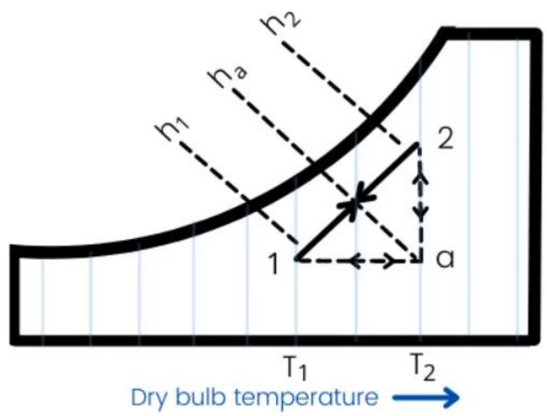
Sensible heat ratio (S.H.R)

$$S.H.R=\frac{sensible\ heat}{sensible\ heat+latient\ heat}$$



Process 1-2 indicates the total heating or cooling process.

While process 1-a indicates the part of heat used for sensible heating or cooling and process a-2 indicates the part of heat used for latent heating or cooling.

Therefore, the sensible heat ratio (SHR) is given by,

$$SHR=\frac{sensible\ heat}{sensible\ heat+latient\ heat}=\frac{h_a-h_1}{(h_a-h_1)+(h_2-h_a)}=\frac{h_a-h_1}{(h_2-h_1)}=\frac{sensible\ heat}{Total\ heat}$$

There are actually two SHR scales on the chart, the protractor shaped on the left side and a vertical axis on the right side.

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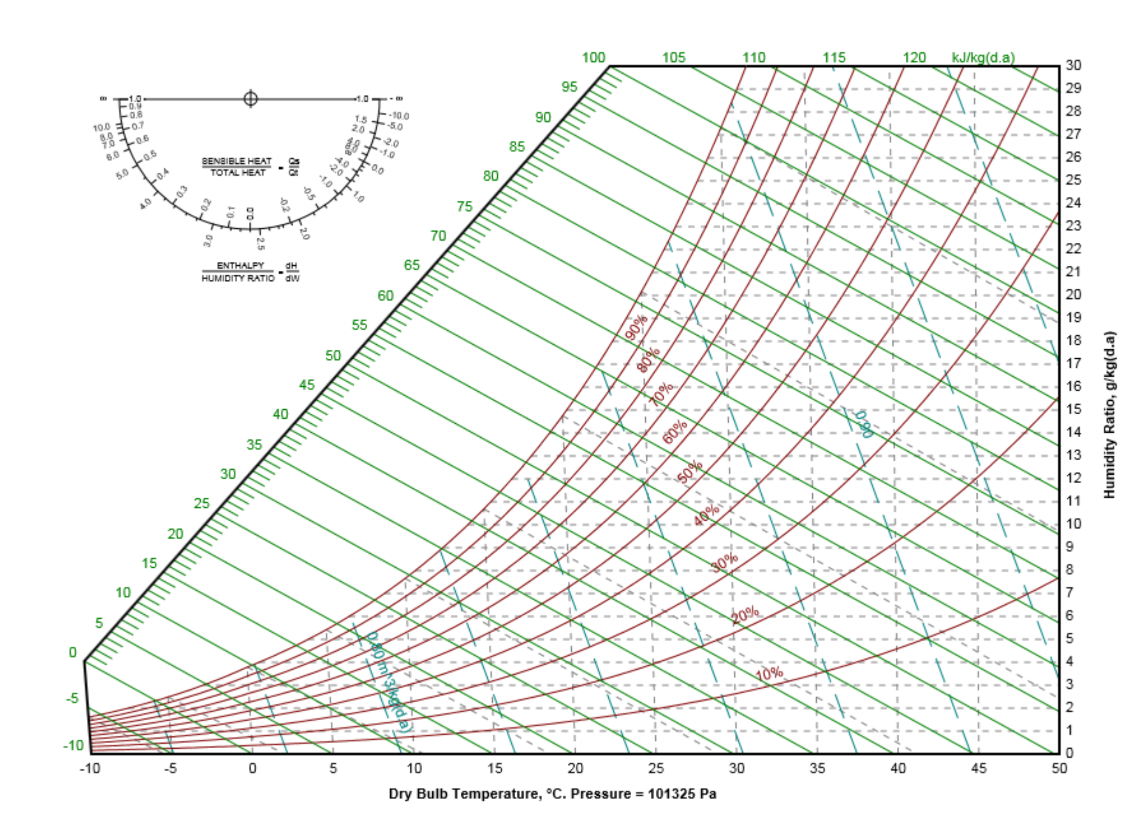
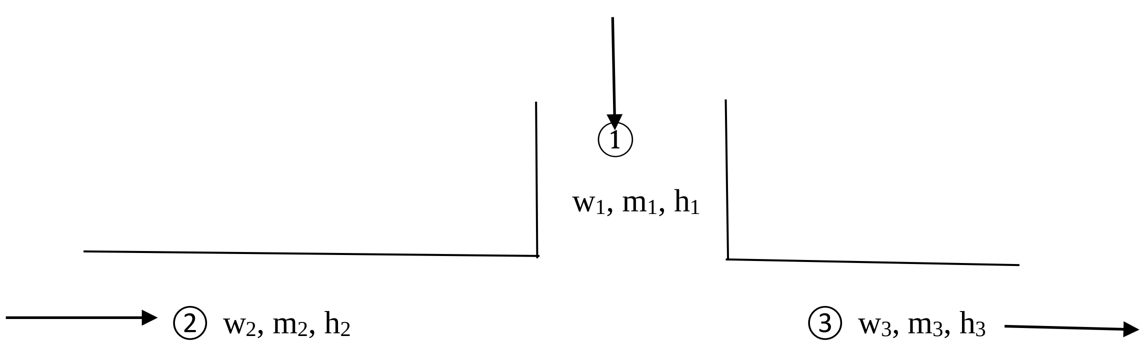


2-Air mixing:

When two air streams are mixed without external heating or cooling, the process is considered adiabatic, and transfer of heat & moisture is internally conserved.



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Mass conservation:

$m_1+m_2=m_3$ ………… (a)

For water vapour mass:

$m_1w_1+m_2w_2=m_3w_3$ ………… (b)

Enthalpy balance:

$m_1h_1+m_2h_2=m_3h_3$ …………... ©

subtract (m_1w_3) from both sides of equation (b):

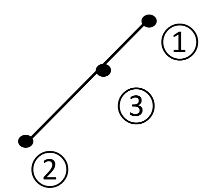
$m_1w_1- m_1w_3+m_2w_2=w_3(m_3-m_1)=w_3m_2$

$m_1(w_1-w_3)=m_2(w_3-w_2)$

$$\frac{w_1-w_3}{w_3-w_2}=\frac{m_2}{m_1}$$

Similarly for enthalpy:

$$\frac{h_1-h_3}{h_3-h_2}=\frac{m_2}{m_1}$$



From the above we conclude that the three states point must lie on a straight line in a coordinate system of mass and energy.

Note: length 2-3 is proportional to mass at state 1.

length 1-3 is proportional to mass at state 2.

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e.g: Moist air at 60°C d.b. & 32°C w.b. & standard atmospheric pressure mixed adiabatically with moist air at 5°C d.b. & 1°C w.b. & standard atmospheric pressure. If the masses of dry air are 3kgs & 2kgs respectively, calculate the enthalpy, specific humidity & dry bulb temperature of the mixture.

Sol:

$W=0.622*\frac{P}{P_B-P}$

$P_1=P_{sw}-P_B.A.(t_d-t_w)$

$=4.7596 - 101.325*6.66*10^{-4}*(60-32) = 2.8702$ kPa.

$W_1= 0.622*\frac{2.8702}{101.325-2.8702} = 0.01813$ kgw/kg d.a.

$h_1 = (1.007\ t - 0.026) + w\ (2501+1.84\ t)$

$=(1.007*60 - 0.026) + (2501+1.84*60) = 107.738$kJ/kg

$P_2 = P_{sw}-P_B.A.(t_d-t_w)$

$= 0.6571 - 101.325*6.66*10^{-4}*(5-1) = 0.38717$kPa

$w_2=0.622*\frac{0.38717}{101.325-0.38717} = 0.002385$ kg/kg dry air.

$h_2= (1.007*5-0.026) + 0.002385(2501+1.84*5) = 10.995$ kJ/kg.

from mass balance for moisture.

$W_3=\frac{m_1w_1+m_2w_2}{m_1+m_2}$ from equation (b) as $m_3=m_1+m_2$

$=\frac{3*0.01813+2*0.002385}{3+2}=0.011832$ kgw/kg d.a.

Likewise, from equation ©.

$h_3 = \frac{m_1 h_1 + m_2 h_2}{m_1 + m_2} = \frac{3*107.738+2*10.995}{3+2} = 69.0408$ kJ/kg d.a.

to find the dry bulb temperature.

$h_3 = (1.007\ t_3 - 0.026) + w_3\ (2501+1.84\ t_3)$

$69.0408 = (1.007\ t_3 - 0.026) + 0.011832\ (2501+1.84\ t_3)$

$69.0408 + 0.026 - (0.011832*2501) = t\ (1.007+0.011832*1.84)$

$t_3 = 38.37^oC.$

temperature may be obtained from a temperature balance for normal conditions thus.

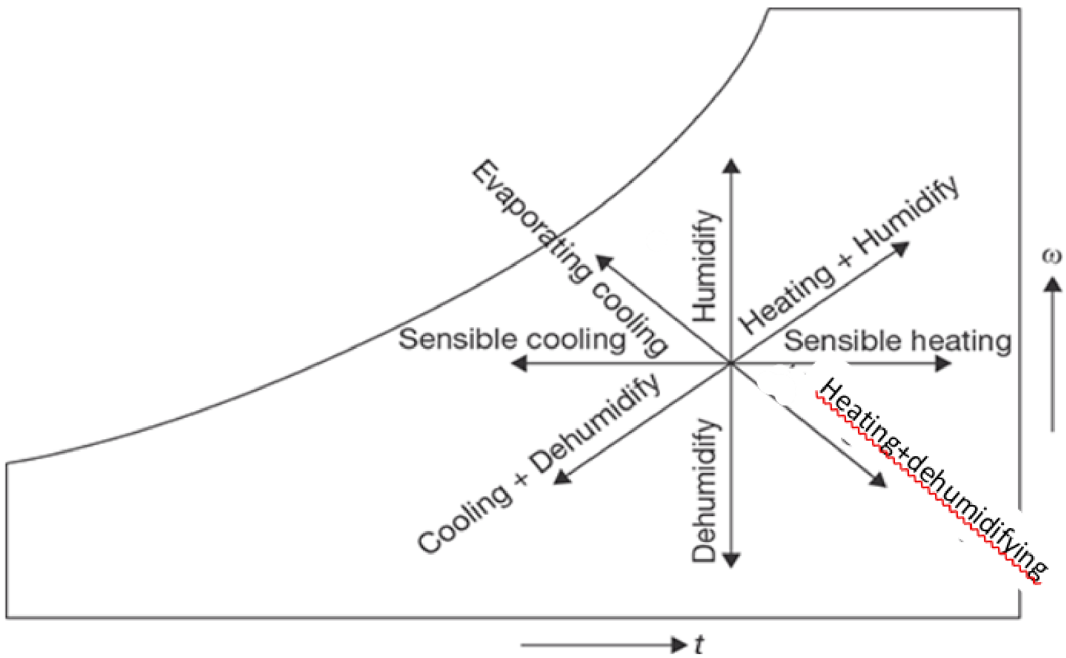
$m_3 t_3 = m_1 t_1 + m_2 t_2$

$t_3 = \frac{m_1 t_1 + m_2 t_2}{m_3} = \frac{3*60+2*5}{5} = 38^oC$

Note: this approach is basically wrong since it assumes air is dry. However, it gives approximate results with tolerable error.

To calculate t_{wb} [$P = P_{sw} - P_B.A.(t_d - t_w)$]

3- Processes on the psychrometric chart.



Psychrometric Processes

There are five basic processes on the psychrometric chart:

1- Constant sensible heat process (humidification & dehumidification), indicated by constant dry bulb temperature.
2- Constant latent heat process (sensible heating and cooling) indicated by constant moisture content & constant dew point temperature.
3- Constant enthalpy process (adiabatic saturation) indicated by constant wet bulb temperature.
4- Constant relative humidity process (all other parameters change)-[very unusual].[relative humidity cannot be kept constant, but it can begin with a certain value and finish with the same value).
5- Combination of any of the above 4-processes not falling on any constant process line, (cooling & dehumidification and heating & humidification)

Note:

1. Dry bulb temperature lines are lines of constant sensible heat.
2. Wet bulb temperature lines are lines of constant enthalpy [(not exact), only if neglecting the corrective term (D)].
3. Dew point lines are lines of constant latent heat.

4. Sensible heating & cooling.

   Sensible heating by a heating coil which may either hot water, steam, electric, ……etc.

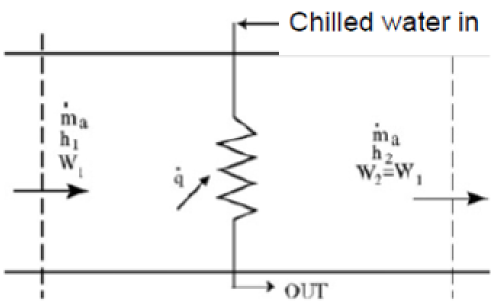
   Sensible cooling, by a chilled coil whose temperature must be above the dew point temperature of the air (To prevent condensation and kept the moisture content of air constant).

The psychrometric chart can be used in analyzing many processes involving moist atmospheric air.

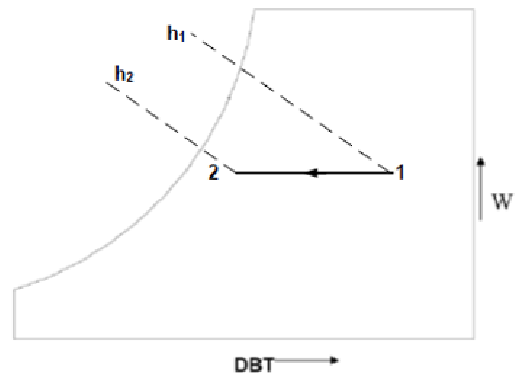
Sensible cooling:

During this process, the moisture content of air remains constant, but its temperature decreases as it flows over a cooling coil. For moisture content to remain constant the surface of the cooling coil should be dry, and its surface temperature should be greater than the dew point temperature of air. If the cooling coil is 100% effective, then the exit temperature of air will be equal to the coil temperature (T_c). However, in practice, the exit air temperature will be higher than the cooling coil temperature. Figure below shows the sensible cooling process 1-2 on a psychrometric chart. The heat transfer rate during this process is given by:

$$Q_s = \dot{m}_a (h_1 - h_2)$$



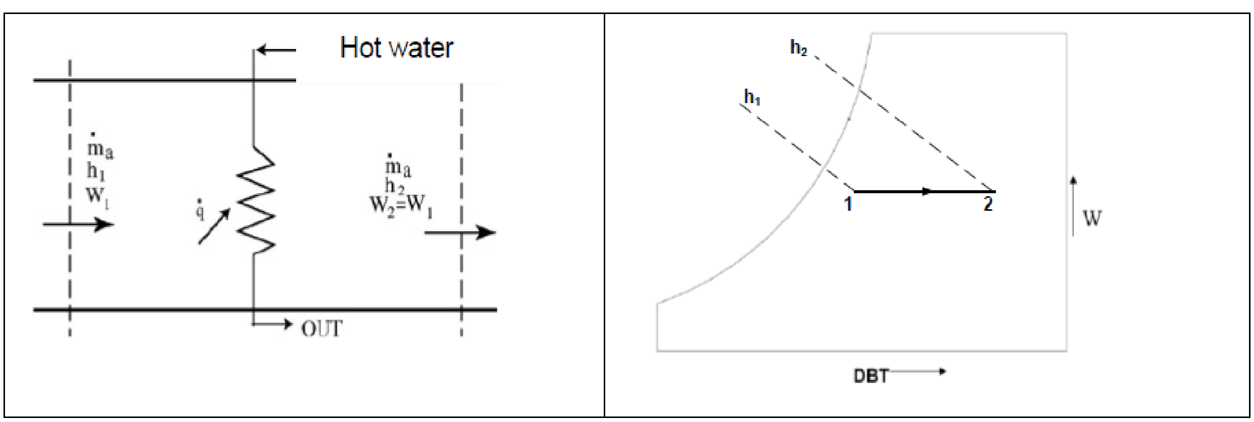
W_1=w2



Sensible heating

During this process, the moisture content of air remains constant, and its temperature increases as it flows over a heating coil, as shown in figure below. The heat transfer rate during this process is:

$$Q_s = \dot{m}_a (h_2 - h_1)$$



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Variation in properties as follows:

	Sensible heating	Sensible cooling
Dry bulb temp.	Increase	Decrease
Specific volume (υ)	increase	Decrease
Wet bulb temp.	Increase	Decrease
Saturation ratio (μ)	Decrease	Increase
Enthalpy.	Increase	Decrease
Humid volume.	Increase	Decrease
Relative humidity (ϕ).	Decreases	Increases
Specific humidity (W).	Constant	Constant
Dew point temp.	Constant	Constant
Vapour pressure.	Constant	Constant

Example1:

Calculate the load on a battery when heats $1.5 m^3/s$ of moist air, initially at a state of 21°C DBT, 15° C WBT and 101.325kPa barometric pressure, by 20° C. If low pressure water at 85° C flow and 75° C return is used to achieve this process. Calculate the mass flow rate necessary of water.

$Q_s = \dot{m}_a(h_2-h_1)$

h1=41.88kJ/kg, h2= 62.31kJ/kg & $\upsilon_1 = 0.843\ m^3/kg$ from the chart. ($W_1=W_2$).

$\dot{m} = \frac{1.5}{0.843} = 1.7793$ kg/ s

$Q_s = \dot{m}_a(h_2-h_1)$

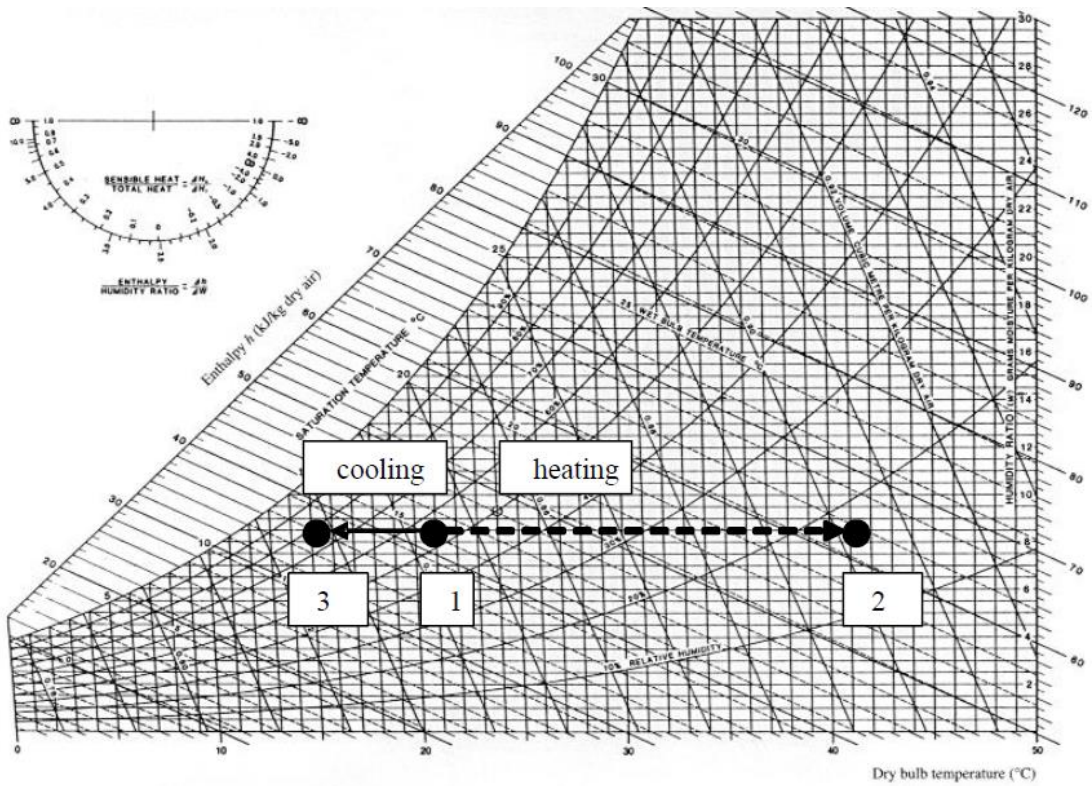
Q1-2=1.7793(62.31-41.88)=36.35 kW

Heat gain by moist air= heat lost from the water

$Q = m_w.c_w.(tw_{out}-tw_{in})$

$36.35 = m_w * 4.186(85-75)$.

m_w=0.8683kgw/s.



Example2:

If the moist air mentioned in example 1 is cooled sensibly by 5° C using cooler coil, what is the flow rate of chilled water necessary to affect this cooling if the flow return temperature of 10° C and 15° C satisfactory.

$Q1\text{-}2 = m_a * (h1 - h3)$

$h3 = 36.77$ kJ/kg

$Q1\text{-}2 = 1.7793(41.88 - 36.77) = 9.092$ kW

Heat lost from air = heat gain by water

$9.092 = m_w * 4.186(15 - 10)$

$m_w = 0.4344$ kgw/s.