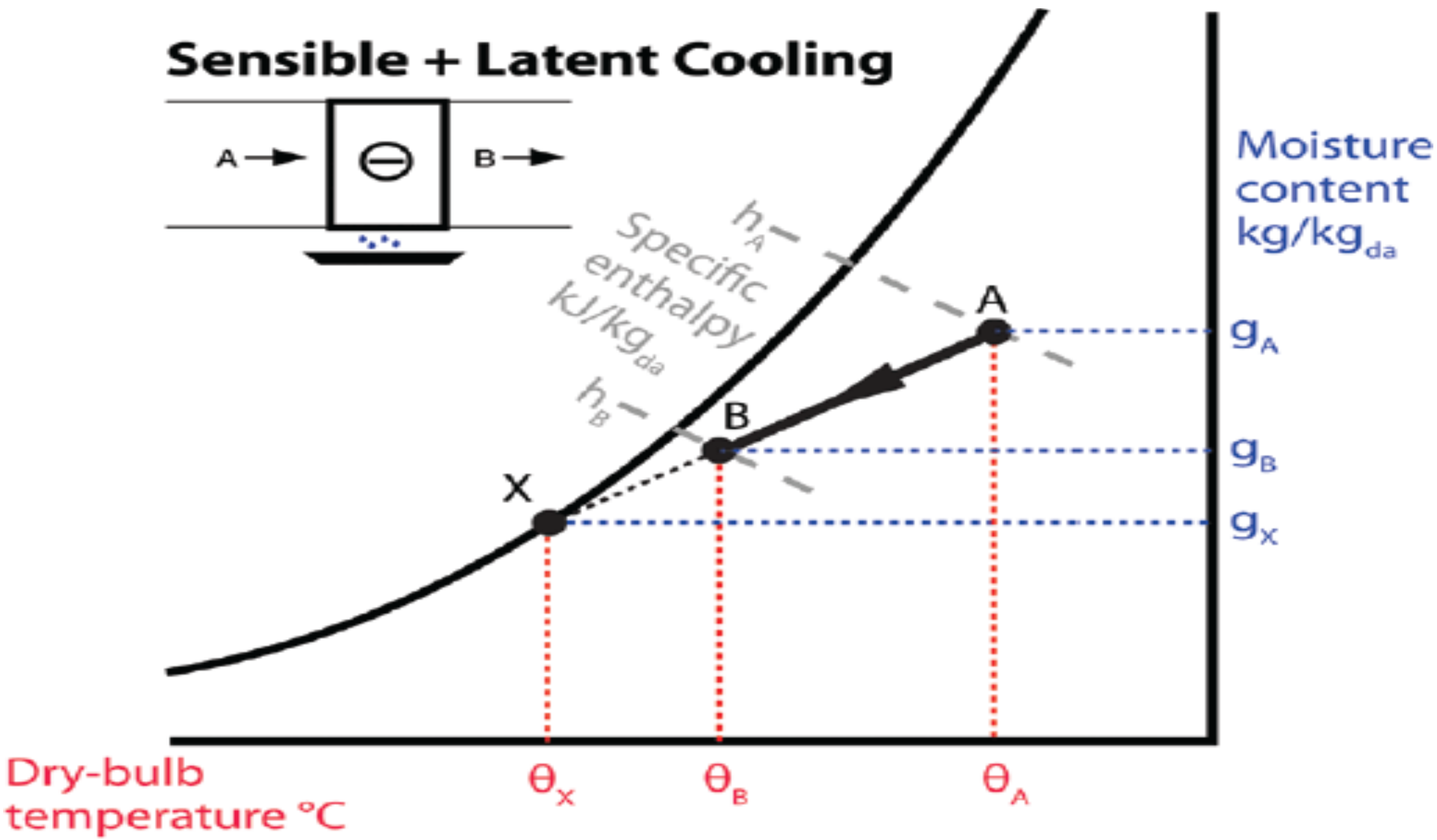
Load Triangle

Summary of Process Line Calculations

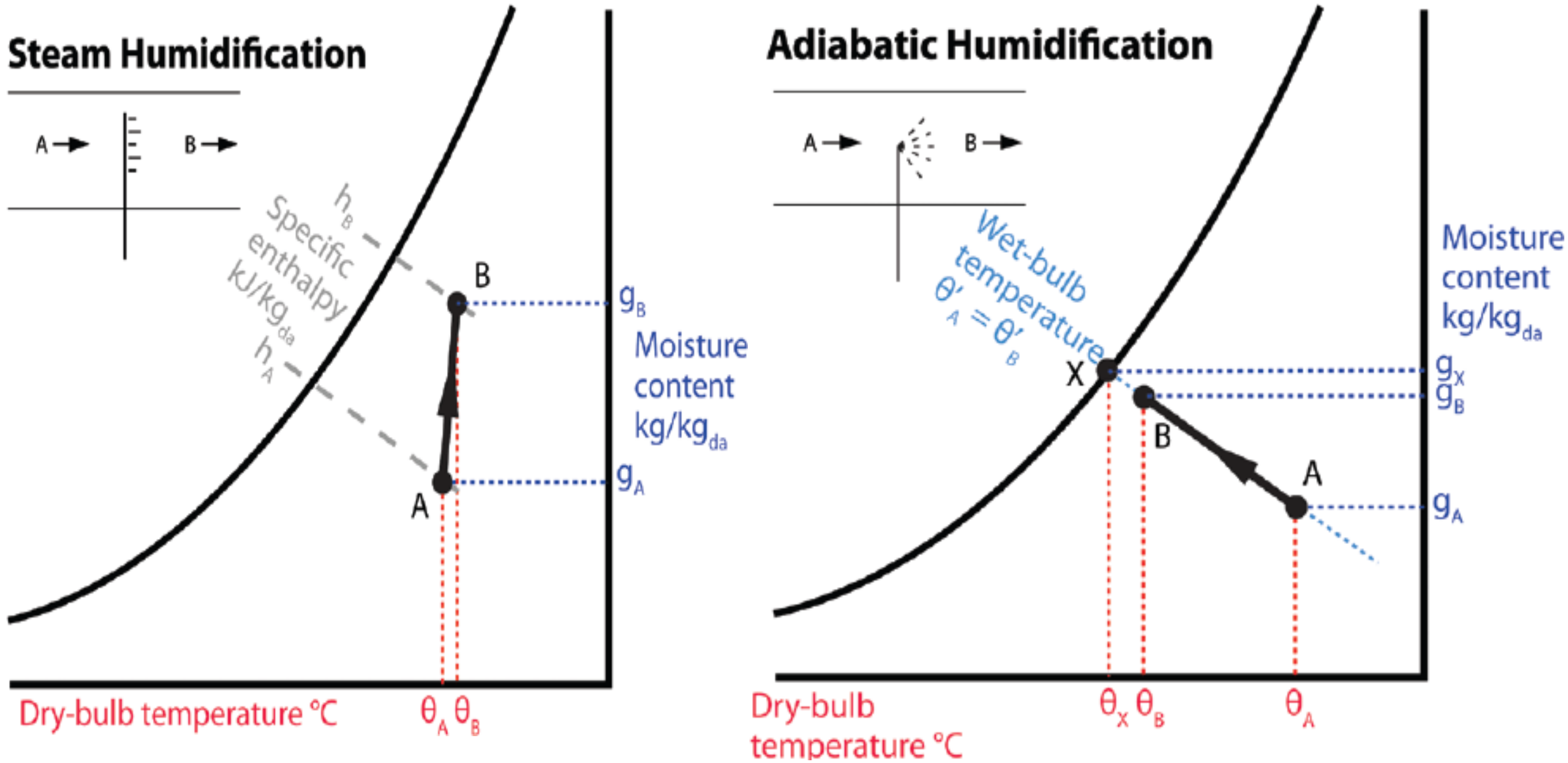




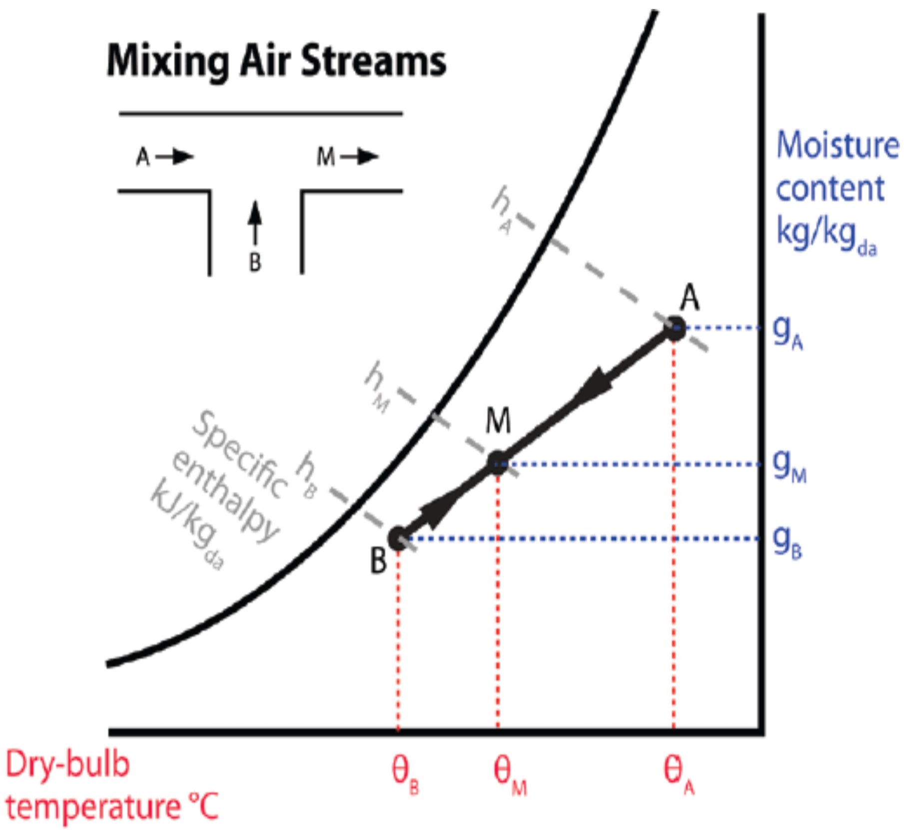
Summary of Process Line Calculations Cont'd



Summary of Process Line Calculations Cont'd



Air Mixing Process



Equations of Mixing Air Streams

$$MixedAir_{DB} = \%oomAir \times Room_{DB} + \%OutdoorAir \times Outside_{DB} \rightarrow (a)$$

or

$$MixedAir_{DB} = \%RoomAir \times Po\text{int}\,B + \%OutdoorAir \times Po\text{int}\,A \rightarrow (b)$$

or

$$CFM_{MIXED\times} \times DB_{MIXED} = CFM_A \times DB_A + CFM_B \times DB_B \rightarrow (c)$$

or

$$W_{MIXED} \times CFM_{MIXED} = CFM_A \times W_A + CFM_B \times W_B \rightarrow (d)$$

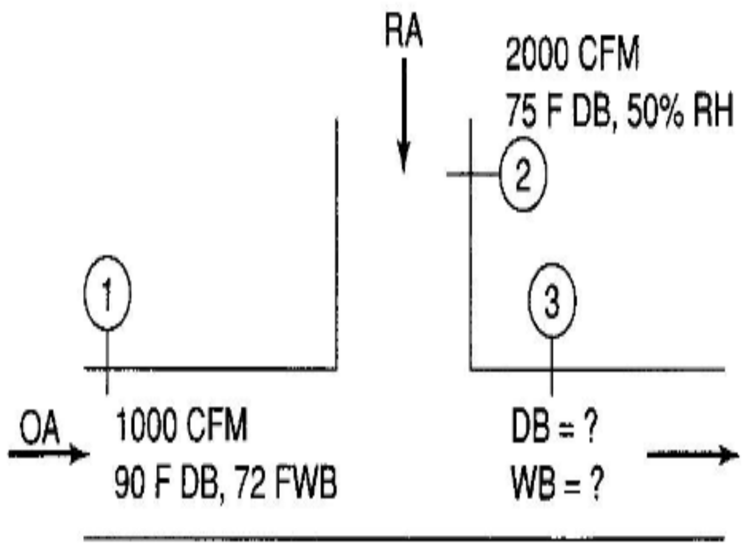
Where;

$DB = \text{Dry Bulb Temperature,}^{\circ}\text{F}$

$W = \text{Humidity Ratio}$

$$CFM = Flowrate, \frac{ft^3}{\text{min}\,ute}$$

Air Mixing Sample Question



Example: Outside Air (OA) and Return Air (RA) as shown are mixed. Find the mixed air (MA) Dry Bulb (DB) and Wet Bulb (WB).

Using the equations

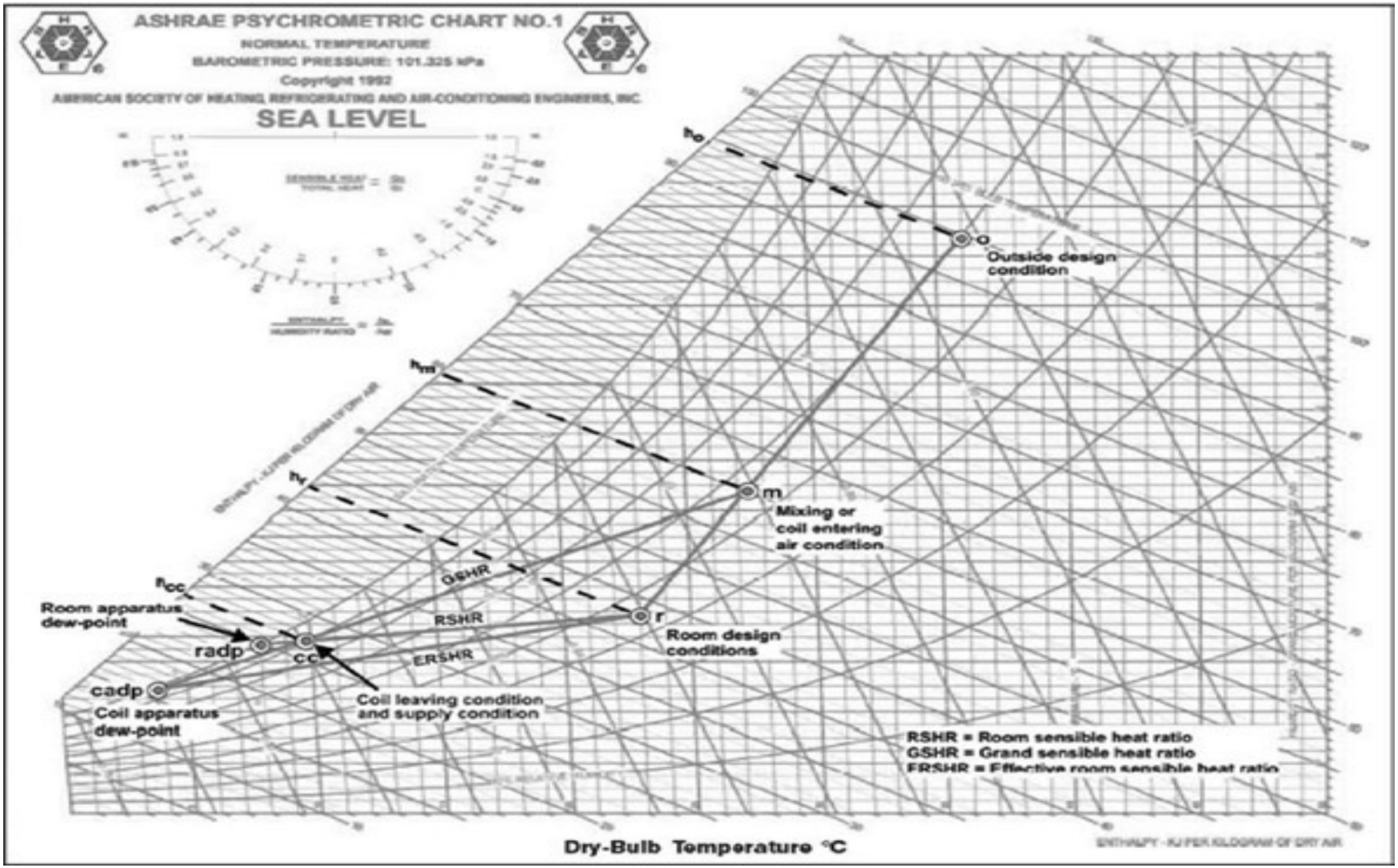
$$DB_3 = \frac{2000\,\frac{ft^3}{\min} \times 75^o F + 1000\,\frac{ft^3}{\min} \times 90^o F}{3000\,\frac{ft^3}{\min}} = 80^o F$$

From psychrometric chart, $W_1 = 89\text{gr/lb}_m$; $W_2 = 64\text{ gr/lb}_m$

$$W_3 = \frac{2000cfm \times 64gr/lb_m + 1000cfm \times 89gr/lb_m}{3000cfm} = 72gr/lb_m$$

$\therefore$ From psychrometric chart, the Wet Bulb Temperature (WB) $= 66^\circ F$

Room Sensible Heat Ratio (RSHR)



Room Sensible Heat Ratio (RSHR)

- Example: The following rooms are maintained at 75ºF DB, and 55% RH. Estimate the RSHR of each room and average RSHR of all the rooms.

Btu/hr	Room 1	Room 2	Room 3
Sensible Heat	8,000	10,500	15,000
Latent Heat	1,000	2,000	4,000

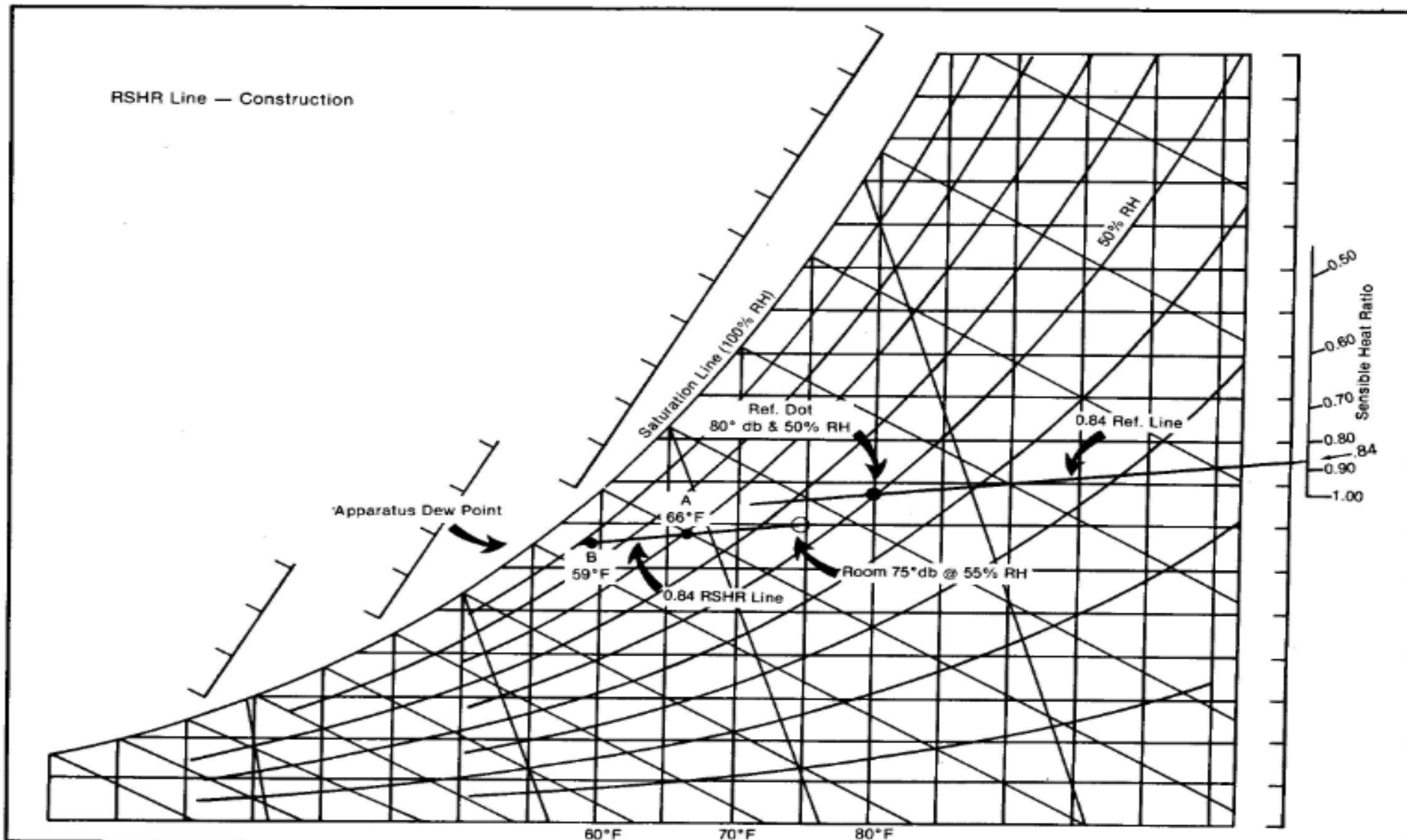
- Solution:

$$RSHR = \frac{Room\ Sensible\ Heat}{Total\ Heat} = \frac{8000}{(8000+1000)} = 0.89 \rightarrow (Room1)$$

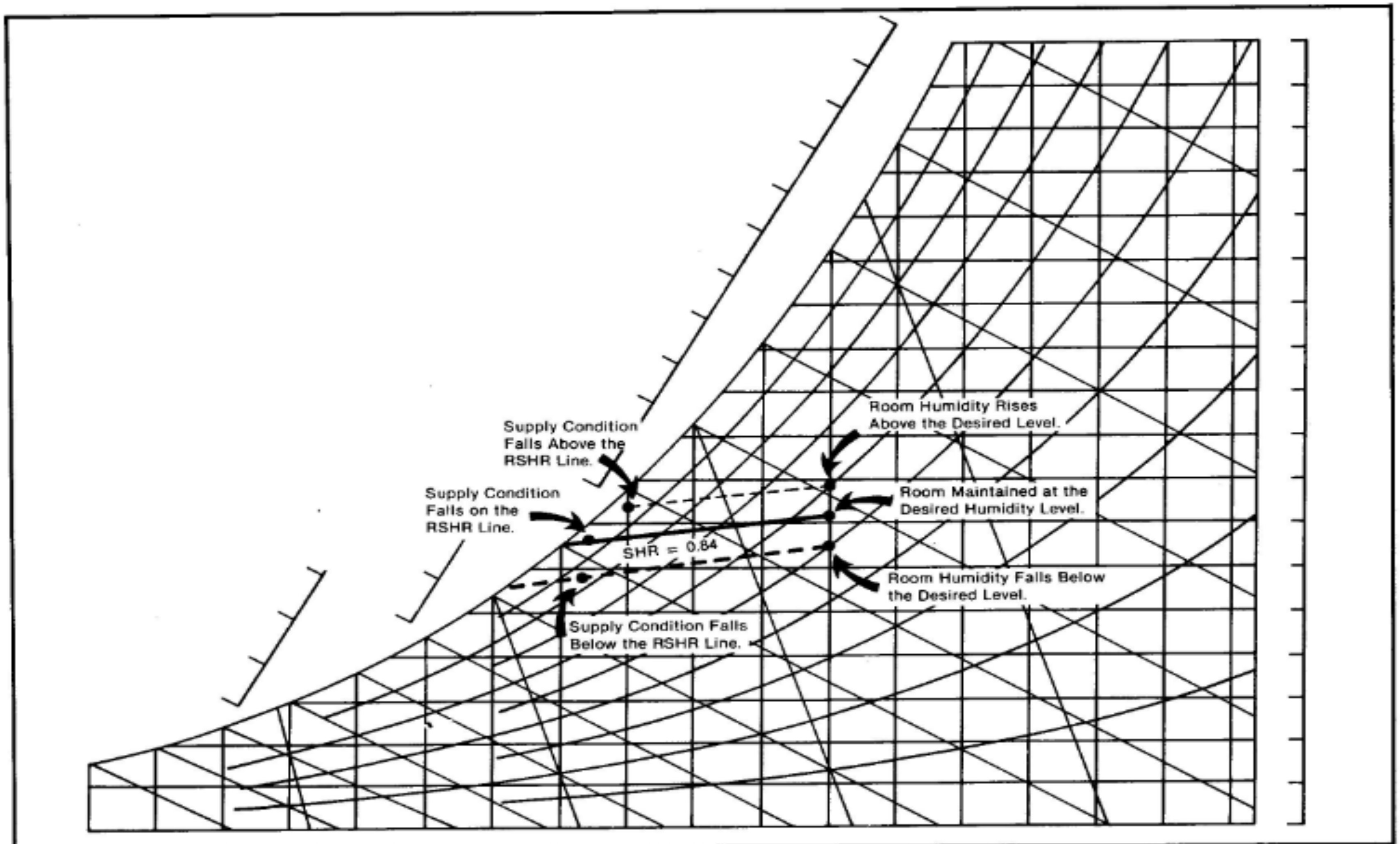
$$RSHR = \frac{10500}{(10500+2000)} = 0.84 \rightarrow (Room2)$$

$$RSHR = \frac{15000}{(15000+4000)} = 0.79 \rightarrow (Room3)$$

$$RSHR_{AVERAGE} = \frac{(8000+10500+15000)}{(9000+12500+19000)} = 0.827 \rightarrow (Room\ average)$$



RSHR Line — Construction



Supply Conditions Which Do Not Fall on the RSHR Line

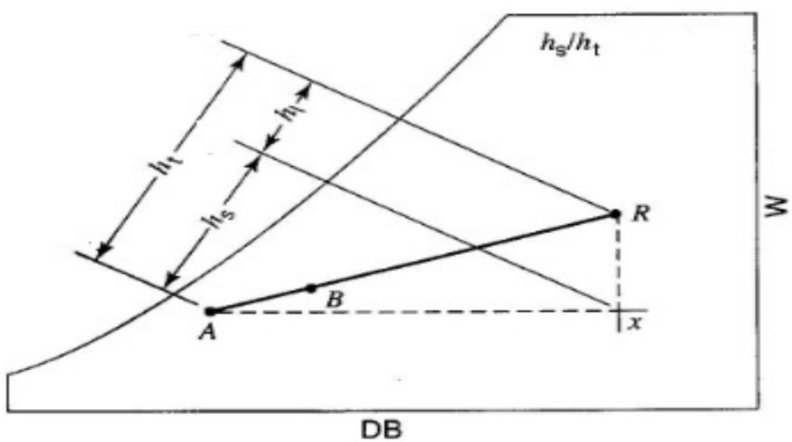
Room Sensible Heat Ratio (RSHR)

1. Room Sensible Heat Ratio (RSHR)

- It is defined as the ratio of room (or zone) sensible heat to room (or zone) total heat.
- Graphically & Mathematically

$$\text{RSHR} = \frac{\text{RSCL}}{\text{RTCL}}$$

Sensible and latent heat removal for two different supply air conditions.



$$= \frac{Ax}{AR} = \frac{h_s}{h_T} = \frac{RSCL}{RTCL}$$

$\rightarrow$ *Room Sensible Cooling Load*

$\rightarrow$ *Room Total Cooling Load*

Room Sensible Heat Ratio (RSHR)

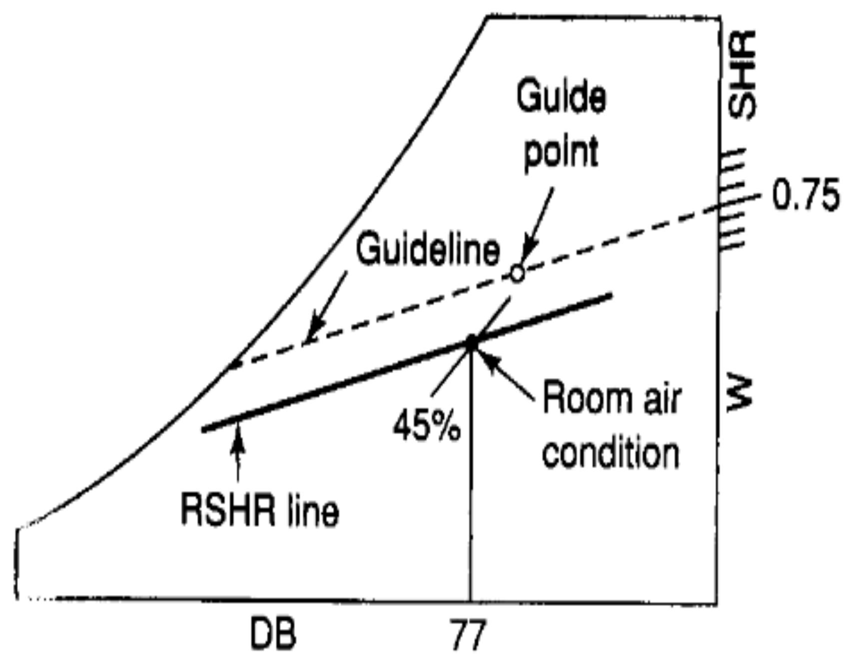
2. Room Sensible Heat Ratio Line:

The **RSHR line** is define as the line drawn through the room conditions with the room sensible heat ratio slope RSCL/RTCL.

Example: Macdonald Restaurant has a sensible cooling load of 45,000 BTU/hr and a latent cooling load of 15,000 BTU/hr. The restaurant is maintained at 77oF DB and 45% RH. Draw the RSHR line.

Solution:

$$RSHR = \frac{RSCL}{RTCL} = \frac{45000}{45000 + 15000} = 0.75$$



Plotting the RSHR line

Room Sensible Heat Ratio (RSHR)

3. Design cubic feet per minutes (CFM) Room:

The amount of supply air (CFM) is required to offset the room sensible and latent loads is determined by sensible heat equation below:

$$CFM = \frac{Room\ Sensible\ Load}{1.1 \times (Room_{DB} - Supply_{DB})}$$

4. Selecting Supply Air Temperature

- To select the optimum supply air temperature, the designer must consider the following:

1. Packaged DX equipment can be expected to produce air temperatures leaving the coil which are 15^{o}F to 20^{o}F below the room temperature.
2. Chilled water coils can produce air temperatures leaving the coil which are 15^{o}F to 25^{o}F below the room temperature.
3. Larger difference between the room temperature and supply CFM and save fan power
4. Lower coil temperatures will reduce the coefficient of performance (COP) of the refrigeration equipment.

Room Sensible Heat Ratio (RSHR)

4. Selecting Supply Air Temperature

5. The lowest theoretical supply temperature is equal to the apparatus dew point which is located at the intersection of the RSHR line and the saturation line.

6. In actual practice, a supply air condition which falls on the RSHR line and has a relative humidity between 85% and 95% is a good choice. However, this condition is what desired for a particular equipment (coil) performance, data must be checked to verify that the equipment is capable of producing at this condition.

7. A supply condition that falls below the RSHR line can be used, but the room humidity will be lower than the desired design humidity

8 If a supply condition that falls above the RSHR line is used, the room humidity will be higher than the desired design humidity. The diagram below shows the effects of supply conditions which do not fall on the RSHR line

Room Sensible Heat Ratio (RSHR)

5. Multiple Room Sensible Heat Ratios:

- Note that if more than one room (or zone) is conditioned by a single central cooling coil, the coil will normally not be able to simultaneously satisfy the latent loads in all the rooms. This happens because the coil can only operate at a single sensible heat ratio may not be equal to any of the individual room sensible heat ratios.
- If it is not possible to satisfy the RSHR condition for all the rooms, one of the following selections must be made:

1. If control of the room humidity in one of the rooms (or zones) is more critical than the other rooms, the RSHR for that room will establish the design sensible heat ratio and all the other rooms will have humidities that will vary from the desired design condition.
2. If none of the room humidity requirements are critical, the coil may be selected to satisfy the average humidity requirements of all of the rooms.

Coil Sensible Heat Ratio (CSHR)

1. Coil Sensible Heat Ratio Without Ventilation (CSHR)

a. When the HVAC equipment does not include a provision for introducing outdoor air (ventilation) through the cooling coil, the room sensible heat ratio (RSHR) line completely defines all the possible supply air conditions.

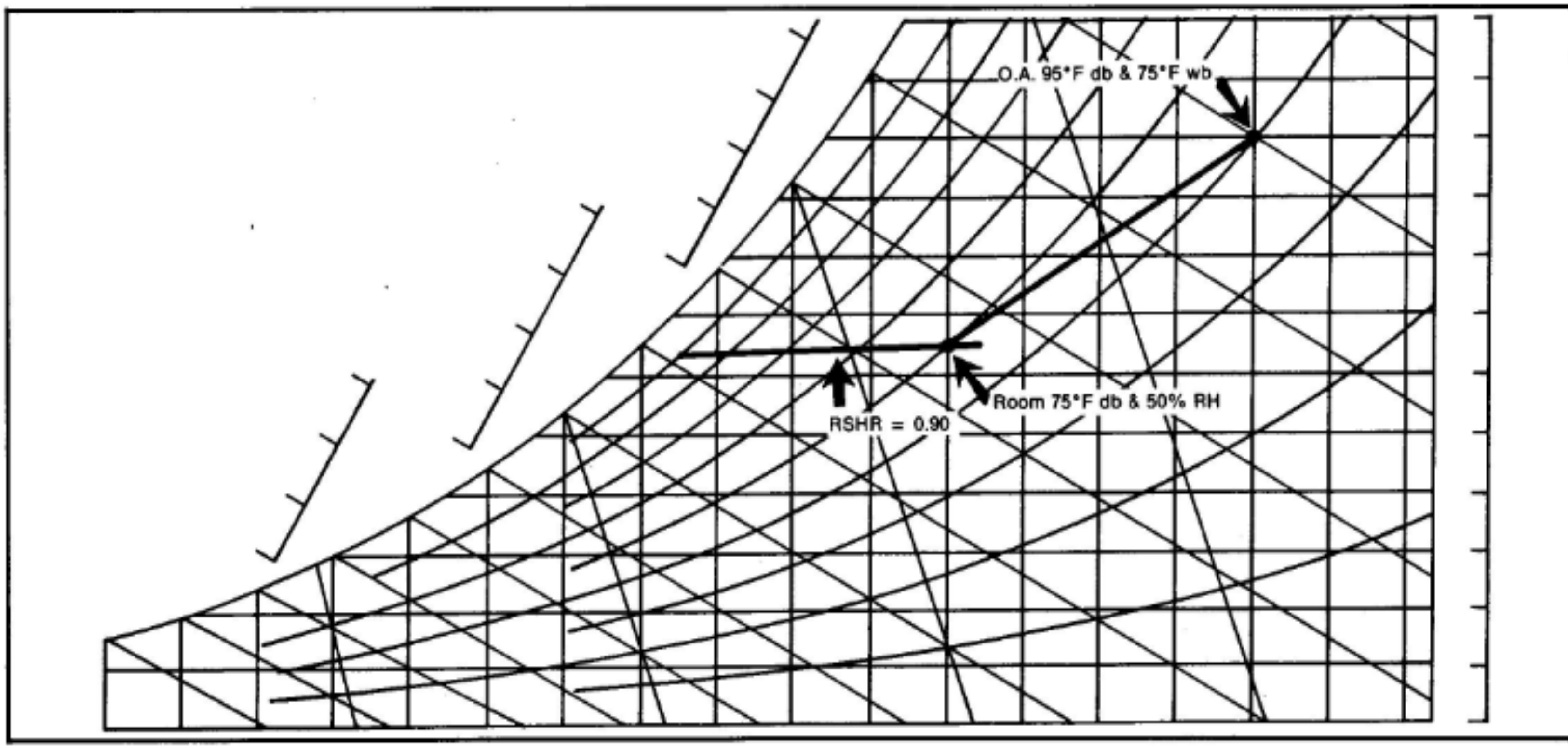
b. In this situation, the sensible and latent loads in the room and on the coil are identical and the room and the coil sensible heat ratio lines are identical.

c. The room resign condition will be maintained if the supply air condition is located anywhere on the room sensible heat ratio line.

2. Coil Sensible Heat Ratio With Ventilation

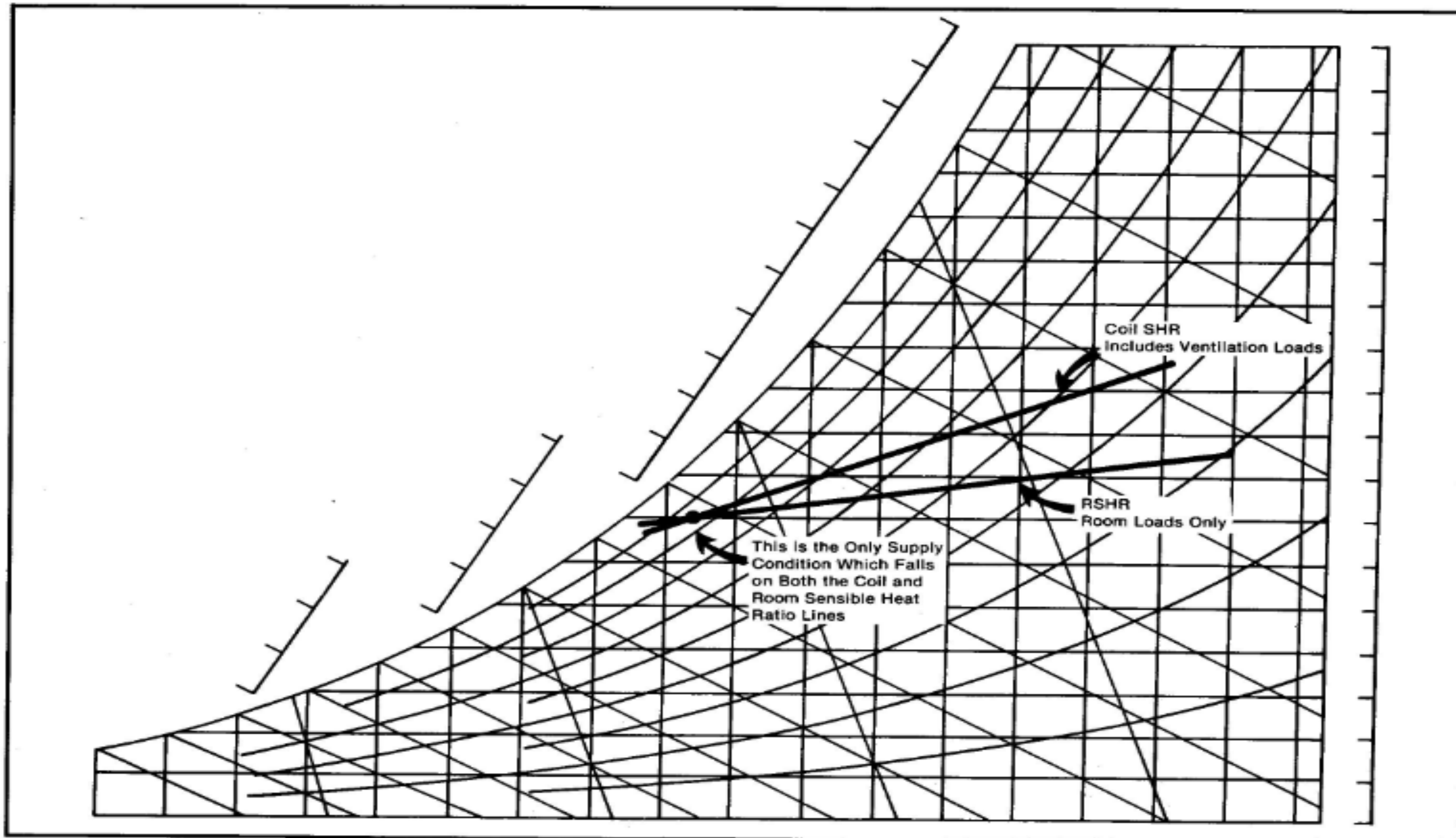
- When outdoor air is mixed with return air before it passes through the cooling coil, the coil is subject to the room sensible and latent loads and the additional sensible and latent loads that are associated with the outdoor (ventilation) air.
- In this case, the ratios of sensible load to total load for the room and for the coil are usually different and the room and the coil sensible heat ratios will be different.

Coil Sensible Heat Ratio (CSHR) Cont'd



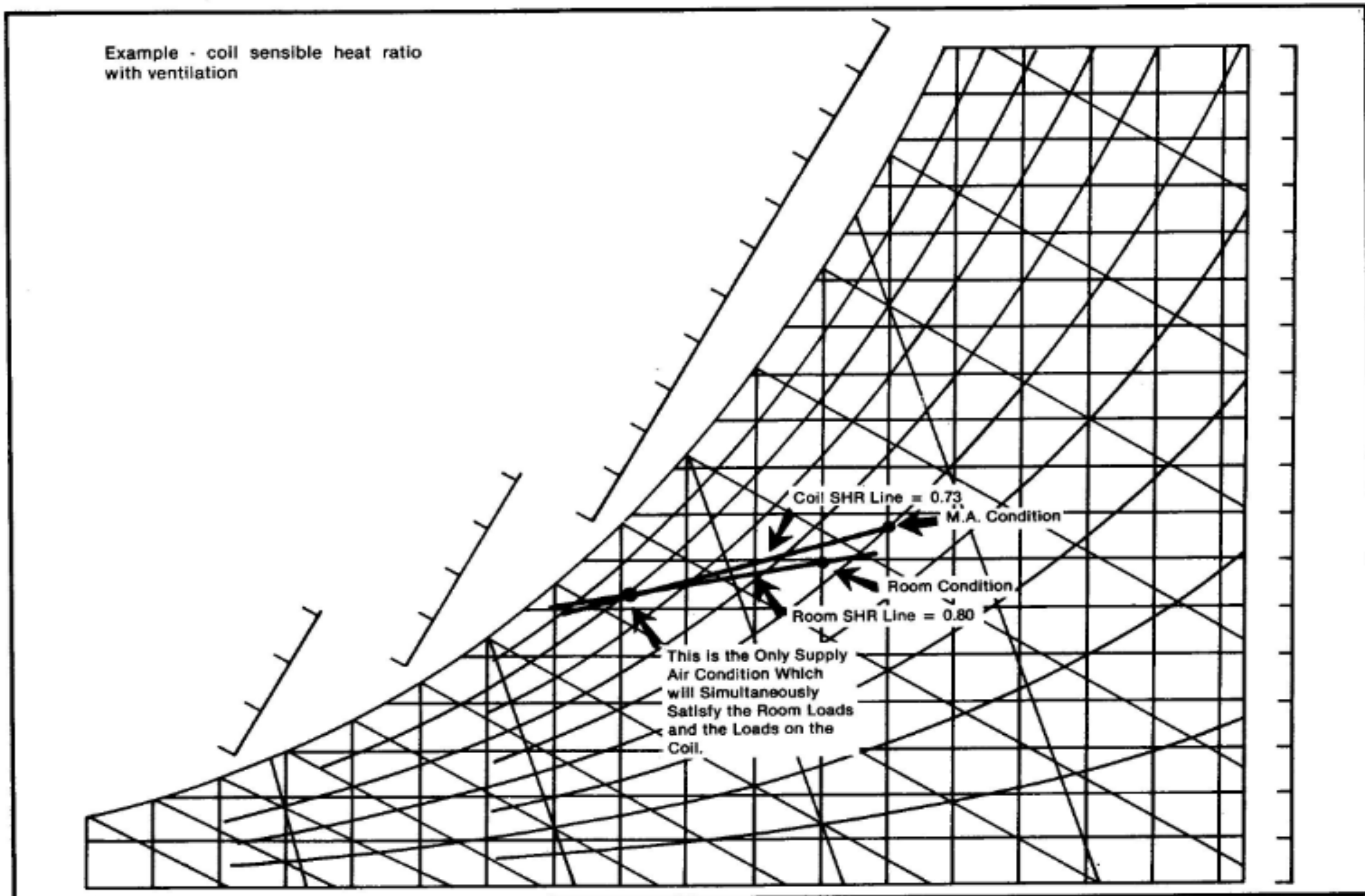
Example of Load Calculation Information

Coil Sensible Heat Ratio (CSHR) Cont'd



Room and Coil Sensible Heat Ratio Lines

Coil Sensible Heat Ratio (CSHR) Cont'd



Intersection of RSHR & CSHR Lines Denotes Supply Condition

Coil Sensible Heat Ratio (CSHR)

3. Construction of the RSHR and CSHR Lines

- It is important to understand that the room sensible heat ratio line can always be drawn on the psychrometric chart with complete certainty. This is because the room sensible heat ratio (RSHR) and the room design condition can always be determined from the load calculation information.
- However, coil sensible heat ratio (CSHR) is drawn using the following procedure:
- Assume water coils can provide leaving air temperatures that are between 15^{o}F and 25^{o}F below the room design temperature at relative humidities between 85% and 95%.
- Also assume that DX coils installed in packaged equipment can provide leaving air temperatures which are between 15^{o}F and 20^{o}F below the room temperature at relative humidities between 85% and 95%.
- The supply condition of CSHR must fall on the RSHR line
- For a packaged DX system, a leaving air DB temperature of 57^{o}F and approximately 90% RH is reasonable.
- The following example illustrate how CSHR can be drawn.

Coil Sensible Heat Ratio (CSHR) Cont'd

- Example: Construct the coil sensible heat ratio line using the following information:
- Room Sensible Heat = 90,000 Btu/hr
- Room Latent = 10,000 Btu/hr
- RSHR = 0.90
- Room Design = 75^{o}F DB and 50% RH
- Outside Design = 95^{o}F DB and 75^{o}F WB
- Ventilation Required = 1,000 CFM

$$Supply\ CFM = \frac{RSH}{1.1 \times Room_{DB} - Supply_{DB}} = \frac{90000}{1.1 \times (75-57)} = \frac{90000}{1.1 \times 18} = 4545 CFM$$

$$\%\ Outside\ Air = \frac{1000 cfm}{4545 cfm} = 22\%$$

$$Mixed\ Air\ Temperature = (0.22 \times 95) + (0.78 \times 75) = 79.4^{o}\ F$$

$$Coil\ Entering\ Conditions = 79.4^{o}\ F;\alpha;65.5^{o}\ F$$

$$Coil\ Leaving\ Conditions = 57^{o}\ F\ DB; \alpha\ 55.3^{o}\ F\ WB,\ 90\%\ RH$$

$$Coil\ CFM = 4545 cfm$$

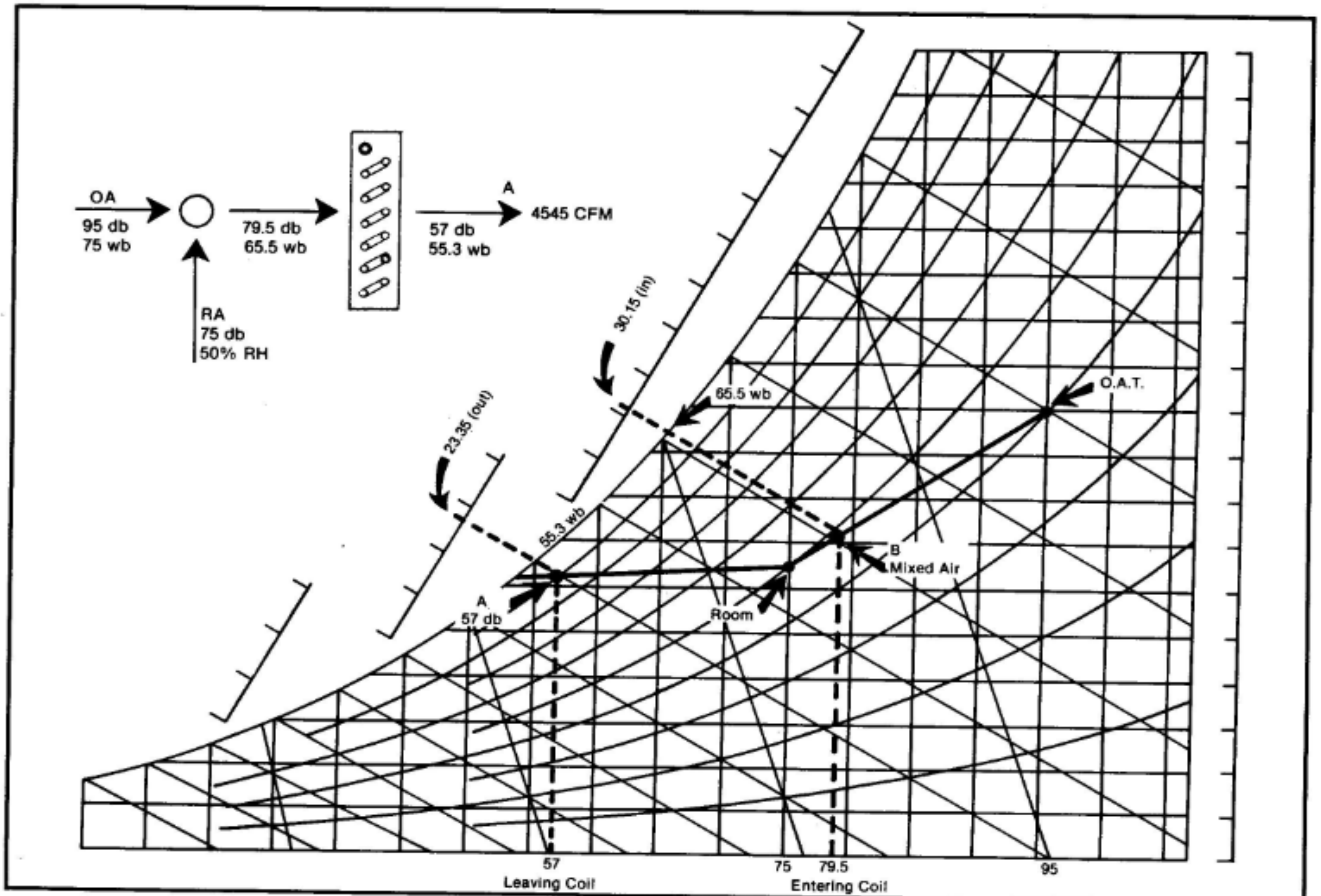
$$Total\ Load\ on\ the\ Coil = 4.45 \times 4545 \times (30.15 - 23.35) = 137{,}530 Btu / hr$$

$$Sensible\ Load\ on\ the\ Coil = 1.1 \times 4545 \times (79.4 - 57) = 112{,}489 Btu / hr$$

$$Coil\ Sensible\ Heat\ Ratio = \frac{112{,}489}{137{,}530} = 0.818 = 0.82$$

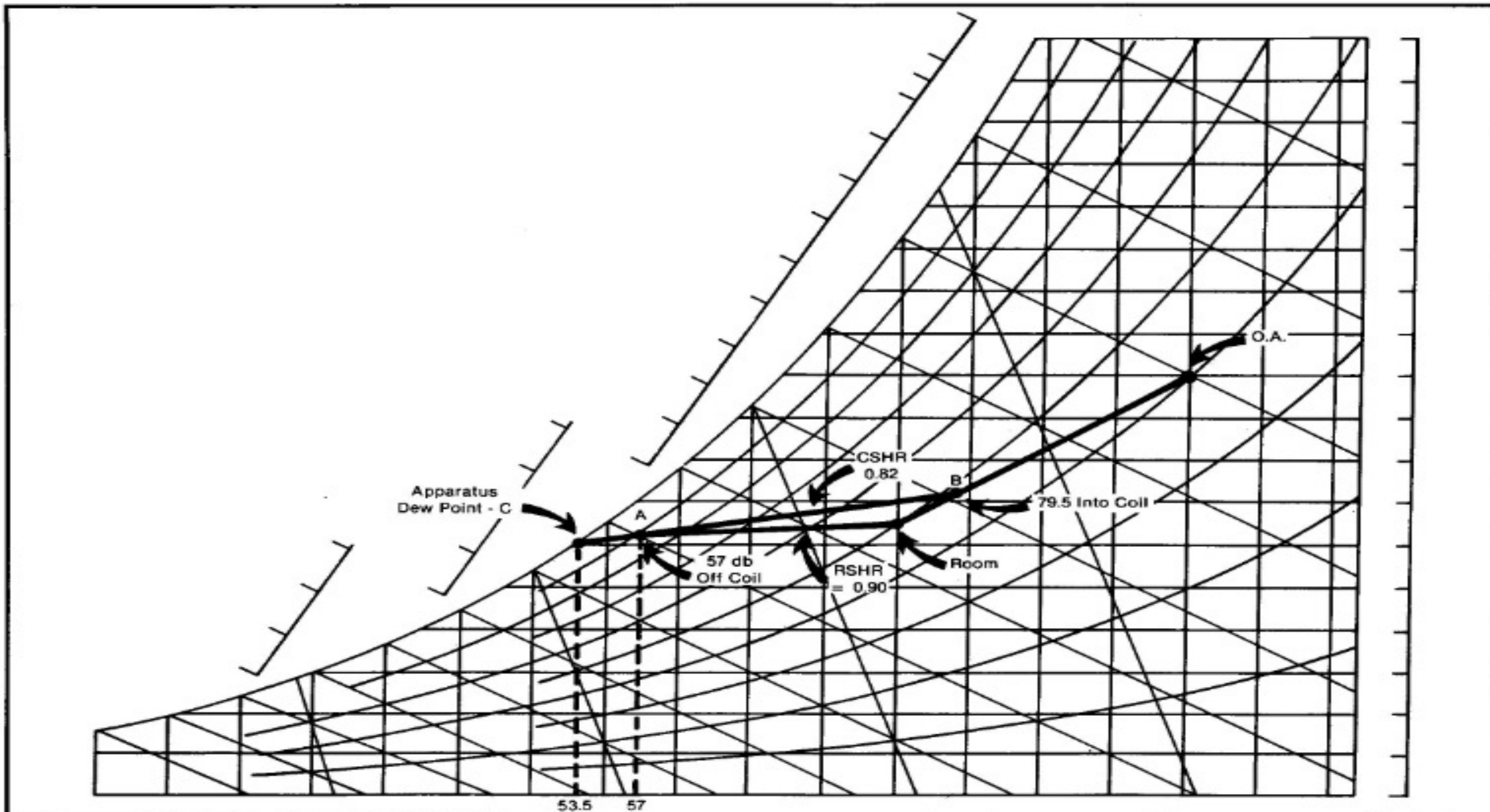
Coil Sensible Heat Ratio (CSHR) Cont’d

•



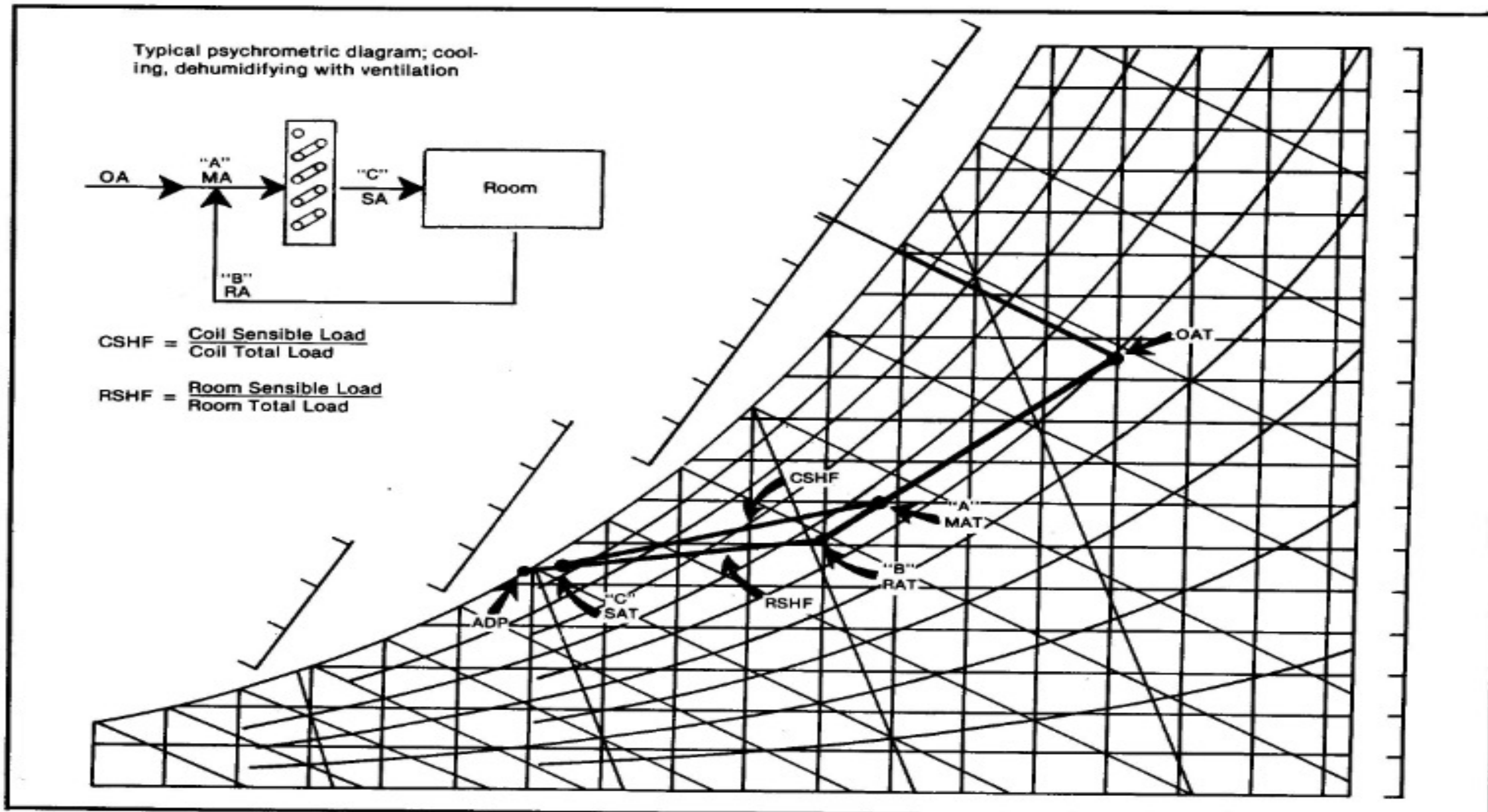
Example of Performance for Assumed Leaving Condition

Coil Sensible Heat Ratio (CSHR) Cont’d



Completed Psychrometric Diagram, RSHR & CSHR

Coil Sensible Heat Ratio (CSHR) Cont'd



Typical Psychrometric Diagram

Coil Bypass Factor & Contact Factor

When air passes across the outside surface of a coil, only part of the air actually contacts the surface and is cooled.

The *Bypass Factor* (BF) is defined as the proportion of air that does not touch the surface (*by-pass air*), and is therefore not cooled.

The *bypass air* is untreated –it leaves the coil at the same conditions as it entered.

- *Mathematically;*

$$BPF = \frac{LAT - ADP}{EAT - ADP} \rightarrow (a)$$

Where;

LAT = *Leaving Air DB Temperature*, ^oF

ADP = *Apparatus Dew Point Temperature*, ^oF

EAT = *Entering Air Temperature*, ^oF

BPF = *Bypass Factor*

The *Contact Factor (CF*) is defined as the proportion of air passing through the coil that touches the cooling surface (*contact air*) and is thus cooled.

It can be assumed that only the air that contacts the cooling surface (*contact air*) is cooled and dehumidified

- *Mathematically;*

$$CF = \frac{b}{a} = \frac{DB_1 - DB_2}{DB_1 - EST} \rightarrow (b)$$

Where;

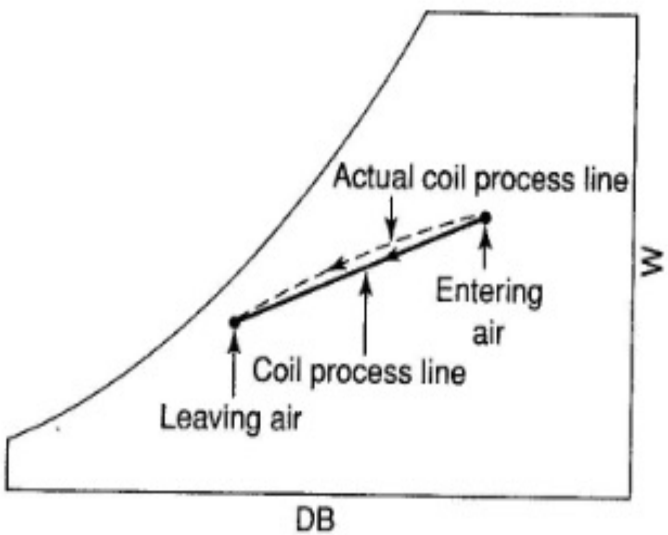
DB_1 = *Dry Bulb Temperature of air entering the cooling coil*, ^oF

DB_2 = *Dry Bulb Temperature of air leaving the cooling coil*, ^oF

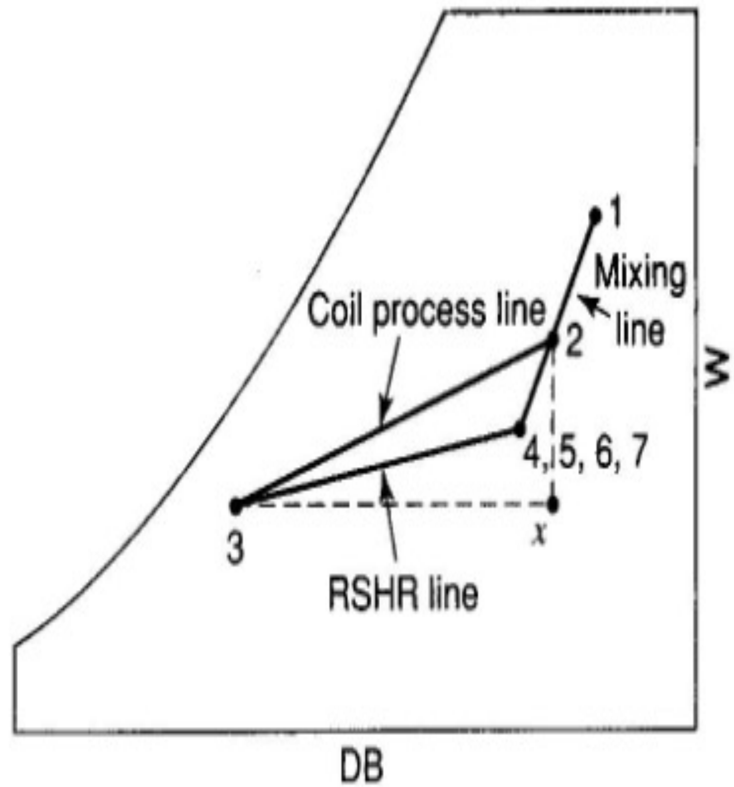
EST = *Effective Surface Temperature of coil*, ^oF

- *BF + CF = 1 -----> (c)*

Coil Bypass Factor & Contact Factor



Coil process line.



Thermodynamics Laws & Heat Transfer Principles

- 1^{st} Law of Thermodynamics States that:
- Energy In – Energy Out = Change in Store Energy --→ (1)
- This implies that, energy cannot be destroyed or created but energy can be converted from energy to another.
- Example: A hot heating convector in a Hotel room is supplying 4000 Btu/hr of heat. Heat is being transferred from the room air to the outdoor at rate of 6500 Btu/hr. What will happen in the room? What size electric heater should the Hotel manager temporarily use to solve the emergency?

$$Energy_{Change} = Energy_{IN} - Energy_{OUT}$$

$$\rightarrow \quad = 4000\frac{Btu}{hr} - 6500\frac{Btu}{hr}$$

$$\rightarrow \quad = -2500\frac{Btu}{hr}$$

The negative sign implies the room air energy is decreasing.
This will cause the room air temperature to drop, making
it uncomfortable.
Installation of electric heater will make up heat loss in the room

$$3410\frac{\text{Btu}}{\text{hr}} = 1000W$$

$$\rightarrow 2500\frac{Btu}{hr} \cong \frac{2500\frac{\text{Btu}}{\text{hr}}}{3410\frac{\text{Btu}}{\text{hr}}} \times 1000W = 733W$$

The most closest size larger heater manufactured would probably be 750W.

Thermodynamics Laws & Heat Transfer Principles

- **1st Law of Thermodynamics emphasizes on:**
  1. Energy Equation to solve problems in HVAC work
  2. How much energy is used for given task (the power of a pump, the capacity of refrigeration machine)
- ***2nd Law of Thermodynamics States that:***

a. "No machine whose working fluid undergoes a cycle can absorb heat from one system, reject heat to another system and produce no other effect" (Clausius' Law)

b. Or 2nd Law of Thermodynamics implies that net heat transfer occurs in the direction of decreasing temperature.

- **Mathematically;**

$$\eta = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H} \rightarrow (1)$$

As the temperatures approach equilibriu $(T_L = T_H)$,

the process efficiency tends towards zero.

- *"No (heat) engine whose working fluid undergoes a cycle can absorb heat from a single reservoir, deliver an equivalent amount of work, and produce no other effect" (Kelvin – Planck).*
- **Analysis of the 2nd Law:**
  1. A heat resource cannot be fully converted to work.
  2. Refrigeration is a process of moving heat (thermal energy) from a cold region to a warmer region.

Thermodynamics Laws & Heat Transfer Principles

- Example of 2nd Law of Thermodynamics:
- An air-conditioned engineered contractor has a choice of using steel or copper piping of the same diameter in chilled water system. Which would be the best choice to minimize energy consumption?
- Solution:
- Applying 2nd Law of Thermodynamics; Copper tubing has a smoother surface and therefore results less frictional loses. Less energy will be used in the pump, according to the Thermodynamics Second Law.
-

Thermodynamics Laws & Heat Transfer Principles

- **Heat Transfer Principles:**
- The principles of heat states that, heat will transfer from the warmer body to the cooler body.
- There are modes of heat transfer. These include:
  1. Conduction
  2. Convection
  3. Radiation

1. Conduction occurs by direct physical contact between two or more bodies i.e. thermal conduction refers to the direct transfer of energy between particles at the atomic level.

Mathematically:

$$q = -kA\frac{dT}{dx} \rightarrow (1) \text{ Where: } k = \frac{1}{R},\ R = \text{Resistance of a material}$$

For a steady state Heat Exchange Formula

$$Q = \frac{A \times (t_1 - t_2)}{\frac{L}{k}} \rightarrow (2) \text{ or } Q = U \times A \times (t_1 - t_2) \rightarrow (3)$$

Where; t_1 = *operation temperature,* ^oF

t_2 = *ambient (surrounding) air temperature,* ^oF

L = *thickness of insulation*

k = *thermal conductivity of insulation*

A = *area through which heat is lost*

Q = *total heat transfer*

U = *overall coefficient of heat transfer*

Thermodynamics Laws & Heat Transfer Principles

2. Convection occurs by air currents: the thermal convection transfer of energy may include some conduction but refers primarily to energy transfer by eddy mixing and diffusion, i.e., by fluids in motion.

- Mathematically;
- For a finned-coil fluid-to-air heat exchanger, the general equation for heat transfer is

$$Q = h \times A \times ROWS \times MED \rightarrow (1)$$

$$\begin{aligned} \text{Where: } Q &= \text{total heat transfer, Btu/hr} \\ h &= \text{heat transfer coefficient per row per square foot} \\ A &= \text{face area of coil normal to airflow direction} \\ ROWS &= \text{number of rows of tubes in direction of airflow} \\ MED &= \text{mean temperature difference} \end{aligned}$$

$$\text{But; } MED = \frac{GTD\text{-}LTD}{In \times \left(\frac{GTD}{LTD}\right)} \rightarrow (2)$$

$$\begin{aligned} \text{Where: } GTD &= \text{greatest temperature difference, air to water} \\ LTD &= \text{least temperature difference, air to water} \\ In &= \text{natural } \log \text{ (base } e\text{)} \end{aligned}$$

Thermodynamics Laws & Heat Transfer Principles

2. Convection transfer cont'd:

- For a shell-and-tube fluid-to-fluid heat exchanger, the equation for heat transfer is

$$Q = h \times A \times (MED) \rightarrow (3)$$

$$\begin{aligned}
\text{Where}: h &= \textit{heat transfer coefficient per square foot per } {}^{o}F \\
A &= \textit{total outside surface area of tubing, } ft^2 \\
\mathrm{Q} &= \text{heat transfer to the fluid, Btu/hr} \\
MED &= \textit{mean temperature Temperature, } {}^{o}F
\end{aligned}$$

3. Radiation occurs by heat rays i.e., thermal radiation describes a complex phenomenon which includes changes in energy form: from internal energy at the source of electromagnetic energy for transmission, then back to the internal energy at the receiver. There is no material medium required for energy transmission, therefore, radiation transfer works best in a perfect vacuum.

Factors that affect radiation heat transfer include:

a. Emittance

b. Absorptance

c. Reflectance

d. Transmittance

e. Absolute temperature difference

f. Geometry

Thermodynamics Laws & Heat Transfer Principles

3. Radiation heat transfer: One general equation for the net radiant heat transfer between two surfaces is:

- Mathematically;

$$Q = \alpha \times F_e \times F_A \times A \times (T_1^4 - T_2^4) \rightarrow (1)$$

$$
\begin{aligned}
\textit{Where}: \quad \mathrm{Q} &= \text{net heat transfer, Btu/hr} \\
\alpha &= \text{Stefan - Boltzmann constant, } 0.173 \times 10^{-8} \\
\mathrm{F_e} &= \text{factor to correct for surface emittances not being equal to } 1.0 \\
\mathrm{F_A} &= \text{factor to correct for geometric relationship of surfaces,} \\
& \quad \text{(F} = 1.0 \text{ if surfaces face each other directly)} \\
\mathrm{A} &= \text{face area of smaller surface, ft}^2 \\
\mathrm{T_1, T_2} &= \text{absolute (Rankine) temperatures of two surfaces}
\end{aligned}
$$

Estimate of Sensible and Latent Heat Changes

- **Sensible heat Equation:**

$$Q_s = m \times c \times \Delta T = m \times c \times (T_2 - T_1) \rightarrow (1)$$

Where;

Q_s = rate of sensible heat added to or removed from substance, Btu/hr

m = mass flow rate of substance, lb_m/hr

c = specific heat of subtance, Btu/lb_m -^{o} F

ΔT = $T_2 - T_1$ = temperature change of substance, ^{o}F

- **Latent Heat Equation:**

$$Q_l = m \times (h_g - h_f) = m \times h_{fg}$$

Where;

Q_l = heat added to or removed from substance, Btu/hr

m = mass flow rate, lb_m/hr

h_f = enthalpy of saturated liquid, Btu/lb_m

h_g = enthalpy of saturated vapor, Btu/lb_m

h_{fg} = latent heat or vaporization, Btu/lb_m

Estimate of Sensible and Latent Heat Changes

- Example 1: There are 5000 GPM of chilled water being circulated from the refrigeration plant to the air conditioning systems of the buildings at the Refinery Company. The water is cooled from 55^{o}F to 43^{o}F.
- Solution: $m = 5000GPM \times \frac{500lb_m / hr}{1GPM} \text{(for water)}$

$$= 2{,}500{,}000 \text{ lb}_\text{m}\text{/hr}$$

$$\text{Q}_\text{s} = m \times c \times (T_2 - T_1)$$

$$= 2{,}500{,}000 \frac{lb_m}{hr} \times 1 \frac{Btu}{lb_m -^o F} \times (43 - 55)^o F$$

$$= -30{,}000{,}000 \text{ Btu/hr}$$

Analysis of Thermal Comfort

- The purpose of thermal comfort is to provide a comfortable indoor environment, that a person cannot sense a difference between themselves and the surrounding air.
- Heating, Ventilating, and air conditioning (HVAC) systems are designed to provide comfort and contain mechanical, pneumatic, electrical, electronic, and chemical components.
- HVAC system components include compressors, controls, valves, dampers, actuators, fuels, refrigerants, and blowers.
- The most common essentials requirements for comfort are proper temperature setpoints, humidity, circulation, filtration, and ventilation

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