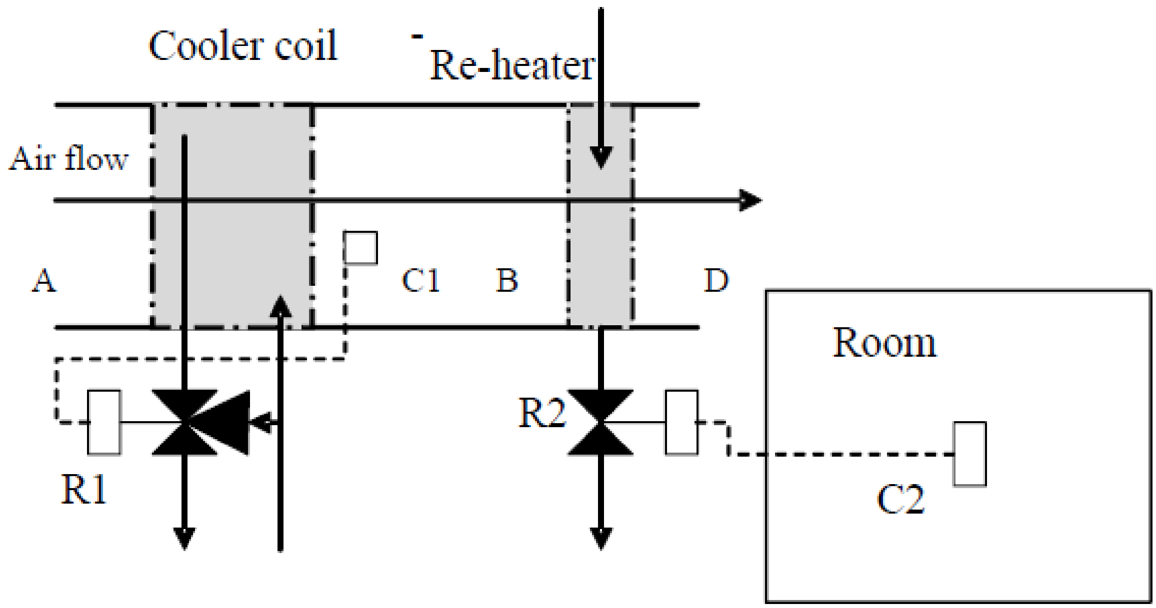
Combined psychrometric Process

Cooling and Dehumidification with re-heat.



Moist air at state **A** passes over finned tube of a cooler coil through which chilled water is flowing. The amount of dehumidification carried out is controlled by a dew point thermostat, **C1**, positioned after the coil. This thermostat regulates the amount of chilled water flowing through the coil by means of three-way mixing valve **R1**. Air leaves the coil at state **B**, with moisture content suitable for the proper removal of latent heat gains occurring in the room being conditioned. The moisture content has been reduced from $\mathbf{W_A}$ to $\mathbf{W_B}$ and cooler coil has a mean surface temperature of $\mathbf{T_C}$.

If the sensible heat gains then required a temperature of $\mathbf{T_D}$, greater than $\mathbf{T_B}$, the air is passed over the tubes of a heater, through which a low pressure hot water may be flowing. The flow rate of water is regulated by means of two port modeling valve **R2** controlled from thermostat **C2** positioned to this room at state **D**, with the correct temperature and moisture content. Reheat is usually only permitted to waste cooling capacity under partial load condition, that is, the design should be such that state B can adequately deal both maximum sensible and maximum latent loads.

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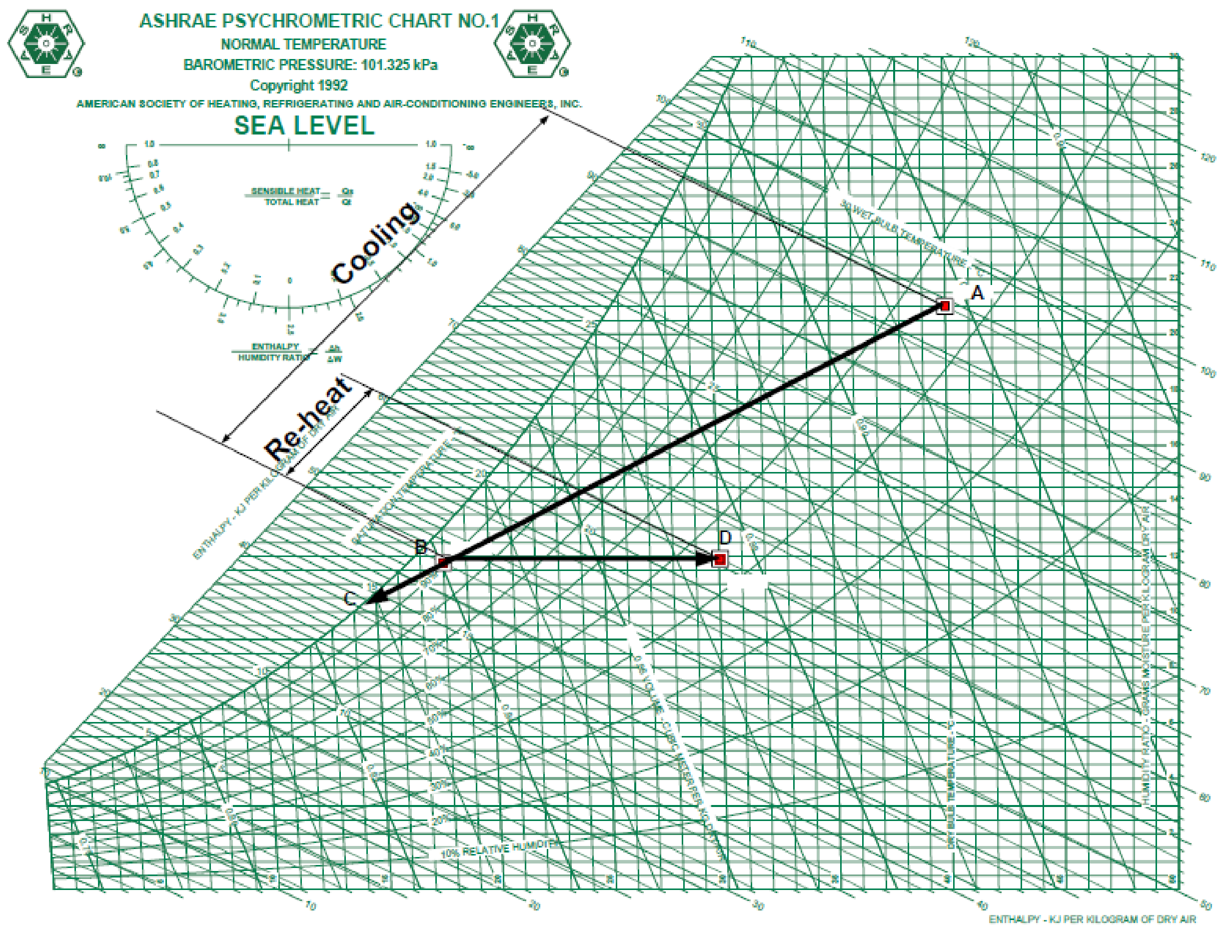

Example

Moist air at 28°C DBT and 21 °C WBT and 101.325 kPa pressure flows over a cooler coil and leaves it at a state 10°C DBT and 7.046 g/kga moisture content.

a- if the air required to offset a sensible heat gain of 2.35 kW and latent heat gain of 0.31 kW in a space being air-conditioned, calculate the mass of dry air which must be supplied to the room in order to maintain a dry bulb temperature of 21°C therein.

b- What will be the relative humidity.

c- If the sensible heat gain diminishes by 1.75 kW but the latent heat remains unchanged, at what temperature and moisture content must be supplied to the room.

$Q_s = m_a\, c_p\, (T_r - T_c)$

$2.35 = m_a.1.005(21\text{-}10)$

$ma = 0.21kg/sec$

$Q_l = m_w.hfg$

$0.31 = mw.(2454)$

$m_w = 0.0001262kgw/sec$

the moisture content with 0.211kga/s is

$W = \frac{0.1262}{0.211} = 0.599\ gw/\ kga$

then the moisture content in the room is

$W_{room} = 7.046 + 0.599 = 7.645$ gw/kga

from the psychrometric the relative humidity is 51%.

c) $Q_S = 2.35\text{-}1.75 = 0.6$kW

$Q_s = m_a\, c_p\, (T_r - T_c)$

$0.6 = 0.21 \times 1.005\ (21 - T_C)$

$T_c = 18.157^o\ C$

$W = 7.645\ g_w\ /kg_{d.a}$. The same value as ($Q_l$) remains unchanged.

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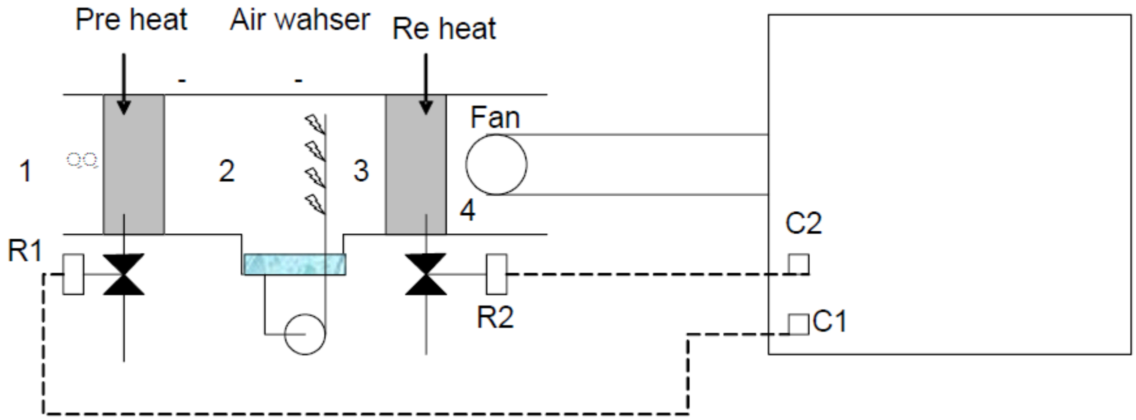
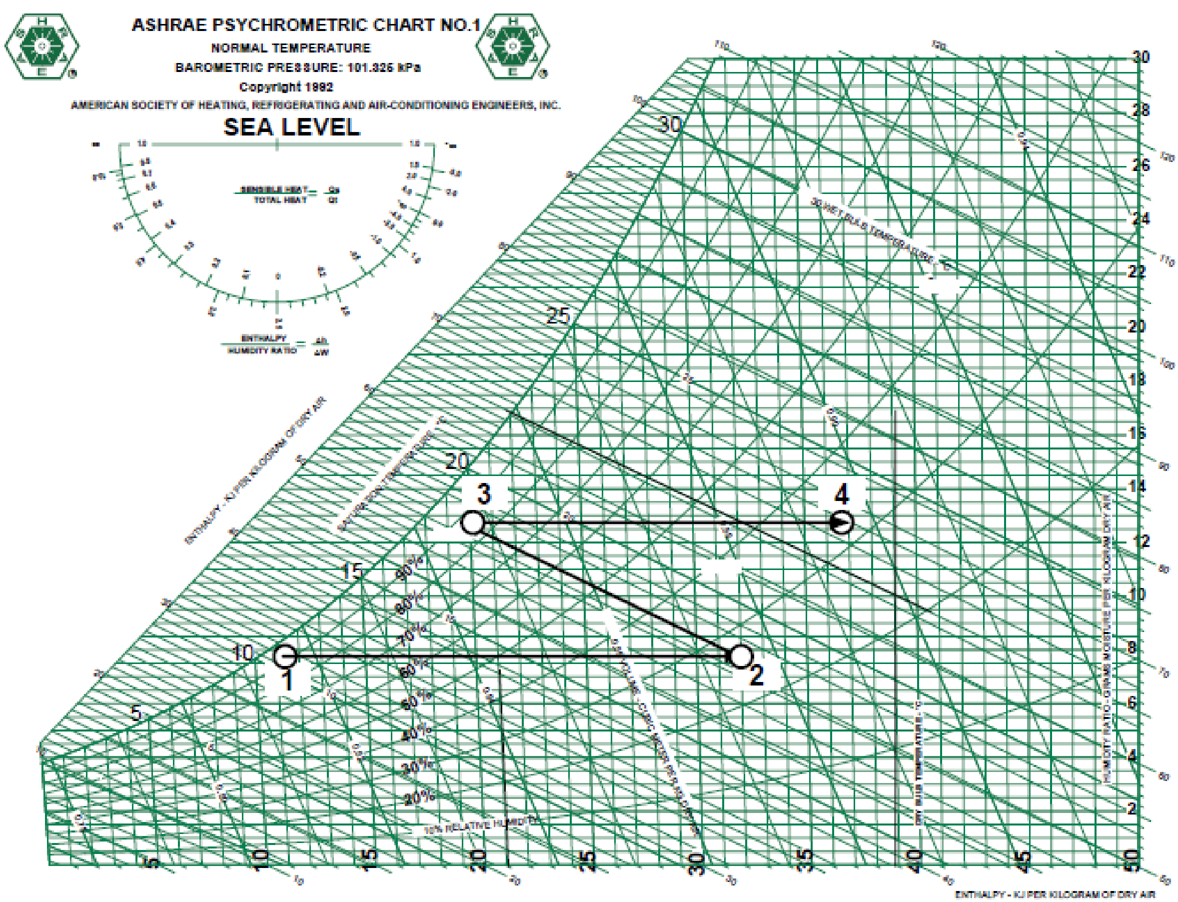
Pre-heating and humidification with re-heat





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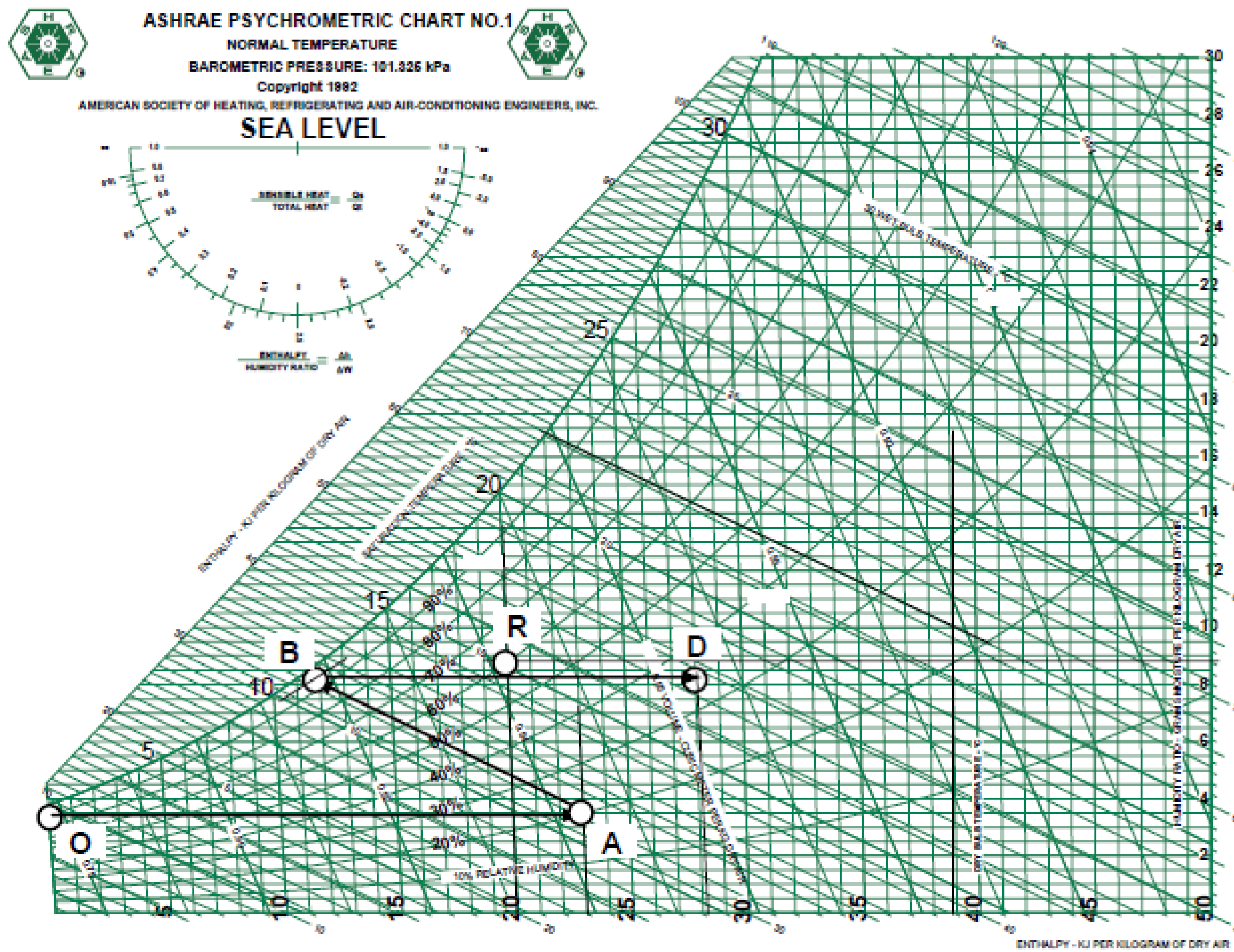
Air-conditioning plants which handle fresh air only are faced in winter with the task of increasing both the moisture content and the temperature of they supply to the conditioned space. Humidification is needed because the outside air in winter may have a very low moisture content, and if this air were to be introduced directly to the room there would be a low moisture content there as well, and when the air is heated to higher temperature its relative humidity may become very low. Therefore the room condition will be far from human comfort. A popular and effective approach is to pre-heat the air(1-2), pass it through air washer(2-3), where it undergoes adiabatic saturation, and then to reheat it to the temperature at which it must be supplied to the room. The figure above shows a typical plant.

Opening the valve R1 in the return pipeline from the pre-heater increases the heating output of the battery. Similarly, opining the control valve R2, associated with the re-heater, allows air at a higher temperature to be delivered to the room being conditioned. C1 and C2 are room humidistat and room thermostat, respectively.

Example:

Air is pre-heat from (0^oC) DBT and 86% RH to 23^oC DBT. It is then passed through air washer having humidifying efficiency of 85% and using re-circulated spray water. Calculate the following:

1. the relative humidity of the air leaving the washer.
2. the cold-water makeup to the washer in lit/s given that 2.5m^3/s leaves the air washer.
3. the duty of the pre-heater in kW.
4. the temperature of the air supplied to the conditioned space if the sensible heat loss from it are 24kW and 20^oC DBT is maintained there.
5. the duty of the re-heater in kW.
6. the relative humidity maintained in the room if the latent heat gains is 5 kW.



The moisture content of point O is 0.38 kgw/kga, and the WBT of point A is 11.5^{o}C.

$E = \frac{T_A - T_B}{T_A - T_C}$

$T_B = 23 - 0.85(23 - 10) = 12^oC.$

1. W_B=0.0082 from psychrometric chart, $\phi = 94\%$.

   cold water makeup= $\rho_a . V_a . (W_B - W_A)$

2. $m_w = 1.284 \times 2.5 \times (0.0082 - 0.0038) = 0.0141 kgw/s.$

load of pre-heater= $\rho_a . V_a . (h_A - h_O)$

3. $Q = 1.284 \times 2.5 \times (32.18 - 8.11) = 77.264\ kW.$

   $Q_s = m_a\, c_p (T_D - T_R)$

4. $T_D = \frac{24}{(1.22 \times 2.5 \times 1.005)} + 20 = 27.8 \approx 28^O C.$

5. $Q_{re\text{-}heater} = m_a . cp\ (T_D - T_B) = 1.22 \times 2.5 \times 1.005 (28 - 12) = 49.04\ kW$

moisture liberated in the room can be found as follows:

$Q_l = m_a (W_R - W_D) . h_{fg}$ $\quad$ $W_D = W_B = .0082\ kgw/kga.$

$W_R = \frac{5}{(1.22 \times 2.5) \times 2454} + 0.0082 = 0.008868\ kgw/kga$

6. Therefore, room condition can be found from psychrometric chart using 20°C DBT & 0.008868 *kgw/ kga* moisture content: then the relative humidity is about 61%.

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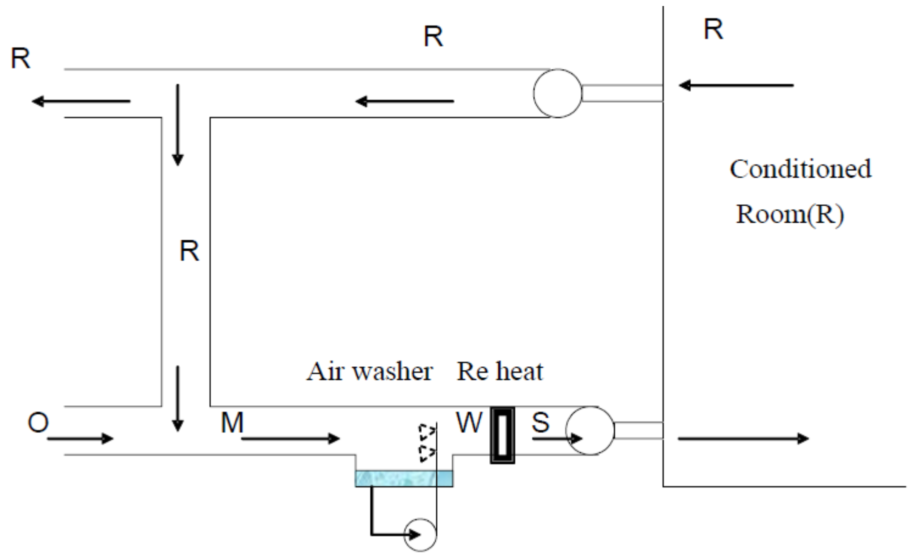
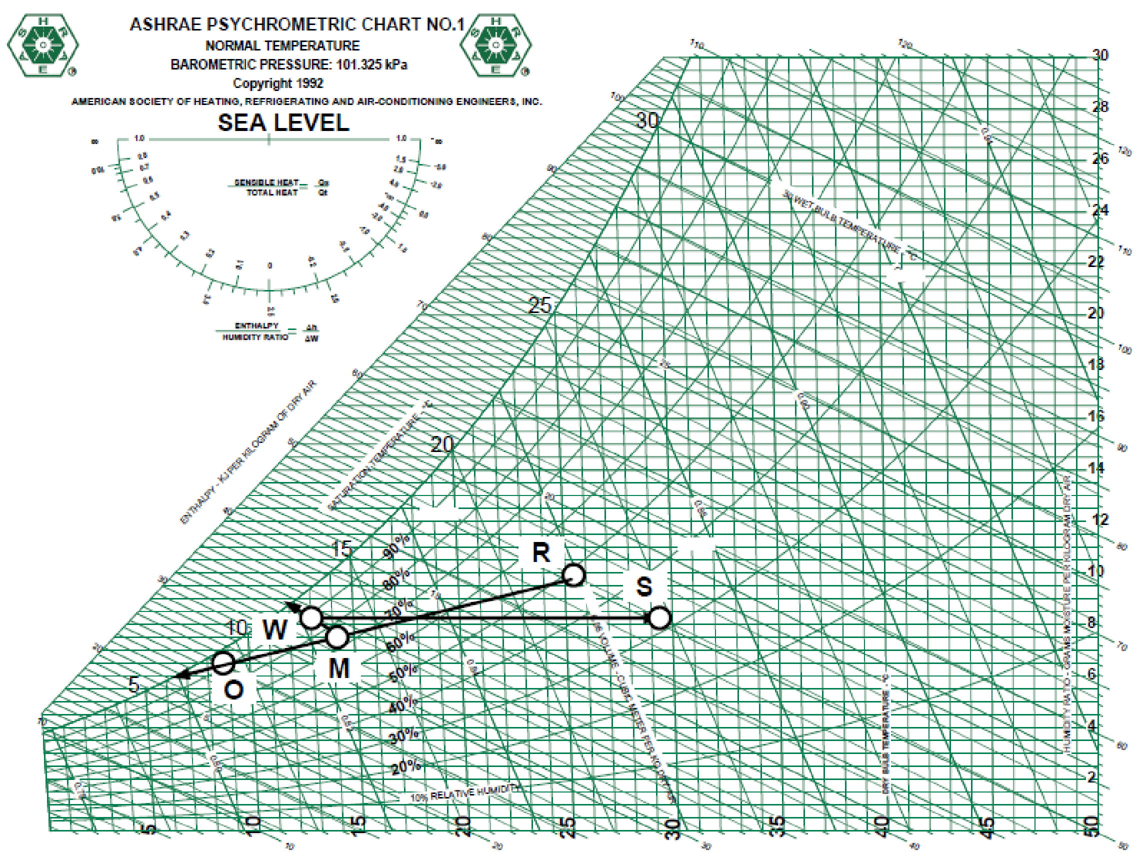
Mixing and Adiabatic Saturation with Re-heat





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The figure above shows a very common type of plant, air at state ***R*** is extracted from the conditioned room and partly recirculated, the reminder being discharged to the atmosphere.

The portion of the extracted air returned to the air conditioned plant mixes with out side air at state ***O***, and forms a mixture at state ***M***. The mixed air is the passed through an air-washer and adiabatic saturation occur, the state of air change from ***M*** to ***W*** at constant WBT, the extension of line ***MW*** cut the saturation curve at ***C*** (the apparatus dew point), the humidified air is then re-heated by a re-heater battery and leave at supply condition ***S***.

Cooling Coil Contact Factor

Some of the air going through a cooling coil does not come into contact with the tubes or fins of the cooling coil and is therefore not cooled to the ADP temperature. A mixing process therefore takes place as two air streams mix downstream of the cooling coil as shown below.

One air stream is cooled down to the ADP and the other air stream by-passes the coil surfaces to give an off-coil air temperature (mixed air stream) a little higher than the ADP. This may be looked upon as an inefficiency of the coil and is usually given as the cooling coil contact factor. The process is shown on the psychrometric chart below.

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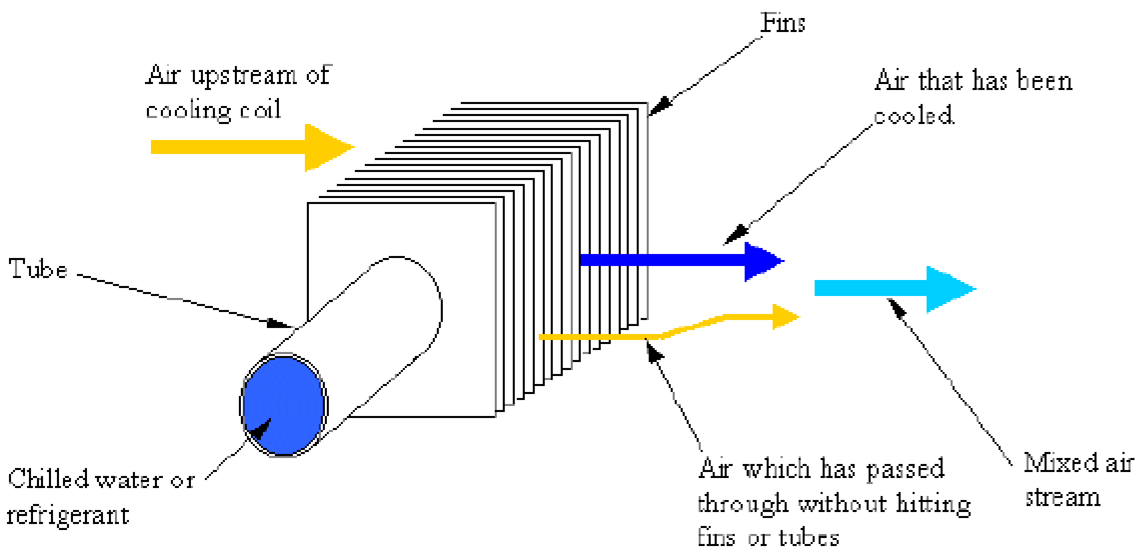
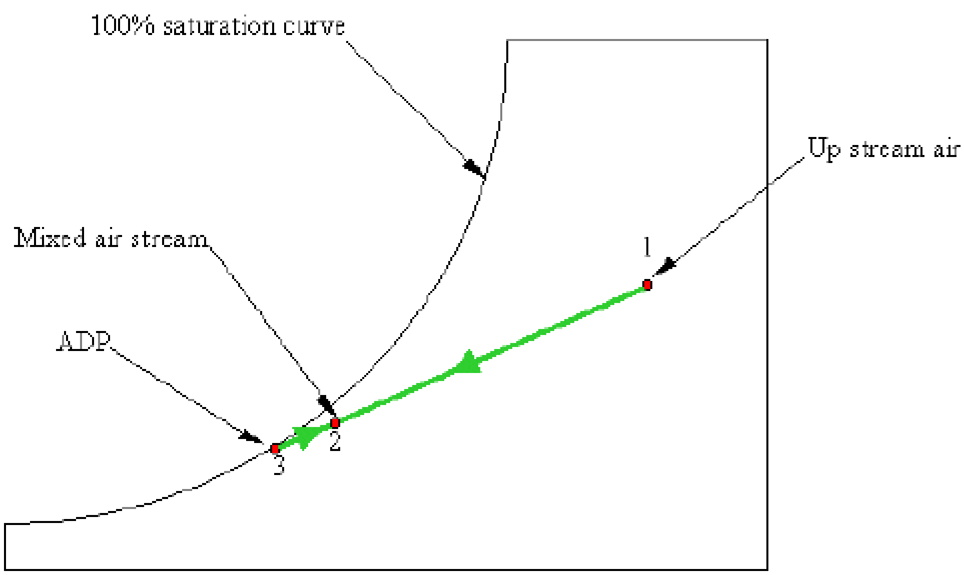


A SECTION OF COOLING COIL SHOWING AIR STREAMS



PSYCHROMETRIC CHART SHOWING COOLING COIL CONTACT FACTOR

$\beta = \frac{Line 1-2}{Line\ 1-3}$

While the by-pass factor is:

B.F $= \frac{Line\ 2-3}{Line\ 1-3}$

The contact factor can be calculated as:

$\beta = 1 - BF$

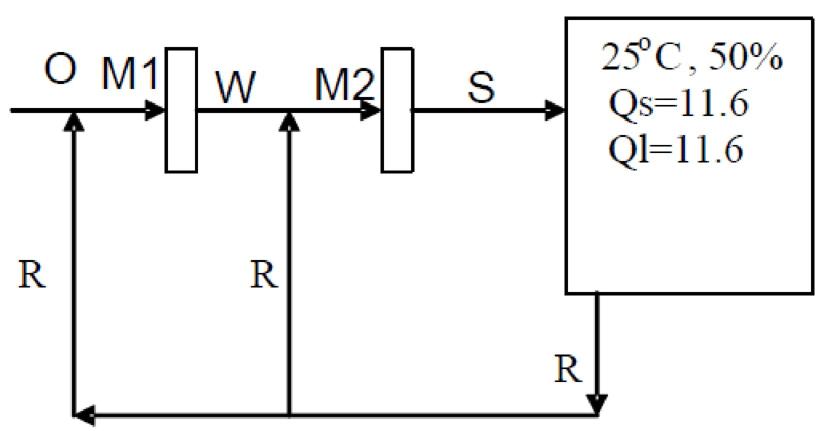
$\beta = \frac{DBT_m - DBT_s}{DBT_m - ADP} = \frac{W_m - W_s}{W_m - W_{ADP}} = \frac{h_m - h_s}{h_m - hg_{ADP}}$

While the by-pass factor can be calculated as:

B.F $= \frac{DBT_s - ADP}{DBT_m - ADP} = \frac{W_s - W_{ADP}}{W_m - W_{ADP}} = \frac{h_s - h_{ADP}}{h_m - hg_{ADP}}$

Example:

The following data apply to an A/C unit. Room sensible heat and latent heat are 11.6kW and 11.6 kW respectively, inside condition is 25°C DBT, 50% RH. Outside design condition is 35°C DBT and 27.8°C, return air from the room is mixed with outside air in the ratio of 4:1 before entering the cooler coil. Return air from the room is mixed with the air leaving the coil in the ratio of 1:4. cooling coil bypass factor 0.1, the air may reheated if necessary before supply to the room. Coil temperature is 10 °C. find a-supply air condition b- refrigeration load due to reheat c- total refrigeration load capacity d- the quantity of fresh air supplied.



$T_{M1}=\frac{4\times T_R+1\times T_o}{5} = \frac{4\times 25+1\times 35}{5} = 27^oC.$

$B = \frac{T_C - T_W}{T_C - T_{M1}}$

$0.1=\frac{10-T_W}{10-27} \rightarrow\rightarrow T_W = 11.7^oC.$

$T_{M2}=\frac{4\times T_W+1\times T_R}{5} = \frac{4\times 11.7+1\times 25}{5} = 14.36^oC.$

$SHR= \frac{Qs}{Qs+Ql} = \frac{Qs}{Qt} = \frac{11.6}{11.6+11.6} = 0.5$

Then the supply condition (S) is Ts=21^{o}C and 54% RH.

$Qs=\dot{m}.c_p.(T_R - T_S).$

$11.6 = \dot{m}.1.005.(25\text{-}21)$

$\dot{m}= 2.885 kg/s.$

$Q_{reheater} = \dot{m}.c_p.(T_S - T_{M2}).$

$Qreheater = 2.885\times 1.005\times (21-14.36) = 19.2 kW$

$\dot{m}_W=\frac{4}{5}\,\dot{m}_S = 0.8\times 2.885 = 2.304 \ kg/s.$

$Q_{cooler} = \dot{m}_W \ . \ (h_{M1} - h_{W1}) = 2.304\ (58.2 - 32). = 60.5 \ kW.$

$\dot{m}_O=\frac{1}{5}\,\dot{m} = 0.2\times 2.304 = 0.4615 \ kg/s.$

Draw the sensible heat line with 0.5 slope, and translate the line to the psychrometric chart beginning from room condition R and. The room condition should on the line of RSH. There for we should reheated the air at M2. since the condition is heating, there for we should draw a horizontal line from M2 till this line is cut the line of RSH, the intersection is at S which is represent the supply condition to the room.

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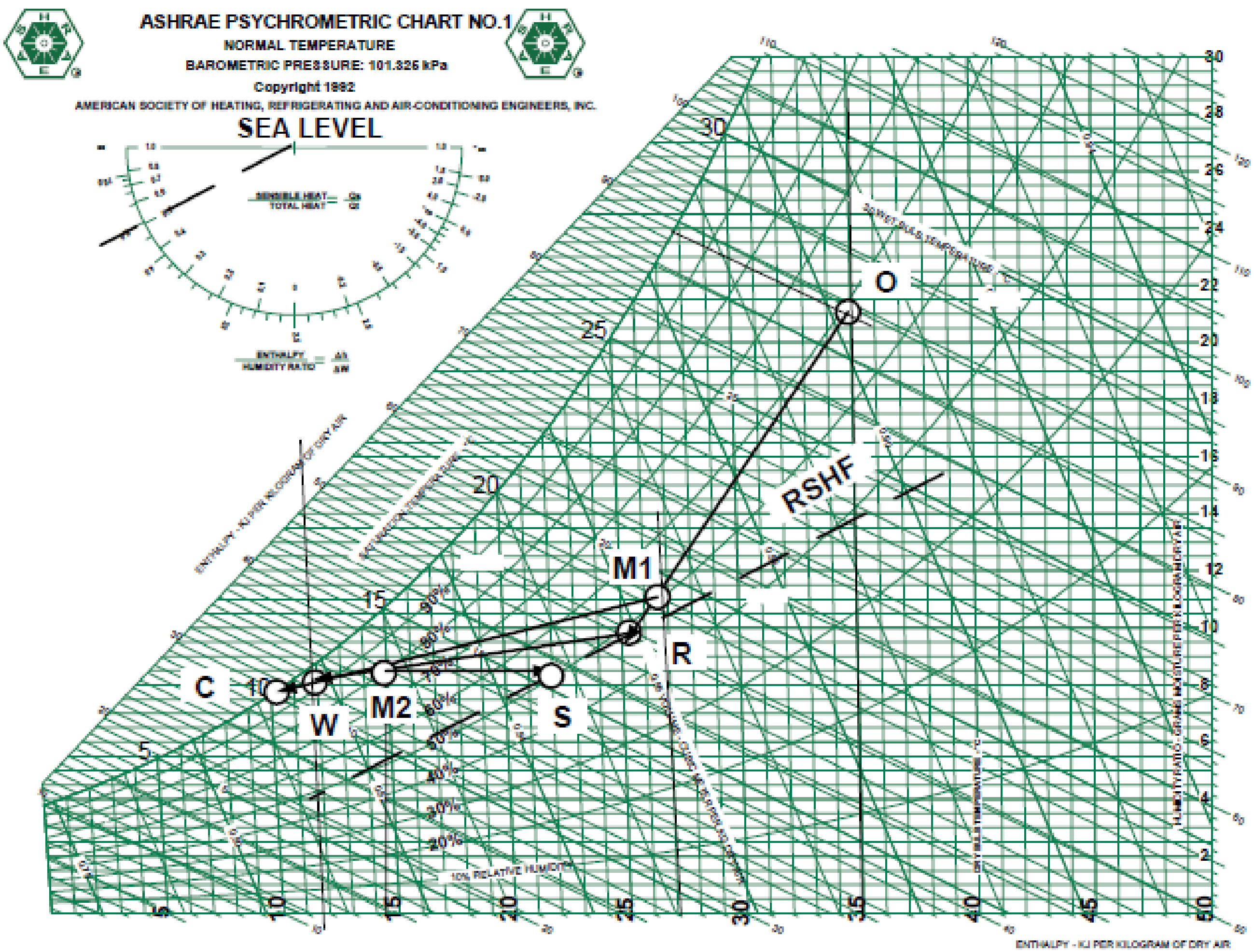

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Summer and winter air conditioning systems

Generally, from the building specifications, inside and outside design conditions; the latent and sensible cooling or heating loads on a building can be estimated. Normally, depending on the ventilation requirements of the building, the required outdoor air (fresh air) is specified.

The topic of load estimation will be discussed in a later lecture. From known loads on the building and design inside and outside conditions, psychrometric calculations are performed to find:

1. Supply air conditions (air flow rate, DBT, humidity ratio & enthalpy).
2. Coil specifications (Latent and sensible loads on coil, coil ADP & BPF).

In this lecture fixing of supply air conditions and coil specifications for summer air conditioning systems are discussed. Since the procedure is similar for winter air conditioning systems, the winter air conditioning systems are not discussed here.

Summer air conditioning systems

Simple system with 100 % re-circulated air:

In this simple system, there is no outside air and the same air is recirculated as shown in the following figure also shows the process on a psychrometric chart. It can be seen that cold and dry air is supplied to the room and the air that leaves the condition space is assumed to be at the same conditions as that of the conditioned space. The supply air condition should be such that as it flows through the conditioned space it can counteract the sensible and latent heat transfers taking place from the outside to the conditioned space, so that the space can be maintained at required low temperature and humidity. Assuming no heat gains in the supply and return ducts and no energy addition due to fans, and applying energy balance across the room; the Room Sensible Cooling load (Qs,r), Room Latent Cooling Load (Ql,r) and Room Total Cooling load (Qt,r) are given by:

$$Q_{sr} = \dot{m}_a \,.C_{pa}\,.\,(DBT_r - DBT_S) = \dot{m}_a\,.(h_A - h_S)$$

$$Q_{lr} = \dot{m}_a\,.h_{fg}\,.\,(W_r - W_S) = \dot{m}_a\,.(h_r - h_A)$$

$$Q_{tr} = Q_{sr} + Q_{lr} = \dot{m}_a\,.(h_r - h_s)$$

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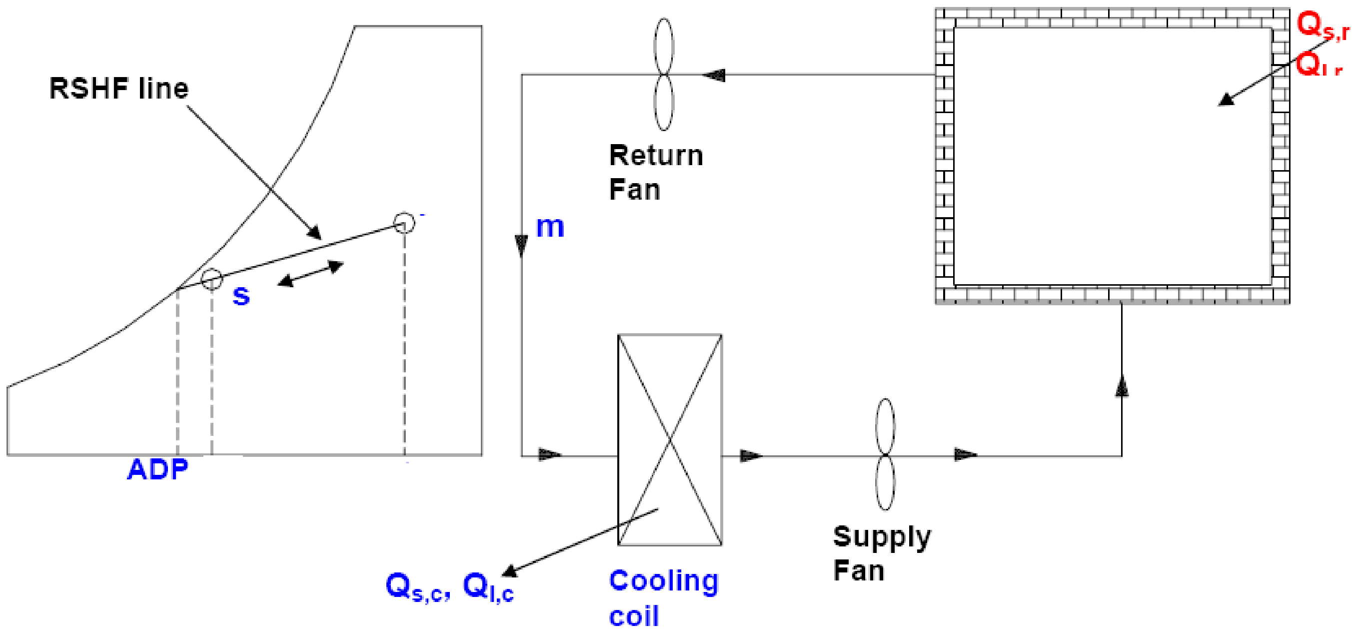

The psychrometry of Simple system with 100 % re-circulated air.

From cooling load calculations, the sensible, latent and total cooling loads on the room are obtained. Hence one can find the Room Sensible Heat Factor (RSHF) from the equation:

$$RSHF=\frac{Q_{sr}}{Q_{sr+}Q_{lr}}=\frac{Q_{sr}}{Q_{tr}}$$

The intersection of this line with the saturation curve gives the ADP of the cooling coil as shown in Fig. above. It should be noted that for the given room sensible and latent cooling loads, **the supply condition must always lie on this line so that it can extract the sensible and latent loads on the conditioned space in the required proportions.**

System with outdoor air for ventilation:

In actual air conditioning systems, some amount of outdoor (fresh) air is added to take care of the ventilation requirements. Normally, the required outdoor air for ventilation purposes is known from the occupancy data and the type of the building (e.g. operation theatres require 100% outdoor air). Normally either the quantity of outdoor air required is specified in absolute values or it is specified as a fraction of the re-circulated air.

Case i) By-pass factor of the cooling coil is zero:

The following figure shows the schematic of the summer air conditioning system with outdoor air and the corresponding process on psychrometric chart, when the by-pass factor B.F. is zero. Since the sensible and latent cooling loads on the conditioned space are assumed to be known from cooling load calculations, similar to the earlier case, one can draw the process line s-R, from the RSHF and state R. The intersection of this line with the saturation curve gives the room ADP. As shown on the psychrometric chart, when the by-pass factor is zero, the room ADP is equal to coil ADP, which in turn is equal to the temperature of the supply air. Hence from the supply temperature one can calculate the required supply air mass flow rate (which is the minimum required as B.F. is zero) using the equation:

$$\dot{m}_a = \frac{Q_{s,r}}{C_{pm}.(DBT_R - DBT_s)} = \frac{Q_{sr}}{(h_A - h_s)}$$

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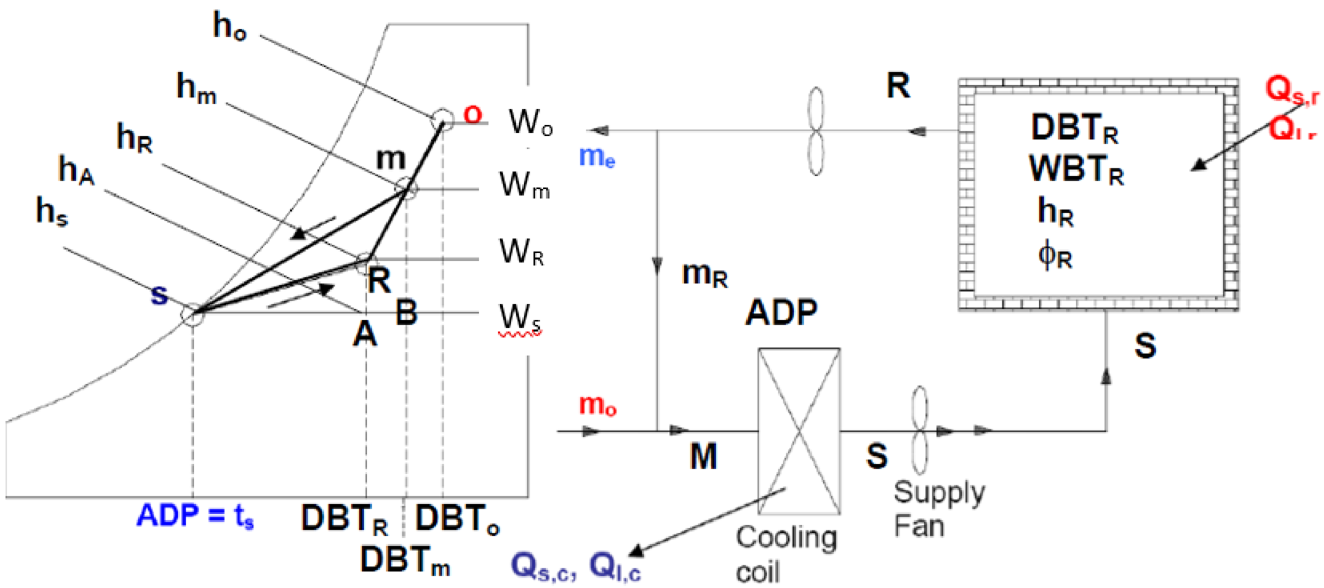

Schematic of the summer air conditioning system with outdoor air.

Room Load:	Cooling Coil Load
Sensible load	Sensible load
$Q_{sr} = \dot{m}_a \cdot C_{pm} \cdot (DBT_R - DBT_S)$	$Q_{sc} = \dot{m}_a \cdot C_{pm} \cdot (DBT_M - DBT_S)$
$= \dot{m}_a \cdot (h_A - h_S)$	$= \dot{m}_a \cdot (h_B - h_S)$
Room Total Load	Total Load
$Q_{Tr} = \dot{m}_a \cdot (h_R - h_S)$	$Q_{Tc} = \dot{m}_a \cdot (h_M - h_S)$
Latent load	Latent load
$Q_{lr} = 2501 \cdot \dot{m}_a \cdot (W_R - W_S) = (Q_{T\,r} - Q_{Sr})$	$Q_{lr} = 2501 \cdot \dot{m}_a \cdot (W_M - W_S) = (Q_{TC} - Q_{SC})$

The line joining the mixed condition (M) with the coil (ADP) is the process line undergoes by the air as it flows the cooling coil. The slope of this line depends on the Coil Sensible Heat Factor (CSHF) given by :

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$$CSHF = \frac{Q_{sc}}{Q_{sc}+Q_{lc}} = \frac{Q_{sc}}{Q_{Tc}}$$

Mixing conditions

Mass balance

$$\dot{m}_M = \dot{m}_R + \dot{m}_O$$

$$\dot{m}_M . h_M = \dot{m}_R . h_R + \dot{m}_O . h_O$$

Or

$$\dot{m}_M . DBT_M = \dot{m}_R . DBT_R + \dot{m}_O . DBT_O$$

The load on the cooling coil is greater than on the conditioned space. This is due to the fact that during mixing, some amount of hot and humid air is added and the same amount of relative cool and dry air is exhausted.

Case ii: Coil by-pass factor, BF > 0:

For actual cooling coils, the bypass factor will be greater than zero, as a result the air temperature at the exit of the cooling coil will be higher than the coil ADP. This shown in the following figure along with the process on psychrometric chart, it can be seen from the figure that when BF >0, the room ADP will be different from the coil ADP. The system shown in Figure is adequate when the RSHF is high (> 0.75).

Calculate the supply conditions using Contact factor:

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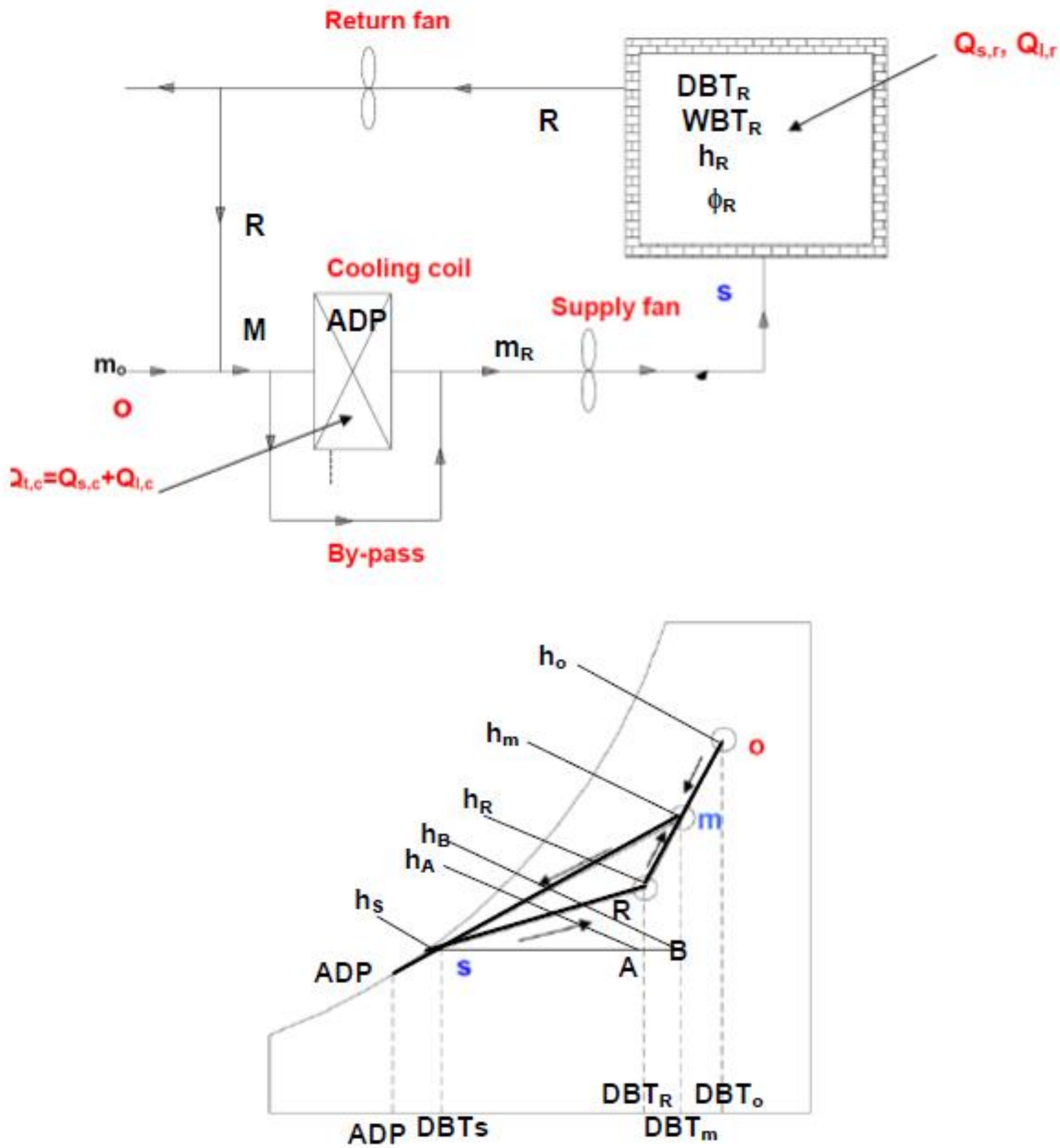

Schematic of the summer air conditioning system with outdoor air and by pass factor.

Winter Air Conditioning Systems

In winter the outside conditions are cold and dry. As a result, there will be a continuous transfer of sensible heat as well as moisture (latent heat) from the buildings to the outside.

Hence, in order to maintain the required comfort conditions in the occupied space an air conditioning system is required which can offset the sensible and latent heat losses from the building. Air supplied to the conditioned space is heated and humidified in the winter air conditioning system to the required level of temperature and moisture content depending upon the sensible and latent heat losses from the building. In winter the heat losses from the conditioned space are partially offset by solar and internal heat gains.

Thus, in a conservative design of winter A/C systems, the effects of solar radiation and internal heat gain are not considered. Heating and humidification of air can be achieved by different schemes. The following figure shows one such scheme along with the cycle on psychrometric chart. As shown in the figure, the mixed air (mixture of return and outdoor air) is first pre-heated (m-w1) in the pre-heater, then humidified using a humidifier or an air washer (w1-w2) and then finally reheated in the reheater (w2-s). The reheated air at state 's' is supplied to the conditioned space. The flow rate of supply air should be such that when released into the conditioned space at state 's', it should be able to maintain the conditioned space.

The humidification of air can be achieved in several ways, e.g. by bringing the air into contact with a wetted surface, or with droplets of water as in an air washer, by adding aerosol sized water droplets directly to air or by direct addition of dry saturated or superheated steam. Humidification by direct contact with a wetted surface or by using an air washer are not recommended for comfort applications or for other applications where people are present in the conditioned space due to potential health hazards by the presence of micro-organisms in water. The most common method of humidifying air for these applications is by direct addition of dry steam to air. When air is humidified by contact with wetted surface as in an air washer, then temperature of air decreases as its humidity increases due to simultaneous transfer of sensible and latent heat. If the air washer functions as an adiabatic saturator, then humidification proceeds along the constant wet bulb temperature line.

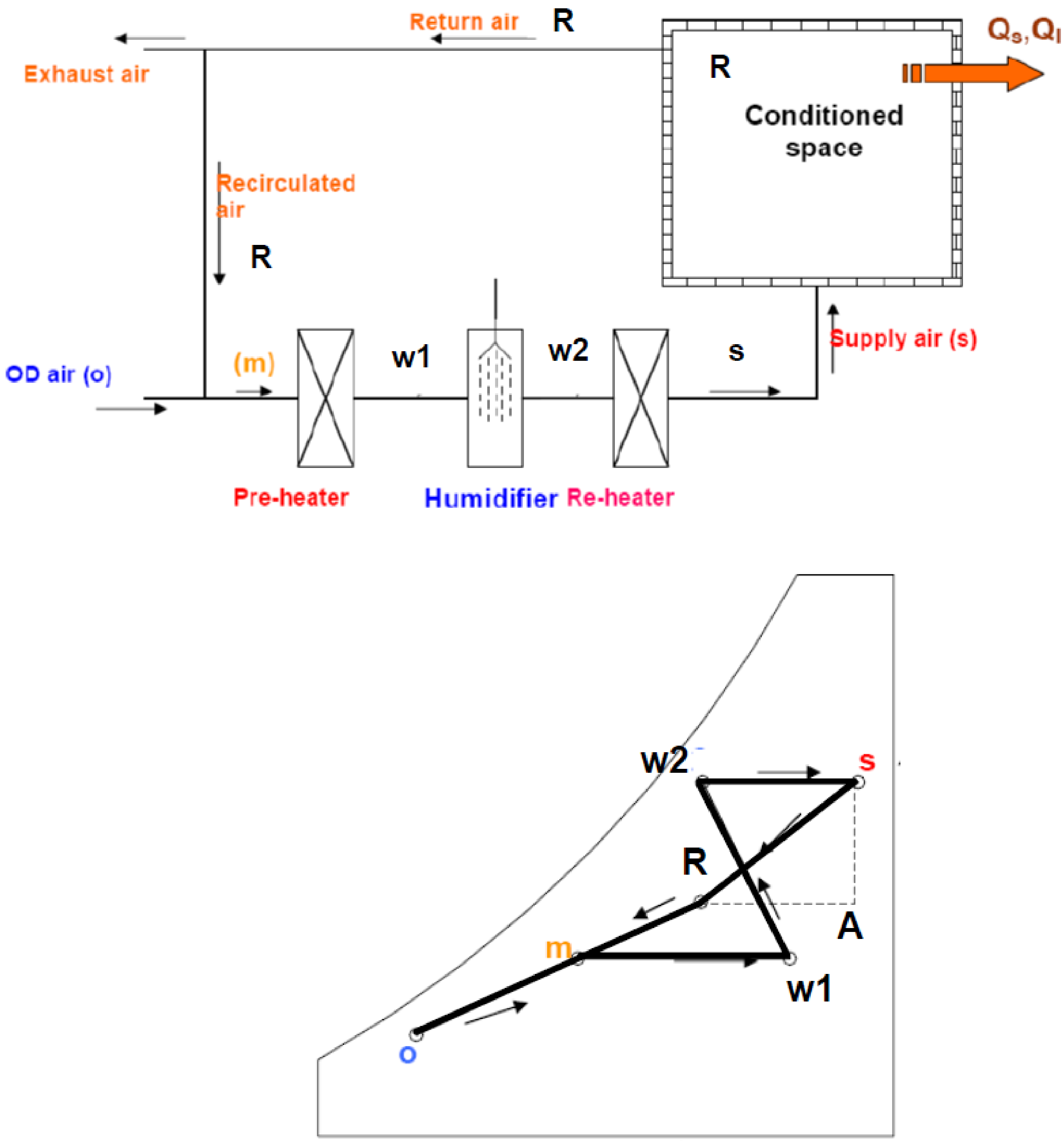

Figure: *A winter air conditioning system with a pre-heater.*

By applying energy balance across the conditioned space, at steady state, the sensible and latent heat losses from the building can be written as:

Pre-heater Load:	Room Load
$Q_{sp} = \dot{m}_a . C_p . (DBTw_1 - DBTm)$	Sensible load
$= \dot{m}_a . (hw_1 - hm)$	$Q_{sr} = \dot{m}_a . C_p . (DBTs - DBT_R)$
Re-heater Load:	$= \dot{m}_a . (h_A - h_R)$
$Q_{sre} = \dot{m}_a . C_p . (DBTs - DBT_{w2})$	**Total Load**
	$Q_{Tr} = \dot{m}_a . (hs - h_R)$
$= \dot{m}_a . (hs - h_{w1})$	**Latent load**
	$Q_{lr} = 2501 . \dot{m}_a . (Ws - W_R)$
	$= \dot{m}_a . (hs - h_A)$

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