Air Properties

Lecture One

1. Introduction:

Air conditioning, often abbreviated as A/C or AC, is the process of removing heat and controlling the humidity of air in an enclosed space to achieve a more comfortable interior environment by use of powered "air conditioners" or a variety of other methods, including passive cooling and ventilative cooling. Air conditioning is a member of a family of systems and techniques that provide heating, ventilation, and air conditioning (HVAC).

Air conditioners, which typically use vapor-compression refrigeration, range in size from small units used within vehicles or single rooms to massive units that can cool large buildings. Air source heat pumps, which can be used for heating as well as cooling, are becoming increasingly common in cooler climates.

1.2 Comfort conditioning

Human beings are born into a hostile environment, but the degree of hostility varies with the season of the year and with the geographical locality. This suggests that the arguments for air conditioning might be based solely on climatic considerations, but although these may be valid in tropical and subtropical areas, they are not for temperate climates with industrialized social structures and rising standards of living. Briefly, air conditioning is necessary for the following reasons. Heat gains from sunlight, electric lighting and business machines, in particular, may cause unpleasantly high temperatures in rooms, unless windows are opened. If windows are opened, then even moderate wind, speeds cause excessive draughts, becoming worse on the upper floors of tall buildings. Further, if windows are opened, noise and dirt enter and are objectionable, becoming worse on the lower floors of buildings, particularly in urban districts and industrial areas. In any case, the relief provided by natural airflow through open windows is only effective for a depth of about 6 meters inward from the glazing. It follows that the inner areas of deep buildings will not really benefit at all from opened windows. Coupled with the need for high intensity continuous electric lighting in these core areas, the lack of adequate ventilation means a good deal of discomfort for the occupants. Mechanical ventilation without refrigeration is only a partial solution. It is true that it provides a controlled and uniform means of air distribution, in place of the unsatisfactory results obtained with opened windows (the vagaries of wind and stack effect, again particularly with tall buildings, produce discontinuous natural ventilation), but tolerable internal temperatures will prevail only during winter months

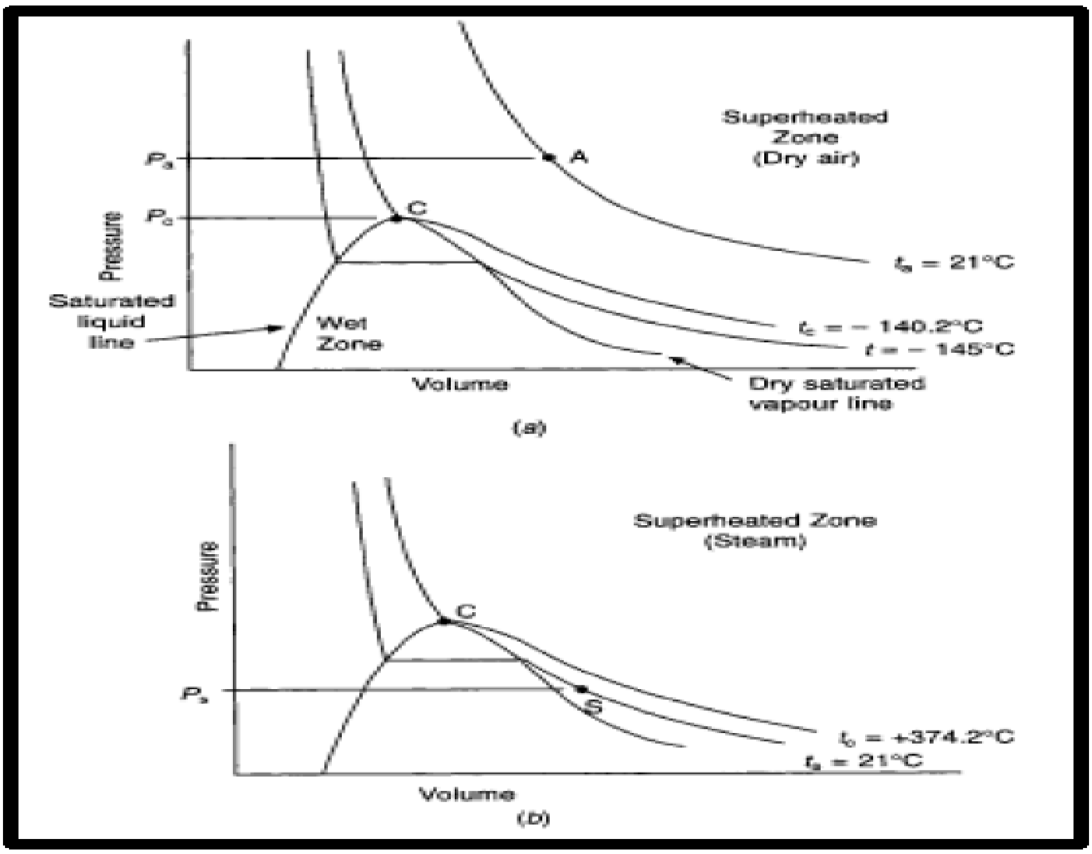
1.3 Industrial conditioning

An industrial air conditioning system will usually be a centralized cooling system that has a sophisticated ducting system that enables the cold air to be distributed. It is similar to the ducted system that can be used in residential cooling, but on a much bigger and more sophisticated level. The industrial air conditioner is a special tool that can be used in a variety of natural environments to reduce temperature. It is small and exquisite, has high-energy efficiency, does not need to be installed, and can be placed in a mobile central air conditioner at different addresses. Refrigeration compressors, exhaust fans, electric water heaters, air-conditioning evaporators, air-cooled finned coolers and other equipment are all available in the human body.

1.4 The composition of dry air

Dry air is a mixture of two main component gases together with traces of a number of other gases. It is reasonable to consider all these as one homogeneous substance but to deal separately with the water vapor present because the latter is condensable at everyday pressures and temperatures whereas the associated dry gases are not. One method of distinguishing between gases and vapors is to regard vapors as capable of liquefaction by the application of pressure alone but to consider gases as incapable of being liquefied unless their temperatures are reduced to below certain critical values. Each gas has its own unique critical temperature, and it so happens that the critical temperatures. In the second diagram, Figure (1.1), a similar case for steam is shown. Here, point S represents water vapor at the same temperature, 21°C as that considered for the dry air. It is evident that atmospheric dry air and steam, because they are intimately mixed, will have the same temperature. However, it can be seen that the steam is superheated, that it is far below its critical temperature, and that an increase of pressure alone is sufficient for its liquefaction.

Gas	Proportion%	Molecular mass
N_2	78.03	28.0
H_2	20.01	2.02
O_2	20.99	32
Ar	0.94	39.9
CO_2	0.03	44



Standard properties

- Density of air 1.293 kg/m^3 at 101325 Pa and 0^oC
- Density of water 1000 kg/m^3 at 4^oC & 998.23 kg/m^3 at 0^oC
- Barometric pressure 101325 Pa
- Specific force due to gravity 9.802 N/kg or m / sec^2
- Specific heat of air at constant pressure 1.005 kJ/kg.K & at constant volume 0.871 kJ/kg.K.
- Gas constant of air 0.287 kJ/kg.K
- Gas constant of water vapor 0.461 kJ/kg.K

The General Gas Law

•It is possible, as we saw from the 1st year of thermodynamics subject" to combine

•Boyle's and Charle's laws as one equation:

PV= mRT

(P) Pressure of gas Pa

(V) Volume of gas m^3

(m) Mass of gas kg

(R) Gas constant kJ/kg.K

(T) Absolute temperature K

•Molecular weight for dry air 28 and gas constant R=287 j/kg.k.

•Molecular weight for water vapor 18 and gas constant R=461 j/kg.k.

2 .Difference between dry, moist and saturated air are:

1 .Dry Air- :

The pure dry air is mixture of a number of gases such nitrogen, oxygen, carbon dioxide, hydrogen, argon, helium etc. The composition of dry air varies slightly at different geographic locations and from time to time. The approximate composition of dry air by volume is nitrogen, 79.08%; oxygen, 20.95%; argon, 0.93%; carbon dioxide, 0.03%; other gases (e.g., neon, sulfur dioxide), 0.01%.

2 .Moist Air- :

It is a mixture of dry air and water vapor. The amount of water vapor, present in the air depends upon the absolute pressure and temperature of mixture.

3 .Saturated Air- :

It is a mixture of dry air and water vapor, when the air has diffused the maximum amount of water vapor into it.

4 .Estimating properties of moist air

In order to perform air conditioning calculations, it is essential first to estimate various properties of air. It is difficult to estimate the exact property values of moist air as it is a mixture of several permanent gases and water vapor.

4.1 Dry Bulb Temperature (DBT).

It is the temperature of moist air as measured by a standard thermometer or other temperature measuring instruments. Saturation pressure is the saturated pressure of water vapour at the dry bulb temperature DBT. This is readily available in thermodynamic tables and charts.

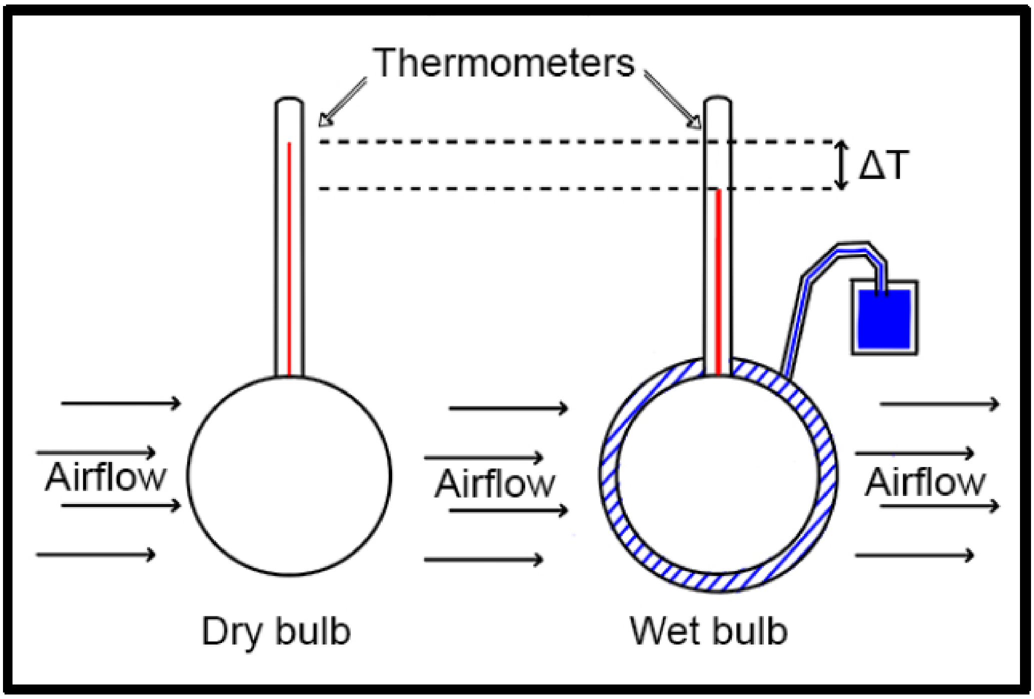
H.W.: Find saturation pressure at:

No.	Temperature (°C)	Pressure (Pa)
1	23	
2	35	
3	60	
4	100	

4.2 Wet Bulb Temperature (WBT):

In practice, it is not convenient to measure the WBT using an adiabatic saturator. Instead, a thermometer with a wetted wick is used to measure the wet bulb temperature as shown in figure (1-2):

1. **Saturation Vapour Pressure:** there are two requirements for the vapor of liquid water to occur: 1. Thermal energy must be supplied to the water. 2. the vapor pressure of the liquid must be greater than that of the steam in the environment



4.3 Air Pressure:

Applying this equation to calculate total pressure (Barometric Pressure P_B) of moist air:

$$P_B = P_a + P_v$$

- (p_B) Barometric pressure.
- (P_a) partial pressure of dry air.
- (p_v) partial pressure of water vapor.

The vapor pressure of steam in moist-air p_v calculate by using the question arises; how do we determine the vapor pressure for relative humidity less than 100%, an empirical equation exist which answer this question:

$$p_v = p_{sw} - p_B \times A \times (DBT - WBT)$$

- **(p_{sw})** Saturation vapor pressure at wet bulb temperature (WBT) **.**
- **(A)** constant $A = 6.66\text{x}10^{-4}\ {}^oC^{-1}$ when $WBT \geq 0\ {}^oC$

$A = 5.94\text{x}10^{-4}\ {}^oC^{-1}$ when $WBT < 0\ {}^oC$

Ex: Calculate vapor pressure in moisture air at DBT=20 ^oC and WBT= 15 ^0C and barometric pressure 950 mbar?

Sol:

From steam table at t_w= 15 ^0C then p_{sw}=1.707 kpa

$$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$$

$$p_v = 1.707 - 95 \times 6.66 \times 10_v = {}^{-4} \times (20 - 15) = 1.391 \text{ kpa}$$

H.W: Calculate vapour pressure in moisture air at DBT=25 ^{o}C and WBT= 20 ^{0}C and barometric pressure 950 mbar?

2. Relative humidity Ø:

The ratio of the partial pressure of the water vapour in the moist air, at a given temperature, to the partial pressure of the water vapour pressure in saturated air, at the same temperature.

$$\text{Ø} = \frac{P_v}{P_{sd}}$$

- **(P_{sd})** saturated water vapour pressure at dry bulb temperature kPa.

H.w: Prove that relative humidity for saturation air equal 1?

Ex: Calculate vapour pressure in moisture air at DBT=20 ^{o}C and WBT= 15 ^{0}C and barometric pressure 950 mbar?

Sol: From steam table at t_w= 15 ^{0}C then p_{sw}=1.707 kpa

$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$

$p_v = 1.707- 95 \times 6.66 \times 10_{v} = {}^{-4} \times (20 - 15) = 1.391$ kpa

from steam table at t_d=20 ^{o}C then p_{sd}=2.339 kpa

$$\text{Ø} = \frac{P_v}{P_{sd}}$$

$$\text{Ø} = \frac{1.391}{2.339}$$

= 0.5946 =59.46 %

3. Moisture-content, humidity ratio or specific humidity (W)

It is the mass of water vapour in kilograms, which is associated with one kilogram of dry air in air-vapour mixture. It is sometimes called humidity ratio or specific humidity.

$$\mathbf{W} = \frac{m_v}{m_a}$$

- **(m_v)** mass of water vapour kg
- **(m_a)** mass of dry air kg

H.w: drive the equation (Assuming both water vapor and dry air to be perfect gases and substuting the value of gas constants (R_v & R_a) in relative humidity equation to get

$$\mathbf{W}=0.622\,\frac{p_v}{p_a}$$

$$\mathbf{W}=0.622\,\frac{P_a}{pB-p_v}$$

Ex: Calculate moisture content for moisture air at DBT=20 ^oC and WBT= 15 ^oC and barometric pressure 950 mbar?

Sol: From steam table at tw= 15 ^oC then p_{sw}=1.707 kpa

$$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$$

$$p_v = 1.707 - 95 \times 6.66 \times 10^{-4} \times (20 - 15) = 1.391 \text{ kpa}$$

From steam table at t_d=20 ^oC then p_{sd}=2.339 kpa

Degree of saturation

The ratio of moisture content of the moist air at a given temperature to the moisture content of saturated air at the same temperature

$$\mu = \frac{W_s}{W}$$

Ex: Calculate degree of saturation moisture content for moisture air at DBT=20 ^oC and WBT= 15 ^oC and barometric pressure 950 mbar?

Sol: From steam table at t_w= 15 ^oC then p_{sw}=1.707 kpa

$$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$$

$$p_v = 1.707 - 95 \times 6.66 \times 10P^{-4} P \times (20 - 15) = 1.391 \text{ kpa}$$

$$\mathbf{W}=0.622 \frac{P_a}{pB - p_v}$$

$$\mathbf{W} = 0.622 \frac{1.391}{95 - 1.391} = 9.24 \times 10^{-4}\ kg_v/kga_v$$

For saturation air $t_a = t_w$= 20 ^oC

from steam table at t_d= 20 ^oC then p_{sd} = 2.339 kpa

$$\mathbf{W}_s=0.622\frac{p_{sd}}{pB - p_{sd}}$$

$$\mathbf{W}_s=0.622 \frac{2.339}{95 - 2.339}$$

$$=15.7\times10^{-3}\ kgv/kga$$

$$\mu = \frac{9.24\times10^{-4}}{15.7\times10^{-3}} = \mathbf{58.85}\ \%$$

4. Specific Volume

This is the volume in cubic meters of one kg of dry air together with the mass of water vapour associated with it.

$$P_aV_a=m_a\ R_aT_d \quad \text{for dry air}$$

$$P_VV_V=m_V\ R_V\ T_w \quad \text{moist air}$$

5. Moist Air Enthalpy (h)

The enthalpy of moist air is the sum of the enthalpy of dry air and the water vapor comprising the mixture:

$$\mathbf{h = 1.005 \times DBT + W \times (2501.3 - 1.86 \times DBT)}$$

Ex: Calculate moisture air enthalpy at DBT=20 ^{o}C and WBT= 15 ^{o}C and barometric pressure 950 mbar?

Sol: From steam table at t_w= 15 ^{o}C then p_{sw}=1.707 kpa

$$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$$

$$p_v = 1.707 - 95 \times 6.66 \times 10^{-4} \times (20 - 15) = 1.391 \text{ kpa}$$

from steam table at t_d=20 ^{o}C then p_{sd}=2.339 kpa

$$\mathbf{W} = 0.622 \frac{P_a}{pB - p_v}$$

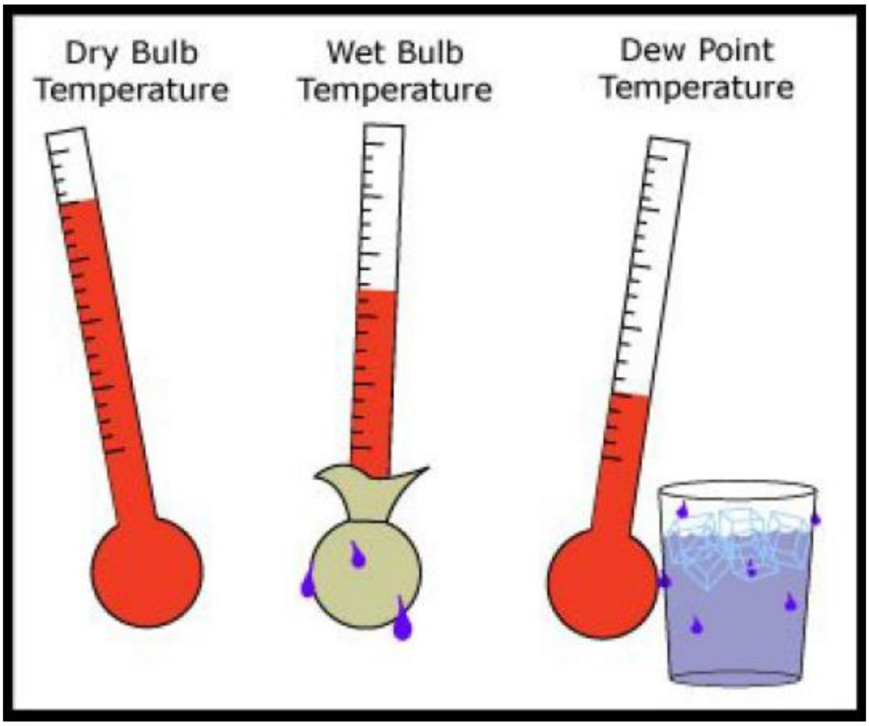
$$\mathbf{W} = 0.622 \frac{1.391}{95 - 1.391} = 9.24 \times 10^{-4}\ kg_v/kga_v$$

h= 1.005 ×DBT + W × (2501.3 – 1.86 × DBT)

$$h = 1.005 \times 20 + 9.24 \times 10^{-4} \times (2501.3 - 1.86 \times 20) = 41.764 \text{ kj/kg}$$

6. Dew point T_{dew}

It is the temperature at and below which moist air saturated. Since the air at dew point temperature contain maximum possible amount of water vapour. The moisture content of air remain constant as its cooled until the dew point reached, below dew point, condensation occurs and the moisture content decreases. The dew point temperature can be found from p_v by using the following expression for temperature above freezing.



Hint: An other method to find DPT by using value of p_v and take the value of saturaton temperature at that pressure from steam table, and this temperature represented value of DPT?

Ex: Calculate relative DPT for moist air at DBT=20 ^oC and WBT= 15 ^0C and barometric pressure 950 mbar?

Sol:

From steam table at t_w= 15 ^0C then p_{sw}=1.707 kpa

$$p_v = p_{sw} - p_B \times A \times (t_d - t_w)$$

$$p_v = 1.707 - 95 \times 6.66 \times 10^{-4} \times (20 - 15) = 1.391 \text{ kpa}$$

at p_v= 1.391 kpa then use steam table to find saturation temperature at this value of pressure, this temperature represent DPT?

From table at p_v= 1.391 kpa then T_{dp}= 12 ^oC

Sheet No. One

1. Air at 30oC DBT, 17 ^{o}C and 105 kPa enters a piece of equipment where it undergoes a process adiabatic saturation, the air leaving with a moisture content of 5 gw/kga higher than entering. Calculate (i) the moisture content of the air entering the equipment (ii) the dry bulb temperature and enthalpy of the air leaving the equipment. (6.15 gw/kga, 18 ^{o}C, 46.52kJ/kg)

2. Calculate the moisture content of air at 17 ^{o}C DBT and 40% relative humidity where the barometric pressure is 95 kPa. (5.18gw/kga)

3. Calculate from the first principles the enthalpy of air at 28 ^{o}C DBT and 1.926 kPa vapour pressure, at atmospheric pressure. (59.03 kJ/kg)

4. Calculate the dew point temperature and the enthalpy of air at 28 ^{o}C DBT, 21 ^{o}C WBT and 87.7 kPa barometric pressure. (18.11 ^{o}C, 66.7 kJ/kg)

5. Calculate the relative humidity and percentage saturation of air at 101.325 kPa, 21 ^{o}C DBT, 14.5 ^{o}C WBT. (48.7%, 48.2%)

6. Calculate the specific volume of an vapour mixture of dry air at 30 ^{o}C DBT, moisture content of 0.015kgw/kga and barometric pressure of 90kPa . . . (0.99m^{3}/kg)

7. a sample of air at 30 ^{o}C DBT, 25 ^{o}C WBT and barometric pressure of 101 kPa, calculate the enthalpy of air if this air is adiabatically saturated, the humidity ratio if this air is adiabatically saturated, the humidity ratio of the sample, the partial pressure of water vapour in the sample, the relative humidity .

(0.0201kgw/kga, 76.2kJ/kg, 0.018kgw/kga, 2480Pa, 67%)

8. Find all properties for saturation air, at 35 ^{o}C and barometric pressure 740 mmHg?

9. One particular day air was found DBT= 35 ^{o}C and WBT = 25 ^{o}C and barometric pressure 780 mmHg. Calculate all moist air properties?