Psychrometric Processes

Chapter 2

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Psychrometry Processes

Learning Outcomes

Learning Outcomes:

When you have studied this chapter you should be able to:

1. Explain what is meant by 'sensible heating'.
2. Indicate an example of a sensible heating process on a Psychrometric Chart and use this to estimate the 'heater duty'.
3. Indicate an example of 'sensible cooling' (both at constant moisture content and with dehumidification) on a Psychrometric Chart.
4. List and compare the common methods of humidification.
5. Explain what is meant by the 'Room Ration Line' and its application.
6. Show how a Psychrometric Chart can be used to determine the 'mixed' condition for a mixture of two streams of air.

Suggested Study Time:

(a) For study of chapter material;

(i) Initial on-screen study **1 hour**

(ii) Printing of notes and subsequent in-depth study **2 hours**

(b) For completion of the quick revision study guide **½ hour**

Total estimated study time 3½ hours

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Chapter Contents

Introduction

Having established the relationships between all the different properties of humid air, the next step is to investigate the processes (changes in condition) that occur when the air is thermally '**conditioned**'. Within this chapter these processes are trated individually at first and later combined to form complete cycles. But you may ask yourself why is it necessary to condition air? Consider therefore the problem of supplying air to a room throughout the year.

In winter, the outside air might be at -5°C and 90% saturation and this must be treated before it can be introduced into a room where we are trying to achieve conditions of say +20°C and 50% saturation. But in heating the air from -5°C to 20°C, the moisture content remains constant (so that the percentage saturation decreases), and if this air was introduced into the room at this low moisture content, problems of static electricity and dry eyes, nose and throat could result. In order to get the air into a suitable room condition, it is necessary to heat the air and then have it humidified by injecting steam or water.

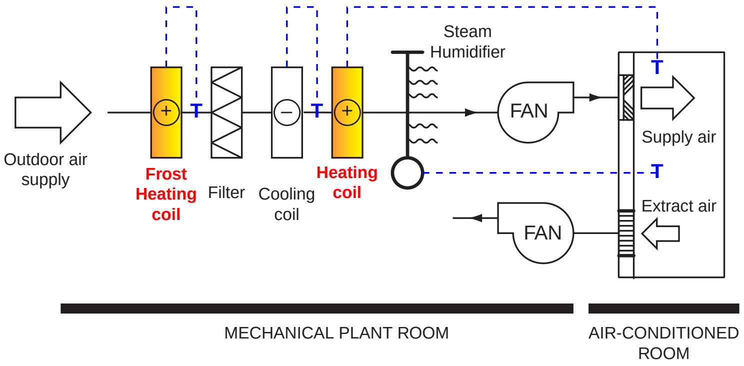
Alternatively, during the summer months, the outside air temperature might be 28°C, 80% saturation. In this case the air needs to be cooled below its dew-point in order to extract moisture.

Hence in this part of the module we shall be considering the 'building blocks' (items of air-conditioning plant) from which complete systems are constructed. The processes intoduced are considered (in thermodynamic terms), as **steady state flow** and as such, are represented as **straight lines** on the psychrometric chart connecting two different **states** or conditions of air. The simplified air-conditioning cycles are intended to illustrate the principles of air conditioning and are not necessarily practicable.

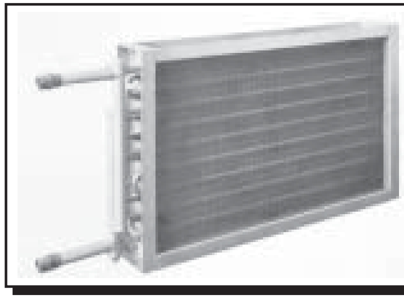
Sensible Heating Coils

Air is heated in an air-conditining plant by passing it through an air heater battery (or coil).

Schematic Representation of All Fresh-air, Constant Volume Air Conditioning System

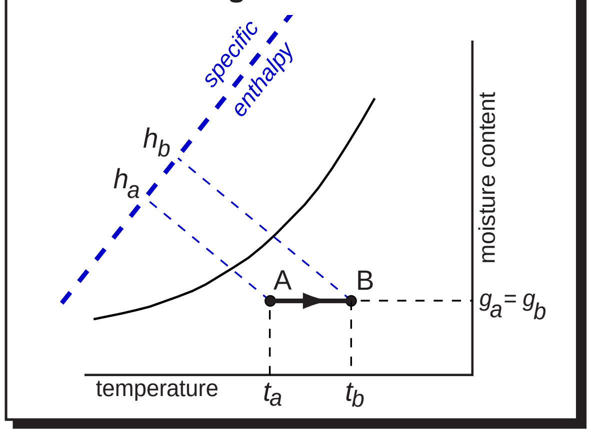


An air heater battery (or coil) normally comprises of a number of heating elements, arranged at right angles to the directio of air flow, contained within a sheet metal casing with flanged ends. The heating elements are either plain or finned tubes, carrying water or steam, or electric heating elements. Steam tubes (always) and electric elements (usually) are arranged vertically and hot water tubes horizontally. Tubes are of copper with either copper or aluminium fins.



Hot water heating coil

With larger heating loads, several banks of tubes will be required and each bank of tubes is called a '**row**'. The tubes in each row are usually connected in parallel.



Sensible heating coil

If air at condition A is heated to condition B, it will increase in dry-bulb temperature but the moisture content will remain constant. The enthalpy will increase and all the increase will be sensible heat (i.e. heat causing a temperature rise).

Note that although the moisture content remains constant, the percentage saturation (relative humidity) reduces. This increases the '**drying force**' of the air. The drying force is the difference between the vapour pressure and the saturation vapour pressure (at the same temperature) for an air sample, i.e. the drying force increases from $p_{ssA} - p_{sA}$ to $p_{ssB} - p_{sB}$.

The specific enthalpy difference measured from the psychrometric chart (*click adjacent symbol*) when multiplied by the mass flow rate of air will give a value for the heater duty required:

$$q = m \times (h_b - h_a)$$

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Psychro Chart

Alternatively, it can be calculated using the temperature difference and the specific heat capacity for the air sample. The specific heat capacity is a property of a substance; for dry air it has a value of 1.01 kJ/kg K and for water a value of 4.18 kJ/kg K With humid air, the value changes according to the moisture content but is generally taken as 1.02 kJ/kg K for practical air-conditioning.

Thus the heater duty can be calculated from:

$$q = m \times c_p \times (t_b - t_a).$$

Effectiveness

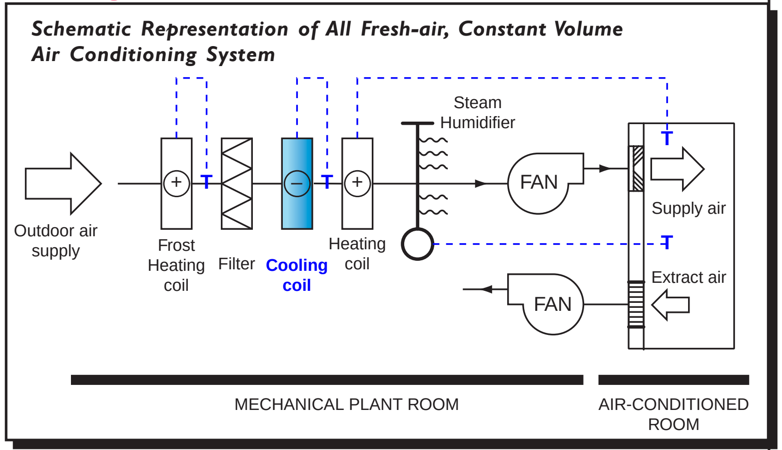
Air heaters, like all heat exchangers, are basically 100% efficient. Their performance is judged in terms of '**effectiveness**' which can be defined as follows:

$$\text{Effectiveness} = \frac{(t_b - t_a)}{(t_{hc} - t_a)}$$

where t_{hc} is the mean surface temperature of the heater coil.

The more rows to the heater, the higher will be the effectiveness. However there is no particular merit in having a high effectiveness and the greater the number of rows, the higher the resistance to air-flow and the greater the energy consumption of the fan. Thus the fewest number of rows that will heat the air to the design temperature is all that is required.

Cooling Coils



Air cooling coils (or batteries) are similar to air heaters with the additional provision of a collection tray and drain for condensate.

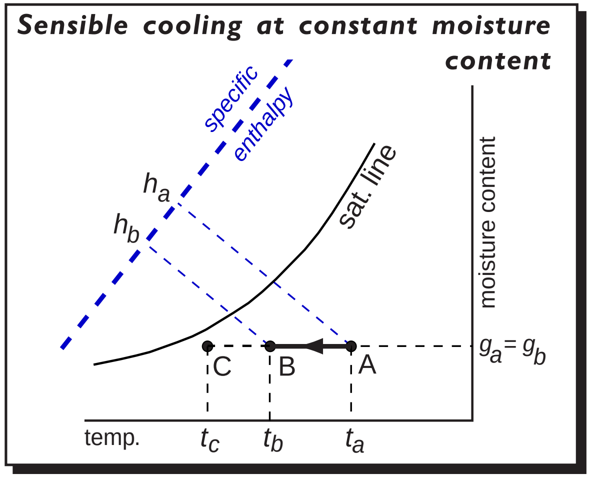
The cooling medium is either chilled water or a refrigerant and the tubes are normally arranged horizontally. Tubes are usually fed in parallel for each row and the rows fed from 'back to front' to approximate to contaflow with air-flow. With refrigerant systems, the coils are often interlaced. Cooling coils usually have more rows than heater coils, typically 4 to 6 compared to 1 or 2 for an air heater battery.

The cooling process is the reverse of the heating process with an added complication. The crucial parameter is the relationship between the dew-point temperature of the air entering the coil to the temperature of the cooling coil surface – the **apparatus dew-point** *(t_{adp})*.

Psychro Chart

Sensible Cooling

When the dew-point of the entering air is above, or equal to, the apparatus dew-point, the process is entirely sensible and the psychrometic process will be the exact reverse of the heating process *(click adjacent symbol)*.



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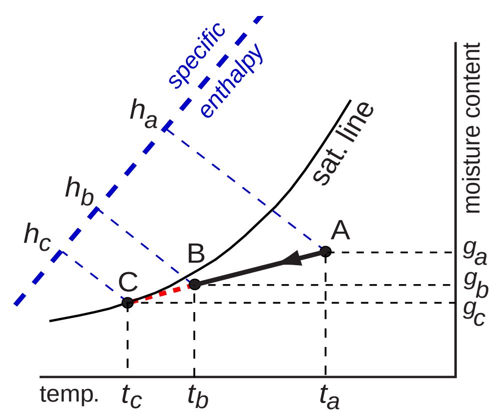
Latent/Sensible Cooling

When the dew-point of the entering air is below the apparatus dew-point, both sensible and latent heat (heat exchange without a change in temperature) processes take place.

The cooling process will again follow a straight line linking A to B, but the extended line will pass through point C – the saturation condition of the apparatus dew-point.

Sensible cooling with dehumidification



Thus there will be both a reduction in temperature and a reduction in moisture content and condensation will occur on the cooling coil surface.

Again, the specific enthalpy difference measured from the psychrometric chart (*click adjacent symbol*) when multiplied by the mass flow rate of air will give a value for the heater duty required:

$$q = m \times (h_a - h_b)$$

Psychro Chart

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Or again it can be calculated in two separate components:

Sensible heat $q_S = m_a \times c_p \times (t_b - t_a)$

and Latent heat $q_L = m_a \times h_{fg}$

where h_{fg} is the latent heat of evaporation for water (approx 2500 kJ/kg)

Contact Factor (β)

With cooling coils, the effectiveness of a coil is usually expressed as a percentage, or it can be referred to as a '**contact factor**' and expressed as a decimal value from:

$$\beta = \frac{g_a - g_b}{g_a - g_c} = \frac{h_a - h_b}{h_a - h_c} \approx \frac{t_a - t_b}{t_a - t_c}$$

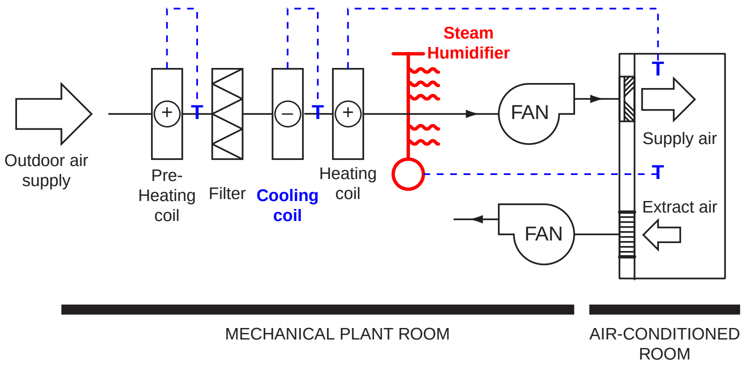
Additionally, the term '**bypass factor**' is sometimes used which is given by:

Bypass factor = 1 – Contact factor

Humidifiers

Humidifiers are devices for increasing the moisture content of humid air. They either inject water (which is evaporated into the air), or inject steam which is simply hot-water vapour. Early steam humidifiers used 'live steam; from steam heating systems but latterly have produced their own steam using electric heating elements. Recent developments have included ultrasonic humidifiers and water injection using compressed air to avoid recirculating water and thus reduce the chance of Legionaires' disease.

Schematic Representation of All Fresh-air, Constant Volume Air Conditioning System



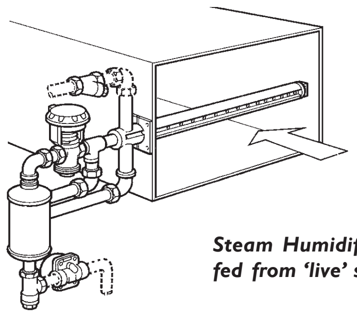
In some instances, particularly industrial applications requiring high humidity **Direct Humidification** is used. This can be achieved using water which can be "atomised", either by injecting with compressed air through high pressure nozzles, or mechanical impingement. Alternatively steam can be injected directly into the space.

In the majority of cases however **Indirect Humidification** is used where a steam or water humidifier is incorporated in an air supply system which supplies treated air to the space through ductwork.

Until comparatively recently nearly all humidifiers were of the water type. However, in the last decade or so, water type humdifiers have become less popular due to their high maintenance, large size and largely unfounded fears of legionella. Steam humidifiers have therefore become more popular due to their compactness and ease of maintenance.

Steam Humidifier

The original steam humidifiers were fed directly with steam available on site for other purposes. They were very common in the USA, as was steam heating. They are fitted with a superheater to avoid introducing water into the airstream and are fully modulating.



Steam Humidifier fed from 'live' steam.

Electric steam humidifiers, generating steam locally, were at first introduced to satisfy small demands and had only on/off control. There use has become more and more common and they are now available in a range of sizes with on/off, step or modulating control.

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Water Spray Types

Water humidifiers are often referred to as **"washers"** and this name can be confusing in that they are not in any way intended to be air cleaners. They are not commonly used today but have been included with these note because there are may systems still operating today, which may contain thse types of humidifier.

All water spray humidifiers are relatively bulky constructions which require regular maintenance. They air velocity through them is usually limited to about 2.5 m^3/s. Eliminator plates are fitted downsteam to minimise the amount of water carried over into the system in the airstream. All of these humidifiers are prone to bacteriological growth and other forms of contamination since the water collection ponds may remain uncirculated for long periods in summer. Regular water treatment, cleaning and "blow-down" are therefore necessary.

Spray Washers

These humidifiers comprise a bank or banks of spray nozzles arranged across the airway through which water is forced at high pressure to produce a fine spray of water. The unevaporated water is collected in a tray or pond and then recycled. In some cases the water supply can be chilled to give a sensible cooling effect and even dehumidify the air although this arrangement is not common today.

Capilliary Washers

These are fitted with "cells" filled with glass fibre or open meshed polythene foam which are wetted with water sprays. They have an extremely high effectiveness (usually referred to as efficiency) of as high as 97%. However they offer a high resistance to the air stream as air has to pass through the packed cells.

Sprayed Coils

The most common of the water spray types. This takes the form of nozzles similar to the spray washer which spray water onto the system cooling coil using its extended surfaces to achieve high evaporation rates and an effectiveness of up to 0.95.

Spinning Disc

These consist of a copper disc fitted with stainless steel teeth around its periphery mounted on a conical brass hub. The disc is rotated by a directly connected induction motor and water fed into the hub is thrown outward by centrifugal force where the teeth "atomise" it into a fine spray mist. They are relatively compact and can achieve a humidifying effectiveness of up to 90%.

Pan Humidifiers

The simplest form of humidifiers these comprise a shallow tray heated by a submerged heating element - usually electric or steam. They have a very low efficiency and their use is discouraged because still, heated water is the most desirable breeding ground for bacteria.

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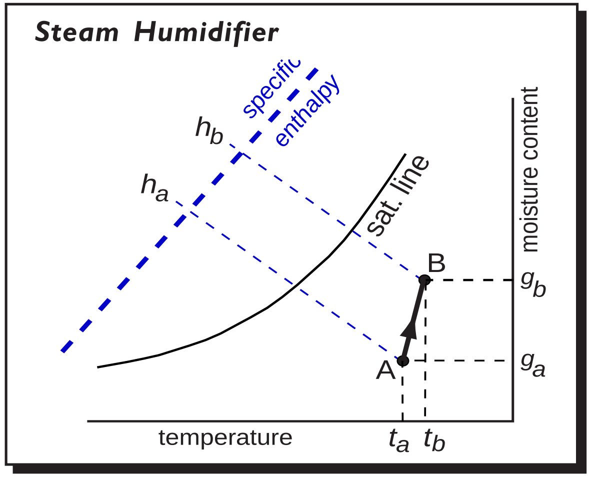
Humidifier – Psychrometric Processes

The psychrometric process through a humidifier depends upon the humidifying medium:

Steam humidifiers

Steam humidifiers have a psychrometric process which approximates to isothermal ie. constant temperature. There will actually be a very small temperature rise. ie normally Δt < 1K *(click on adjacent symbol).*



It should be noted that effectiveness does not apply to either steam or direct water injection humidifiers. It is possible to supply too much steam to an air stream in which case “fogging” will occur and some form of safeguard is usually fitted to prevent this.

With steam humidifiers there is a direct injection of water vapour and the process is almost isothermal, that is at constant temperature. In fact, as the steam is hotter than the air, there will be a small increase in temperature, usually less than 0.5K. The temperature rise is small because the amount of vapour added is normally very small

Psychro Chart

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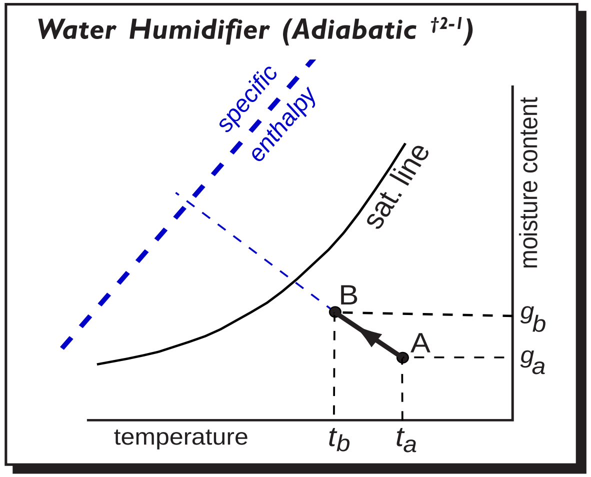
Psychro Chart

Water Humidifiers

Water humidifiers have a psychrometric process approximating to adiabatic saturation. ie. constant enthalpy. This results in a gain in moisture content with a reduction in dry-bulb temperature *(click on adjacent symbol).*

As with cooling coils the term “contact factor” is also commonly used. With water humidifiers the process is very close to an adiabatic process, that is no heat is added or subtracted during the process, so that it takes place at constant enthalpy.



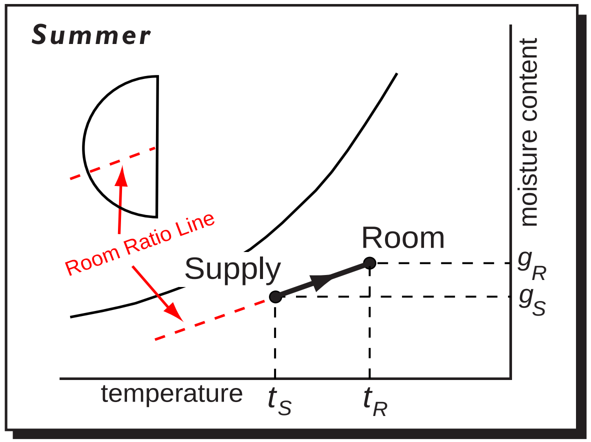
Room Psychrometric Processes

Air entering a room will usually have a different temperature and moisture content to the air within the room. Its temperature and moisture content will therefore be changed as it adds or removes heat from the room air.

Sensible heat exchange causes a change in **temperature** and **latent** heat a change in **moisture content**, and a room may experience either a sensible heat gain or a sensible heat loss depending on the circumstances (ie usually a gain in summer and a loss in winter). Thus the temperature of the air required to be supplied to the room will vary according to whether the air is required to heat or cool the room.

Except for some rare industrial processes a room will not experience a latent loss. Occupancy and most processes give rise to latent gains. Thus the air entering a room will normallyhave a moisture content less than the leaving air irrespective of the season of the year.

The the air entering the room is considered to be at the '**supply condition**' and the air leaving the room the '**room condition**'.



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Room Ratio Line

The line between these two conditions on a psychrometric chart is known as the '**room ratio line (*y*)**' and represents the psychrometric process of air passing through the room *(click on adjacent symbol).*

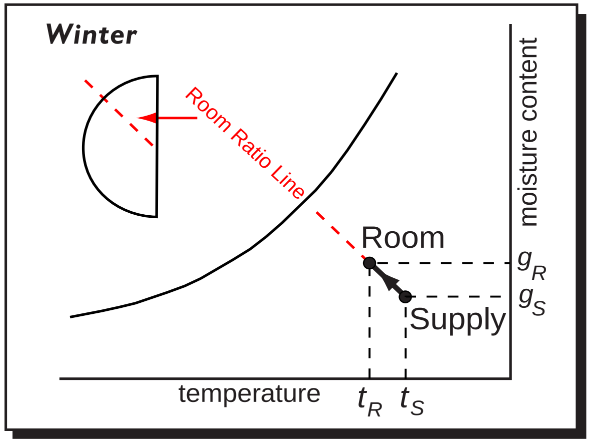
The room ratio line is also known as the room **process** line, and any supply condition on that line will satisfy the room condition at the relevant amounts (supply mass) of air. When designing and before the supply condition is determined, it is usual to draw the room ratio line on the pair of Sensible/Total Heat quadrants shown on the psychrometric chart.

The room ratio line being determined from:

$$y = \frac{q_S}{q_S + q_L}$$

where q_S is the sensible heat gain and q_L the latent heat gain.

A line can then be drawn on the chart, passing through the required room condition, parallel to the Room Ratio Line to determine the required supply condition.



Mixing Air Streams

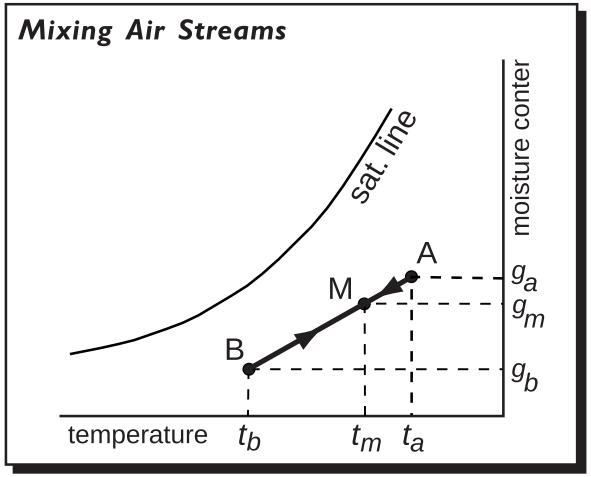
Any two mixing air streams will give rise to a condition having a condition between the two mixing conditions. The actual condition will vary in proportion to the relative masses of the two air streams.

ie $$m_M \cdot t_M = m_A \cdot t_A + m_B \cdot t_B$$

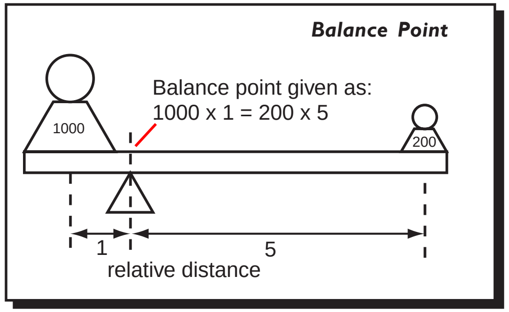
where $$m_M = m_A + m_B$$

The same relationship applies for specific enthalpy and moisture content. On a psychrometric chart, the 'mixed' condition will lie on a straight line joining the conditions of the two mixing air streams *(click adjacent symbol)*.

Psychro Chart



If in doubt, remember that the mixed condition will always be closest to the larger component of the two mixing air streams similar to the fulcrum point for balanced masses.



Quick Revision Study Guide 2

The following questions are intended as a quick study questionnaire to ensure you have grasped the general principles of this and the previouschapter.

It is intended that your answers should be, short-phrased, quick answers or sketches to the questions.

For suggested solutions to these questions, please refer to the Denco Website: www. denco.co.uk

1. Dry air flows over a heating coil and absorbs heat at the rate of 10 kW. If the air temperature and pressure immediately in front of the coil are 325K and 1 bar respectively, and the mass flow rate is 0.5 kg/s, determine the temperature of the air leaving the coil.
   Note any assumptions made.

2. If moist air is at standard atmospheric pressure and the partial pressure of the water vapour is 2.486 kPa, what is the partial pressure of the dry air?
   If the moist air is now cooled (assume constant pressure), at what temperature will the water vapour start to condense?

3. A person loses water by sweating at an average of 0.072 kg per hour. Assuming evaporating is taking place at 30°C, what rate of cooling does this represent?

4. If air at 10°C and 100% saturation is sensibly heated to 22°C, what will be the percentage saturation at the new condition?

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Chapter Notes

†2-1: Adiabatic Humidification

The theoretical process line follows the adiabatic saturation temperature, although in practice, this is usually drawn as a line following the constant wet-bulb temperature line of the entering air condition. As a close approximation for air-conditioning calculations however, it is usual to consider the process occurring at constant specific enthalpy.