Fundamentals of Refrigeration and Air Conditioning

المرحلة الثانية

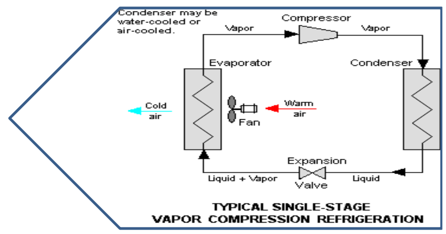
محاضرة رقم (5)

دورات تكييف الهواء الصيفية والشتوية

Air-Conditioning Plant for Summer and Winter

Email (Hassan.Ghanim.Hassan@uomus.edu.iq)

Fundamentals of Refrigeration and Air Conditioning



Hassan Rijabo

Lecture 5
Air-Conditioning Plant for Summer and Winter

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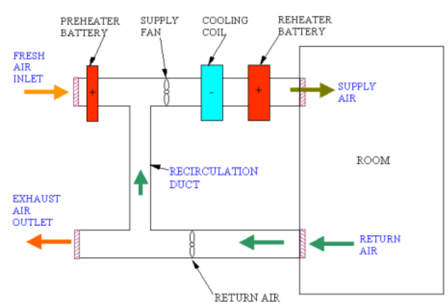
In the summer time when cooling is required by the air conditioning plant it will be necessary to operate the cooling coil, reheater and possibly other plant as well.

In winter time the preheater and reheater will probably be on to provide warm air to overcome heat losses.

Other plant may be switched on as well.



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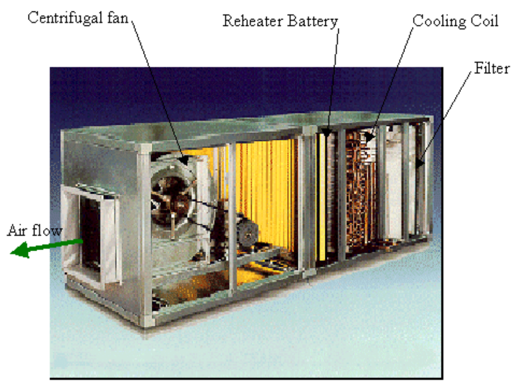
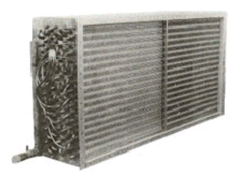
The photographs below show some plant items



AIR HANDLING UNIT WITH FAN, FILTER, COOLING COIL AND REHEATER

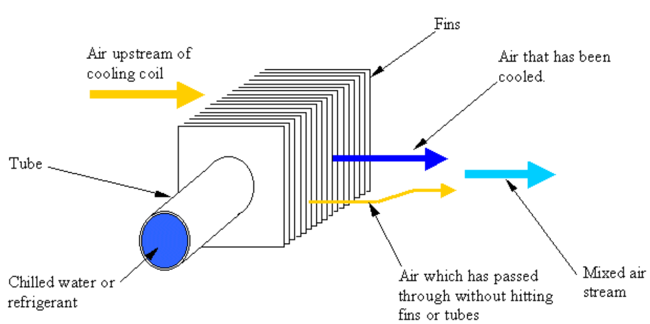


COOLING COIL

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 (Apparatus Dew Point) temperature.

A mixing process therefore takes place as two air streams mix downstream of the cooling coil as shown below.



A SECTION OF COOLING COIL SHOWING AIR STREAMS

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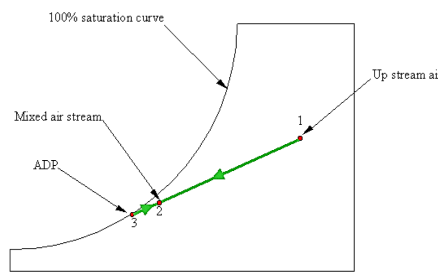
One air stream is cooled down to the ADP and the other air stream by-passes the coil surfaces to give an off-coil air temperature (mixed air stream) a little higher than the ADP.

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.



PSYCHROMETRIC CHART SHOWING COOLING COIL CONTACT FACTOR

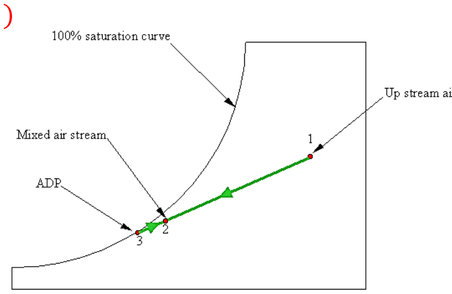
The contact factor of a cooling coil may be found from;

$$\text{Contact Factor (C.F)} = \frac{(h_1 - h_2)}{(h_1 - h_3)}$$

Another expression for contact factor is;

$$\textbf{By-pass Factor (B.P.F)} = \frac{(h2 - h3)}{(h1 - h3)}$$

$$C.F + B.P.F = 1$$



PSYCHROMETRIC CHART SHOWING COOLING COIL CONTACT FACTOR

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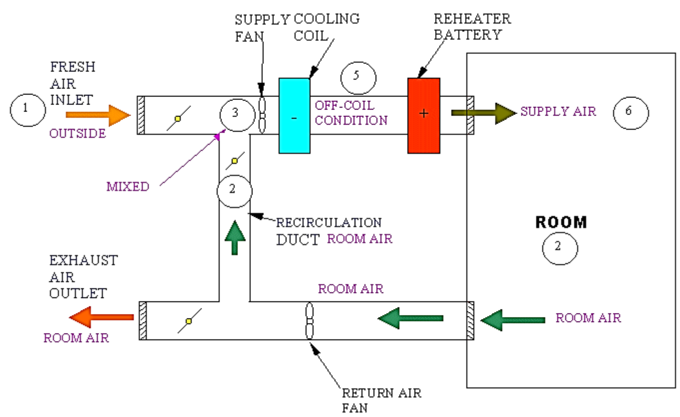
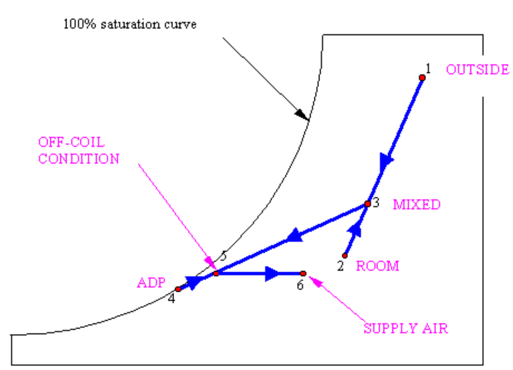
Typical Air Conditioning Processes

The schematic diagram below shows a typical plant system for summer air conditioning.



Typical Air Conditioning Processes

The psychrometric diagram below shows a typical summer cycle.



PSYCHROMETRIC CHART SHOWING TYPICAL SUMMER CYCLE

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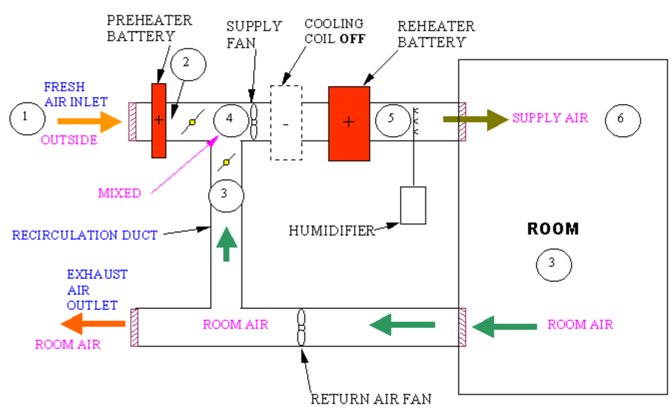
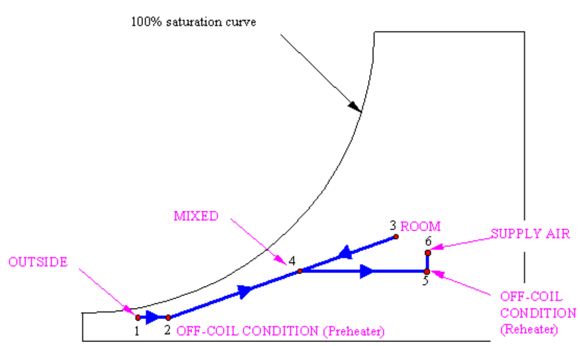
Typical Air Conditioning Processes

The schematic diagram below shows a typical plant system for winter air conditioning.



Typical Air Conditioning Processes

The psychrometric diagram below shows a typical winter cycle.



PSYCHROMETRIC CHART SHOWING TYPICAL WINTER CYCLE

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Annotation

Air State point	Letter
Outside	**O**
Room	**R**
Mixed	**M**
Apparatus Dew Point	**ADP**
Off cooling coil condition	**W**
Room Ratio Line	**RRL**
Preheater off coil condition	**P**
Upstream of Humidifier	**H**
Supply	**S**
Duct, fan gain allowance	**D**

Room Sensible Heat Ratio

This is the ratio of sensible to total heat in the room for summer or winter.

- The total heat gain (summer) or loss (winter) will be determined by adding the Latent and Sensible heat in a room or rooms, i.e.

(SUMMER) Total heat gain = Sensible heat gain + Latent heat gain

(WINTER) Total heat = Sensible heat loss + Latent heat gain

- The room ratio is used on a psychrometric chart to determine the supply air state point.

- A room ratio line is superimposed from the protractor on the psychrometric chart onto the main body of the chart by a line passing through the room state point R.

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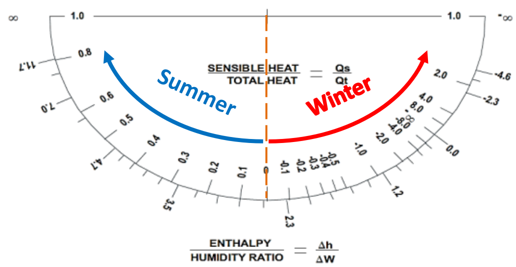
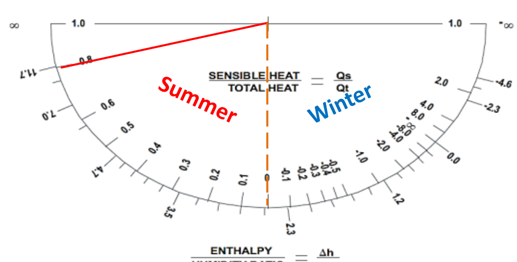
Room Sensible Heat Ratio (RSHR)



Room Sensible Heat Ratio (RSHR)

- An example calculation is as follows:
- Sensible heat gain = 9.0 kW
- Latent heat gain = 2.25 kW
- Total heat gain = 9.0 kW + 2.25 kW = 11.25 kW.
- Room Sensible Heat Ratio (RSHR) = Sensible / Total heat
- Room Sensible Heat Ratio (RSHR) = 9 / 11.25 = 0.8
- The supply air state point must also be somewhere on this room ratio line to meet the room heat gain requirements i.e. the room ratio line always passes through points R and S.



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Al-Mustaqbal University
Department of Mechanical Power Engineering
Class (2nd)
Subject (**Fundamentals of Refrigeration and Air Conditioning**)

Lecturer (Hassan Ghanim Hassan Rijabo)
2nd term – Lect. (**Air Conditioning Plant For Summer and Winter)**

Summer and Winter Cycles

1. SUMMER CYCLE PSYCHROMETRICS

1. Draw schematic diagram of air-conditioning plant.
2. Plot room condition R on psychrometric chart.
3. Plot outside condition O on psychrometric chart.
4. Join points O and R.
5. Find the mix point M by measuring the length of the line O-R and multiply this by the mixing ratio. If there is more recirculated air than outside air at the mix point, then point M will be closer to point R than point O.

6. Find the room ratio. This is the sensible to total heat gain ratio. Plot this ratio on the protractor, bottom segment, on the psychrometric chart and transfer this line onto the chart so that it passes through point R.
7. Plot the Apparatus Dew Point ADP of the cooling coil. This is on the 100% saturation curve. The wet bulb and dry bulb temperatures at this point will be equal.
8. Join points M and ADP.
9. Find the off-coil condition W by measuring the length of the line M-ADP and multiply this by the cooling coil contact factor. Measure down from point M to the point W. The closer the contact factor is to unity, the closer point W will be to point ADP.
10. Plot the supply air condition S. The reheater process will be a horizontal line from point W to point S. Point S is on the room ratio line.

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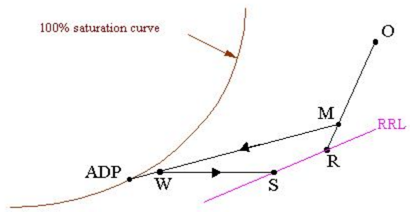


SUMMER CYCLE

TYPICAL AIR HANDLING UNIT

2. SUMMER CYCLE CALCULATIONS

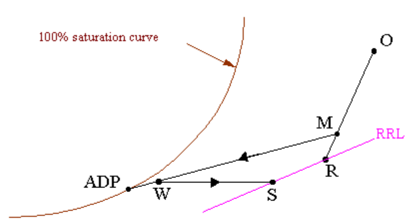
2.1 MASS FLOW RATE

When the supply air temperature has been found from the psychrometric chart then the mass flow rate of air can be calculated from the following formula:

$$Q_s = m_a \times Cp \ (t_r - t_s)$$

where:

Q_s = Sensible heat gain to room (kW)
m_a = mass flow rate of air (kg/s)
Cp = Specific heat capacity of humid air (approx.1.005 kJ/kg degC)
t_r = room temperature (ºC)
t_s = supply air temperature (ºC)



SUMMER CYCLE

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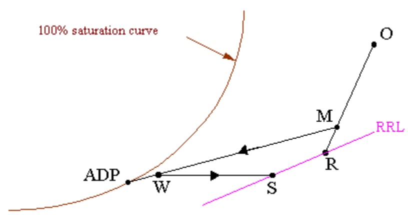
2.2 COOLING COIL OUTPUT

The cooling coil output is as follows:

$$Q_{cooling\ coil} = m_a \ (h_M - h_{ADP})$$

where:

$Q_{cooling\ coil}$ = Cooling coil output (kW)
m_a = mass flow rate of air (kg/s)
h_M = specific enthalpy at condition M (kJ/kg)
h_{ADP} = specific enthalpy at condition ADP (kJ/kg).



SUMMER CYCLE

Lecture5. Air-Conditioning Plant for Summer and Winter

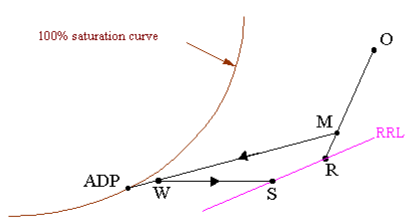
2.3 HEATER OUTPUT

The reheater output is as follows:

$$Q_{reheater} = m_a \ (h_S - h_W)$$

where:

$Q_{reheater}$ = Heater output (kW)
m_a = mass flow rate of air (kg/s)
h_S = specific enthalpy at condition M (kJ/kg)
h_W = specific enthalpy at condition W (kJ/kg)



SUMMER CYCLE

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Summer and Winter Cycles

3. WINTER CYCLE PSYCHROMETRICS

1. Draw schematic diagram of air-conditioning plant.
2. Plot room condition R on psychrometric chart.
3. Plot outside condition O on psychrometric chart.
4. Plot the after Preheater condition P if there is one in the system. The Preheater process will be a horizontal line from O to P and will be only a few degrees dry bulb if it acts as a frost coil.
5. Join points P and R. If there is no frost coil read O-R for P-R.
6. Find the mix point M by measuring the length of the line P-R and multiply this by the mixing ratio. If there is more recirculated air than outside air at the mix point, then point M will be closer to point R than point P.

Lecture5. Air-Conditioning Plant for Summer and Winter

7. Find the room ratio. This is the sensible to total heat ratio. The total heat for the room will be Sensible loss plus Latent gain. Plot this ratio on the protractor, top segment, on the psychrometric chart and transfer this line onto the chart so that it passes through point R.
8. Find the supply air dry bulb temperature by calculation. The mass flow rate of air is the same as that for Summer for a Constant Volume system.
9. Plot the supply air condition S on the room ratio line.
10. Plot condition H on the psychrometric chart. This is vertically down from point S, and horizontally across from point M. This is because M-H is the reheater process and thus a horizontal line and H-S is the humidification process and is close to a vertical line if steam is used.

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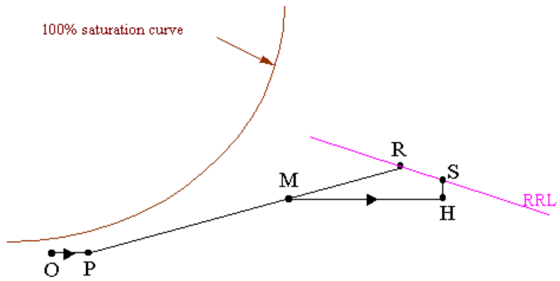


WINTER CYCLE

4. WINTER CYCLE CALCULATIONS

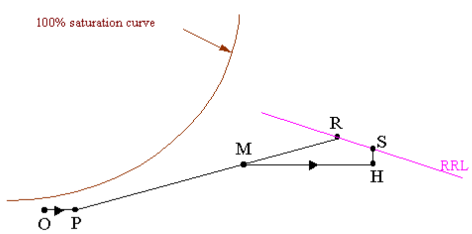
4.1 SUPPLY AIR DRY BULB TEMPERATURE

When the mass flow rate of air is calculated for the summer condition then the winter supply air dry bulb temperature can be calculated from the following formula:

$$Q_s = m_a \times Cp \ (t_s - t_r)$$

where:

Q_s = Sensible heat gain to room (kW)
m_a = mass flow rate of air (kg/s)
Cp = Specific heat capacity of humid air (approx.1.01 kJ/kg degC)
t_r = room temperature (°C)
t_s = supply air temperature (°C)



WINTER CYCLE

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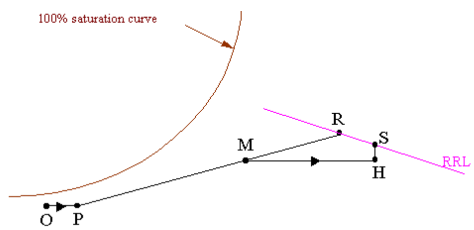
4.2 PREHEATER OUTPUT (or frost coil)

The preheater output is as follows:

$$Q_{preheater} = m_{af} \; (h_P - h_O)$$

where:

$Q_{preheater}$	=	Preheater output (kW)
m_{af}	=	mass flow rate of fresh air (kg/s)
h_P	=	specific enthalpy at condition P (kJ/kg)
h_O	=	specific enthalpy at condition O (kJ/kg)



WINTER CYCLE

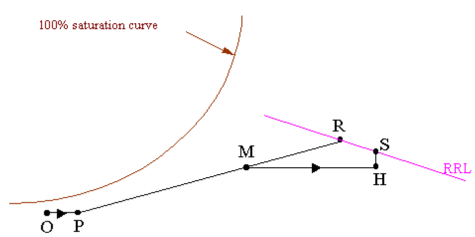
4.3 REHEATER OUTPUT

The reheater output is as follows:

$$Q_{reheater} = m_a \; (h_H - h_M)$$

where:

$Q_{reheater}$	=	Reheater battery output (kW)
m_a	=	mass flow rate of supply air (kg/s)
h_H	=	specific enthalpy at condition H (kJ/kg)
h_M	=	specific enthalpy at condition M (kJ/kg)



WINTER CYCLE

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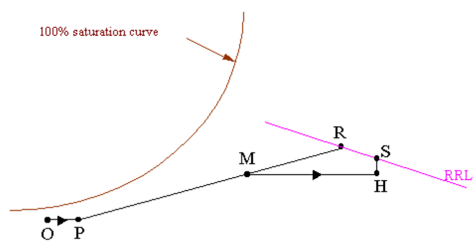
4.4 HUMIDIFIER OUTPUT

The amount of moisture added to the air may be calculated from the following formula:

$$m_{moisture\ added} = m_a \ (W_S - W_H)$$

where:

$m_{moisture\ added}$ = The amount of moisture or added or steam flow rate (kg/s)
m_a = mass flow rate of air (kg/s)
W_S = moisture content at condition S (kg/kg d.a.)
W_H = moisture content at condition H (kg/kg d.a.)



WINTER CYCLE

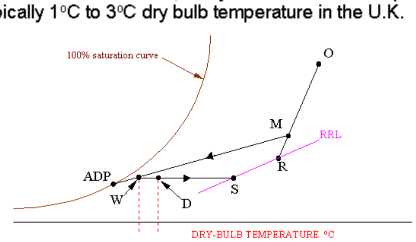
Summer and Winter Cycles

5. DUCT AND FAN GAINS

The air in a duct is slightly heated from the fan electric motor and heat is also transmitted through the duct wall from warm areas Into the air stream, for example;
a duct contains air at 15°C and passes through a roof space at 30°C in summer.
There will be heat transferred through the duct wall, which increases the air temperature slightly.

To allow for this in the summer psychrometric process an additional sensible heating state point D is added as shown below.

The air may be heated by several °C depending on the fan motor, length of duct and type of duct insulation used, if any. The distance from point W to point D may be typically 1°C to 3°C dry bulb temperature in the U.K.



SUMMER CYCLE

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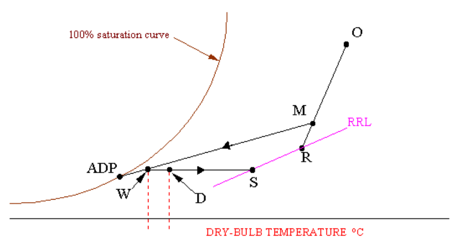
If duct and fans gains are to be allowed for, the reheater output is as follows:

REHEATER OUTPUT

$$Q_{heater} = m_a \ (h_S - h_D)$$

where:

Q_{heater} = Heater output (kW)
m_a = mass flow rate of air (kg/s)
h_S = specific enthalpy at condition S (kJ/kg) determined from psychrometric chart.
h_D = specific enthalpy at condition D (kJ/kg) determined from psychrometric chart.



SUMMER CYCLE

Examples of Psychrometric Calculations for Summer and Winter

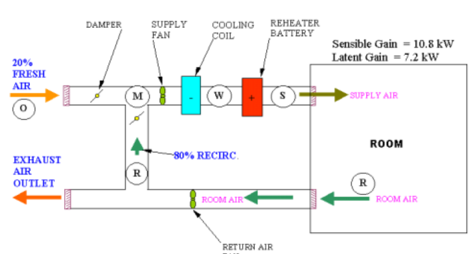
Example 1. Summer Cycle

A room is to be maintained at 22°C dry-bulb temperature, 50% saturation, when the sensible heat gain is 10.8 kW in summer.

The latent heat gain is 7.2 kW

Determine the cooling coil and reheater outputs required by using a psychrometric chart if the plant schematic is as shown below.

DATA:
Outdoor condition is 28°C, 80% saturation.
The outdoor air and recirculated air ratio is 20%/80%.
The Apparatus Dew Point ADP is 8°C
Neglect the cooling coil contact factor.



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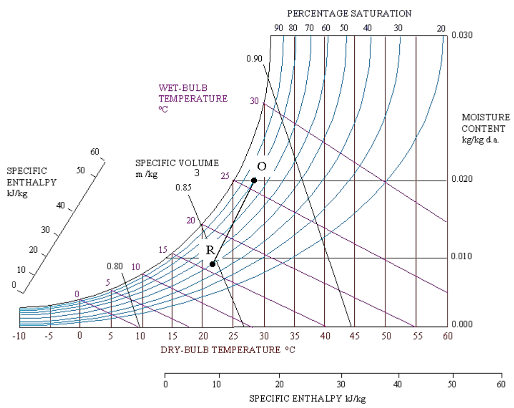
Procedure (Summer Cycle)

1. Draw schematic diagram of air-conditioning plant (see above)
2. Plot room condition R on psychrometric chart.
3. Plot outside condition O on psychrometric chart.
4. Join points O and R.



5. Find the mixed point M

$(0.2\, m_M \times h_o) + (0.8 m_M \times h_R) = m_M \times h_M$

$h_o = 77$ kJ/kg $_{dry\ air}$, $h_R = 43$ kJ/kg $_{dry\ air}$ from psychrometric chart

$(0.2 \times 77) + (0.8 \times 43) = (1 \times h_M)$

$h_M = 50$ kJ/kg $_{dry\ air}$

If there is more recirculated air than outside air at the mix point, then point M will be closer to point R than point O.

6. Find the room ratio.
   This is the sensible to total heat gain ratio.

   Total heat = 10.8 kW sensible + 7.2 kW latent = 18 kW total.
   Heat ratio = 10.8 / 18.0 = 0.6

   Plot this ratio on the protractor, bottom segment, on the psychrometric chart and transfer this line onto the chart so that it passes through point R.

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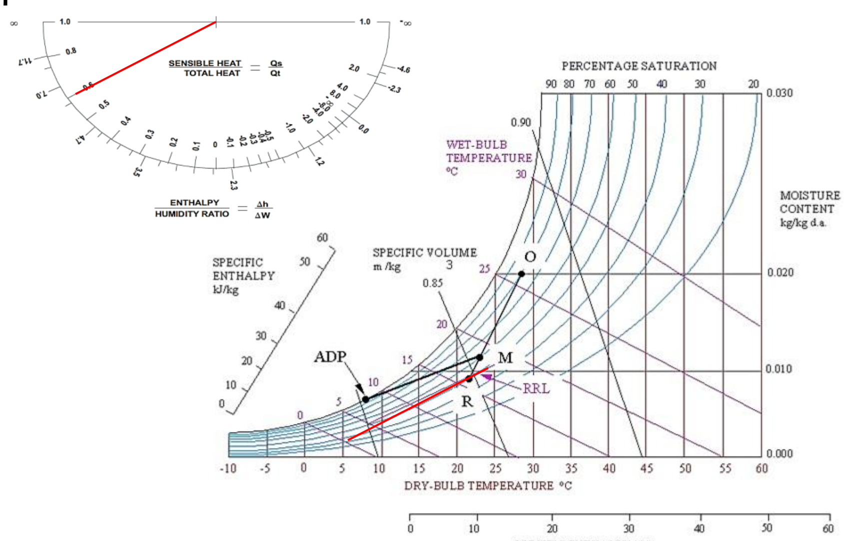
7. Plot the Apparatus Dew Point ADP of the cooling coil. This is on the 100% saturation curve.

   The ADP is 8^0C.

   The wet bulb and dry bulb temperatures at this point will be equal.

8. Join points M and ADP.

TYPICAL SMALL AIR HANDLING UNIT



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Al-Mustaqbal University
Department of Mechanical Power Engineering
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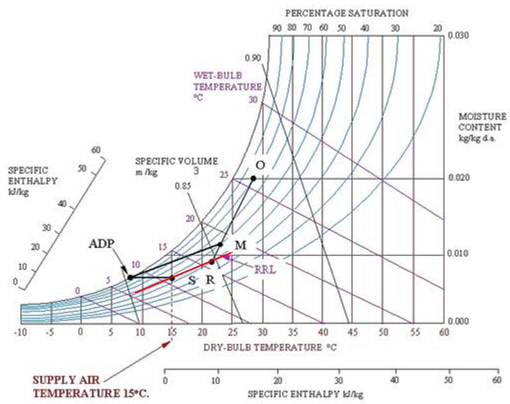
Subject (**Fundamentals of Refrigeration and Air Conditioning**)

Lecturer (Hassan Ghanim Hassan Rijabo)
2nd term – Lect. (**Air Conditioning Plant For Summer and Winter)**

9. Since there is no cooling coil contact factor we can proceed with reheating from point ADP.

10. Plot the supply air condition S.
The reheater process will be a horizontal line from point ADP to point S.
Point S is on the room ratio line.

The supply air temperature is 15°C.



SUMMER CYCLE CALCULATIONS

MASS FLOW RATE

When the supply air temperature has been found from the psychrometric chart then the mass flow rate of air can be calculated from the following formula:

$$Q_s = m_a \times Cp \ (t_r - t_s)$$

where:

- Q_s = Sensible heat gain to room (kW)
- m_a = mass flow rate of air (kg/s)
- Cp = Specific heat capacity of humid air (approx. **1.005** kJ/kg degC)
- t_r = room temperature (°C)
- t_s = supply air temperature (°C)

The supply air temperature is 15°C.
Rearranging the above formula gives:

$$m_a = Q_s \ / \ (Cp \ (t_r - t_s))$$

$$m_a = 10.8 \ / \ (1.005 \ (22 - 15))$$

$$m_a = 1.528 \text{ kg/s}$$

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COOLING COIL OUTPUT

The cooling coil output is as follows:

$$Q_{cooling\ coil} = m_a \ (h_M - h_{ADP})$$

where:

- $Q_{cooling\ coil}$ = Cooling coil output (kW)
- m_a = mass flow rate of air (kg/s)
- h_M = specific enthalpy at condition M (kJ/kg) determined from psychrometric chart.
- h_{ADP} = specific enthalpy at condition ADP (kJ/kg) determined from psychrometric chart

The specific enthalpies at points M and ADP are shown on the psychrometric Chart below.

$$Q_{cooling\ coil} = 1.528 \ (50 - 25)$$

$$Q_{cooling\ coil} = \underline{38.2 \text{ kW}}$$

Note:

The cooling coil output of 38.2 kW is a much higher value than the sensible heat gain of 10.8 kW.

It should be remembered that the difference is these two values is mostly from the fresh air cooling load.

It takes quite a lot of energy in summer to cool fresh air coming into air handling units.

This can be minimized by bringing in minimum fresh air but not too little otherwise the building will suffer from lack of oxygen and feel stuffy.

Sometimes mistakes are made when sizing cooling apparatus.

If a cooling coil or indoor cooling unit is sized on the sensible heat gain only without allowing for fresh air load then it will be grossly undersized.

That is why psychrometric charts are required to calculate cooling coil output including fresh air loads.

So, don’t size cooling coil and indoor cooling units on sensible heat gain only if there is fresh air coming into the plant.

Size these items of plant using a psychrometric chart.

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HEATER OUTPUT

The heater or reheater output is as follows:

$$Q_{heater} = m_a \; (h_S - h_{ADP})$$

where:

Q_{heater} = Heater output (kW)
m_a = mass flow rate of air (kg/s)
h_S = specific enthalpy at condition S (kJ/kg) determined from psychrometric chart.
h_{ADP} = specific enthalpy at condition ADP (kJ/kg) determined from psychrometric chart.

The specific enthalpies at points ADP and S are shown on the psychrometric Chart below.

$$Q_{heater} = 1.528 \; (31.5 - 25)$$

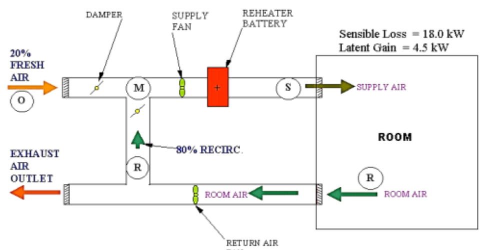
$$Q_{heater} = \underline{9.932 \text{ kW}}$$

Example 2. Winter Cycle

A room has a 18.0 kW sensible heat loss in winter and a 4.5 kW latent heat gain from the occupants.

Determine the supply air temperature and heater load using the following information.

DATA:
Indoor condition: 21°C dry-bulb temperature, 50% saturation.
Outdoor condition: -2°C d.b., 80% saturation.
The outdoor air and recirculated air ratio is 20%/80%.
No preheating or humidification takes place in this simplified example.



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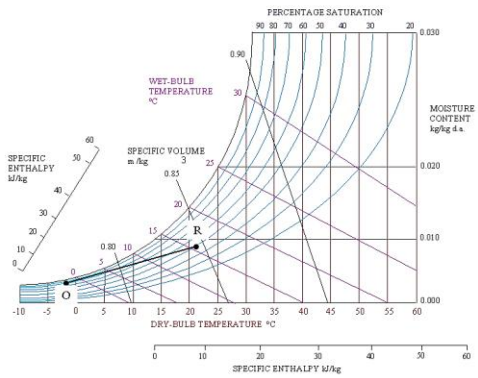
Procedure (Winter Cycle)

1. Draw schematic diagram of air-conditioning plant (see above)
2. Plot room condition R on psychrometric chart.
3. Plot outside condition O on psychrometric chart.
4. No Preheater condition P
5. Join points O and R



6. Find the mixed point M

h_o = 4.4 kJ/kg $_{dry\ air}$, h_R = 40.8 kJ/kg $_{dry\ air}$ from psychrometric chart

$(0.2\ m_M \times h_o) + (0.8 m_M \times h_R) = m_M \times h_M$

$(0.2 \times 4.4) + (0.8 \times 40.8) = (1 \times h_M)$
h_M = **34 kJ/kg** $_{dry\ air}$

7. Find the room sensible ratio line

$$RSHR = \frac{Q_{sensible}}{Q_{sensible} + Q_{latent}}$$

$$RSHR = \frac{-18}{(-18) + (4.5)}$$

$$RSHR = 1.33$$

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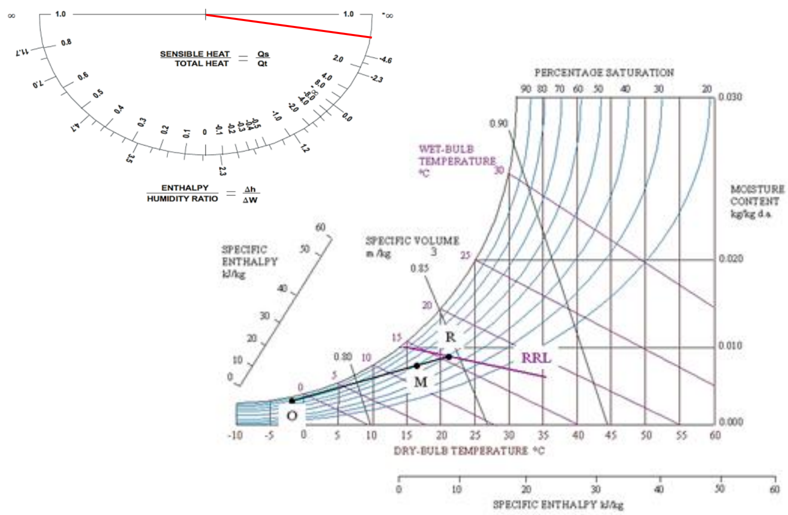
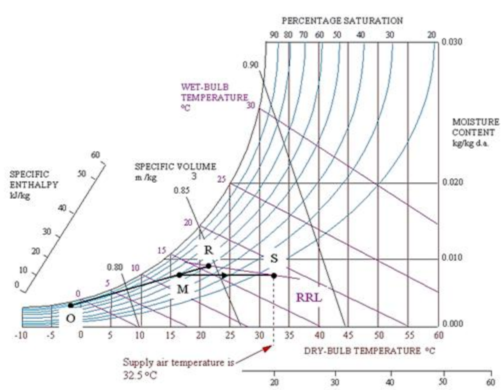


8. Find the supply air dry bulb temperature by calculation.
9. Plot the supply air condition S on the room ratio line.

This is on a horizontal line from point M to the right hand side of the chart, and intersects with the RRL.

The supply air Temperature is found to be 32.5°C.



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Supply Air Flow Rate

When the sensible heat loss and supply air temperature in winter are known then the mass flow rate of air is calculated from the following formula:

Qs = ma x Cp (ts - tr)

where:

Qs = Sensible heat loss (kW)
ma = mass flow rate of air (kg/s)
Cp = Specific heat capacity of humid air (approx. 1.005 kJ/kg degC)
tr = room temperature (°C)
ts = supply air temperature (°C) ....therefore:

ma = Qs / Cp (ts - tr)

ma = 18 / 1.005 (32.5 - 21)

ma = 18 / 11.615

ma = 1.55 kg/s

Heater Output

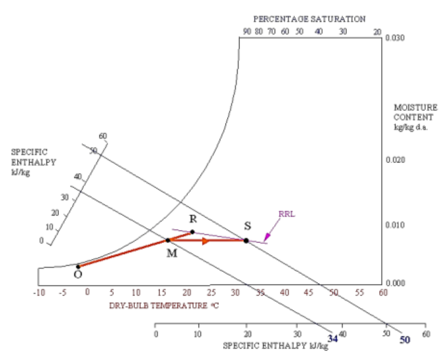
The heater output is as follows:

$Q_{reheater} = ma\ (h_S - h_M)$

where:

$Q_{reheater}$ = Reheater output (kW)
ma = mass flow rate of air (kg/s)
h_S = specific enthalpy at condition S (kJ/kg)
h_M = specific enthalpy at condition M (kJ/kg)

The specific enthalpies at points S and M are shown on the psychrometric chart.



Q_{heater} = ma (hS - hM)
Q_{heater} = 1.55 (50 – 34)
Q_{heater} = 24.8 kW
Therefore the heater load is **24.8 kW.**

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