Subject :Principle of Refrigeration and A\C | الموضوع : مبادىء التكييف والتجميد

Weekly Hours :Theoretical: 2 | الساعات الأسبوعية: نظري:2

Tutorial:1 | مناقشة:1

Experimental:1 | عملي :1

Units: 5 | عدد الوحدات: 5

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## Subject: Principles of Refrigeration and Air Conditioning

**Lecturer: Assistant Professor Dr. Waheed Shaty Mohammed**

**Refrences:**

**1-A. R. Trott and T. Welch " Refrigeration and Air conditioning ",Third Edition Butter Worth Heinemann , 2000 .**

**2-C. P. Arora " Refrigeration and Air Conditioning " .Tata McGraw Hill 1984 .**

**٣- خالد الجودي " مبادى هندسة تكييف الهواء والتثليج " كلية الهندسة جامعة البصرة ١٩٨٦**

First Term

Chapter one: Introduction and definitions:

Lecture No. 1

1.1: Review of basic principles
Air conditioning : Is the science and practice of controlling the indoor climate in term of temperature , air motion , humidity , air purity and noise.

Refrigeration :Is the process of removing the undesirable heat from a given body to maintain it at a desired lower temperature .

1.2: Moist air :
Working substance in air conditioning is the moist air which is a mixture of two gases . One of these is dry air which itself is a mixture of a number of gases and the other is water vapor which may exist in a saturated or super heated state . Both are treated as perfect gases since both exist in the atmosphere at low pressures . In addition Gibbs-Dalton laws for non reactive mixture of gases can be applied to the dry air part only to obtain its properties as a single pure substance .

$T_1 = T_2 = T$

$V_1 = V_2 = V$

$P_1 + P_2 = P$

$m_1 + m_2 = m$

$P_1 V_1 = m_1 R T_1 \quad \& \quad P_2 V_2 = m_2 RT_2$

$P_t = P_a + P_v$

$m_1h_1 + m_2h_2 = mh$

1.3: Properties of moist air : The properties of moist air are called psychrometric properties and the subject which deals with the behavior of moist air is known as psychrometry . In air conditioning practice all calculations on the dry air part since the water vapor part is continuously variable . The actual temperature of moist air is called the dry bulb temperature DBT . The total pressure which is equal to the barometric pressure is constant . The other relevant properties are :

Humidity ratio, RH, DPT, h, $C_{ph}$ and WBT.

Humidity ratio or moistur cntent ( $\omega$ ) = $m_v/m_a = V/v_v / V/v_a = v_a/v_v$

$$\omega = 0.622\ P_v/P_a = 0.622\ P_v/(P_t-P_v)$$

However the vapor pressure may be given by the following equation :

$P_V = P_S - P_{at} A\ (DBT - WBT)$

Where A is constant =6.66 E-4 $^oC^{-1}$ & $P_{at}$ = atmospheric pressure

Relative humidity ( RH ) :

( RH = $\Phi$ % ) = $v_s/v_v = P_v/P_s$

DPT ( $T_d$ ) : Is the temperature of saturated moist air at which the first drop of dew will be formed the moist air is cooled at constant pressure i.e. the water vapor in the mixture will start condensing .

Enthapy of moist air ( h ) : $h = h_a + \omega\ h_v$

$$h_a = C_{pa}\ T = 1.005\ T$$
$$h_v = C_{pw}\ T_d + h_{fg} + C_{pv}\ (T - T_d) \quad \text{at } T_d = 0.0$$
$$h_v = 2501 + C_{pv}\ T = 2501 + 1.84\ T$$
$$h = 1.005\ T + \omega\ (2501 + 1.84\ T)$$

Humid specific heat ($C_{ph}$) = $C_{pa} + \omega\ C_{pv}$

Wet bulb temperature ( WBT ) : Is the temperature of moist air reads by a wicked bulb thermometer with its wick is thoroughly wetted by water .

1.4: Sensible and latent heats :

Sensible heat ( $Q_s$ ) : Is the heat added or removed from the moist air at constant moisture content ( $\omega$ ) .

Latent heat ( $Q_l$ ) : Is the heat added or removed from the moist air at constant DBT i.e. inceases or decreases its moisture contents .

1.5: Examples :

1- Calculate the vapor pressure of moist air at a state of DBT = 20 ċ , WBT = 15 ċ and $P_{at}$ = 95 kPa

Solution : from steam tables for $P_{at}$ = 101.3 kPa the saturation pressure $P_s$ = 1.704 kPa at WBT = 15 ċ.

Use the equation of vapor pressure :

$P_v$ =1.704 -6.66 E-4 * 95. * (20 -15 )
 = 1.388 kPa

2- Calculate the relative humidity of moist air the state condition of example 1 .

Solution : at DBT = 20 ċ the saturated pressure $P_s$ = 2.337 kPa therefore

$\Phi$ % = $P_v$ / $P_s$ = 1.338/ 2.337 = 59.5 % .

3- Calculate the moisture content of moist air at the same state condition of example 1.

Solution : $\omega = 0.622 ( P_v /P_a )$ and $P_a = P_{at} - P_v$ = 95. – 1.388

Then $\omega$ = 0.00923 kg water vapor / kg dry air .

3- Calculate the dew point of moist air at the same state condition of example 1.

Solution : the vapor pressure of moist air at this state has already been calculated as 1.388 kPa . At its dew point temperature the moist air must have a saturation pressure Equal to this value .Therefore from steam table at this value ( i.e 1.388 kPa ) the saturation temperature is approximately 12 ċ which represent the dew point temperature of the moist air the accurate value by interpolation is ( 11.57 ċ ) .

4- Calculate the specific volume of moist air at similar state of previous examples .

Solution : use the ideal gas law to the dry air alone .

$V_a = m_a R_a T_a /P_a$

$P_a = P_{at} - P_v$ ; $P_a$ =95000-1388 =93612 Pa

Then $V_a$ = 1. * 287 *( 273+20 ) / 93612

= 0.898 $m^3$

Alternatively we can consider water vapor mixed with the dry air .

$V_v = m_v R_v T_v / P_v$

$V_v$ = 0.00923 *461 * (273 + 20) / 1388 = 0.898 $m^3$ ;
where for one kg of dry air $\omega = m_v$ = 0.00923 kg water vapor / kg dry air

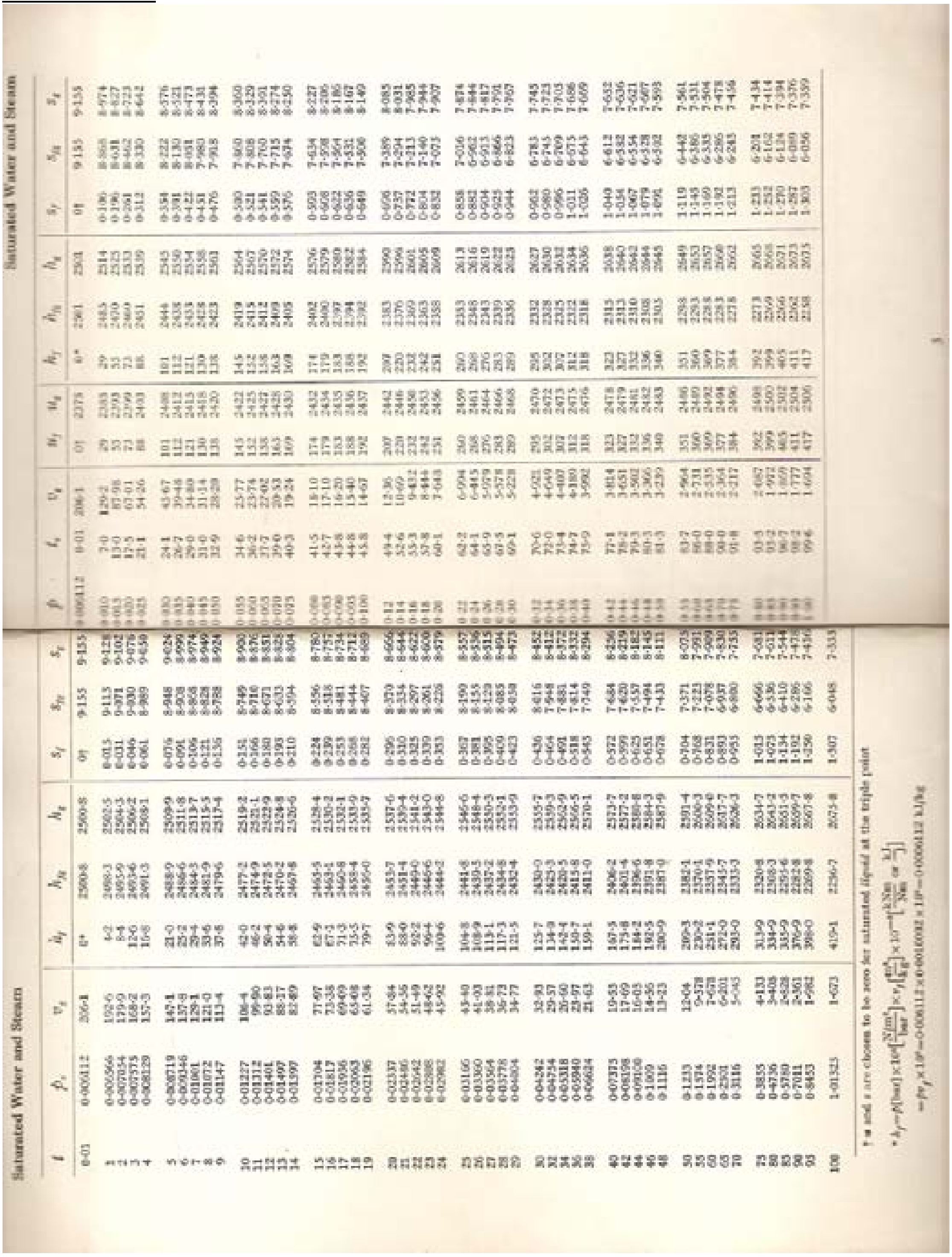
It can be seen that the volume of dry air and that of water vapor are the same as expain earlier $V = V_a = V_v$ .

5- Calculate the approximate enthalpy of humid air at DBT = 20 ċ and WBT = 15 ċ and 101.325 kPa .

Solution : h = 1.005 *  20. + 0.00923 * (2501.  + 1.84 * 20. ) = 43.5 kJ/kg .

H.W. :Calculate (i) Relative humidity ,(ii) Humidity ratio , (iii) Dew point temperature , (iv) Entahlpy of moist air  when the DBT= 35 ċ , WBT=23 ċ and the Pa = 101.35 kP .

Steam tables :


Saturated Water and Steam

Saturated Water and Steam

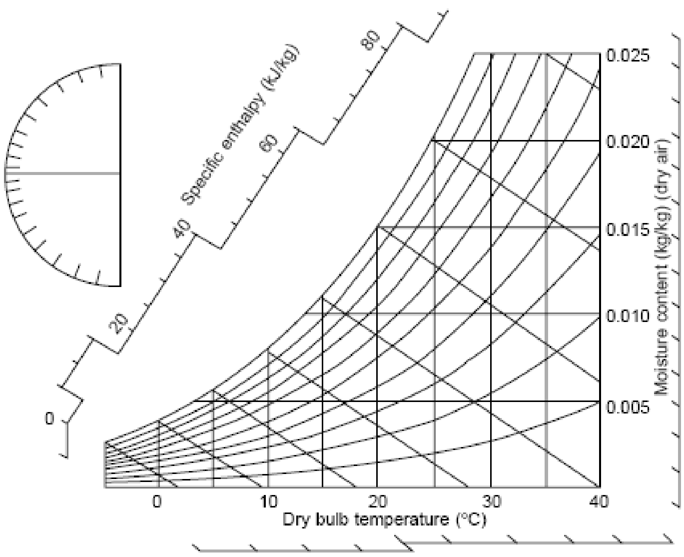
Lecture No. 2

Chapter two: Psychometric processes:

2.1: Psychrometric Chart :

All data essential for the complete thermodynamic and psychrometric analysis of air-conditioning processes can be summarized in a psychrometric chart .

**PSYCHROMETRIC CHART**
Based on a barometric pressure of 101.325 kPa
Sensible/total heat ratio for water added at 30°C
Specific enthalpy (kJ/kg)
Wet bulb temperature (°C) (sling)
Specific volume ($m^3$/kg)
Percentage saturation
Dry bulb temperature (°C)
Specific enthalpy (kJ/kg)
Moisture content (kg/kg) (dry air



The chart which is most commonly used is the ω vs. t i.e. a chart which has specific humidity or water vapor pressure along the ordinate and the dry bulb temperature along the abscissa . The chart is normally constructed for a standard atmospheric pressure of 101.325 kPa corresponding to the pressure at the mean sea level . A typical layout is shown in the figure . The procedure of drawing various constant properties is now considered .

The saturation line represents the states of saturated air at different temperatures . The saturation line on the chart is ,therefore, the line of 100% RH since for all points on this line $P_v = P_s$ .

Similarly one can show the lines of constant thermodynamic Wet bulb temperature , constant specific enthalpy and constant specific volume .

The particular psychrometric chart given in the figure is for normal DBT range of 0 ċ to 50 ċ and humidity ratios of 0.0 to 0.03 kg/kg dry air . Psychrometric charts for other conditions such as subzero or high temperature can also be prepared .

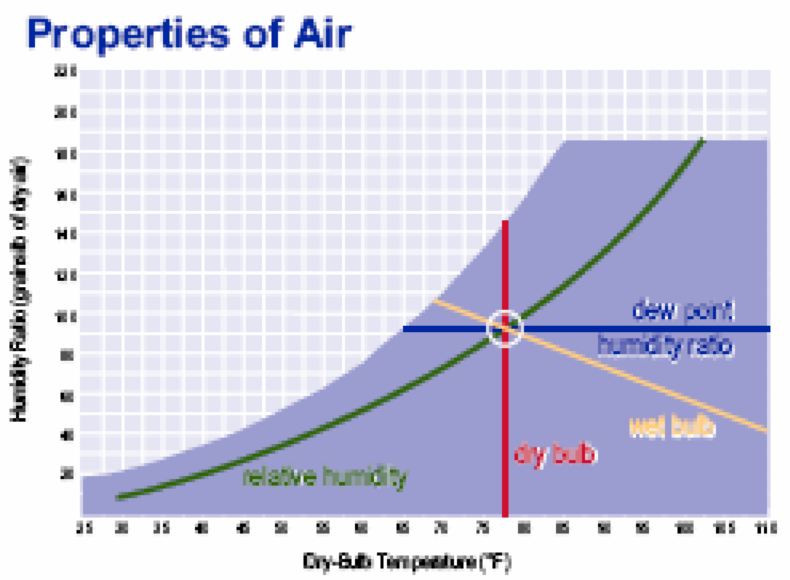



Figure 83

The lines of the psychrometric chart represent five physical properties of air: **dry bulb, wet bulb, dew point, humidity ratio,** and **relative humidity.** If any two of these properties are known, the remaining properties can be determined from the chart.

Examples :

1- A sample of moist air has a DBT of 43 ċ and WBT of 29 ċ , find using the psychrometric chart the following :

a- Specific humidity
b- Relative humidity
c- Dew point temperature
d- Specific enthalpy
e- Specific volume .

2- A sample of moist air has DBT of 24ċ and at a saturation state , find using the psychrometric chrat the followings :

a- Specific humidity
b- Relative humidity
c- Dew point temperature
d- Specific enthalpy
e- Specific volume .

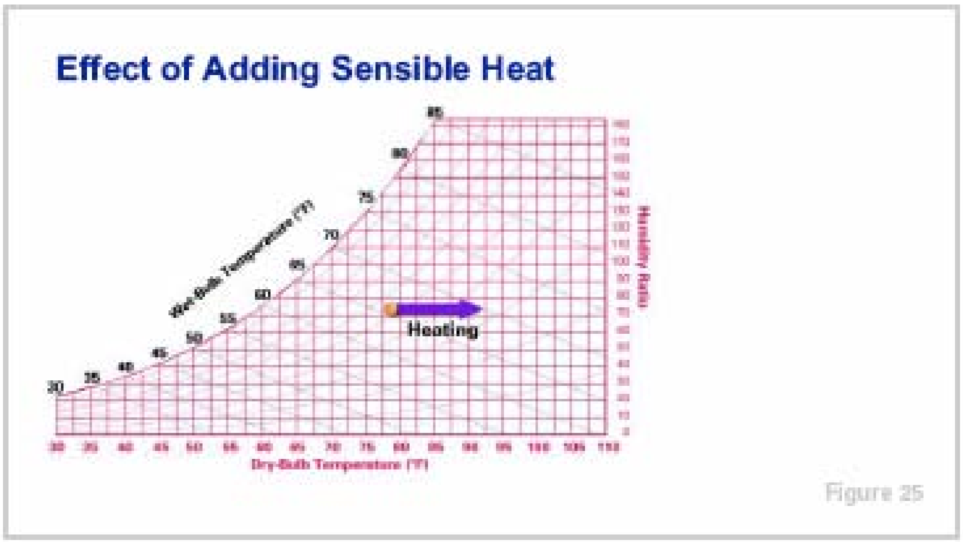
3- A sample of moist air has DBT of 30 ċ  and with dry state , find the following using psychrometric chart .

a- Specific humidity
b- Relative humidity
c- Dew point temperature
d- Specific enthalpy
e- Specific volume .

Lecture No. 3

2.2: Basic air conditioning processes:

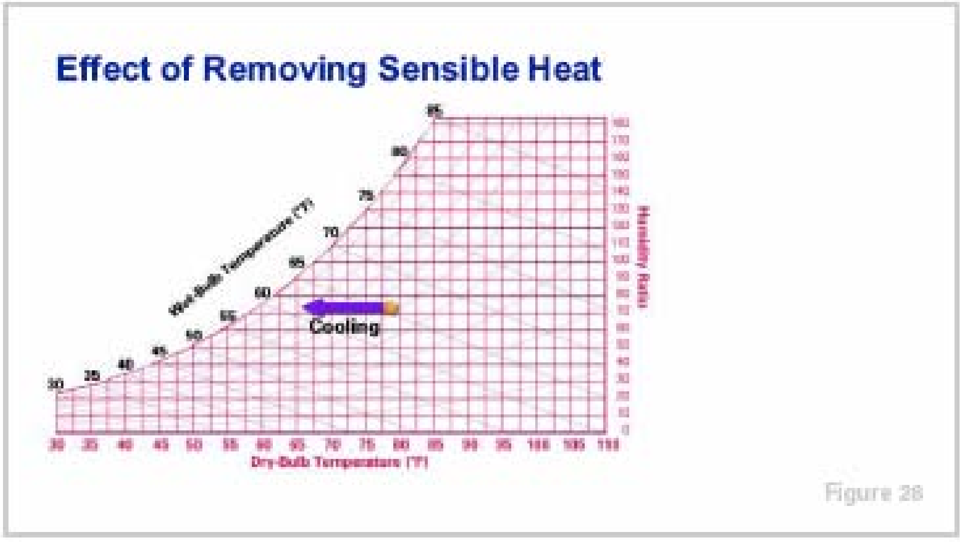
Sensible heating, sensible cooling :




**Effect of Sensible Heat and Moisture Changes**

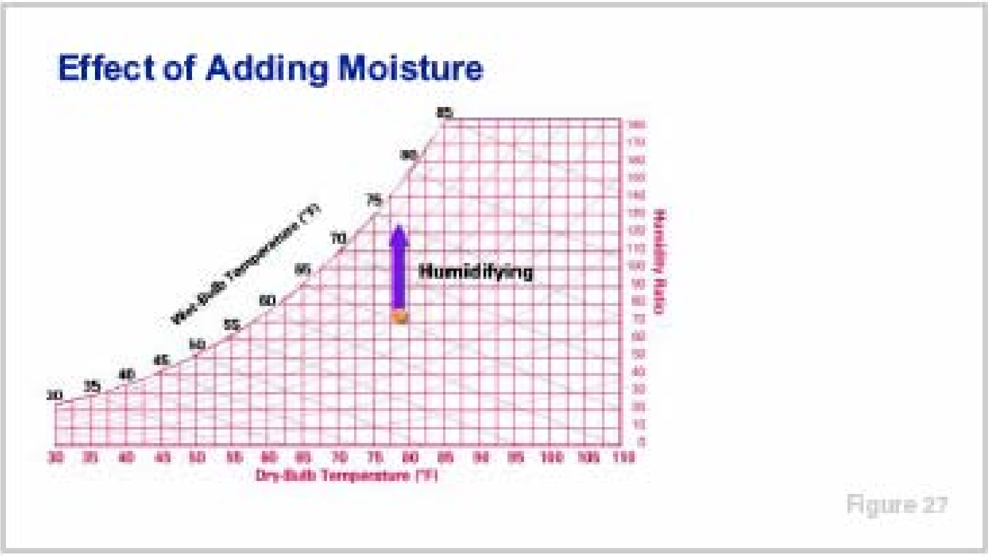
When either the sensible heat content or the moisture content of air changes, the point on the psychrometric chart that represents the original air condition moves to a position that represents the new condition of temperature and/or humidity.

For example, if sensible heat is added to air, the air condition moves horizontally to the right.

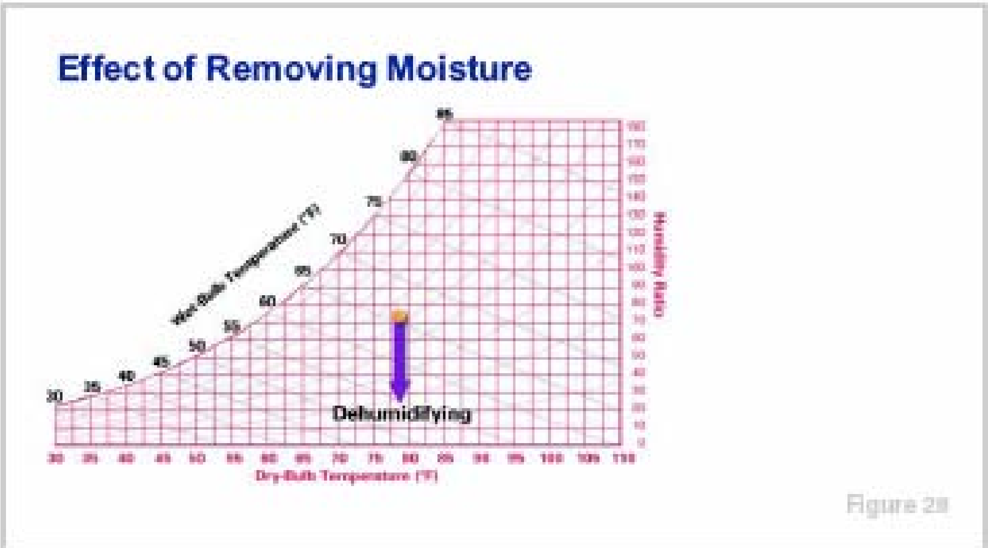



Conversely, if sensible heat is removed from air, the air condition moves horizontally to the left. As long as the moisture content of the air remains unchanged, the humidity ratio remains the same. Therefore, this movement follows the horizontal humidity-ratio lines.

Humidification, dehumidification:

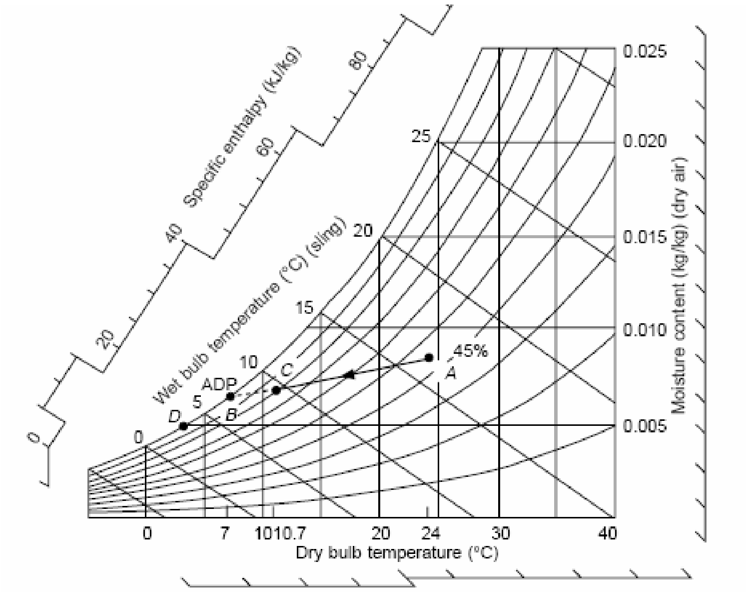



On the other hand, if moisture is added to air without changing the dry-bulb temperature, the air condition moves upward along a dry-bulb temperature line.

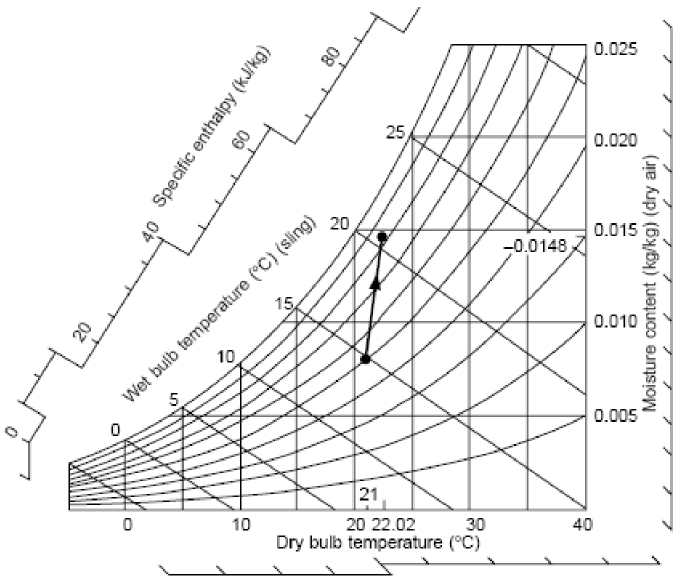



Finally, if moisture is removed from the air without changing its dry-bulb temperature, the air condition moves downward along a dry-bulb temperature line.

Cooling and dehumidification:

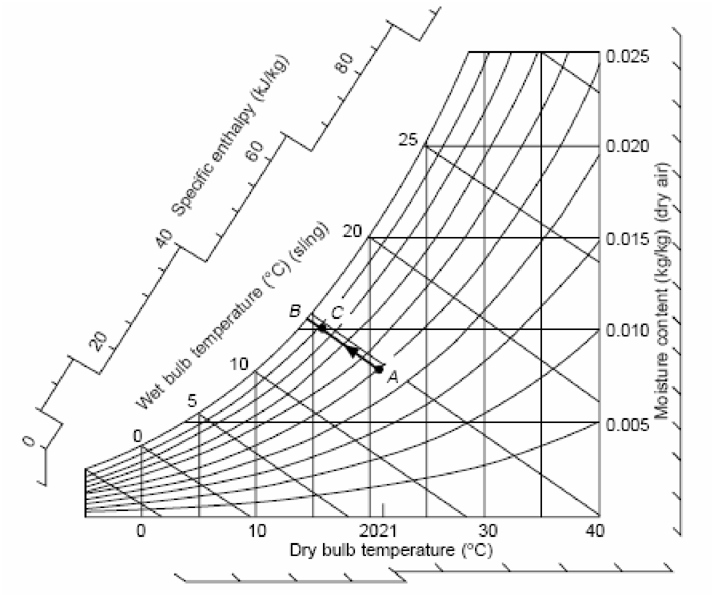



Heating and humidification:



Adiabatic cooling :

The process of adding latent heat and removing sensible heat at constant enthalpy as in the air cooler .




Examples :

1- Air at a state of DBT = 14 ċ , RH= 50% is passed through a heating coil . The DBT is increased up to 42 ċ . The moisture content remain constant in this process. Find : a) WBT of the exit air. b) The dew point temperature. c) The sensible heat added by the heating coil for 1.0 kg/s of air .{answers a) 19.5ċ , b) 3.9ċ , c) 28.6 kW}

2-Air at condition of DBT = 45ċ , RH= 20 % enter to an air cooler and exit at RH= 60 % . Find : a) DBT of exit air . b) The moisture content (ω ) at exit . c) plot the psychrometric process . ( answers a- 31.5 ċ , b- 5.5 kg wv /kg da ) .

3- Moist ait at DBT =30ċ and WBT = 25ċ enter a cooling coil and exit from it at saturation state with DBT = 15 ċ . IF the air is supplied to the coil at 3 $m^3$ /s find :
a) All the properties of air at inlet and outlet . b) The sensible heat that has been removed by the cooling coil . c) The a mount of moisture that has been removed from the air by the cooling coil. ( answers a-$h_{in}$ = 76 kJ/kg , $\omega_1$=0.081 kg wv/kg da , $v_1$= 0.882 $m^3$/s , $RH_1$ = 66. , $T_{dp}$ = 23.2 ċ , $h_2$ = 42 kJ/kg , $\omega_2$ =0.0107 kg wv /kg da , $v_2$= 0.831 $m^3$/s , $RH_2$ = 100 % b- 115.6 kW c- 0.0248 kg wv/kg da ) .

Lecture No. 4

Mixing process: Adiabatic mixing of different quantities of air in two different states at constant pressure . The conditions of the mixing state may be found by the following relations and as shown the figure below :

$T_3 = (m_1 T_1 + m_2 T_2) / (m_1 + m_2)$ or ;

$h_3 = (m_1 h_1 + m_2 h_2) / (m_1 + m_2)$ or;

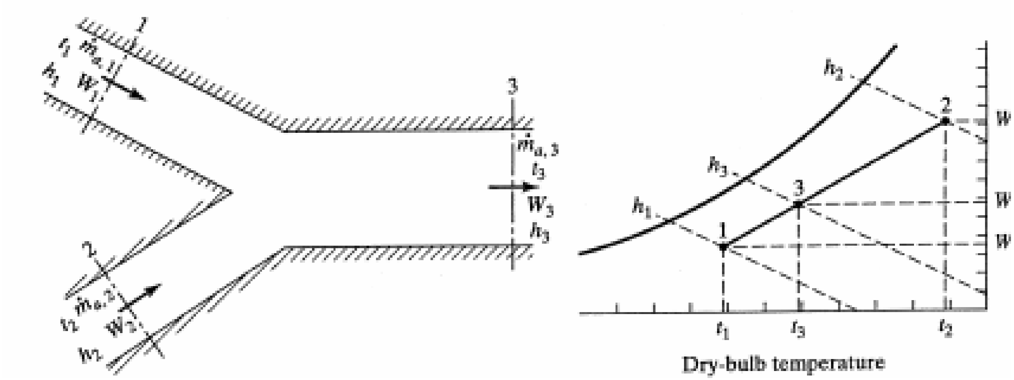
$\omega_3 = (m_1 \omega_1 + m_2 \omega_2) / (m_1 + m_2)$ ;where m in kg/s

It is acceptable practice in air conditioning to use volume ratio rather than mass ratio:

$T_3 = (v_1 T_1 + v_2 T_2) / (v_1 + v_2)$ ; similarly

$h_3 = (v_1 h_1 + v_2 h_2) / (v_1 + v_2)$ ; and similarly for $\omega$

$\omega_3 = (v_1 \omega_1 + v_2 \omega_2) / (v_1 + v_2)$ ;where v in $m^3/s$




Example :
Two air streams are mixed the first at DBT=21ċ ,WBT= 14ċ and the second at DBT= 28ċ ,WBT= 20 ċ with mass flow rates of 1 kg/s and 3 kg/s for the first and second respectively . Find the moisture content ,enthalpy ,and the DBT for the mixture and plot the process on the psychrometric chart . (answers : 0.01 kgwv/kgda , 52.15 kJ/kg , 26.25 ċ ) .

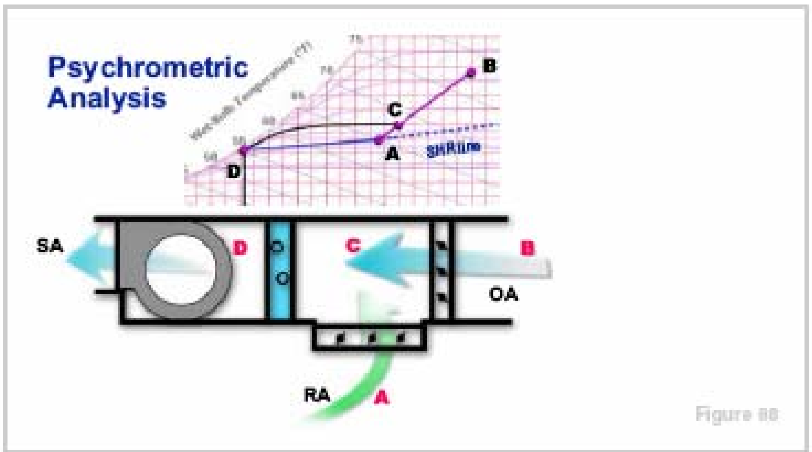
2.3 : Psychrometric analysis and air conditioning cycles :
These analysis include summer air conditioning cycle and winter air conditioning cycle which may cover the four basic combined processes discussed previously :-

1- Cooling and dehumidification process: There four methods that may be used to carry out the dehumidification process . a) cooling the air to temperature below its dew point, b) using absorption process , d) using adsorption materials, c) compress and cool the air . The first method represents the normal practice to cool and dehumidify the moist air in air conditioning systems .

2-Humidification of air : It is take place by injecting saturated or super heated steams inside the air conditioning ducts using fine nozzles and the equipment is called a humidifier.

<u>2.3.1 Summer cooling and dehumidification processes:</u>

1- All outside air :
2- All return air :
3- Mixing of fresh air with return air : as shown in the figure below .



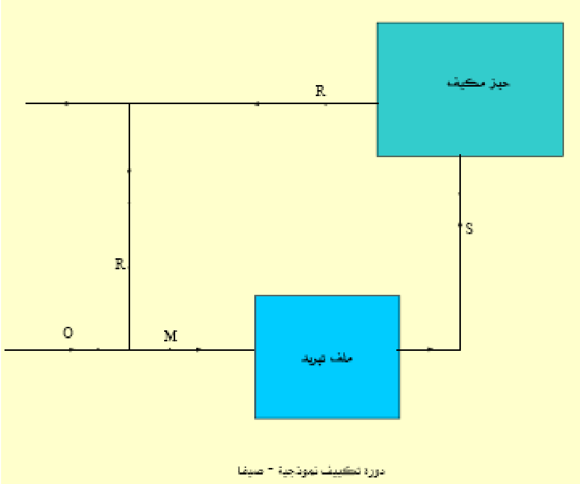

The resulting psychrometric chart plot represents the changes that a volume of air undergoes as it travels through a typical air conditioning system.

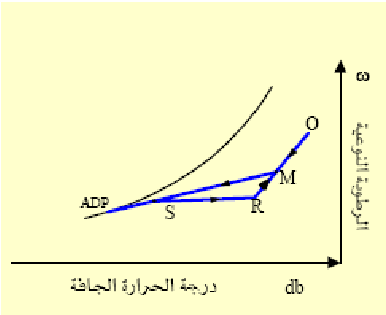
In this illustration, recirculated air **A** is mixed with outdoor air **B**, producing a mixed air condition **C**.

This air mixture passes through the cooling and dehumidifying coil, with the changes in dry-bulb temperature and humidity ratio represented by the coil curve from **C** to **D**.

This supply air **D** enters the room and mixes with the room air along the SHR line from **D** to **A**, absorbing the room's sensible and latent heat gains, to maintain the room at desired conditions **A**.

Again, for this specific supply air condition, a specific airflow is required to maintain the desired room conditions.




Sensible Heat Ratio ( SHR ) = Sensible heat/Total heat

$$SHR = Q_s / (Q_s + Q_l)$$

By Pass Factor (BPF) : Is the factor that determine the quantity of air that by pass the cooling coil with out contacting its surfaces .

$$BPF = (T_s - T_{ADP}) / (T_r - T_{ADP})$$

Where $T_{ADP}$ is the apparatus dew point temperature of the cooling coil .

Calculation procedure :

In order to solve the psychrometric questions the following steps should be done :

1- Mark the inside and out side design conditions on the chart .

2- calculate the SHF if the sensible and latent heat are given , and plot it as a parallel line starting from the inside design conditions.

3- Plot the assumed supply condition of RH= 90 % . IF other conditions is given plot them and neglect this value .

4- IF a state of mixing is given , calculate the mixing conditions and plot them on the line between the inside and out side conditions .

5- Connect the mixing point with the supply point by a line and find $T_{ADP}$ which represent the point where this line cross the saturation line.

6-Use the following equations to calculate the required variables :-

$Q_s = 1.22\ V_s\ (T_r - T_s)$ , this can be used to find $V_s$ .
$Q_{coil} = 1.2\ V_s\ (h_m - h_s)$ , if there is mixing
$Q_{coil} = 1.2\ V_s\ (h_o - h_s)$ , for all ouside air
$Q_{coil} = 1.2\ V_s\ (h_r - h_s)$ , for all return air
$m_{vap} = m_s\ \Delta\omega$ and the condition as in $Q_{coil}$
$Q_{water} = m_{water}\ c_p\ \Delta T_{water}$ where $c_p = 4.2$

Examples :

1- An air conditioned space is maintained at DBT= 24 ċ and RH=50% .The out side condition is DBT=38 ċ with WBT= 27 ċ .The space has a sensible heat gain of 24 kW and latent heat gain of 6 kW . Use all out side air system and find :-
a) the supply condition of the air if the relative humidity at the supply point is taken to be 90% . b) volume flow rate of supplied air . c) the total cooling load of the cooling coil . d) the chilled water volume flow rate if its temperature rise is 5.6ċ .
( answer : $T_s$= 12.2 ċ , $h_s$ = 32.6 kJ/kg , $Q_{coil}$ =95.6 kW , 4.06e-3 $m^3/s$ )
2- The sensible heat gain of a given space is 50 kW and its latent load is 15 kW . The inside design condition is 26 c with 50% relative humidity . The space is air conditioned using all return air system .Find by assuming 90% saturation for the supply air . a) the supply conditioned of the air b) volume flow rate of supplied air c) cooling coil load .
(answers : $T_s$= 14.5 c $h_s$=38.2 kJ/kg ,$v_s$= 3.56 $m^3/s$ , $Q_{coil}$ =60.5 kW )

3- An air conditioned space with inside design condition of DBT=25.5 c ,WBT=18 c has a sensible heat gain of 17.5 kW and a latent heat gain of 12.3 kW . The space required an outside air of o.35 $m^3/s$ at DBT= 32.5 c , RH= 50% . Find a) the state of the supplied air and its mass flow rate , b) cooling coil load , c) plot the process on the psychrometric chart and calculate the BPF .
( answers : $T_s$= 11.5 c , $h_s$= 29.5 kJ/kg ,$m_s$ = 0.813 kg/s , $Q_{coil=}$ 24.8 kW , BPF=0.25 )

Air Conditioning Cycles : There are two air conditioning cycle one for summer air conditioning and the other for winter air conditioning . The summer cycle is as explained previously of three types i.e. all out side air , all return and mixed air .

The winter air conditioning cycle can be done into two methods . The first method is to preheat the air and then cooling it adiabatically up to a given point and then reheat it to the supply conditions . The other method is to heat the air and then used an air washer to humidify the air up to a given point then reheat it to the supply conditions .

Example :
An air conditioned space is need to be maintained at DBT =24 c , RH= 50% . The sensible heat loss of the space is 66 kW and its latent is 16.5 kW . The space required 28.3 $m^3$/min fresh air .The outside design condition is DBT= 7 c , RH= 80% .
a ) plot the air conditioning process on the chart . b) find the mass flow rate of the supplied air given that $T_s$= 49 ċ , c) the heating coil load d) the humidifier heating load , e ) the amount of steam required by the humidifier .
( answers $m_s$= 2.77 kg/s , $Q_{coil}$=78.0 kW , $Q_{hum}$= 16.9 kW , $m_{vap}$= 0.00825 kg/s )

Lectures No. 5 & 6 :

Applications : The following examples represent practical applications to the psychrometrics processes in air conditioning field .

Q1- 30 cmm of stream of moist air at DBT = 15 ċ and WBT= 13 ċ are mixed with 12 cmm of a second stream at DBT = 25 ċ and WBT= 18 ċ . Determine the DBT and WBT of the resulting mixture .

Use the mixing equation for DBT :

$DBT_m\ cmm_m = DBT_1\ cmm_1 + DBT_2\ cmm_2$

$DBT_m$= 16 ċ

Locate on the psychrometric chart the three points ( i.e. point 1 , point 2 and the mixing point ) . From the chart you may find the $WBT_m$= 14.5 c .

Notes :

i- You may given the flow rates as a ratio of one stream to the other (for example , mix one part of the first stream to three parts of the second stream)
The mixing equation then takes the following form :

$DBT_m = DBT_1\ (V_1/V_m) + DBT_2\ (V_2/V_m)$

Where : $V_m = V_1 + V_2 = 1 + 3 = 4$ ,
$V_1/V_m = 1/4 = 0.25$ .
$V_2/V_m = 3/4 = 0.75$
Substitute and find $DBT_m$

ii- You may given the flow rates as a percentage ( % ), (for example , 80 % fresh air is mixed with 20 % room or return air ) .

The mixing equation then takes the following form :

$DBT_m\ V_m = DBT_o\ V_o + DBT_r\ V_r$

Or :

$DBT_m = 0.8\ DBT_o + 0.2\ DBT_r$

Where : $V_m = 0.8 + 0.2 = 1.0$ or 100 %
$V_o/V_m = 0.8$ or 80 %
$V_r/V_m = 0.2$ or 20 %

1- 4- 5&6

Q2- In an air conditioning system 39.6 cmm of a mixture ( room air and fresh outdoor air ) enter a cooling coil at DBT=31 c and WBT= 18.5 c . The effective surface temperature ( $T_{ADP}$ ) of the coil is 4.4 c .The cooling coil capacity ( Load ) is 12.5 kW Determine :

a) the dry and wet bulb temperature of the leaving air from the coil
b) the by pass factor ( BPF) of the coil .

$Q_{coil} = 1.2\, V_s (h_m - h_s)$ where $V_s$ in $m^3/s$

$V_s = 39.9 / 60$

Find $h_s = 36.7$ kJ/kg . Connect the point of mixing , the supply point and the ADP where the $T_{ADP}$ lies on the saturation line . Find the wet and dry temperature of the supply state or as it called in the question the state of air leaving the coil .
DBT = 18.6 c
WBT =12.5 c

Use the equation of the bypass factor
$BPF = (T_s - T_{ADP}) / (T_m - T_{ADP}) = 0.53$

Q3- The sensible heat and the latent heat gain of a given space are 20 kW and 5 kW respectively . The inside design condition of the space are DBT = 25 c , RH= 50 %. The out side design condition are DBT =43 c , WBT = 27.5 c . The room (return ) air is mixed with outside (fresh ) air before entering the cooling coil of the air conditioning plant in a ratio of 4:1 by volume .The supplied air may be taken 1.3 cms. Determine :
a) $T_{ADP}$
b) the condition of the leaving air ( the supply condition )
c) the dehumidified (supplied ) air quantity
d) ventilation ( outside ) air load
e) the refrigeration (cooling ) load of the plant .

Solution :

Find the mixing point as before .
Locate the given conditions and the mixing point on the chart
Calculate the SHF
$SHF = Q_s/Q_T = 0.8$ and plot it on the chart
Find the the supply state ( i.e the temperature or enthalpy )

$Q_s = 1.22\, V_s (T_r - T_s)$ OR $Q_T = 1.2\, V_s (h_r - h_s)$

$T_s = 13.3$ c or $h_s = 35.2$ kJ/kg
Locate the supply conditions on the chart .
Connect the mixing point and the supply point up to the saturated curve . This will give $T_{ADP} = 11.6$ c .
Find the ventilation load $Q_{vnt} = 1.2\, V_o (h_o - h_r) = 11.8$ kW
Find the refrigeration load $Q_{coil} = 1.2\, V_s (h_m - h_s) = 36.8$ kW

2 – 61 , 5x6

We need to find the point before the air entering the air washer and this is obtained using the saturation efficiency of the air washer to find $\omega_{saturated}$ as :

$\eta = (\omega_s - \omega_m)/(\omega_{saturated} - \omega_m)$ $\omega_{saturated}$ = 8.72 g.w.v/kg.d.a

where the supply point ( s ) is the point between the mixing state and the saturation state that cut the SHR line say point (1) .
The location of point 1 on the chart gives the conditions of air entering air washer:
$T_1 = 11.6$ $WBT_1 = 11.5$ $h_1 = 33$ kJ/kg
At air washer the temperature of water may be assumed to be
$T_{water\ out} = WBT_1$
Use the heat balance in the air washer between air and water gives
$m_w\ cp_w\ \Delta T_w = m_a (h_1 - h_m)$
$T_{water\ in} = 34.$ c

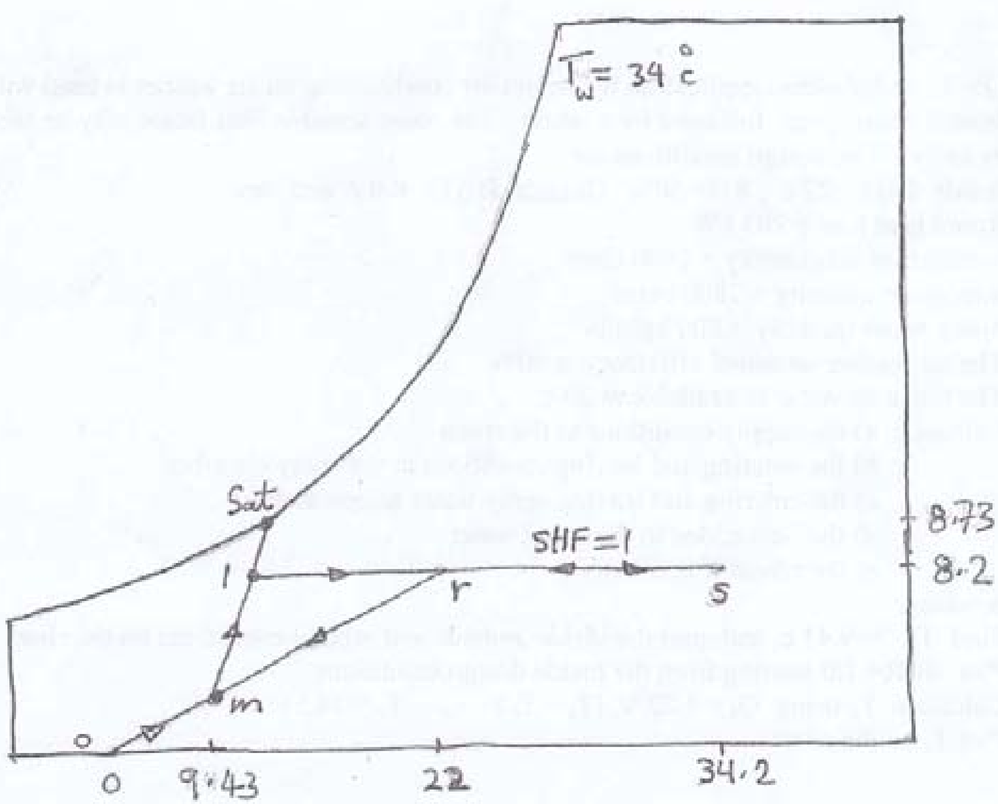
Make up water = $m_s (\omega_1 - \omega_m)$ = 0.25 kg/s

$Q_{makeup} = m\ cp\ \Delta T_{makeup}$ $\Delta T_{makeup} = 34 - 20$

$Q_{water} = m\ cp\ \Delta T_{water}$ $\Delta T_{water} = 34 - 11.5$

$Q_{spray\ water} = Q_{makeup} + Q_{water}$

$Q_{rehet} = 1.22\ V_s\ (T_s - T_1)$ = 1290 kw



Q4- The following data apply to an air conditioning systems :

Room sensible heat = 10 kW
Room latent heat =10 kW
The inside design conditions is DBT = 25 c , RH = 50 %
The outside design conditions is DBT = 35.0 , WBT = 27.8 c
The mixing ratio of room air to fresh air is 4: 1
The room air is mixed with the air after the cooling coil in the ratio of 1:4
The cooling bypass factor is 0.1
The air may be reheated if necessary before supplying to the room
The apparatus dew point temperature $T_{ADP}$= 10 c . Determine :

a) Supply air conditions
b) heat load due to reheat
c) coil capacity in Tones Refrigeration (TR)
d)the quantity of fresh air supplied
e)plot all the psychrometric processes.

Solution :
Find the first mixing point $T_{m1}$= 27. c
Find $T_{s1}$ = 11.7 c from the BPF
Find the second mixing point $T_{m2}$ = 14.4
Find SHF = 0.5
Find $T_{s2}$ =21.8 c , you can see that this point need to be preheated .
Find $V_s$= 153.2 from $Q_s$= 1.22 $V_s$ ( $T_r - T_{s2}$ )
Find the reheat load $Q_{reheat}$ = 22.5 kW
and refrigeration load $Q_{coil}$= 64.7kW = 64.7/3.51 = TR

Q5- In an industrial application for winter air conditioning an air washer is used with heated water spray followed by a reheat . The room sensible heat factor may be taken as unity . The design conditions are :
Inside DBT =22 c , RH= 50% ,Outside DBT= 0.0 c and dry
Room heat loss = 703 kW
Ventilation air quantity = 1600 cmm
Supply air quantity = 2800 cmm
Spray water quantity = 500 kg/min
The air washer saturated efficiency is 90%
The make up water is available at 20 c ,
Calculate a) the supply conditions to the space
b) the entering and leaving conditions at the spray chamber
c) the entering and leaving spray water temperatures
d) the heat added to the spray water
e) the reheat if necessary .

Solution:
Find $T_m$ = 9.43 c and plot the inside ,outside and mixing conditions on the chart
Plot SHR= 1.0 starting from the inside design conditions .
Calculate $T_s$ using $Q_s = 1.22\, V_s (T_s - T_r)$ , $T_s = 34.3$ c
Plot $T_s$ on the chart .

Lecture No. 7

## Chapter three: Thermal comfort and design

### 3.1: Inside air design conditions:

The general practice is to recommend the following optimum inside design conditions for comfort Summer air conditioning :

DBT = 25.0 ± 1.0 °C and RH = 50 ± 5 % . The corresponding room velocity is 0.4 m/s .

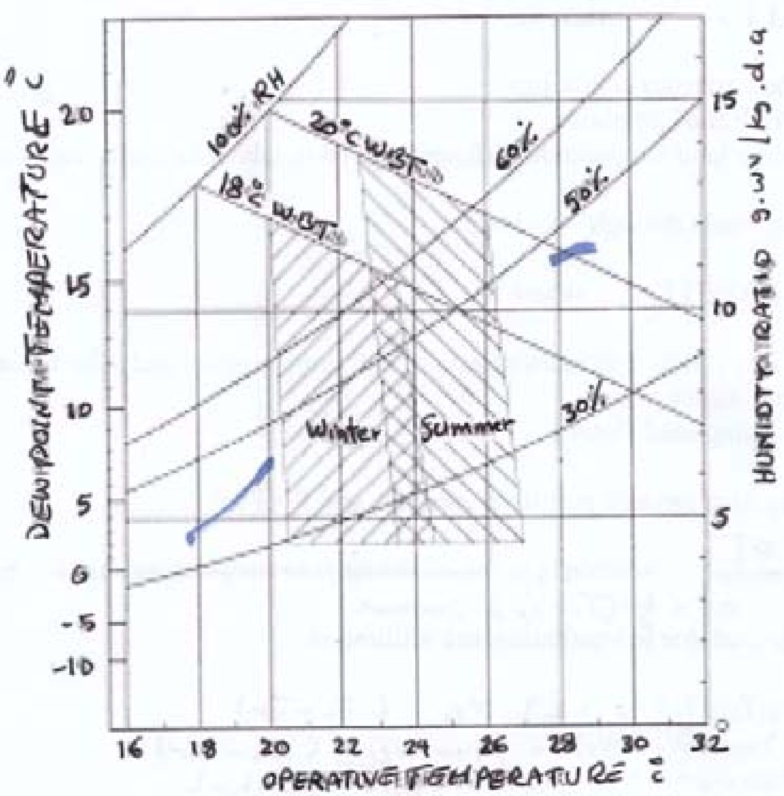
During winter the body gets acclimatized to with stand lower temperatures . Consequently the following Winter design conditions is quite comfortable :

DBT = 21 °C at RH = 50 % and air velocity of ( 0.15 – 0.2 ) m/s .

### 3.2: Out side air design conditions :

See the air conditioning tables or weather data for Iraqi Cities .

### 3.3: Comfort zone for Summer and Winter :




Examples :

Lecture No. 8

Chapter Four: Cooling load calculations:

Cooling load is the rate at which heat must be removed to maintain the temperature and humidity required at design values through :
Structural components ,
Windows ,
Infiltration ,
Occupants and appliances .

4.1 : Cooling load through structural components :

The Cooling Load Temperature Difference (CLTD) method will be used to calculate the structural components load .This method combine the effect of the temperature difference between indoor and outdoor , solar radiation and considered thermal capacity of the enclosure .

$Q = U\,A\,(CLTD)$ where :

U : overall heat transfer coefficient
A : area of wall ,roof ,or glass
CLTD : cooling laod temperature difference given in tables for walls ,roofs and glass

4.2 : Cooling loads through windows:

$Q = A\ SHG\ SF\ CLF$ , where :

Solar Heat Gain ( SHG ) includes effects of both transmission and solar radiation ,
SF is the shade factor ,
CLF is the cooling load factor.

4.3 : Cooling load through partitions ,ceiling , and floor :

$Q = U\,A\,\Delta T$ ~~$(T_b - T_i)$~~ where $\Delta T$ is t~~he adjacent space temperature~~. given by
$\Delta T = \frac{2}{3}(T_o - T_r)$ summer

4.4 : Cooling load due to ventilation and infiltration :

$Q_s = \rho . \dot{V} c_p (T_o - T_i) = 1.22\ \dot{V}_{flow}\,(T_o - T_r)$
$Q_l = 2500\,\rho\,V_{flow}\,(W_o - W_i) = 2940\ \dot{V}_{flow}\,(W_o - W_r)$
$Q_{total} = \rho\,V_{flow}\,(h_o - h_i) = 1.2\ \dot{V}_{flow}\,(h_o - h_r)$

$\dot{V}_{flow} = \dot{V}_{out}$

Where : $V_{flow}$ is the ventilation requirements from standard tables .

1-2-8

4.5: Internal cooling load due to occupants , lights and appliances :

People :
Q = 70 W/person or from tables according to activities .
Qs =N * ( sensible heat gain ) * CLF
Ql = N * (latent heat gain )

Where N is the number of people in the space and , CLF is cooling load factor .

Lights :

$Q_{elc}$ =W $F_u$ $F_s$ CLF , where : W is the watts input of the light , $F_u$ is lighting use factor , $F_s$ is special allowance factor.

Power :

$Q_p$ = P $E_f$ CLF where P is power rating , $E_f$ is efficiency factor .

Appliances :
Q = 470 W for both kitchen and laundry for single family
Q = 350 W for multi-family
For latent cooling load calculate for individual components or estimate as 30% $Q_s$ .
OR :
Qs = sensible heat gain * $F_u$
Ql = latent heat gain * $F_u$

~~Examples~~

4.6 Applications

Six examples. lecture (9 & 10 & 11)

Load of Partitions

$$Q = U_p \cdot A_p \times \Delta T$$

$\Delta T = \frac{2}{3} (T_o - T_r)$ for summer

$\Delta T = \frac{1}{2} (T_r - T_o)$ for Winter

# OUT SIDE DESIGN CONDITION DATA FOR IRAQ

(MECHANICAL SEC.)

| No. | CITIES | LOCATION | ACTUAL LATITUDE "N" | | APPROX. LATITUDE "N" | LONGITUDE "E" | | ELEVATION ABOVE MSL.* "M" | SUMMER * | | | WINTER * | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | D.B. °C | R.H. % | DAILY RANGE °C | D.B. °C | R.H. % |
| 1 | SALAHADDIN | NORTH | 36° | 23′ | 35° | 44° | 13′ | 1088 | 37.5 | 23 | 11.4 | -0.5 | 50 |
| 2 | SINJAR | NORTH | 36° | 19′ | 35° | 41° | 50′ | 538 | 39.5 | 17 | 12.5 | 1.5 | 78 |
| 3 | MOUSLE | NORTH | 36° | 19′ | 35° | 43° | 09′ | 272.6 | 44 | 19.5 | 21.2 | 0.5 | 92 |
| 4 | SULAIMANIYA | NORTH | 35° | 33′ | 35° | 45° | 27′ | 853 | 40 | 15 | 15 | -1.5 | 77 |
| 5 | KIRKUK | NORTH | 35° | 28′ | 35° | 44° | 24′ | 330.8 | 44 | 14 | 16 | 3 | 81 |
| 6 | AHA | MIDDLE | 34° | 28′ | 33° | 41° | 57′ | 138.5 | 43 | 21 | 17.6 | 1 | 68 |
| 7 | KHAHAQIN | MIDDLE | 34° | 18′ | 33° | 45° | 26′ | 202.2 | 45 | 15 | 18.4 | 3 | 81 |
| 8 | HADITHA | MIDDLE | 34° | 04′ | 33° | 42° | 22′ | 108 | 43.5 | 15 | 18 | 1 | 93 |
| 9 | HABBANIYA | MIDDLE | 33° | 22′ | 33° | 43° | 34′ | 43.6 | 44 | 17 | 18.3 | 2.5 | 85 |
| 10 | BAGHDAD | MIDDLE | 33° | 14′ | 33° | 44° | 14′ | 34.1 | 45 | 15 | 18.7 | 1.5 | 84 |
| 11 | RUTBA | MIDDLE | 33° | 02′ | 33° | 40° | 47′ | 615.5 | 40 | 15 | 17.3 | 0.5 | 82 |
| 12 | HAI | MIDDLE | 32° | 10′ | 33° | 46° | 03′ | 14.9 | 45 | 18.5 | 17.9 | 4 | 84 |
| 13 | NAJAF | SOUTH | 32° | 01′ | 31° | 44° | 19′ | 50 | 45.5 | 14 | 17 | 4 | 82 |
| 14 | DIWANIYA | SOUTH | 31° | 59′ | 31° | 44° | 59′ | 20.4 | 44.5 | 19.5 | 19.3 | 3.5 | 83 |
| 15 | AMARA | SOUTH | 31° | 51′ | 31° | 47° | 10′ | 7.5 | 46 | 16 | 19 | 4.5 | 80 |
| 16 | SAMAWA | SOUTH | 31° | 18′ | 31° | 45° | 16′ | 6 | 45 | 14 | 13.5 | 4.5 | 86 |
| 17 | NASIRIYA | SOUTH | 31° | 05′ | 31° | 46° | 14′ | 3 | 45 | 18 | 18.4 | 4.5 | 79 |
| 18 | BASRAH | SOUTH | 30° | 34′ | 31° | 47° | 47′ | 2.4 | 43 | 38 | 15 | 5.5 | 80 |

*: MEAN-SEA LEVEL  ** $°F = \frac{9}{5}°C + 32°$

Lecture No. (9)

Chapter Five: Heating load calculations:

5.1: Calculation procedure:

Heating load through structural components and windows:

$Q_s = U A ( T_i - T_o )$

Heating load through floor:

$Q_s = U A ( T_i - T_{earth} )$

Heating load by infiltration:

$Q_s = 1.22 \; V_{infiltration} \; ( T_i - T_o )$
$Q_L = 2940 \; V_{infiltration} ( W_i - W_o )$

$V_{inf} = \frac{Volume * N}{3600}$

N = Air changes per Hour

| type of rooms | ACH |
|---|---|
| No doors & windows | 0.5 |
| one side with doors & wind | 1. |
| two sides " " " | 1.5 |
| Three " " " " | 2. |
| Catti doors | 2 |

Where : U is the overall heat transfer coefficient
A is the area of the wall ,roof or floor
$T_o$ is the outside temperature of the space
$T_i$ is the inside temperature of the space
$T_{earth}$ is the floor temperature of the space
ρ is the air density
V is the volume flow rate of the infiltration air
$W_o$ is the moisture content of the outside air
$W_i$ is the moisture content of the inside air

5.2: Ventilation :

The ventilation load can be estimated by knowing the amount of the fresh air required by the given space .This can be found in tables according to the function of building . If the amount of ventilated air is known then the ventilation load may be estimated by :

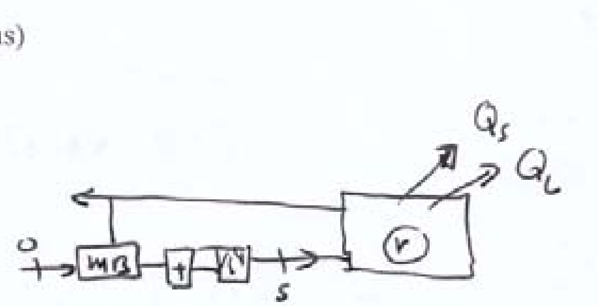
$Q_{vent} = 1.2 * V_{vent} ( h_i - h_o )$

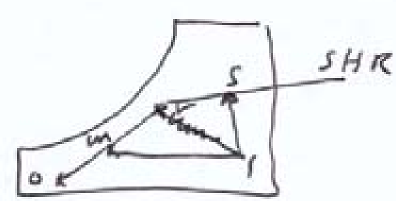
This load represent the total load for ventilation ie(sensible + latent )

5.3: Quantities of air required for heating (cms)

$V_s = Q_s \,/ ( 1.22 ( T_s - T_r ))$

5.4 : Applications :



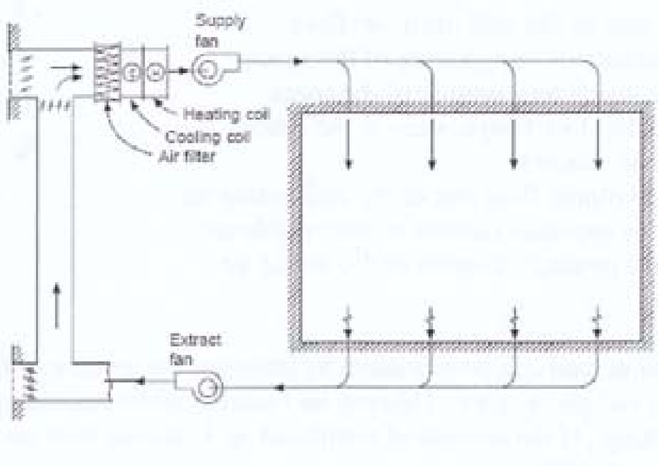



Lecture No. 10

Chapter six: Air conditioning systems

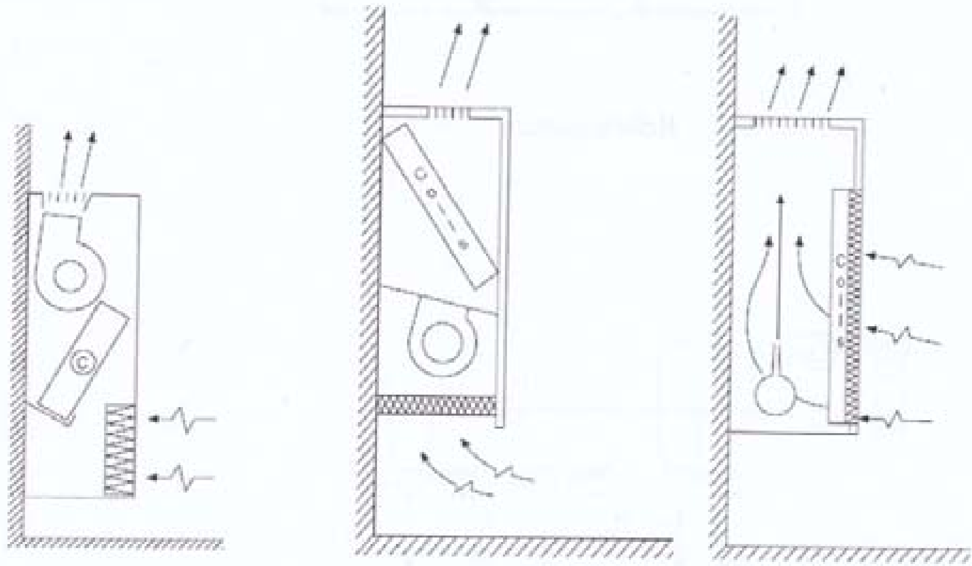
6.1: All air systems: It is consist of the following systems :

- a- Constant air volume systems
- b- Variable air volume systems
- c- Reheat systems
- d- dual duct systems
- e- Air side economizer



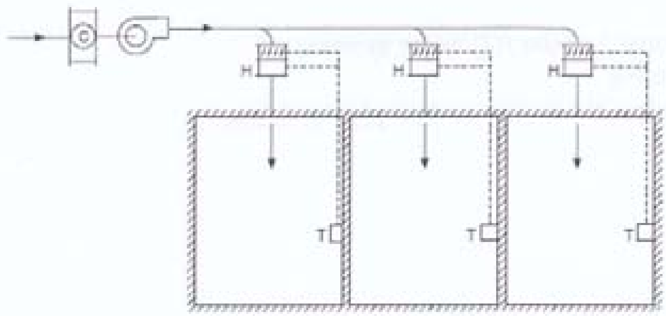

Constant air volume system

6.3: Air water systems : It is consist of the following systems :
a- Air water induction systems
b- fan coil systems : two pipe ,three pipe or four pipe systems

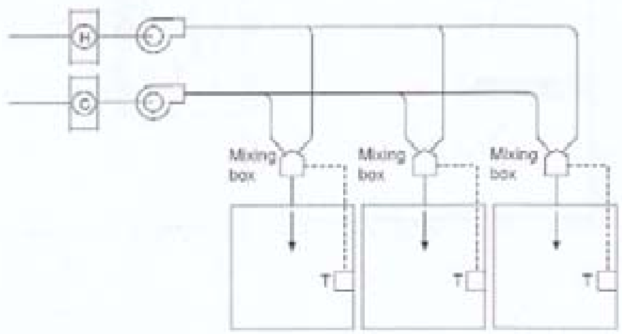



Fan coil unit    Fan coil unit    Induction systems

6.4: Unitry and hybrid systems : It is consist of the following systems:
a- Incremental units ,examples motel units and large single zone units .
b- Heat pumps , air to air heat pumps , water to air heat pumps .
c- Heat recover system , air to air heat exchanger, heat wheel and heat pipe.



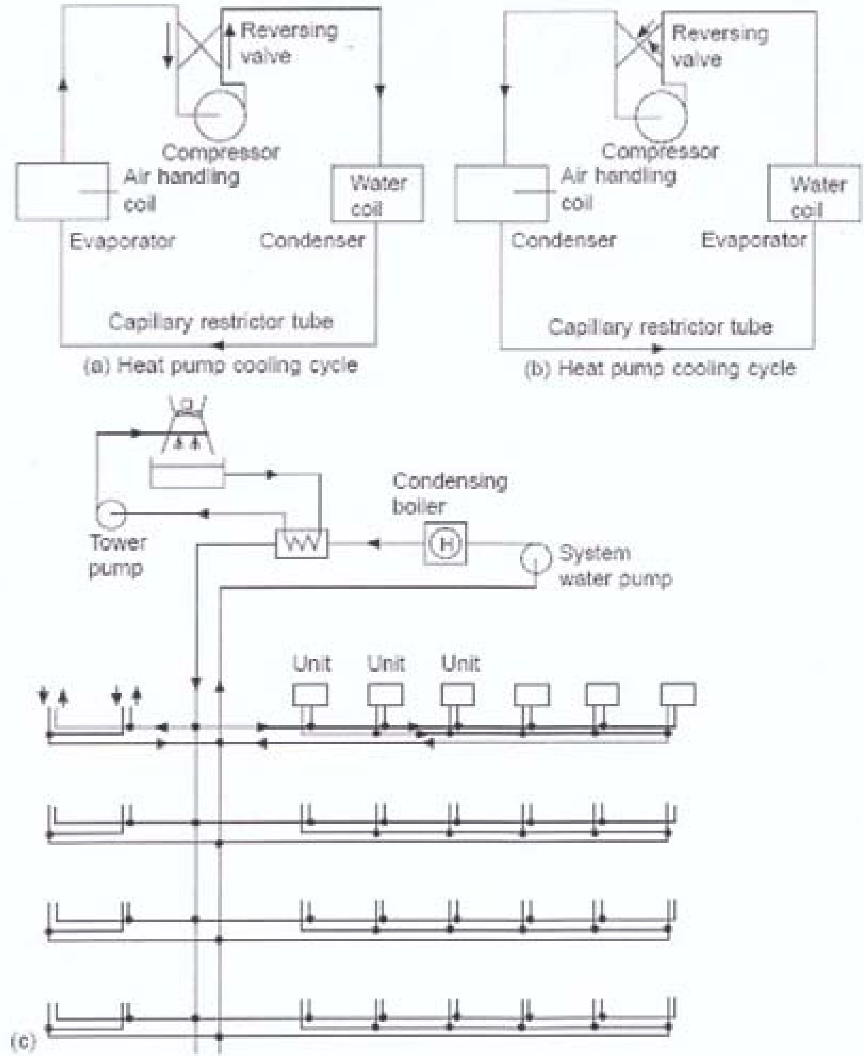

Reheat system




Dual duct system

6.2: All water systems : It is consist of the following systems :

a- Fan coil
b- Unite ventilator
c- Radiant panels



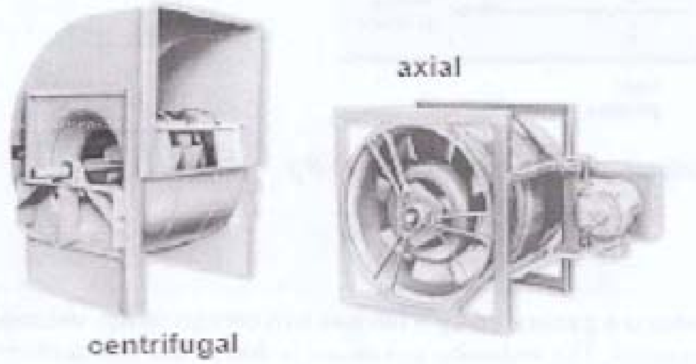

( a , b ) Heat pump system & ( c ) Heat recovery system

Lecture No. 11

Chapter seven: Fans and duct design:

7.1: Types of fans

## Air Conditioning Fans




Efficient distribution of conditioned air needed to heat, cool, and ventilate a building requires the service of a properly selected and applied fan.

The types of fans commonly used in HVAC applications include centrifugal and axial designs. In a **centrifugal fan** the airflow follows a radial path through the fan wheel. In an **axial fan** the airflow passes straight through the fan, parallel to the shaft.

## Fan Selection

- Forward curved (FC)
  - Lower airflow, lower static pressure, lower first cost
- Backward inclined (BI) or airfoil (AF)
  - Higher airflow, higher static pressure, higher efficiency
- Vaneaxial
  - Limited space
- Variable-pitch vaneaxial (VPVA)
  - Large systems, higher airflow

The selection of the type of fan to be used in a particular application is based on the system size and space availability.