# Applied Psychrometrics for Air Conditioning Systems


**By**

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# Course Description

Firstly understanding the basic contents of the psychrometric chart and then discuss the basic psychrometric processes. A detailed Psychrometric approach is carried out utilising the data available from cooling load calculations to determine the coil conditions and selection of the air conditioner. All fresh air, high latent load and humidity control applications are discussed. Importance of Sensible heat ratio is discussed and distinguishes the deference between high & low sensible heat applications. This presentation is suitable for young as well as experienced engineers that provide basic knowledge of Psychometry and its applications in practice.

# Learning Objectives

1. Explain Psychrometric Definitions
2. Describe Psychrometric Properties
3. Understand the basic Psychrometric processes & the Chart
4. Discuss air mixing principle and calculations
5. Explain how Psychrometric calculations used define coil conditions
6. Understand the importance of apparatus dew point to maintain room RH %
7. Recognise the importance of By-pass Factor
8. High latent heat application
9. High Sensible heat application
10. All out door air application

# Psychrometric Definitions

**Dry-bulb Temperature** – Temperature as registered by an ordinary thermometer

**Wet-bulb Temperature** – Temperature as registered by a thermometer with the bulb covered by a wetted wick and exposed to moving air. (*Thermodynamic Wet Bulb -Adiabatic Saturation temperature* )

**Dew point Temperature** – Temperature at which condensation of moisture begins when the air is cooled

# Psychrometric Definitions

**Relative Humidity** – Ratio of actual water vapour pressure of air to the saturated water vapour pressure of air at the same temperature

**Specific Humidity** - Weight of water vapour in grams or Kg per Kg of dry air **(Moisture Content)**

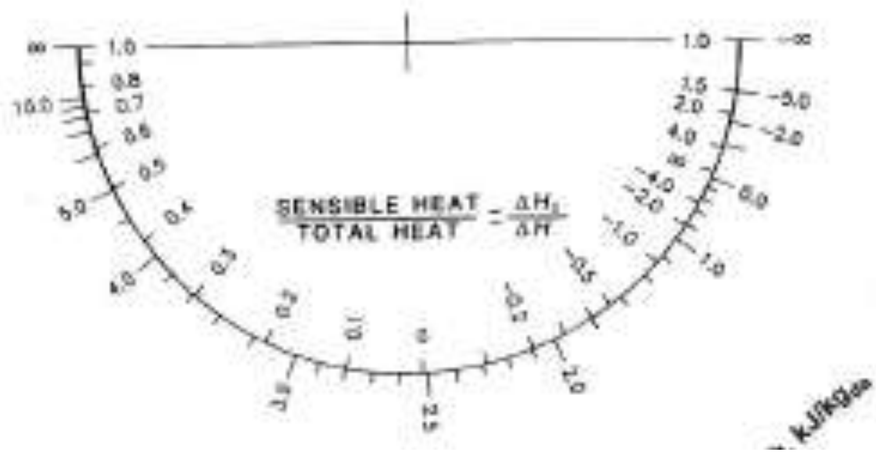
**Enthalpy** - Quantity of heat in the air above an arbitrary datum, in KJ/Kg. of dry air.

(the datum for dry air is $0^{o}C$ and moisture content, water at $0^{o}C$)

# Psychrometric Definitions

**Sensible Heat Factor** - Ratio of Sensible Heat to Total Heat

**Alignment Circle** - Located at 24°C DB and 50% RH used with sensible heat factor to plot various air conditioning processes



# Useful conversion factors

| | |
|---|---|
| **Enthalpy** | Btu / lb of dry air x 2.33 gives KJ / Kg of dry air |
| **Mass** | 1 lb = 7000 grains = 0.454 Kg |
| **Flow rate** | Cubic feet / min x 0.472 gives l / sec |

# History- Psychrometric Pioneers

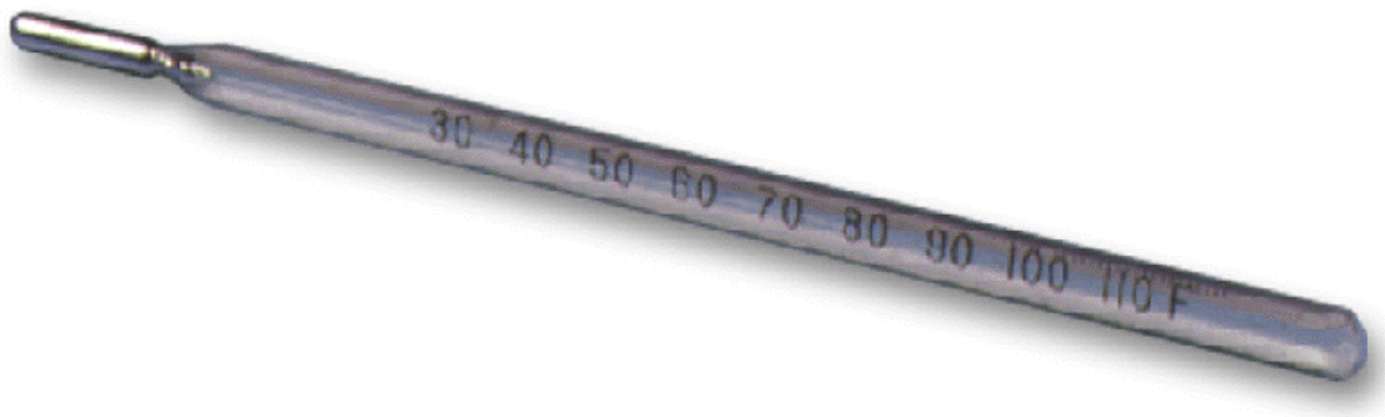
1. Observation & Philosophical Period
   1. Aanaximenes of Miletus, (6th Century B.C.) Greek Philosopher in 570 B.C. to Gaius, Plinus Secundus, (23-79 A.D.)– Roman Naturalist.
2. The Experimental Science Period
   1. Alberti, Leone Battista (1414-1472) Italian Philosopher to Bockmann, Carl Wilhelm, Jr (1773-1821), German.
3. The Beginning of Unifying Theory Regarding The Behaviour of Air And Water Vapour
   1. Dalton, John (1766-1844), English Scientist to Swann, W. F. G., English Scientist
4. Transition From Empirical To Rational Period
   1. **Carrier, Willis H. (1876-1950) to Keenan Joseph H. and Keyes, Fred G. (1936), professors of MIT, USA.**
5. The Mature Science Period
   1. Goodman, William (1903-1993) Consulting engineer Chicago, Illinois to Nelson, H.F. and Sauer, H. J. (2001), USA

   *Curtesy of Donald P. Gatley - Understanding Psychrometrics*

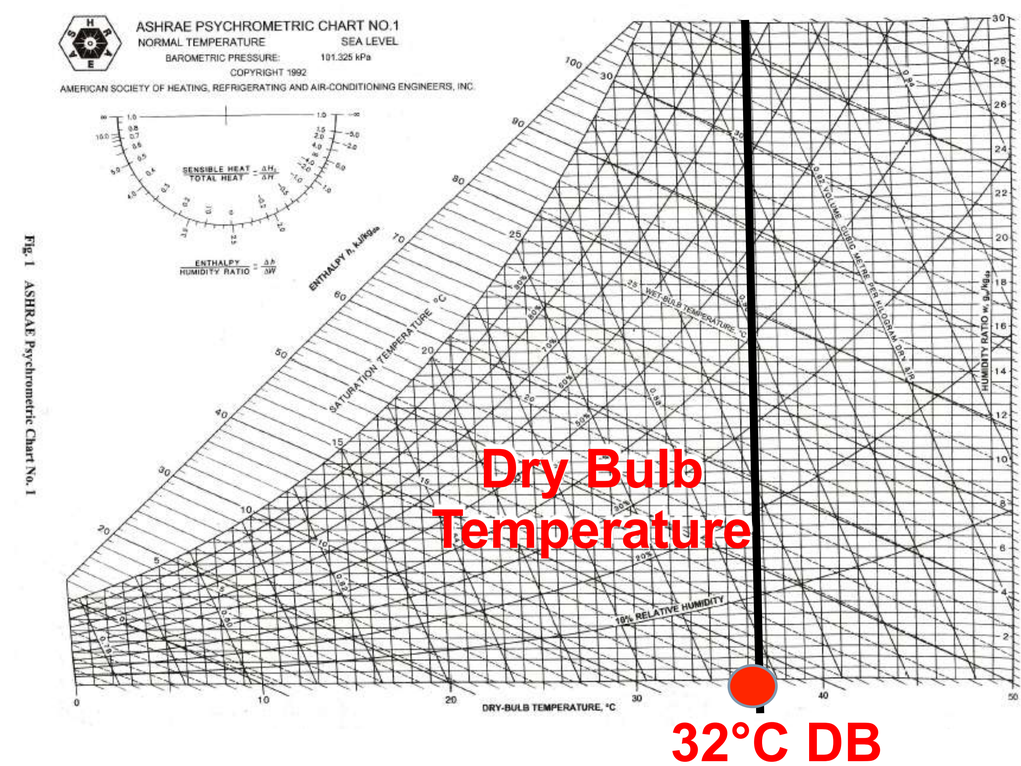
# Psychrometric Properties of Air

- Dry-bulb temperature
- Wet-bulb temperature
- Dew-point temperature
- Relative humidity
- Humidity ratio
- Specific Volume
- Specific Enthalpy

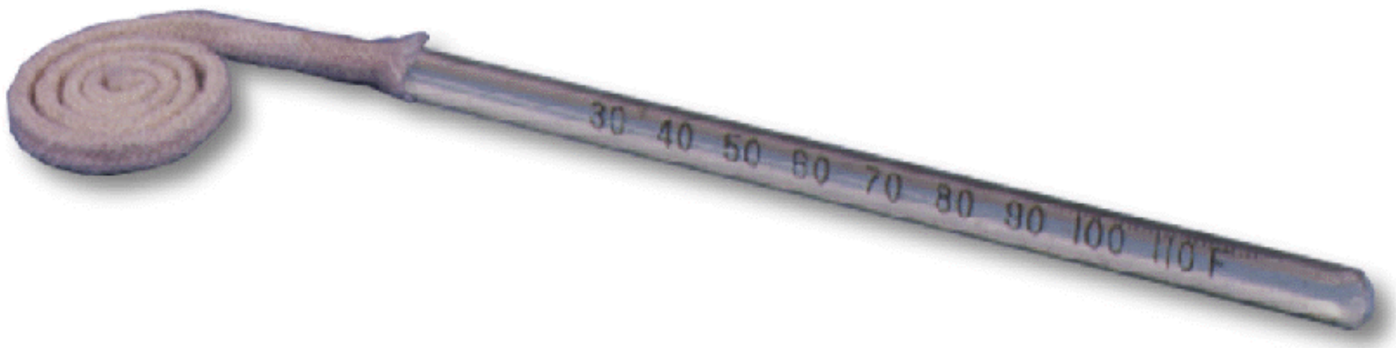
# Dry-Bulb Temperature

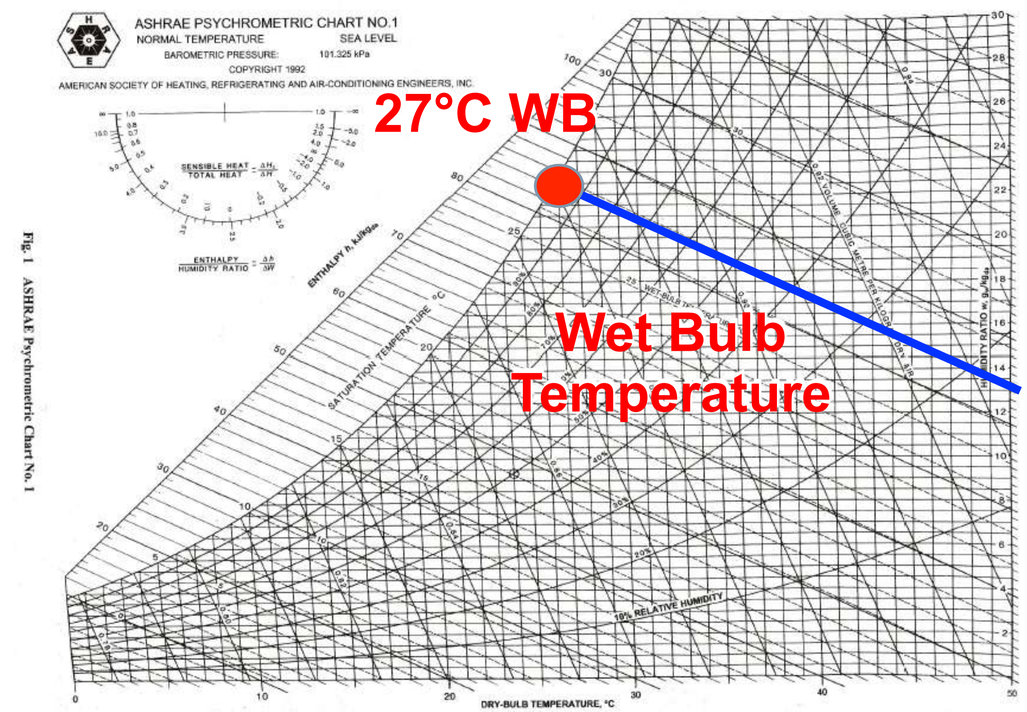



**Dry-bulb temperatures** are read from an ordinary thermometer that has a dry bulb.



# Wet-Bulb Temperature




**Wet-bulb temperatures** are read from a thermometer whose bulb is covered by a wet wick. The difference between the wet-bulb temperature and the dry-bulb temperature is caused by the cooling effect produced by the evaporation of moisture from the wick.
This evaporation effect reduces the temperature of the bulb and, therefore, the thermometer reading.

# Dew-point Temperature

The third property, **dew-point temperature**, is the temperature at which moisture leaves the air and condenses on objects, just as dew forms on grass and plant leaves.



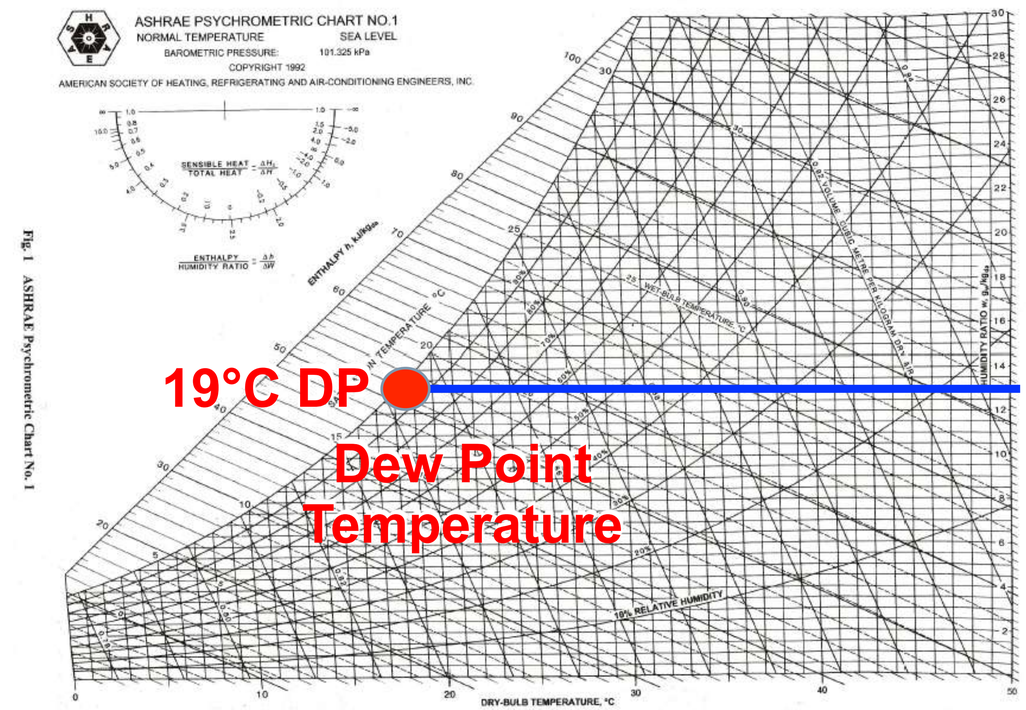



Fig. 1 ASHRAE Psychrometric Chart No. 1

# Humidity

Humidity is the amount of water in the air.  Air is a mixture of gasses & water vapour.

Water vapour condensation on window due to high humidity



High Humidity affects discomfort to occupants in buildings. Also it affects the furniture, equipment & material. Often walls get damp and cause fungus & moulds to form, causing health risks to humans. High humidity can short circuit miniature electronic circuits, hence some IT applications wants close control of Relative Humidity and Temperature in Air-conditioned rooms.

# Relative Humidity

$$\text{Relative Humidity} = \frac{\text{Amount of moisture that a given amount of air is holding}}{\text{Amount of moisture that a given amount of air can hold}}$$

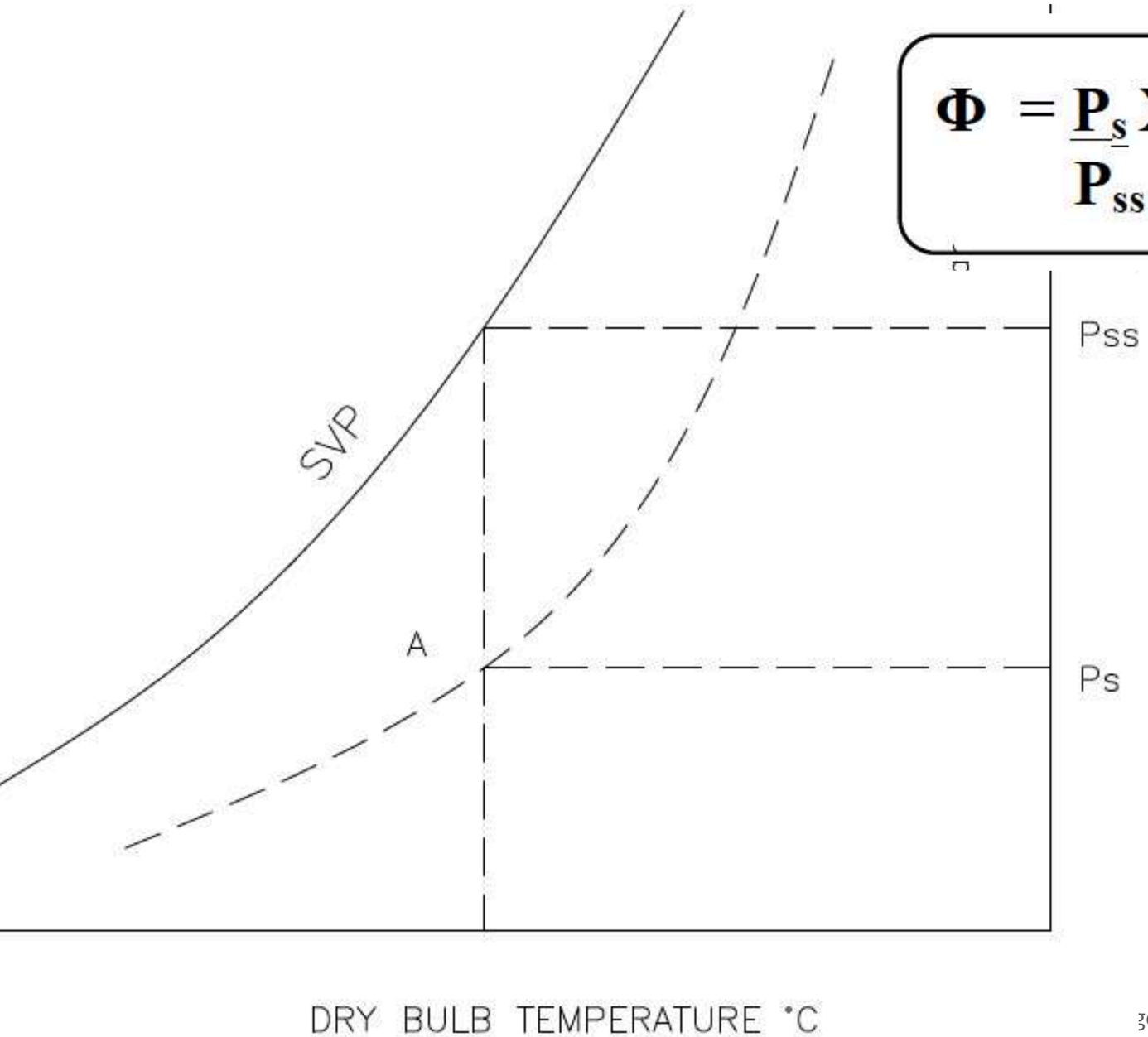
The fourth property, **relative humidity**, is a comparison of the amount of moisture that a given amount of air *is* holding, to the amount of moisture that the same amount of air *can* hold, at the same dry-bulb temperature.

***Definition***

*The ratio of the actual water vapour pressure to the saturated water vapour pressure at the same dry bulb temperature*

# Relative Humidity

$$\Phi = \frac{P_s}{P_{ss}} X\ 100 \text{ -------Relative Humidity \%}$$



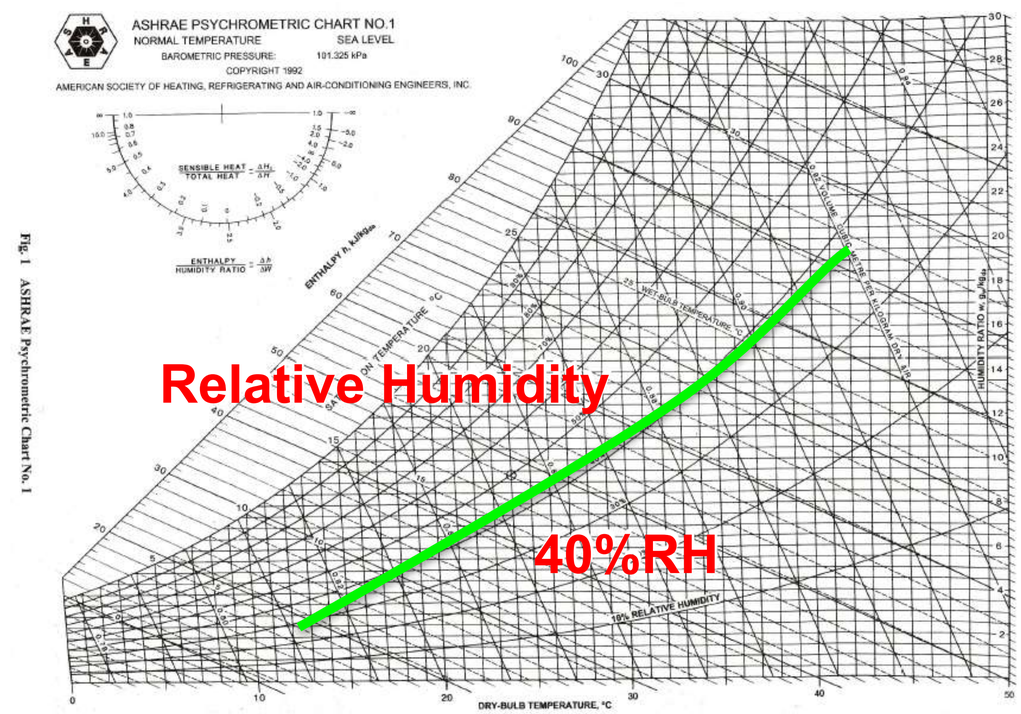




Fig. 1 ASHRAE Psychrometric Chart No. 1

goda

# Humidity Ratio (Moisture Content)

Finally, **humidity ratio** describes the actual weight of water in an air – water vapour mixture. Humidity ratio can be expressed as Kg of moisture per Kg of dry air, or as grams of moisture per Kg of dry air.

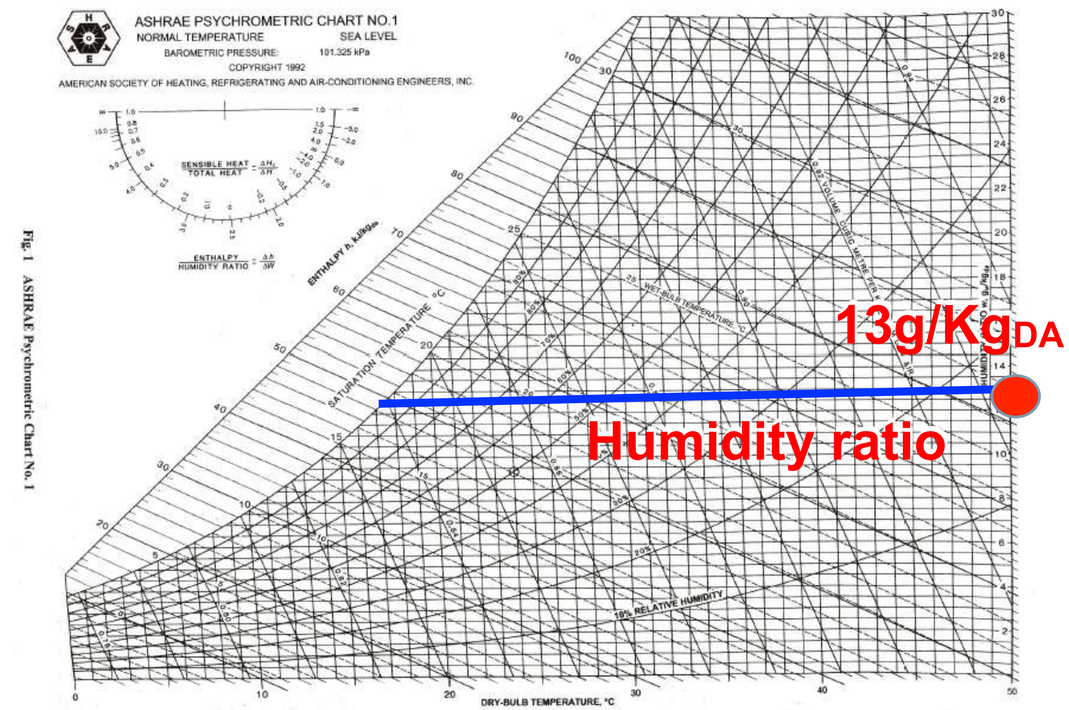



Fig. 1 ASHRAE Psychrometric Chart No. 1

# What is Fog ?

Fog begins to form when water vapour condenses into tiny liquid water droplets that are suspended in the air. Fog can be considered a type of low-lying cloud usually resembling stratus, and is heavily influenced by nearby bodies of water, topography, and wind conditions

# Fog Occurs When Air is Saturated

When the dry-bulb, wet-bulb, and dew-point temperatures are the same, the air is **saturated**. It can hold no more moisture. When air is at a saturated condition, moisture entering the air displaces moisture within the air. The displaced moisture leaves the air in the form of fine droplets. When this condition occurs in nature, it is called fog

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Fog area of the Psychrometric chart

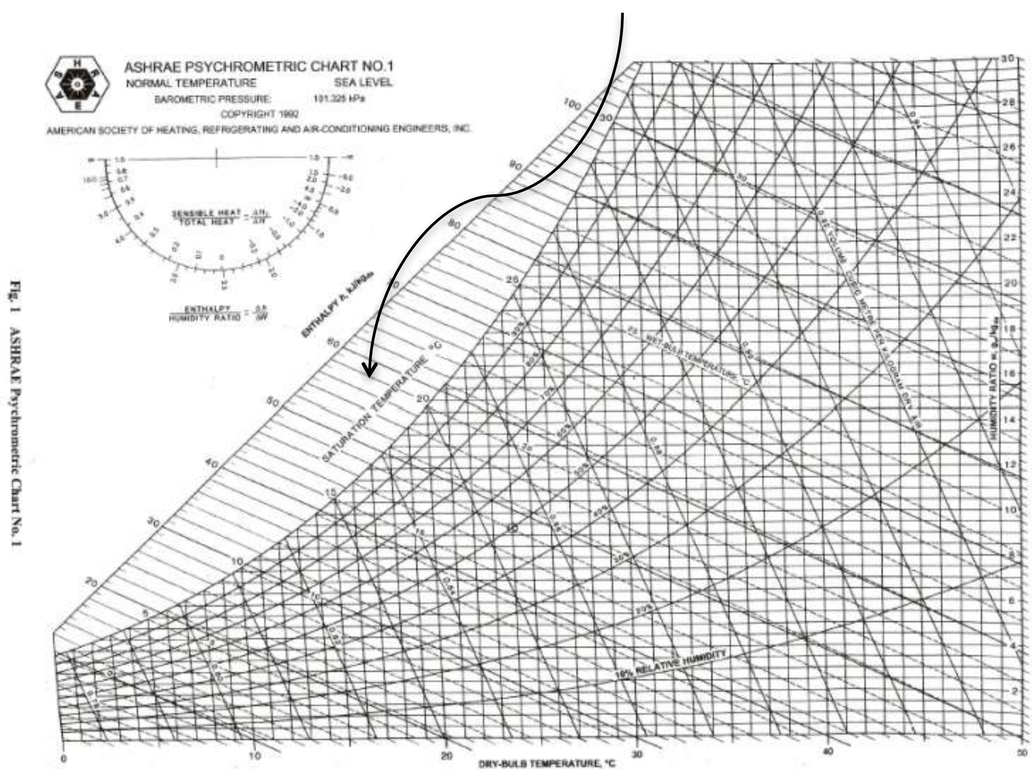
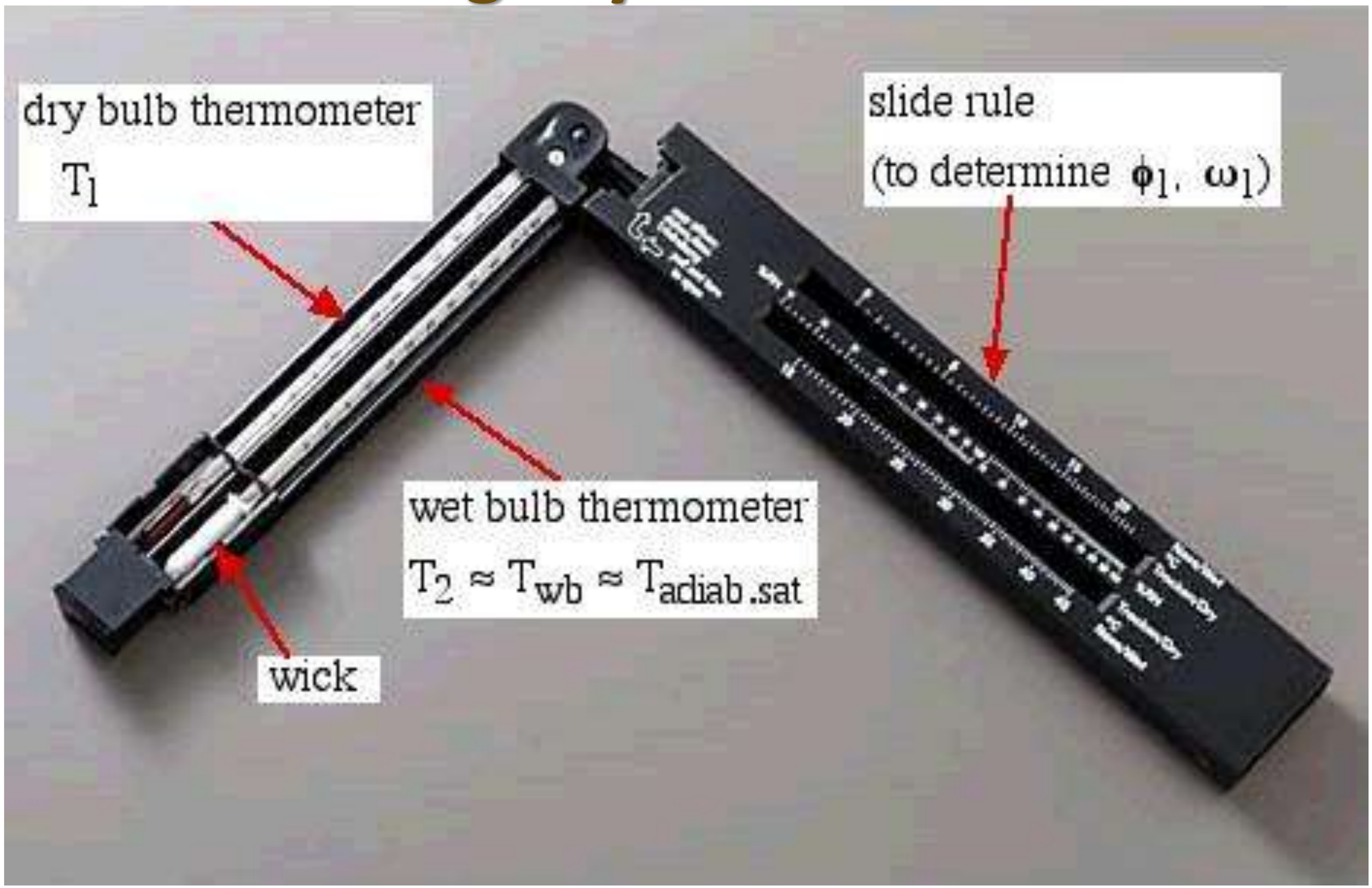



Fig. 1 ASHRAE Psychrometric Chart No. 1

# Sling Psychrometer



# Psychrometric Chart

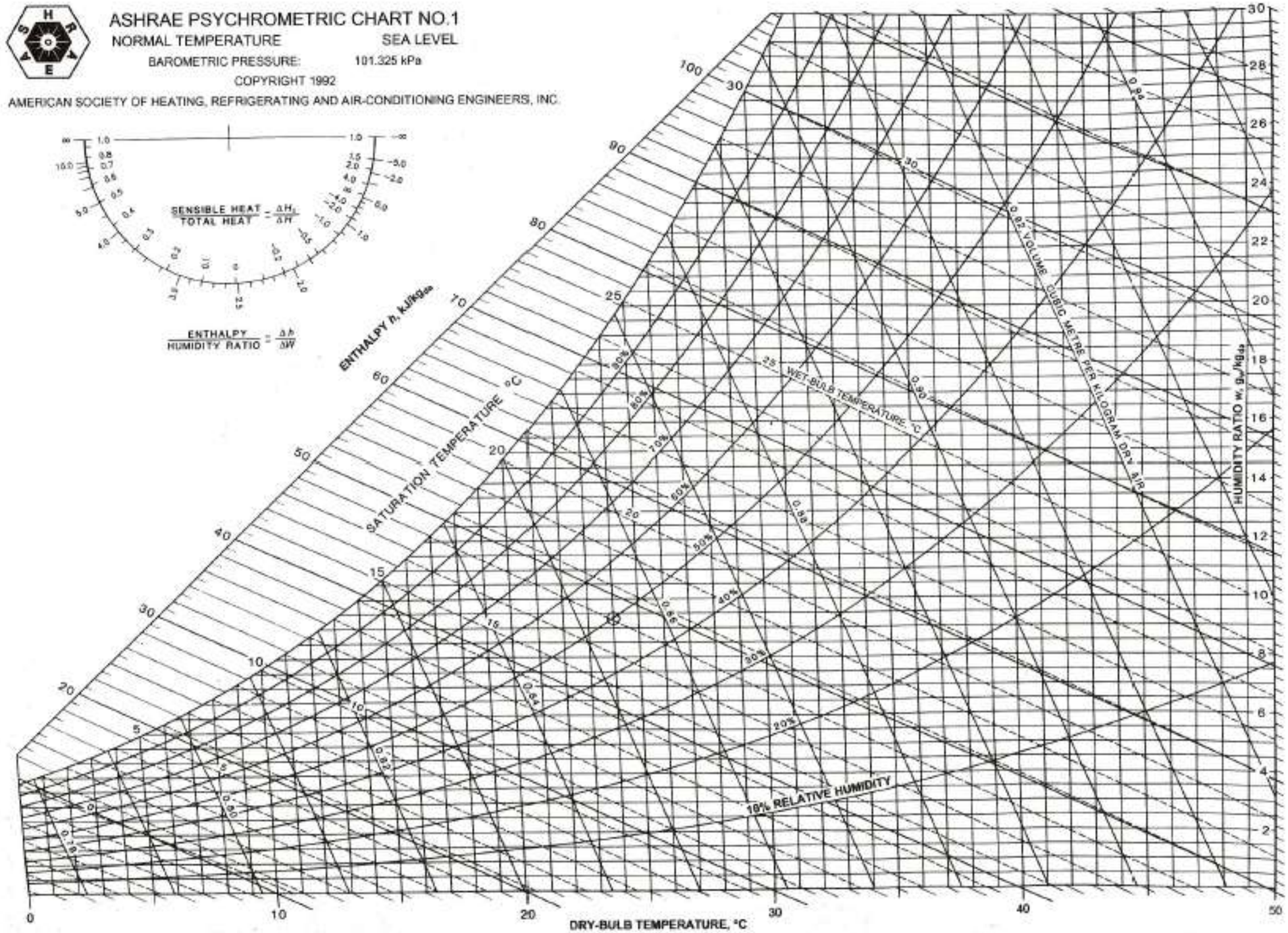
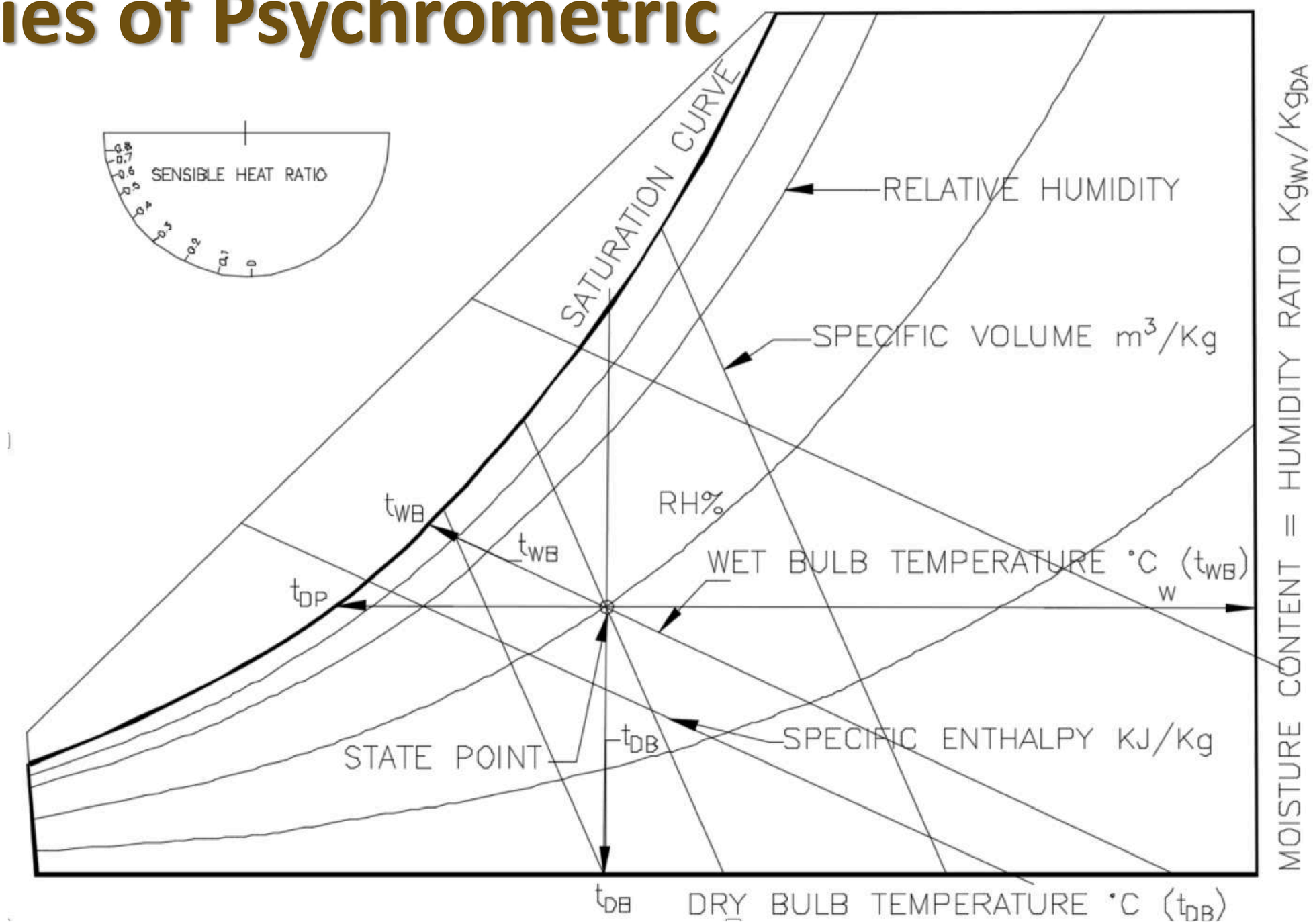



Fig. 1 ASHRAE Psychrometric Chart No. 1

# Properties of Psychrometric Chart



# Temperature & RH

» Comparison of outdoor conditions of deferent locations

| | Unit | **Colombo** | **Chennai** | **Delhi** | **London** |
|---|---|---|---|---|---|
| dry bulb | °C | 33 | 38.5 | 43.8 | 28.3 |
| wet bulb | °C | 28 | 28.3 | 29.6 | 19.8 |
| RH | % | 68 | 46 | 36 | 52 |

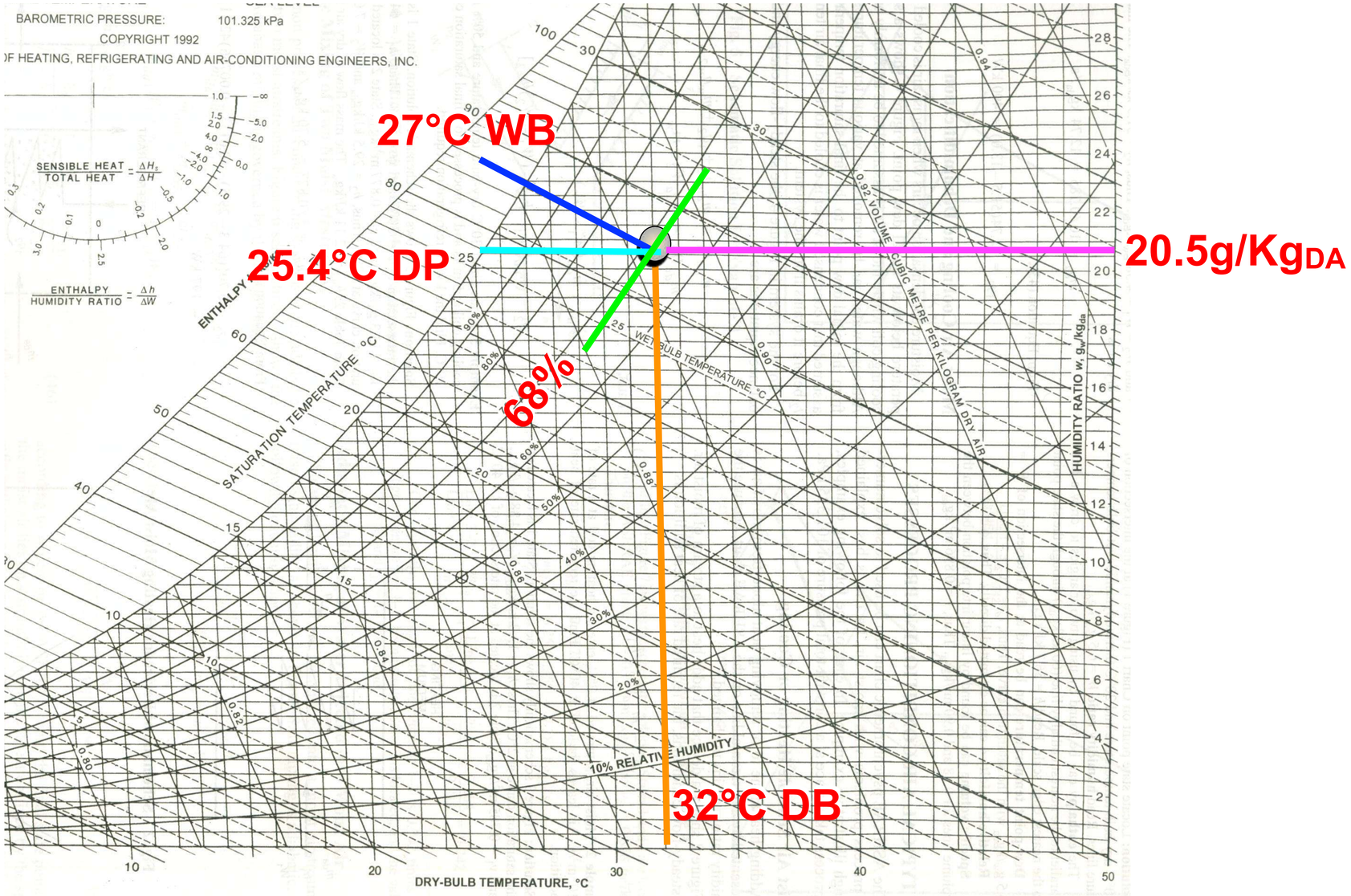
# Summer Design Conditions

EXAMPLE

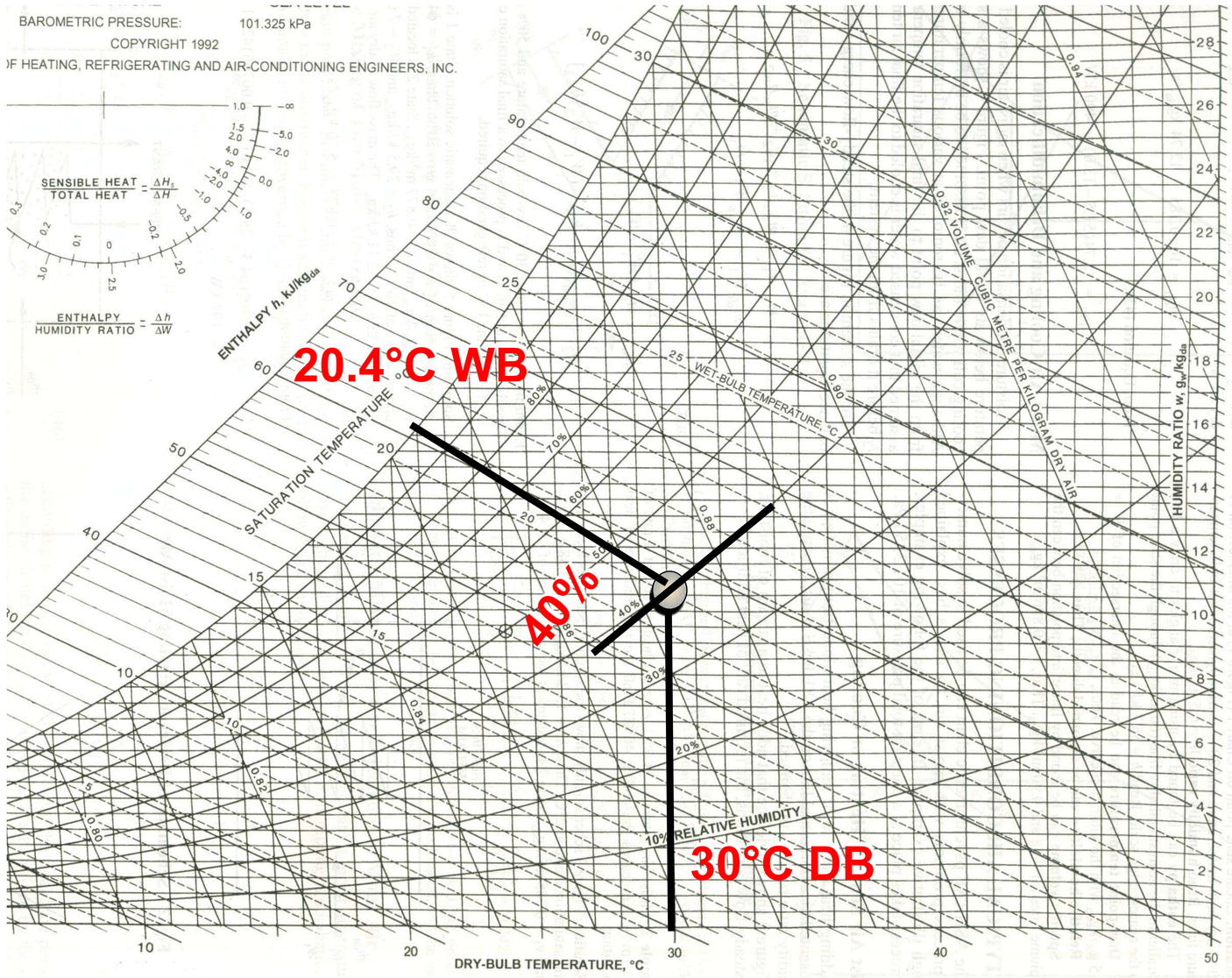
» 32°C DB (dry bulb)
» 27°C WB (wet bulb)

For example, let's assume that the summer design conditions are 32°C dry bulb and 27°C wet bulb. What is the relative humidity, humidity ratio, and dew point?

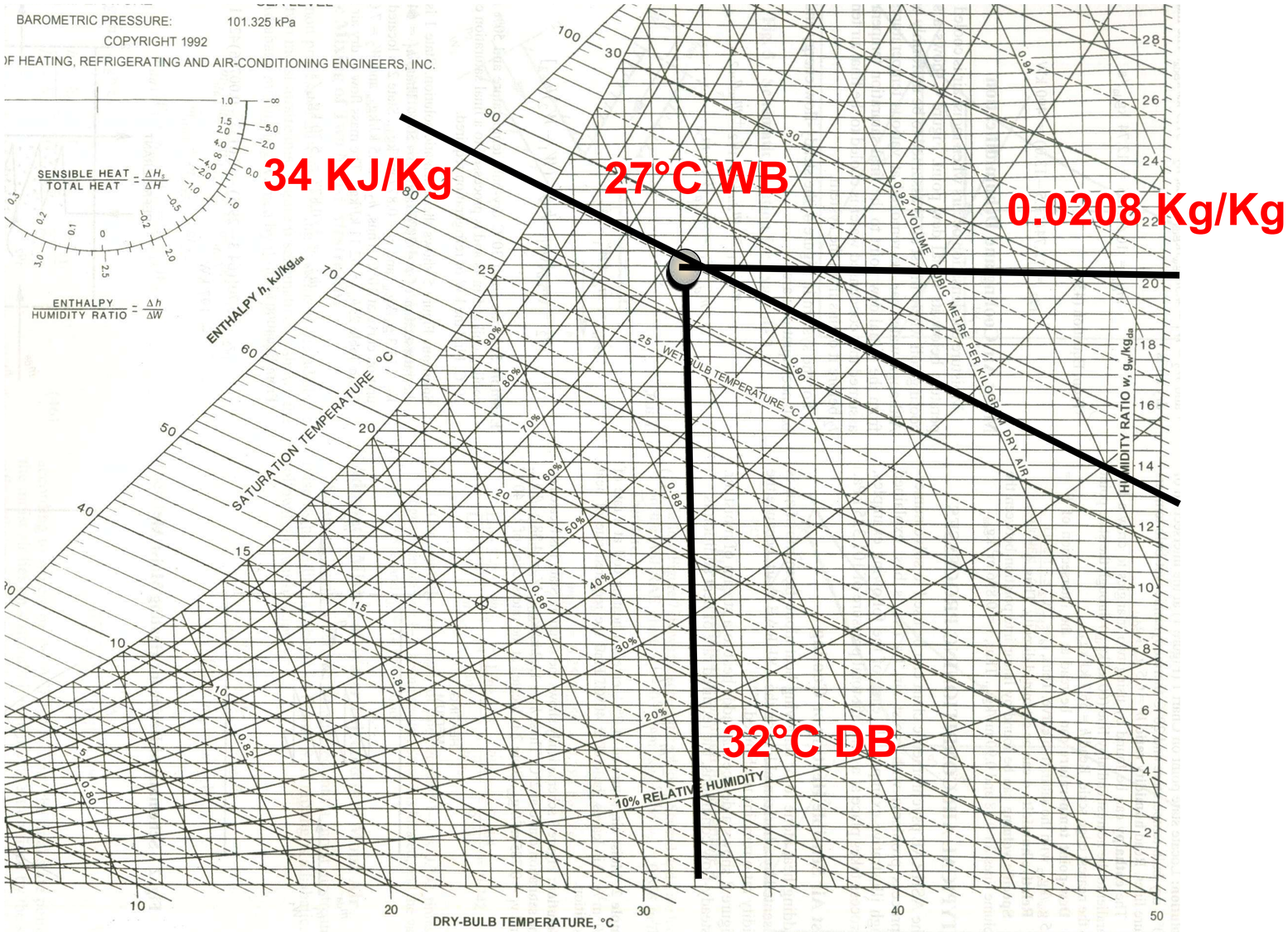
# Given 32°C DB and 27°C WB. What is the dew-point temperature, RH% & Moisture Content



# Given 30°C DB and 40% RH
# What is the wet bulb temperature

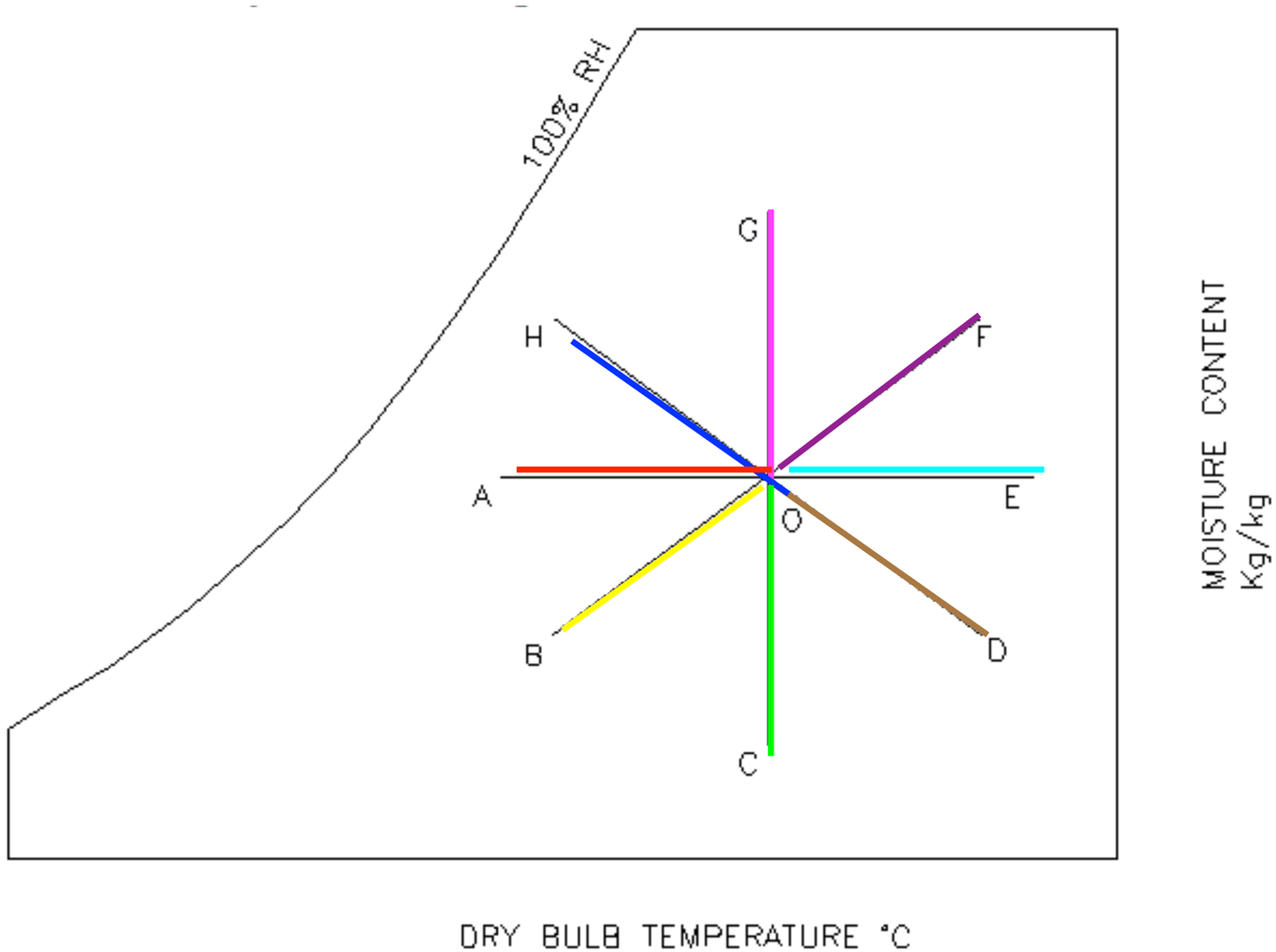


# Given 15°C DB and 12°C WB, what is the moisture content and enthalpy



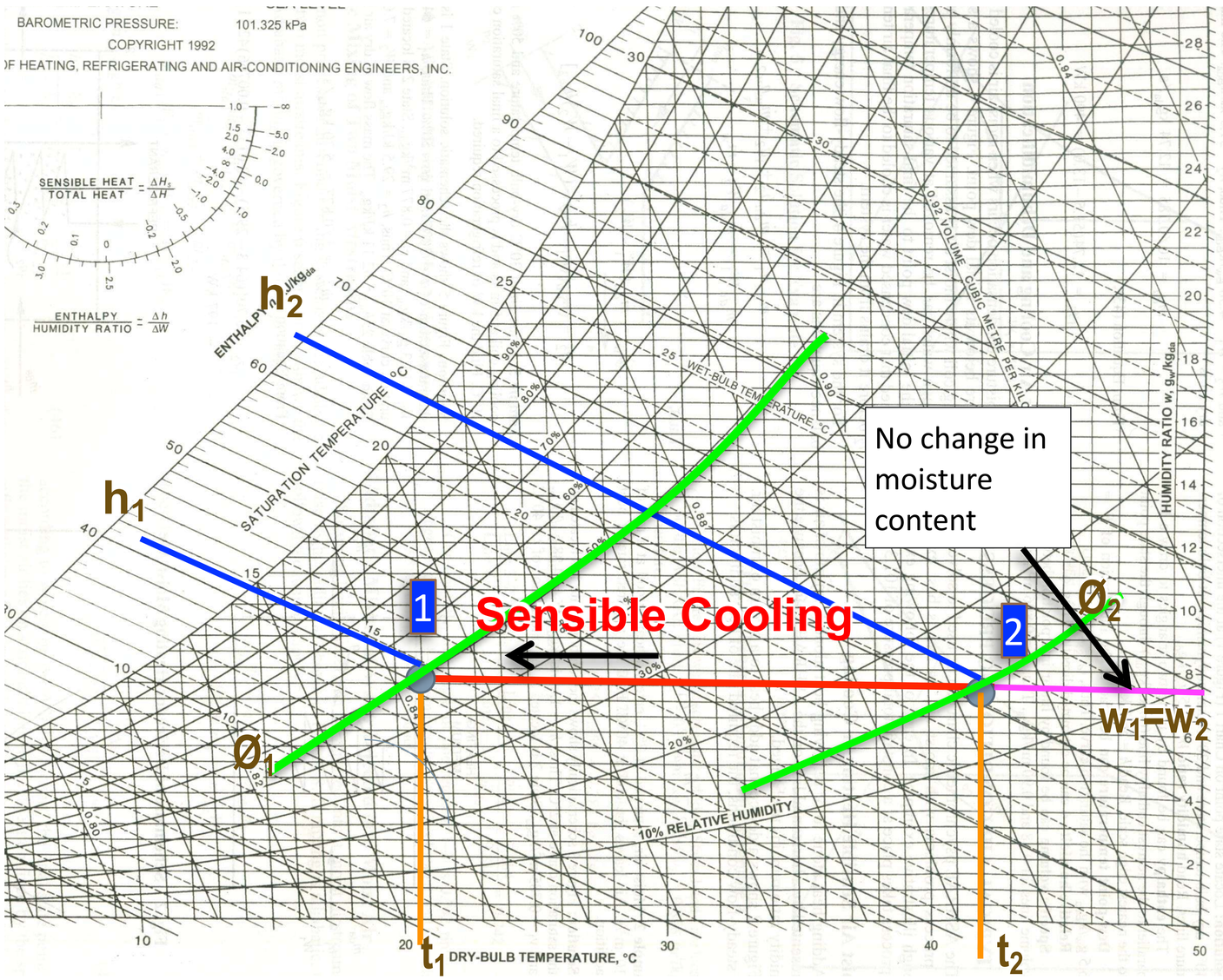
# Psychrometrics Processes

# Psychrometric Processes




1. OA - Sensible Cooling
2. OB - Cooling & De-Humidification
3. OC - De-Humidification
4. OD - Heating & De-humidification
5. OE - Sensible Heating
6. OF - Heating & Humidification
7. OG - Humidification
8. OH - Cooling & humidification

# Sensible Cooling






## Sensible cooling

$t_{DB2} > t_{DB1}$

$t_{WB2} > t_{WB1}$

$RH_2 < RH_1$

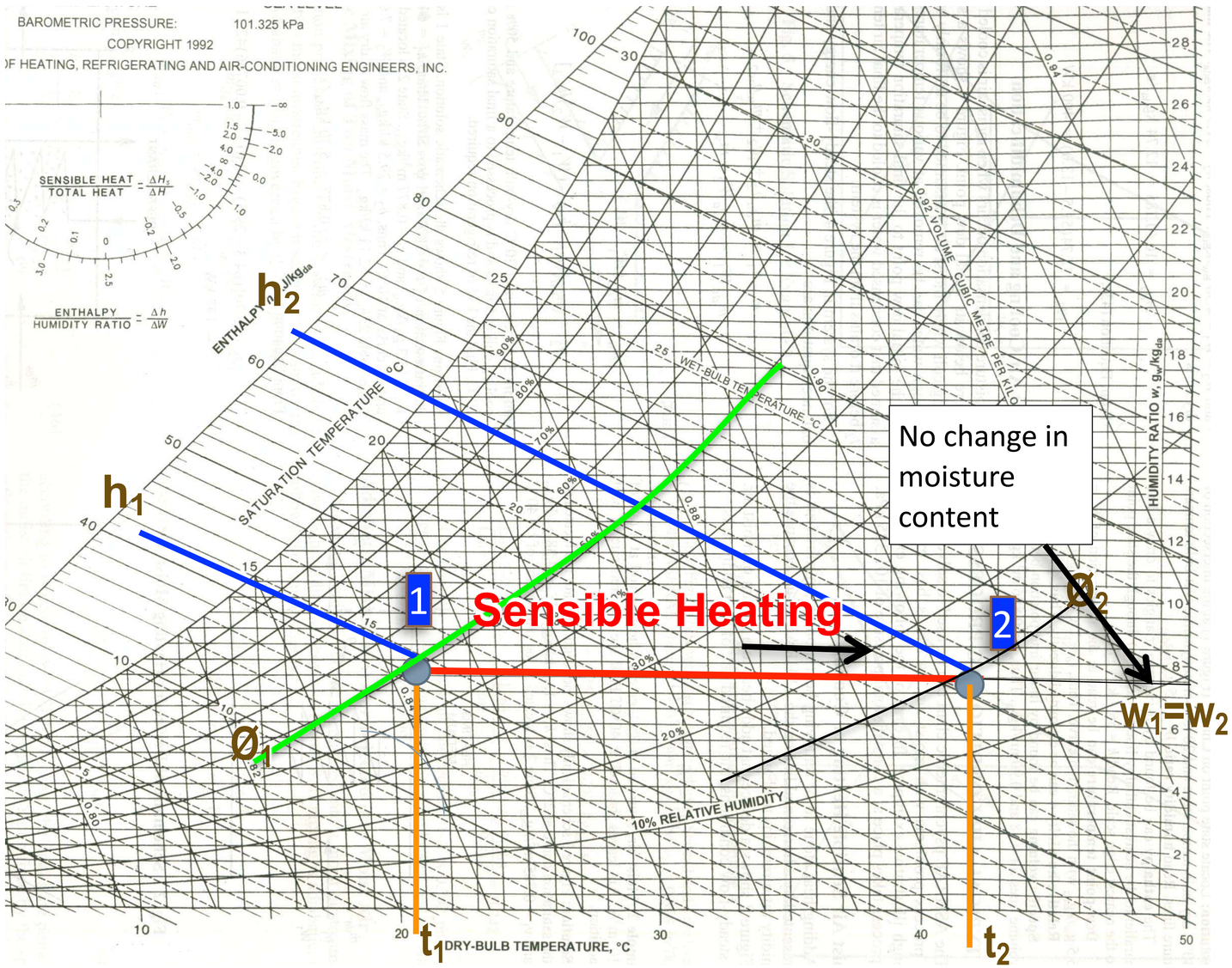
$w_2 = w_1$

$h_2 > h_1$

$Vs_2 > Vs_1$

Active Chilled Beam

# Sensible Heating




## Sensible Heating

$t_{DB1} < t_{DB2}$

$t_{WB1} < t_{WB2}$

$RH_1 > RH_2$

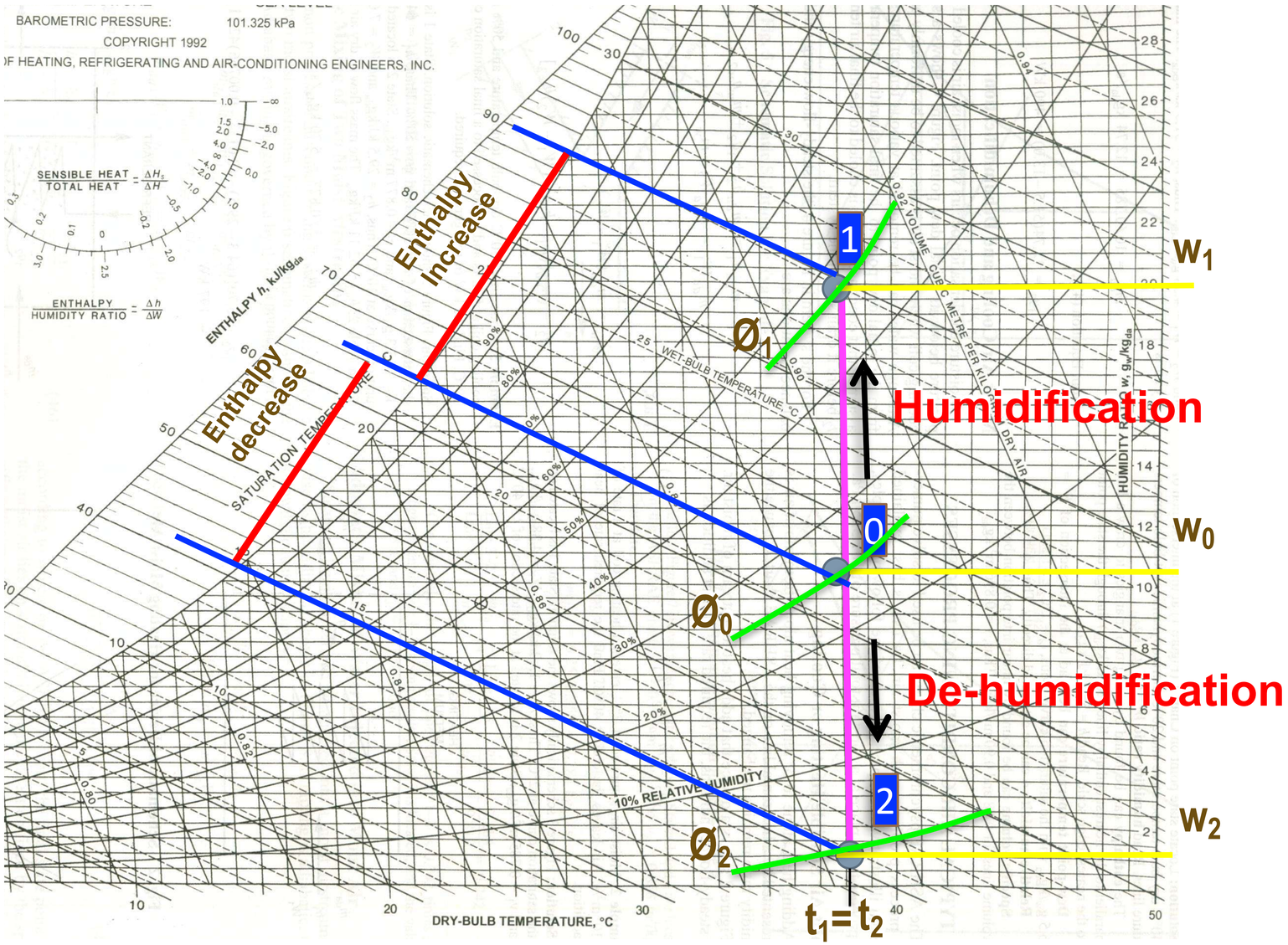
$w_1 = w_2$

$h_1 < h_2$

$Vs_1 < Vs_2$

Hot Water Coil

# Humidification / De-humidification






## Humidification

$t_{DB0} = t_{DB1}$

$t_{wb1} > t_{wb0}$

$RH_0 < RH_1$

$w_1 > w_0$

$h_1 > h_0$

$Vs_1 > Vs_0$

## De-Humidification

$t_{DB0} = t_{DB2}$

$T_{wb0} > t_{wb2}$

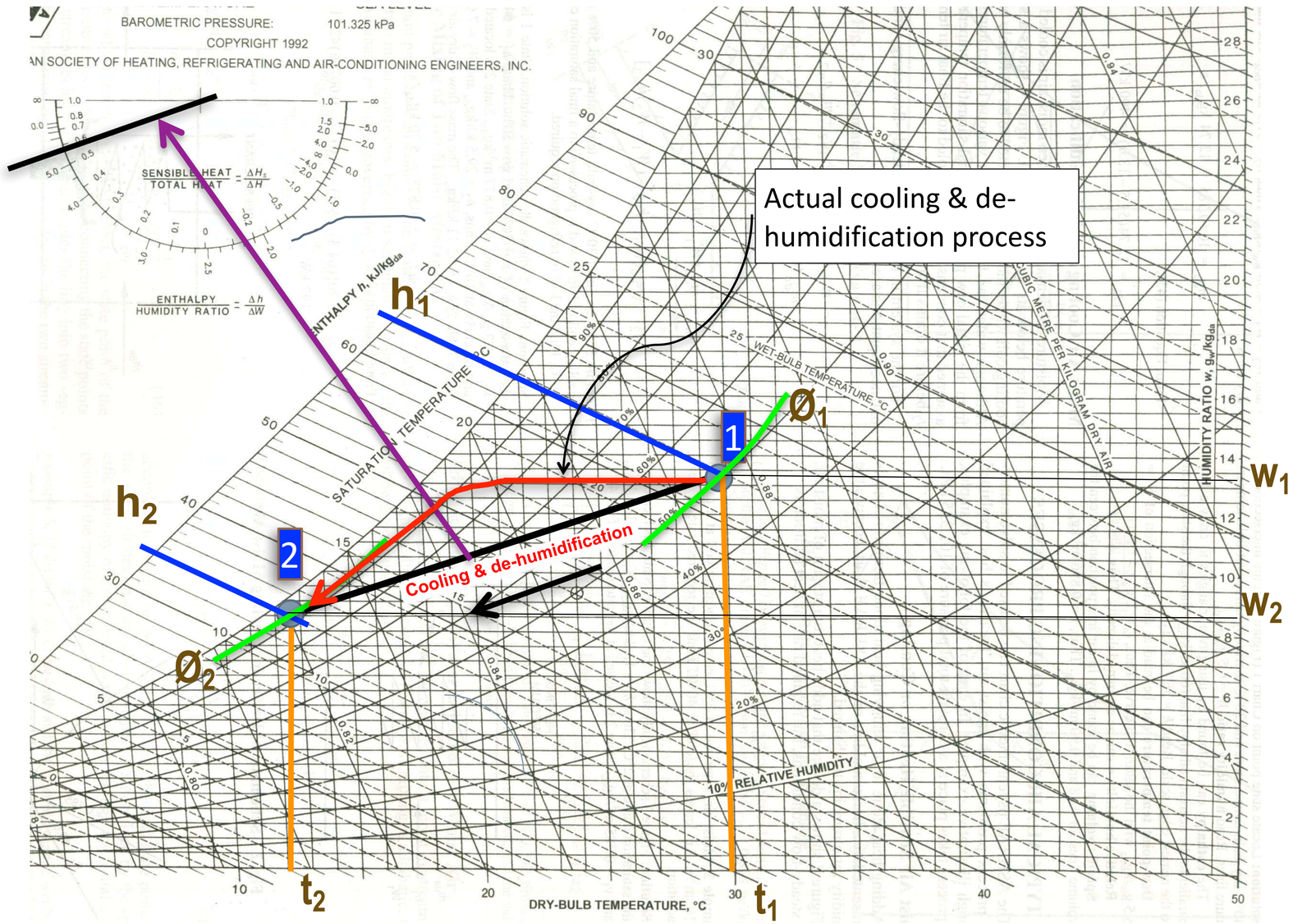
$RH_2 < RH_0$

$w_0 > w_2$

$h_0 > h_2$

$Vs_0 > Vs_2$

# Cooling & De-humidification

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## Cooling & De-Humidification

$t_{DB1} > t_{DB2}$

$t_{WB1} > t_{wb2}$

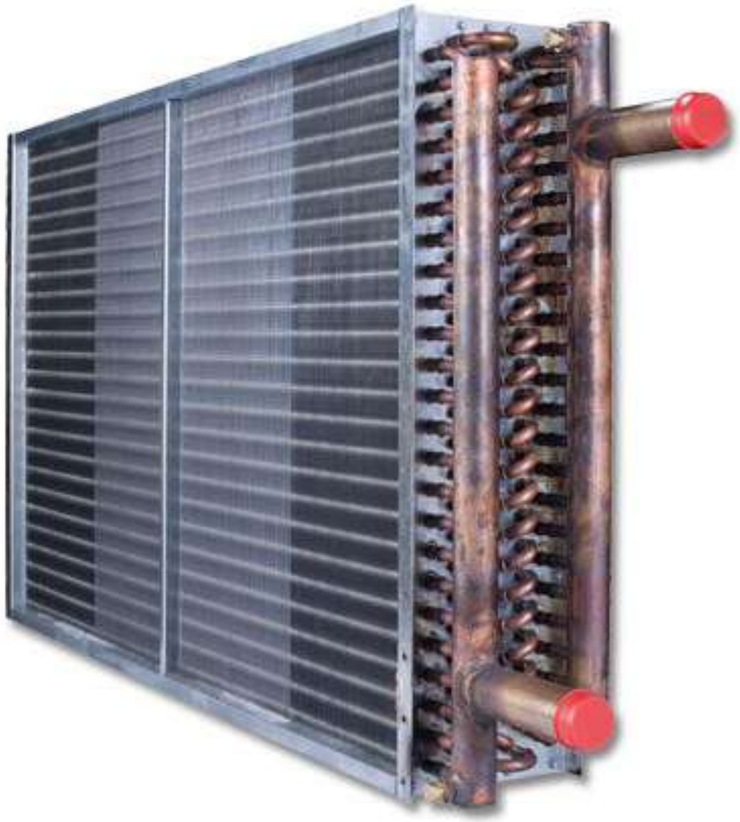
$RH_1 < RH_2$

$w_1 > w_2$

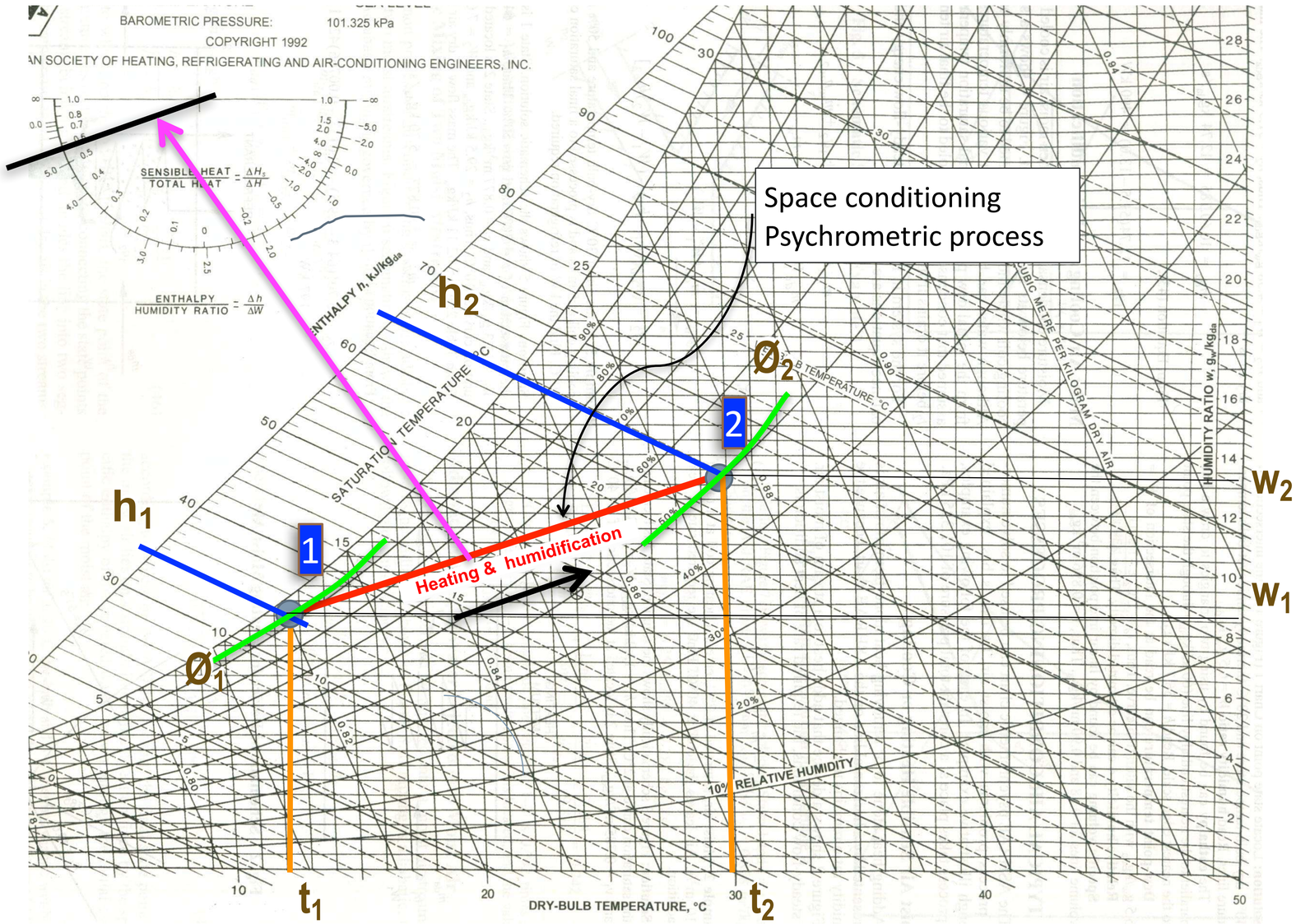
$h_1 > h_2$

$Vs_1 > Vs_2$

Cooling & De-humidifying Coil



# Heating & Humidification

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## Heating & Humidification

$t_{DB1} < t_{DB2}$

$t_{WB1} < t_{wb2}$

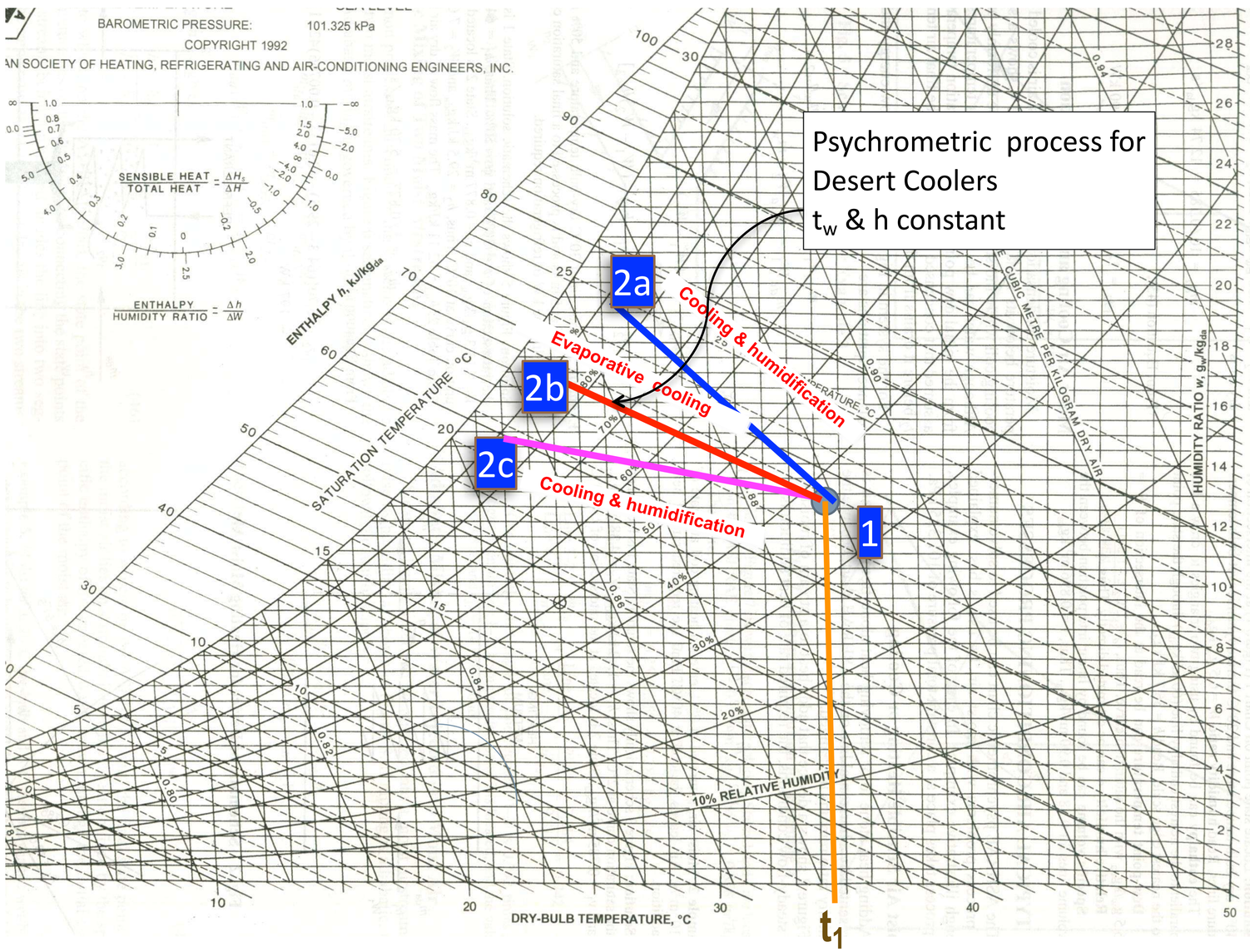
$RH_1 > RH_2$

$w_1 < w_2$

$h_1 < h_2$

$Vs_1 < Vs_2$

# Cooling & humidification




## Cooling & Humidification

$t_{DB1} > t_{DB2a}$

$t_{WB1} < t_{WB2a}$

$RH_1 < RH_{2a}$

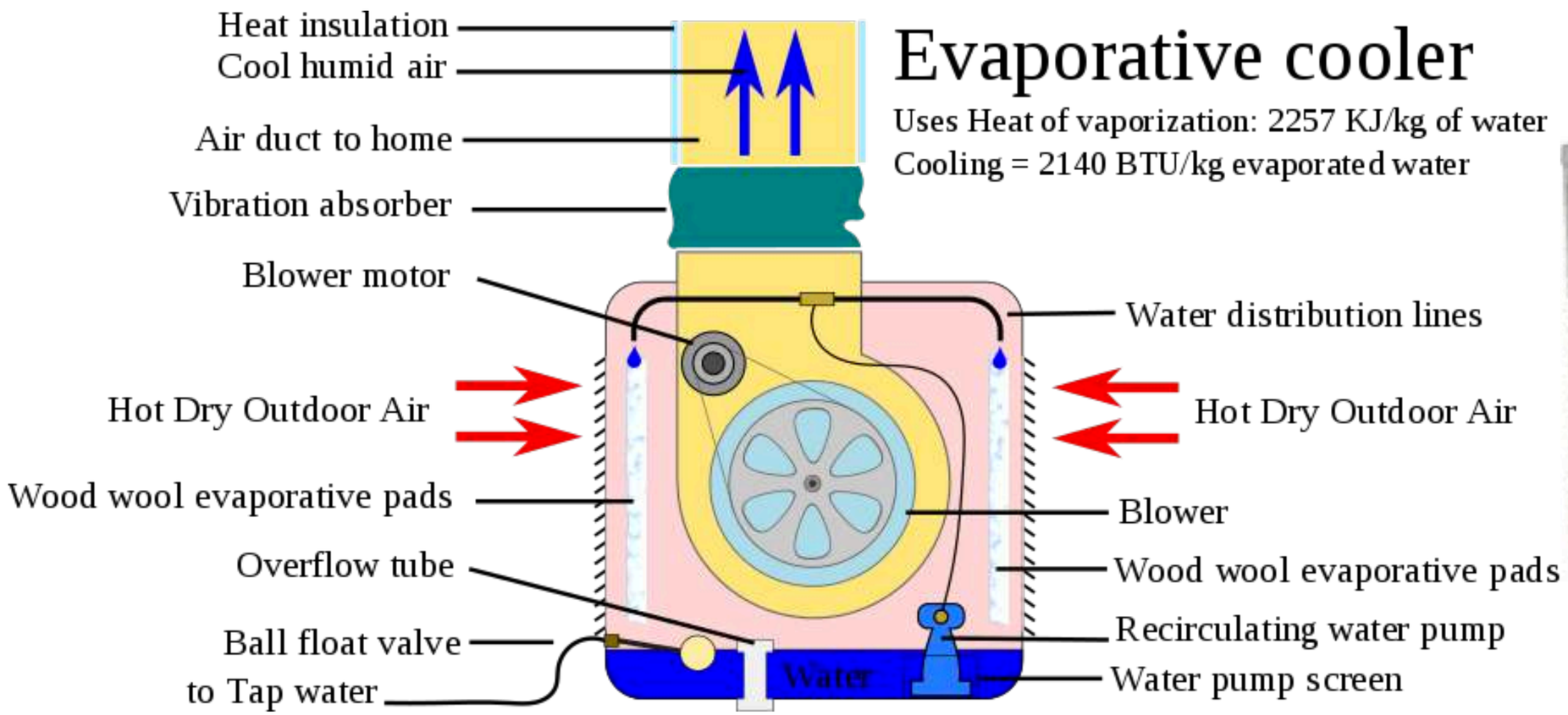
$w_1 < w_{2a}$

Evaporative cooling

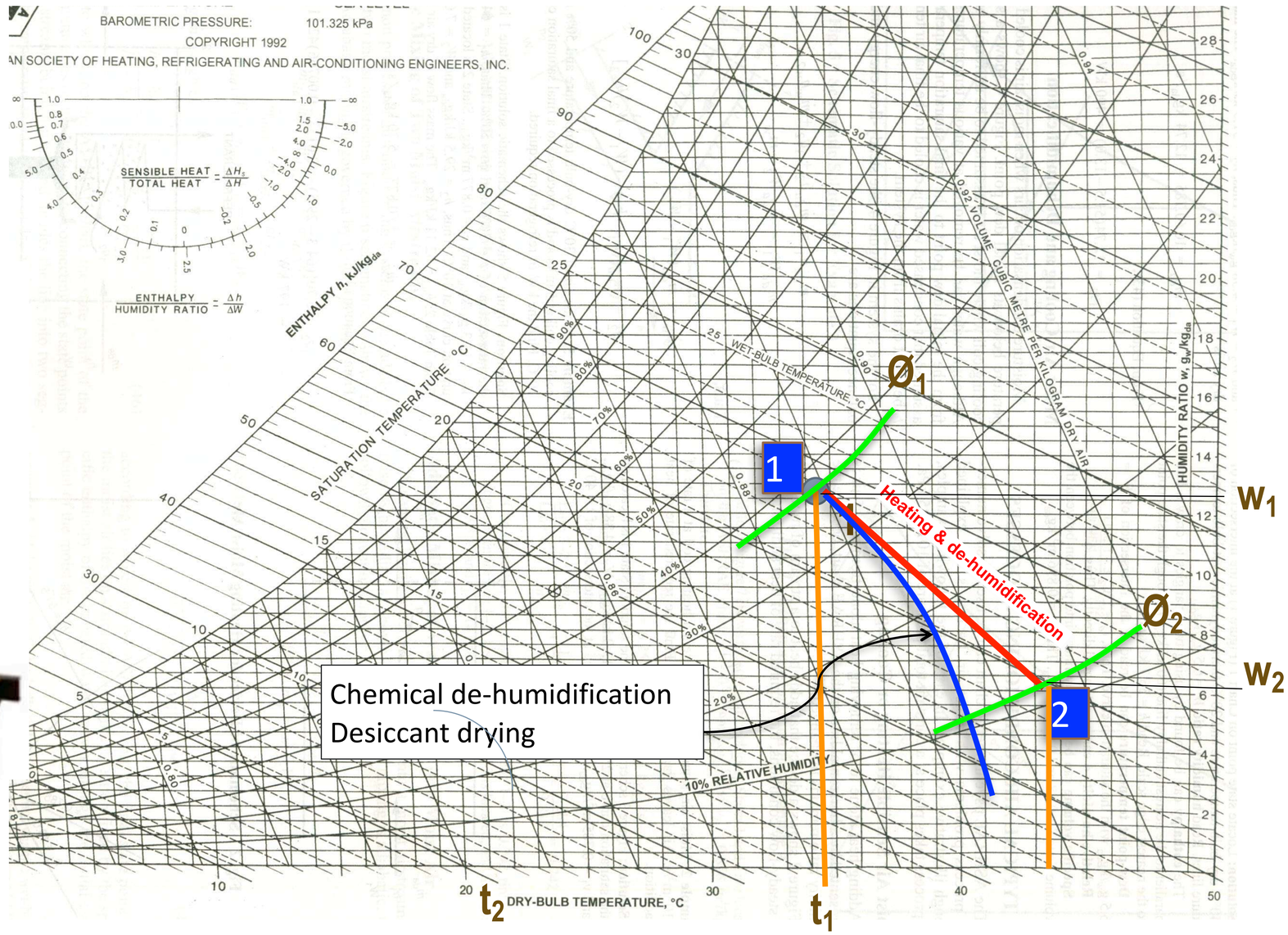
$t_{WB1} = t_{wb2}$

$h_1 = h_{2b}$

# Evaporative Cooling




# Heating & de-humidification




**C&H**

$t_{DB1} < t_{DB2}$

$t_{WB1} > t_{wb2}$

$RH_1 > RH_2$

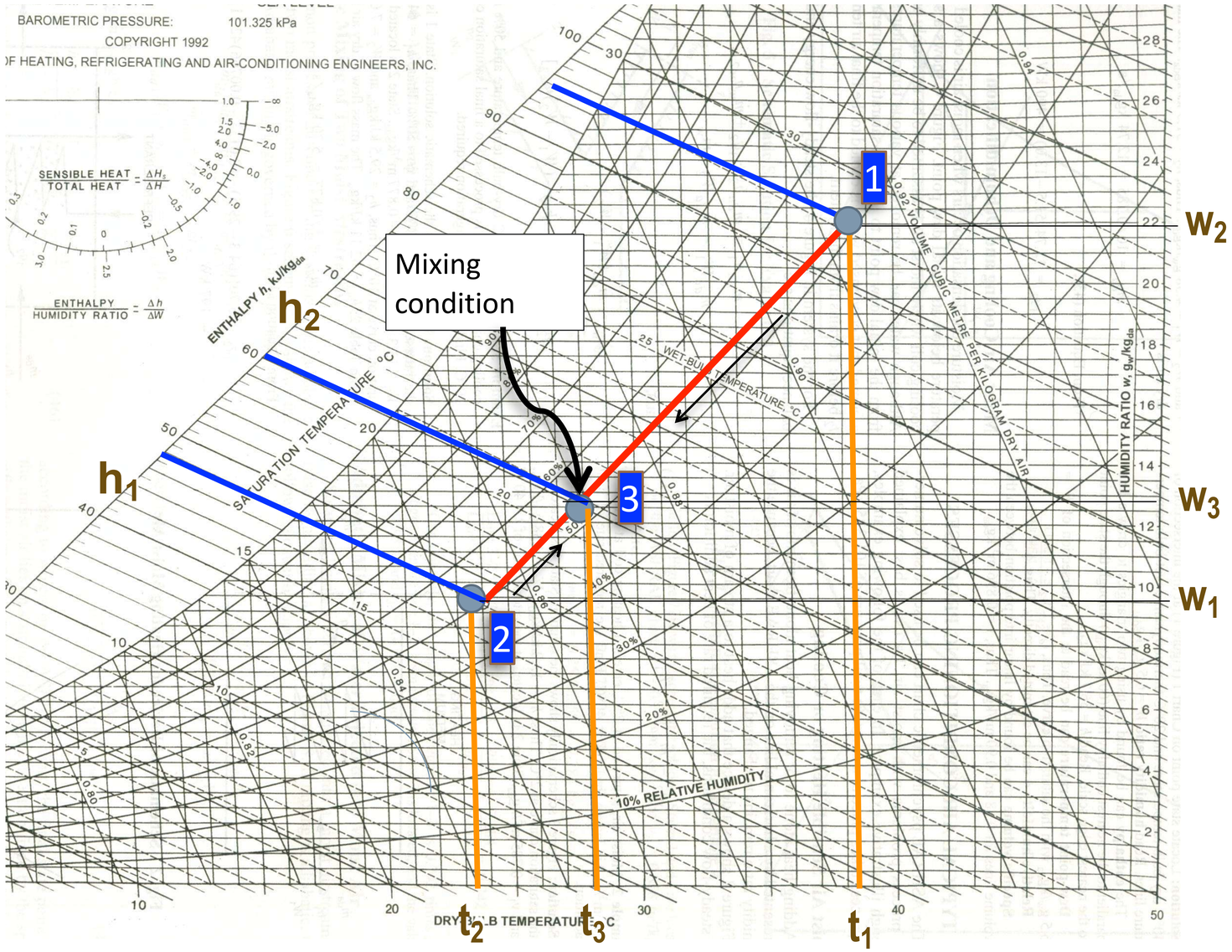
$w_1 > w_2$

$h_1 > h_2$

$Vs_1 < Vs_2$

# Chemical de-humidifiers

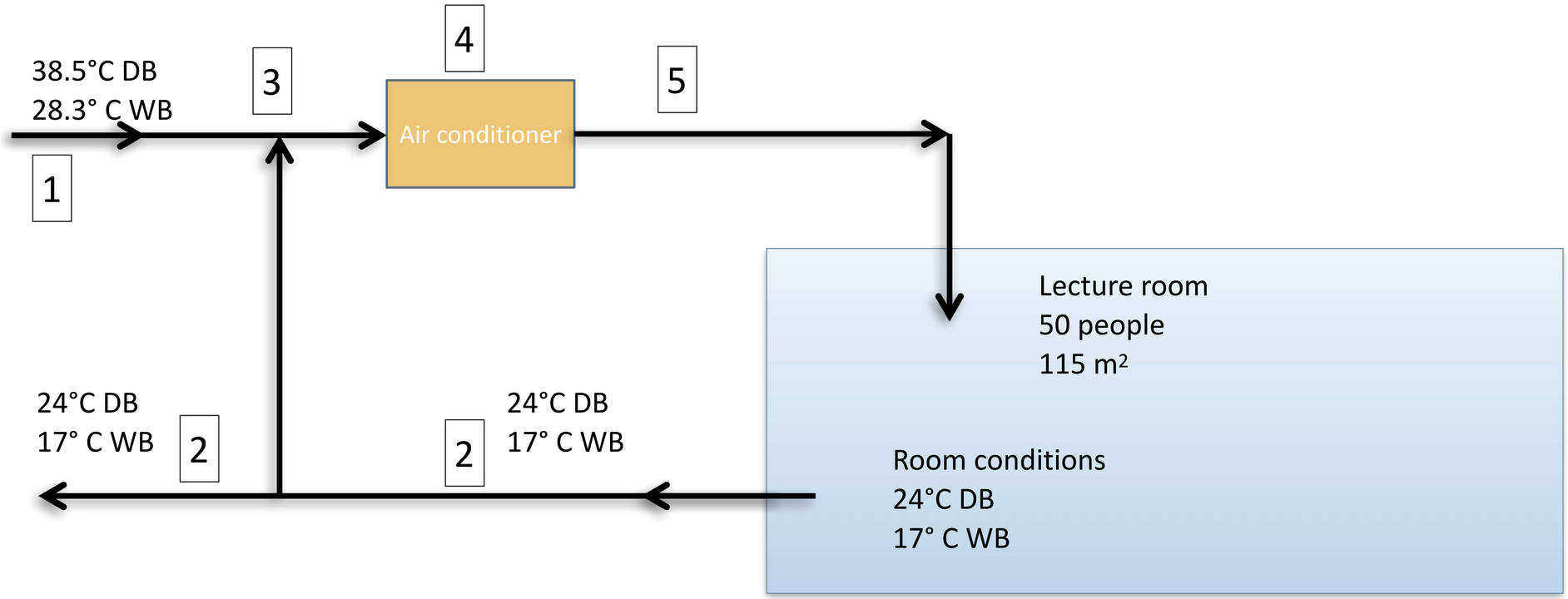
# Air Mixing Calculation




$$t_3 = \frac{(t_1 \times m_1) + (t_2 \times m_2)}{(m_1 + m_2)}$$

# Applied Psychrometrics for Air Conditioning Systems

# Psychrometric Analysis of Air Conditioning System




Outdoor conditions : Chennai 38.5 C DB, 28.3 C WB

Indoor conditions : 24 C DB, 50% (17 C WB)

From cooling load calculations, total cooling capacity: 26.5 kW,

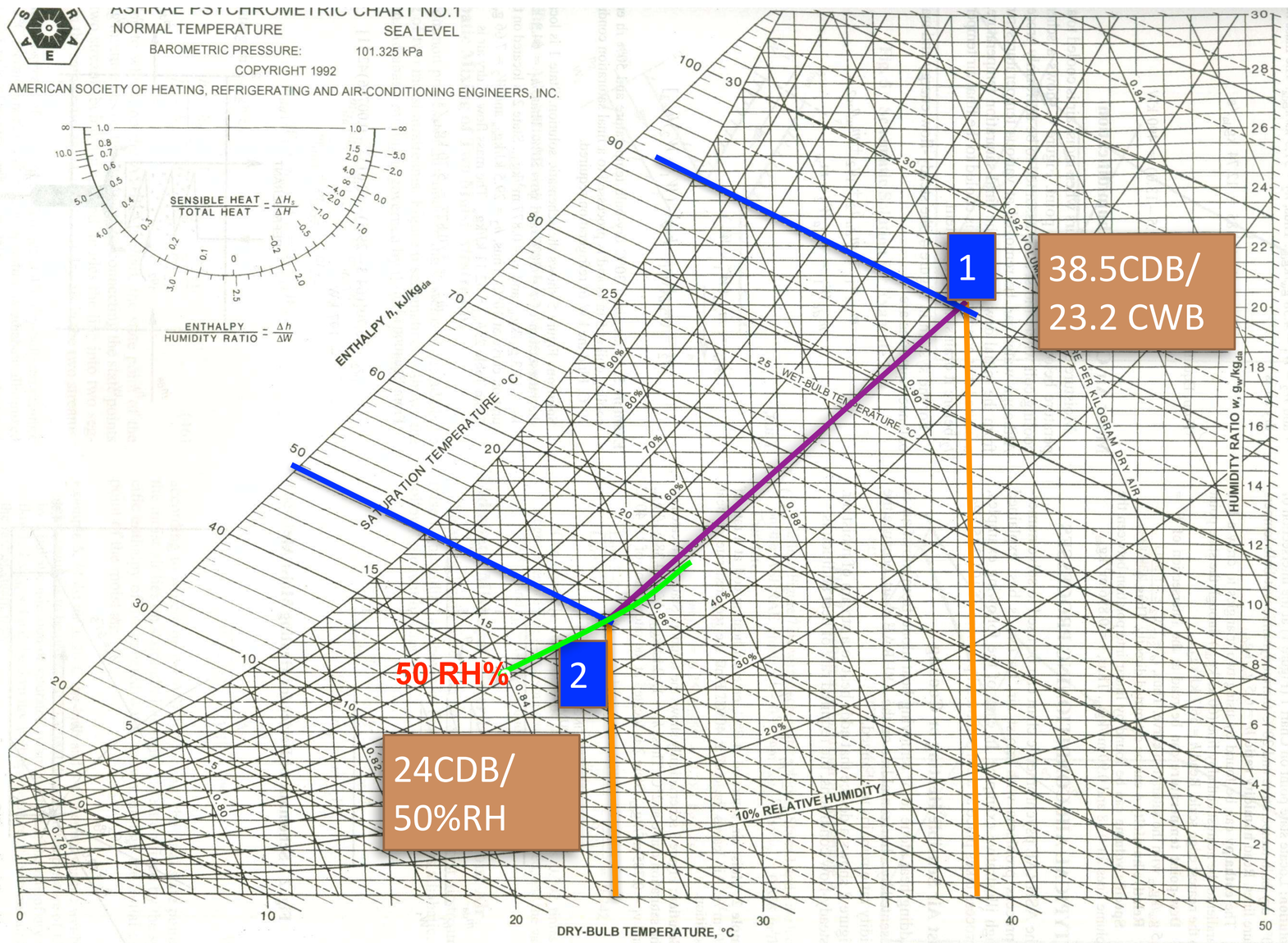
Sensible capacity : 16.5 kW

Occupancy : 50 people

***Determine the entering and leaving conditions of the coil & supply air volume***

# Indoor & outdoor Conditions

**Step-1** Locate points 1 & 2 on the chart



# Constructing SHR line

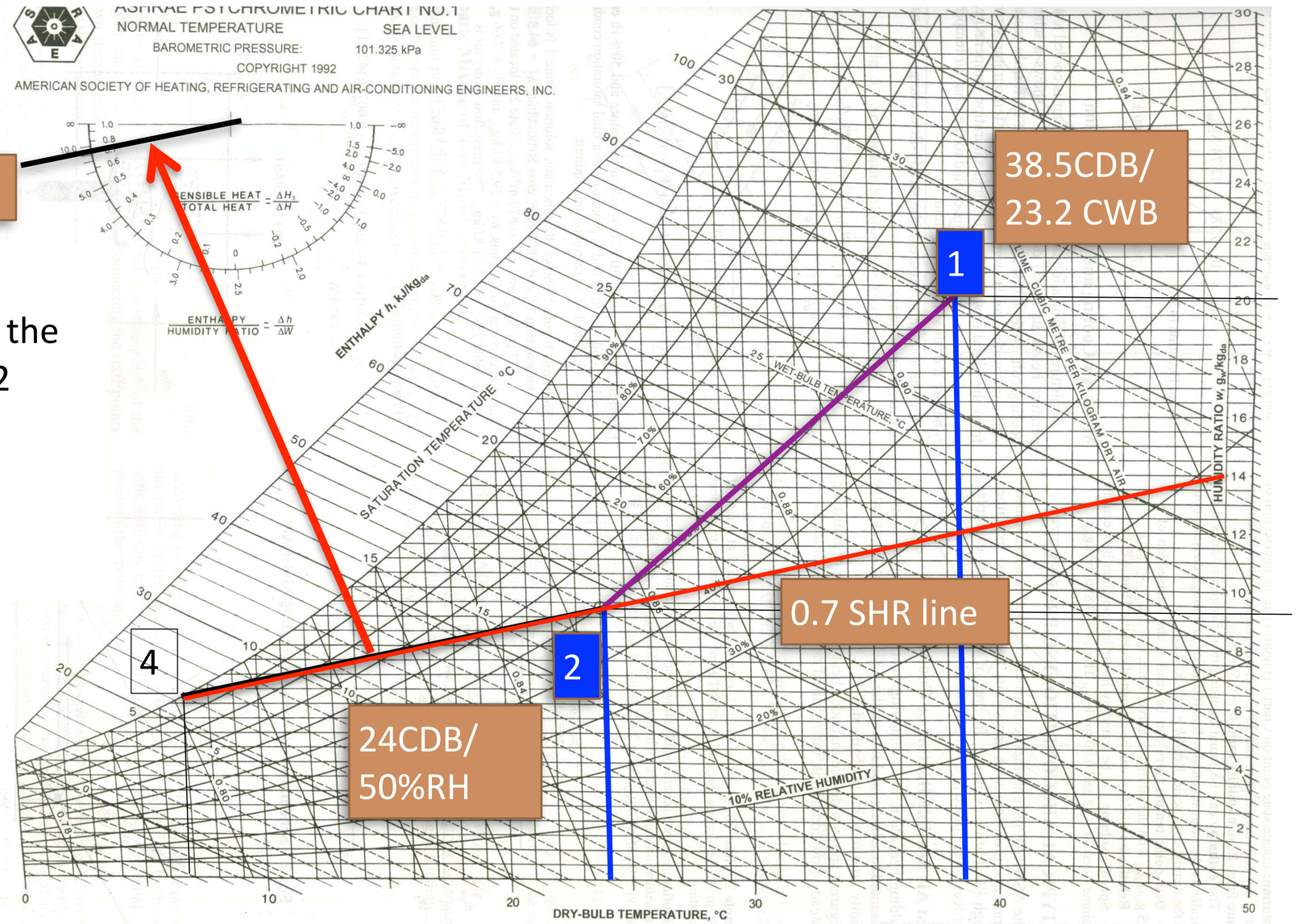
**Step-2**

Determine the SHR and draw the RSHF line Through the point-2

RSHF= SH/TH

= 16.5/23.5

= 0.7



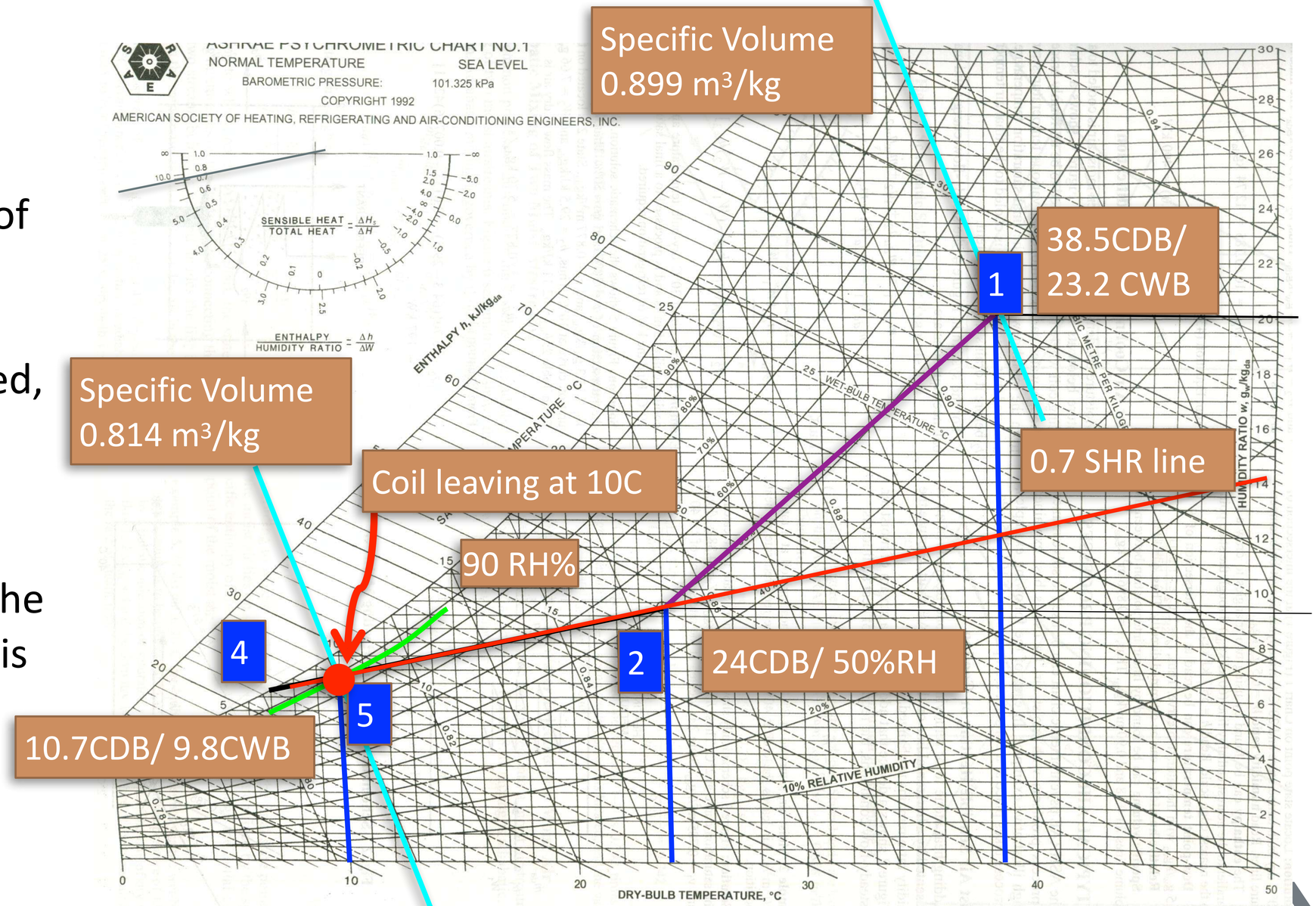
# Coil Leaving Conditions

**<u>Step-3</u>**

Find the leaving condition of the coil.

All ways air leaves the cooling coil almost saturated, thus leaving air can be assumed As 90% RH.

RSHF line intersects with 90% saturation line, gives the coil leaving condition. This is <u>OFF Coil temperature, 10CDB, 9.4CWB</u>



**Step-4**

To find the entering conditions of the coil, air mixing equation is used.

$$t_3 = [ (t_1 \times m_1) + (t_2 \times m_2) ] / (m_1 + m_2)$$

However, at this stage we do not have $m_2$, that is supply air flow rate.

Hence we shall first determine the $m_2$ supply air flow rate.

To find the supply air volume in we can use the following formula

$$q = m\ Cp\ \Delta T$$

$$q = \rho\ v\ Cp\ \Delta T$$ (mass flow rate is replaced with density & volume flow rate

Then; $v = q / \rho\ v\ Cp\ \Delta T$

Volume flow rate $v = 16.5 / (1.2 \times 1.02 \times (24-10))$

$= 0.9628\ m^3/s$

Specific volume at supply air condition read from the chart as 0.814 $m^3/kg$

Then mass flow rate of supply air; $m = v/ vs = 0.9628/ 0.855$ = **1.182 kg/s**

**<u>Step-4</u> continued….**

To find the mass flow rate of fresh air

Volume flow rate V = 50 x 8.0 L/s.p (approximation. Needs to find Vbz)

= 0.4 $m^3$ /s

Specific volume at outdoor condition read from the chart as 0.90 $m^3$/kg

Then mass flow rate of fresh air = v/ vs = 0.4/ 0.90 = **<u>0.44 kg/s</u>**

**<u>Step-5</u>**

To find the entering conditions of the coil, air mixing equation is used.

$t3 = [ (t_1 \times m_1) + (_{t2} \times m_2) ] / (m_1 + m_2)$ $m_2$=1.182, $m_1$=0.44

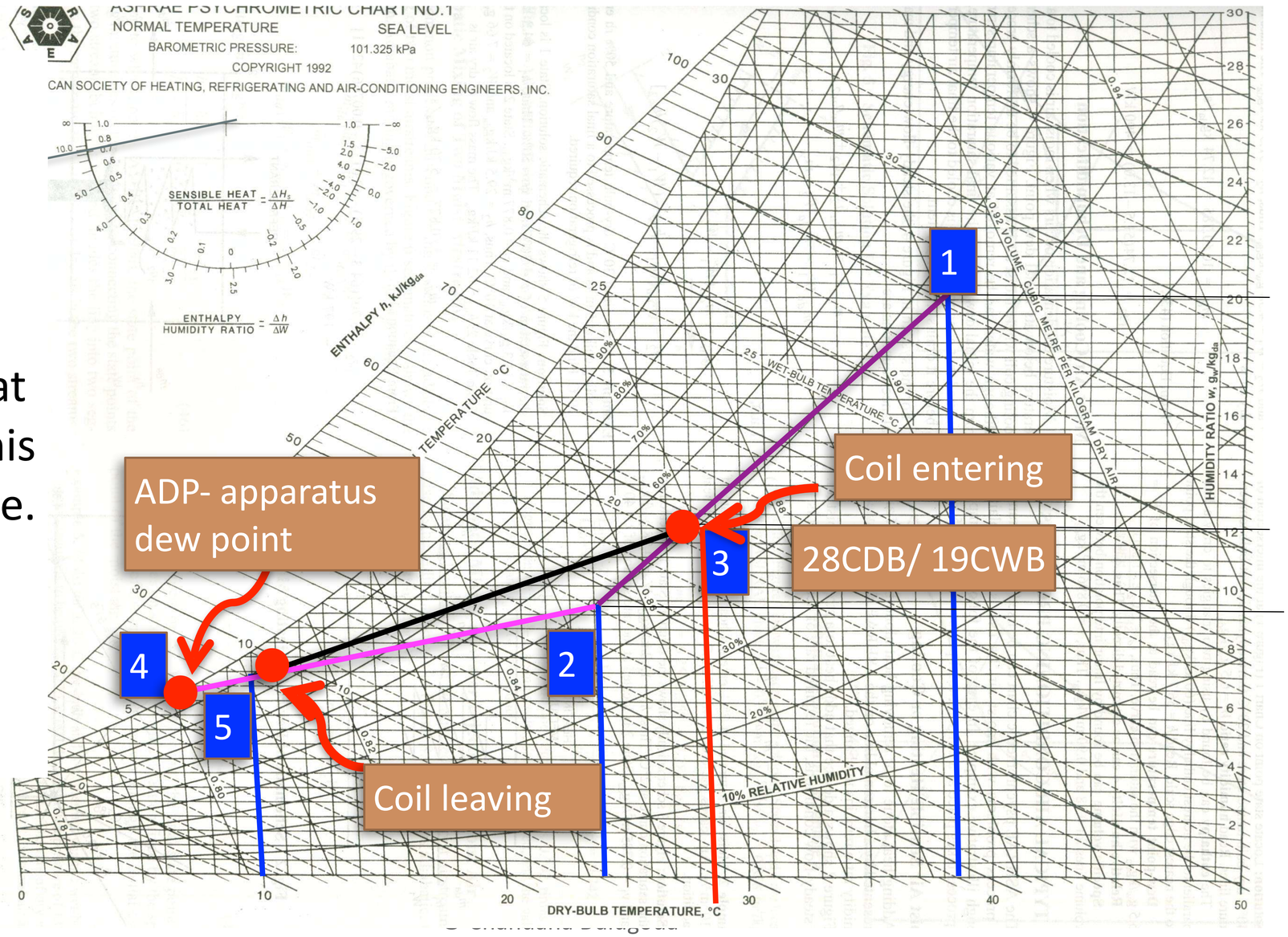
t3 = [ ( 38.5 x 0.44) + ( 24 x 1.187)] / (0.44 + 1.187)

t3 = 27.9 = <u>28.0 C</u>

# Coil Entering Condition

**<u>Step-6</u>**

Draw a vertical line from 28C until it intersects the line 1-2 and this is air mixing at coil entering point. This is ON Coil temperature. <u>This is ON Coil temperature 28CDB, 19C WB</u>



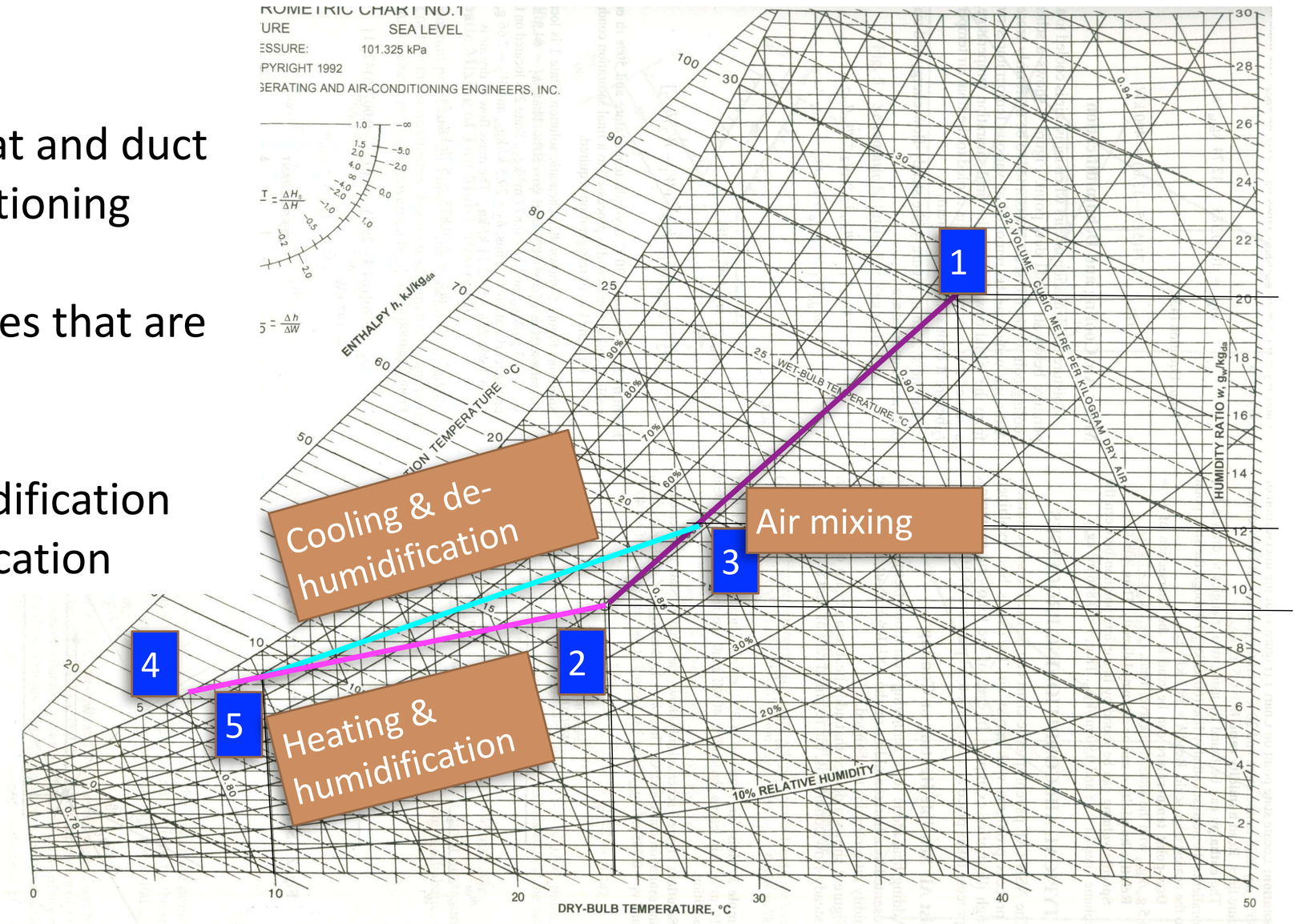
# Air Conditioning Cycle

**Psychromteric Processes of The Air-Conditioning System**

If we neglect the fan heat and duct heat gains, the air conditioning system Looks like below.

3 Psychrometric processes that are involved;

1. Air mixing
2. Cooling & de-humidification
3. Heating & humidification



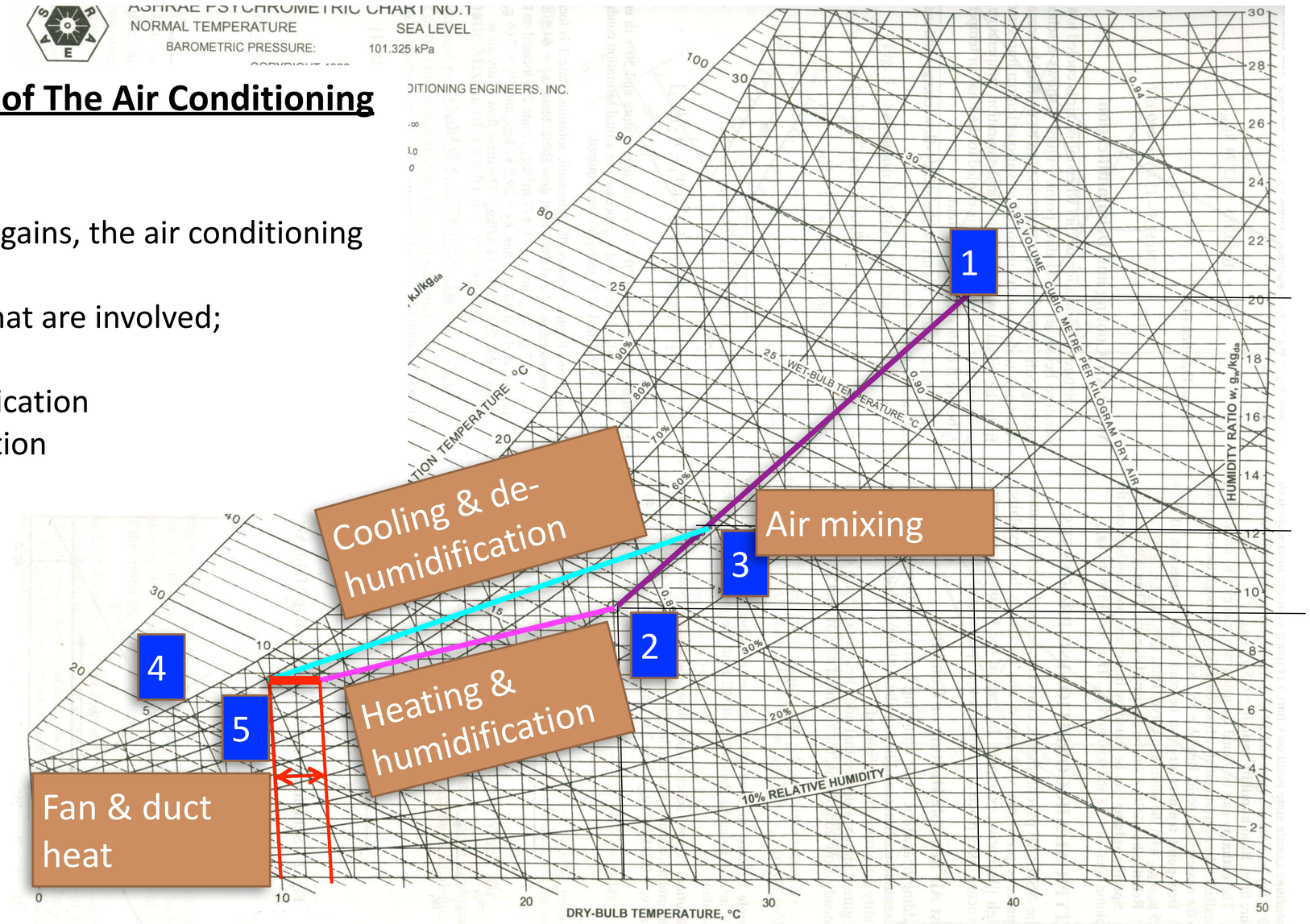
# Actual Air Conditioning Cycle

**Psychromteric Processes of The Air Conditioning System**

With fan heat and duct heat gains, the air conditioning system is given below.

4 Psychrometric processes that are involved;

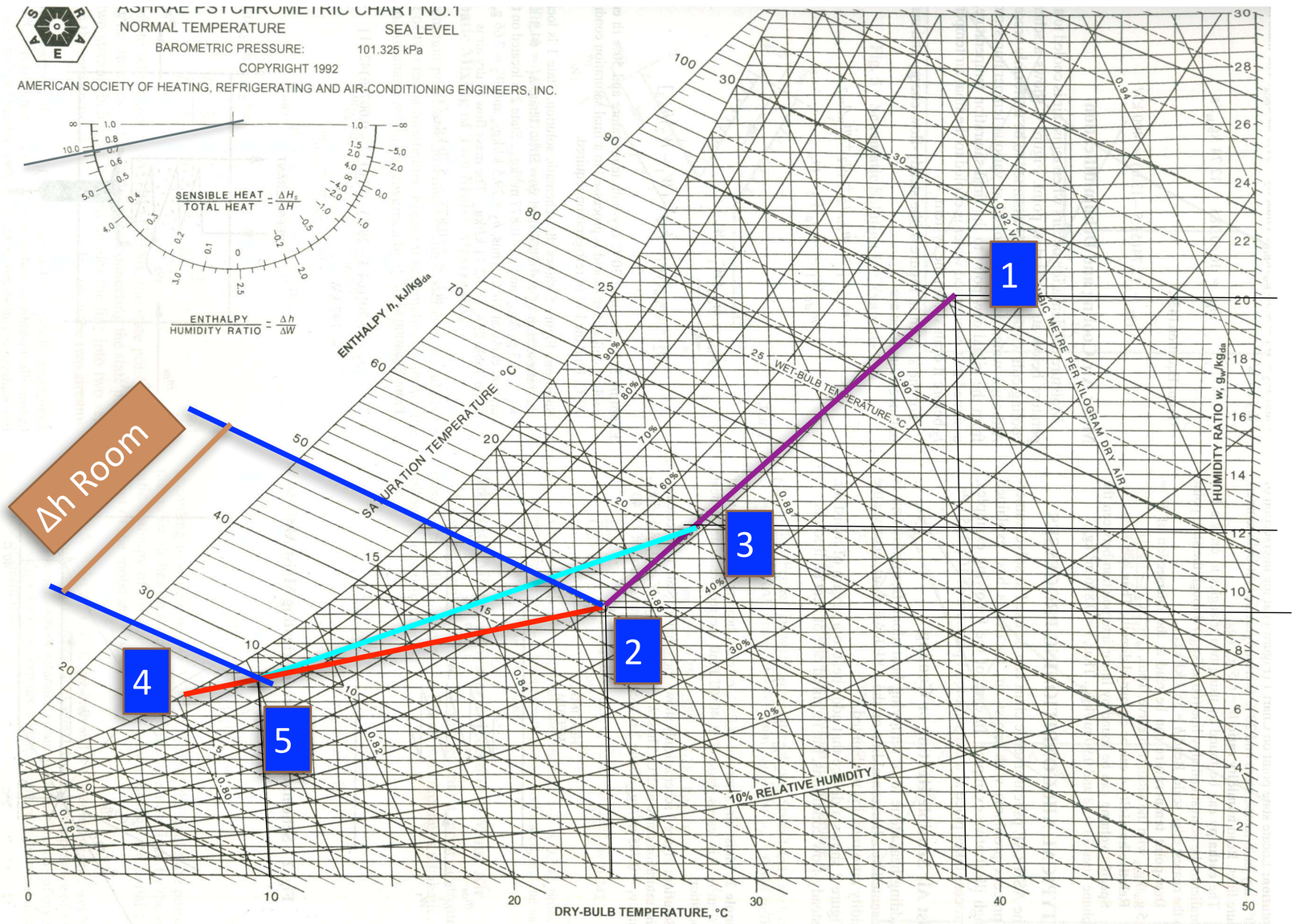
1. Air mixing
2. Cooling & de-humidification
3. Heating & humidification
4. Sensible heating



# Room Total Load

Room load can be determine by

$Q = \Delta h_{room} \times m$

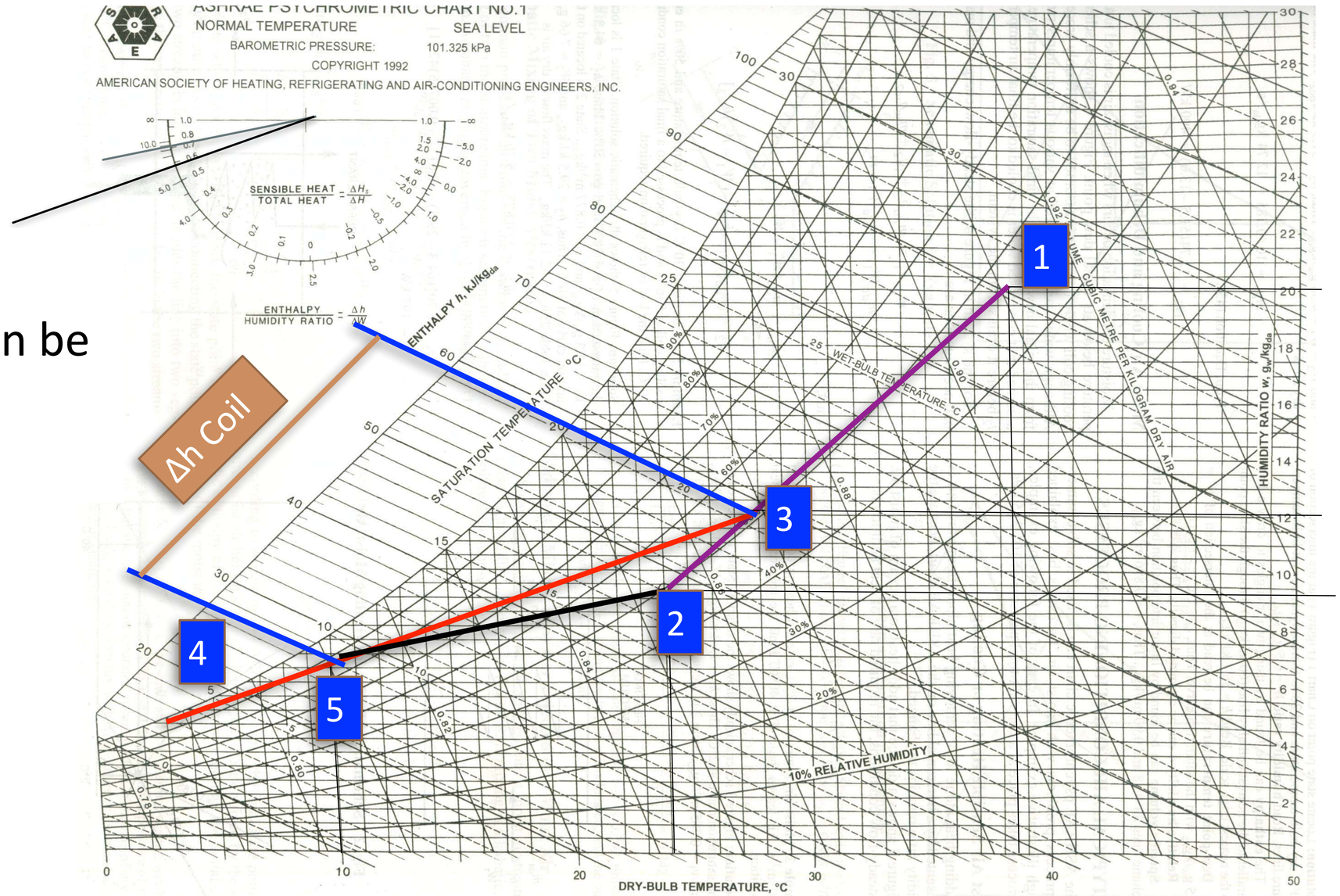


# Cooling Coil Capacity

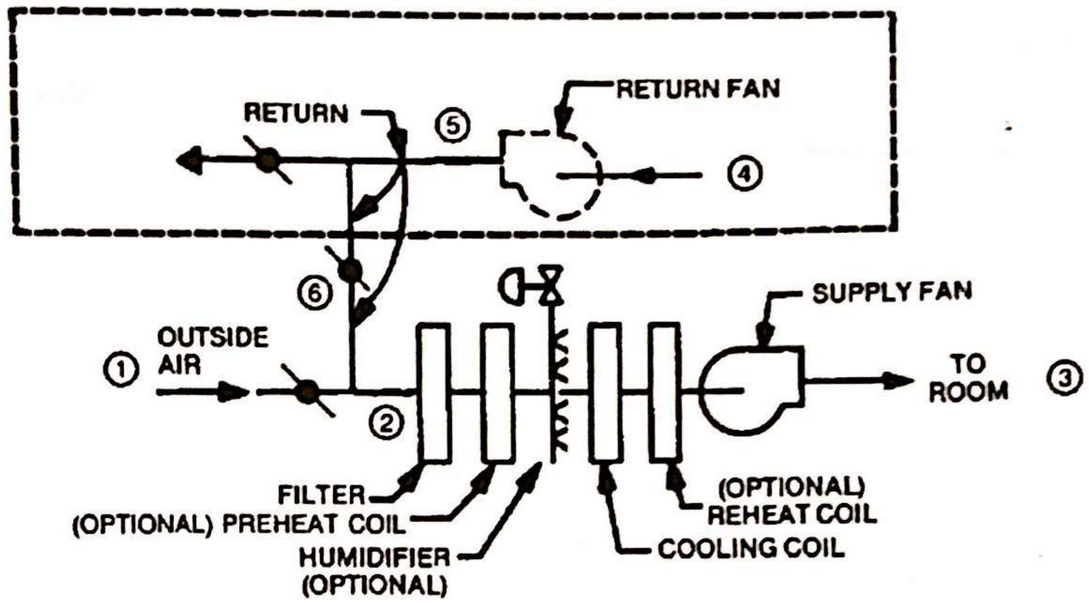
<u>Coil capacity</u>

Coil capacity can be determine by

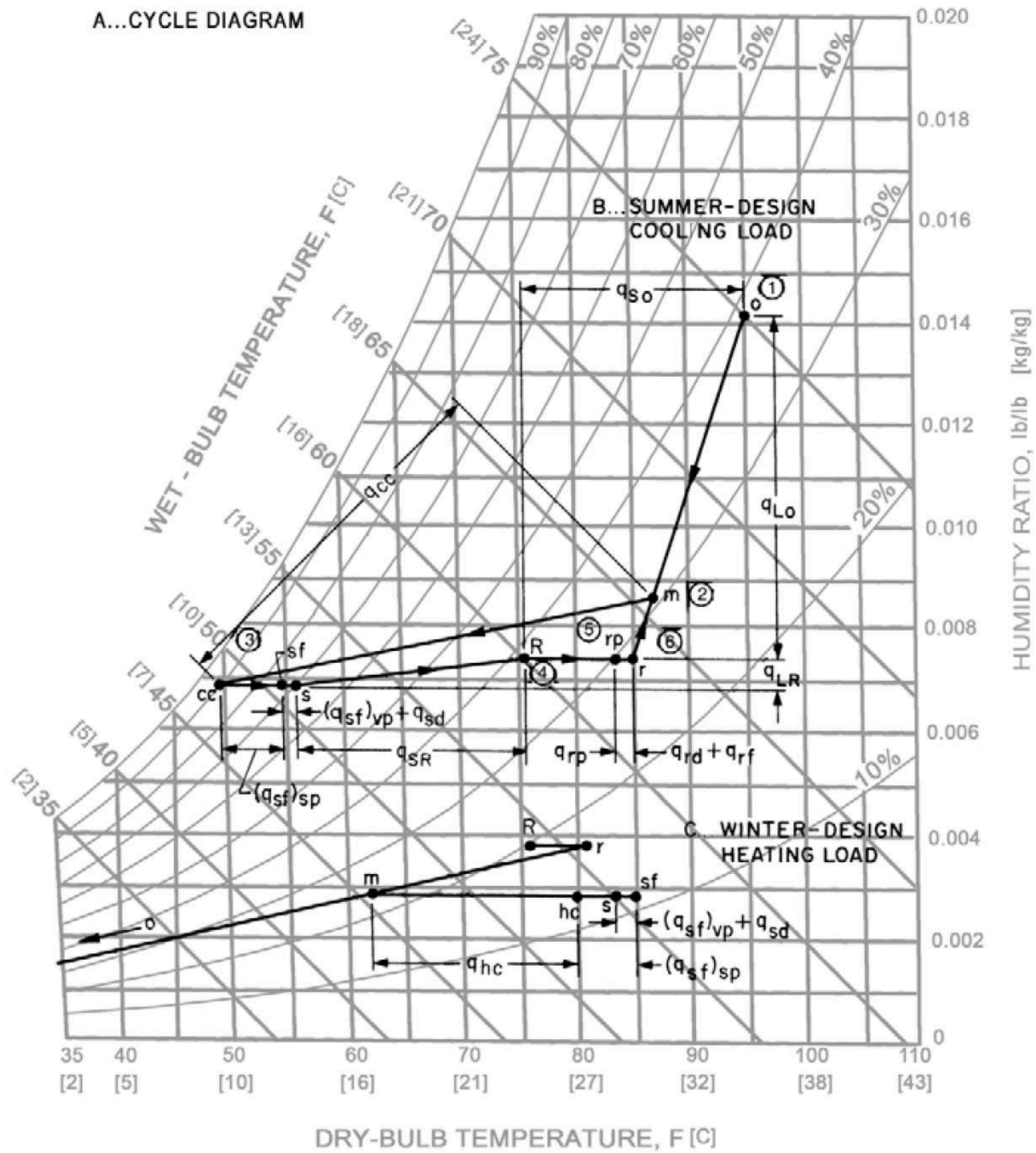
$Q = \Delta h_{coil} \times m$



# Psychrometric Analysis of Actual Air Conditioning Syst

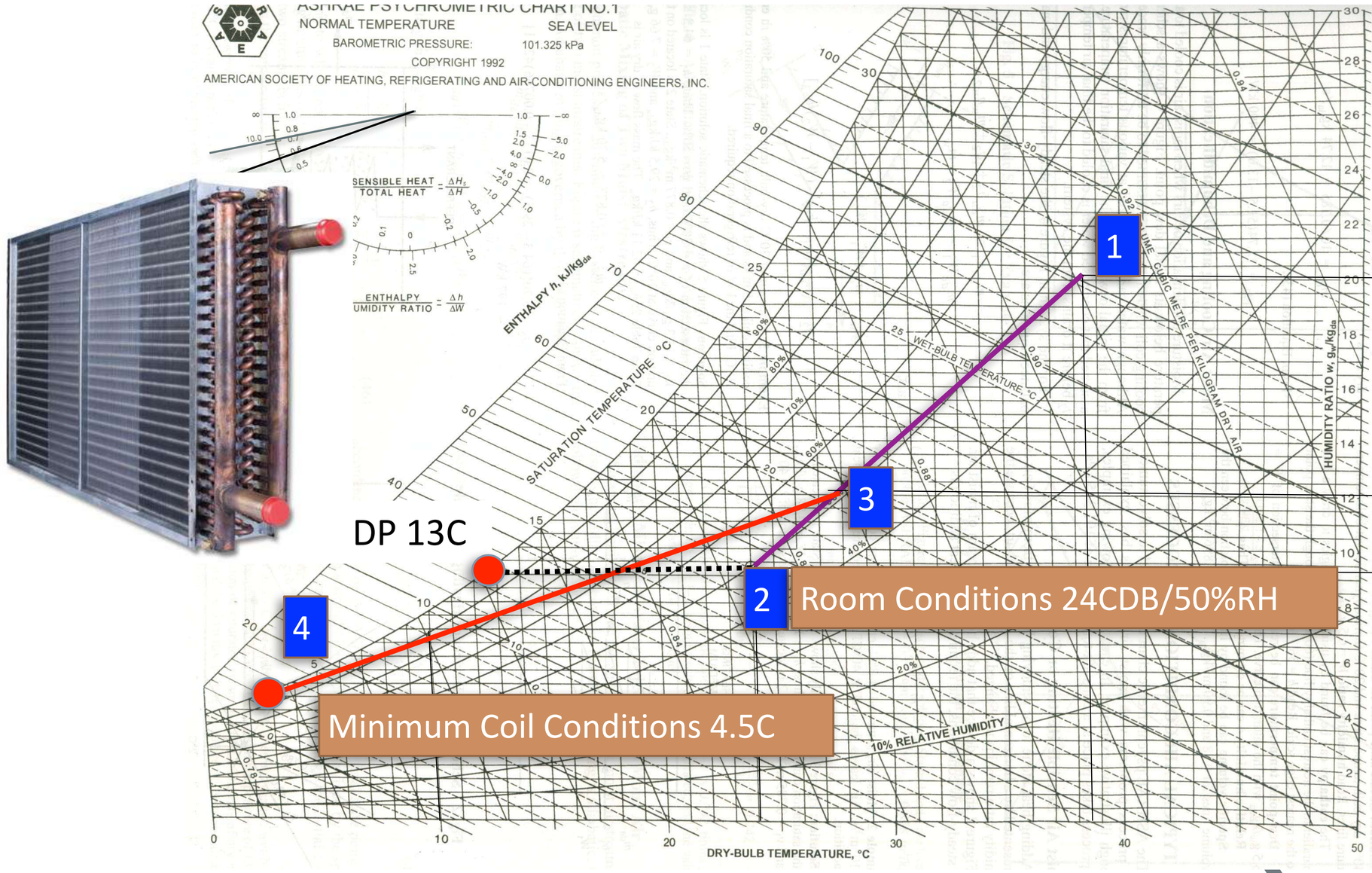



1. Coil process : m to cc
2. Coil leaving :cc
3. Heat gain supply plenum : cc to sf
4. Supply fan : sf
5. Heat gain from supply fan & duct : sf to s
6. Room process : s to R
7. Heat gain return plenum : R to rp
8. Heat gain return duct & fan : rp to r



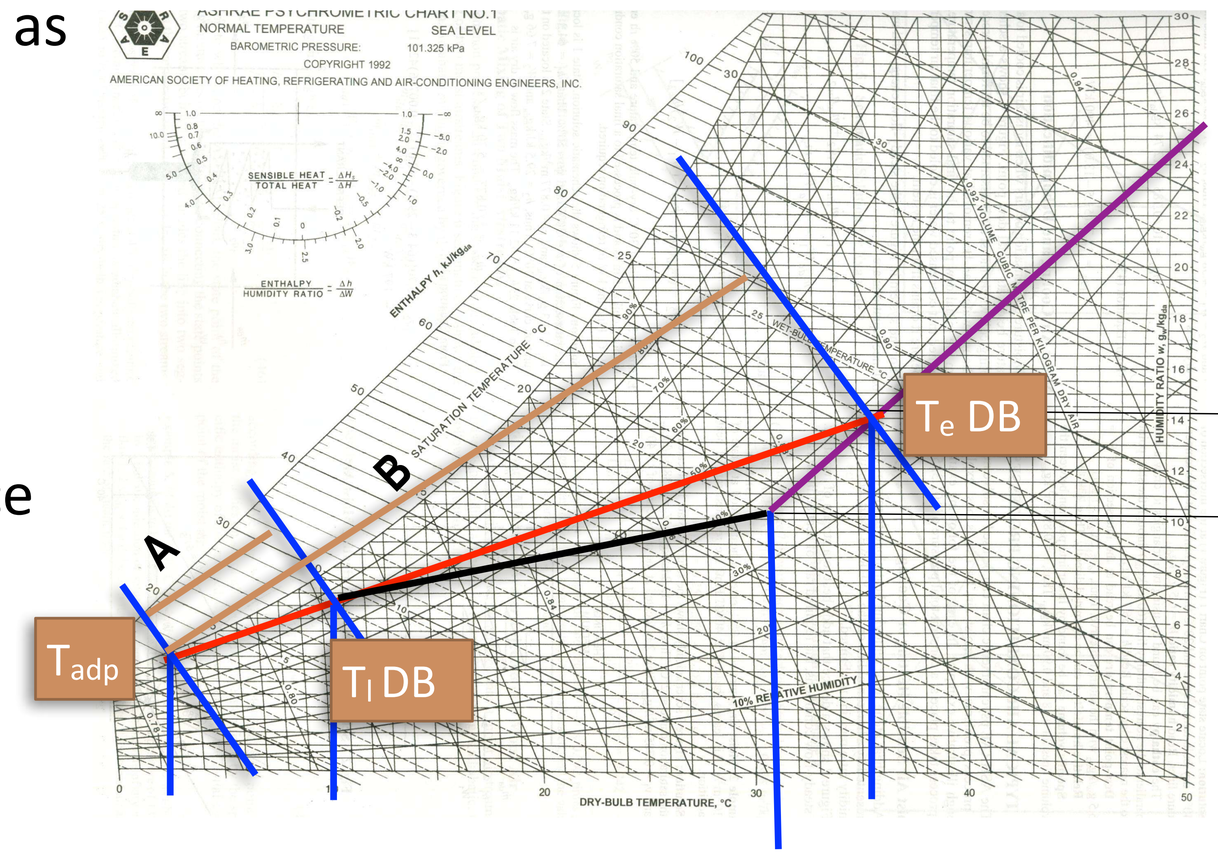
# Importance of Apparatus Dew Point

To maintain indoor design conditions of 24 CDB & do%RH, Coil DP should be below 13C, Requires CHW return near 13C.
If CHW return increase above 13C would increase the room conditions.
CHW outlet temperature restricted minimum 4.5C, to avoid freezing.
Hence, chiller operating conditions used as CHW out 6.6C (44F) & CHW return 12.7C (54F).



# Bypass Factor (BF)

Is a function of the physical and operating characteristics of the conditioning apparatus and, as such, represents that portion of air which is considered to pass through the conditioning apparatus completely unaltered.




Bypass Factor is affected by

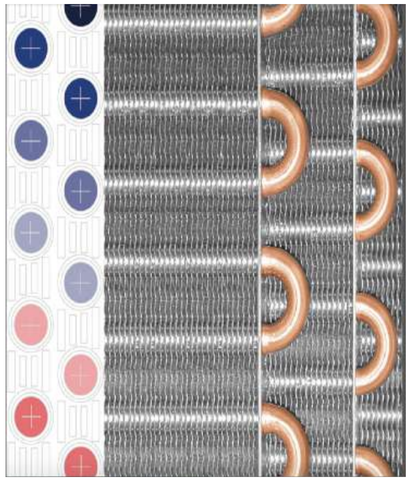
1. Available apparatus heat transfer surface
   Fin spacing, number of rows etc.
2. Velocity of air through the coil

Bypass Factor = A/B

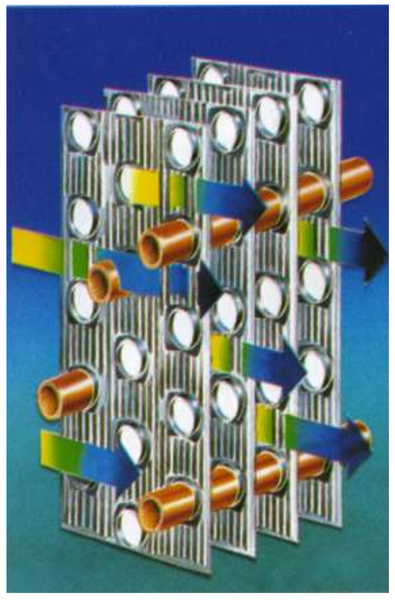
$$BF = (t_{ldb} - t_{adp}) / (t_{edb} - t_{adp})$$

# Typical Bypass Factors

**(For Finned Coils)**



| Depth of coils (rows) | Without sprays | | With sprays | |
|---|---|---|---|---|
| | 8 fins/in | 14 fins/in | 8 fins/in | 14 fins/in |
| | Velocity (fpm) | | | |
| | 300 - 700 | 300 - 700 | 300 - 700 | 300 - 700 |
| 2 | 0.42 – 0.55 | 0.22 – 0.38 | | |
| 3 | 0.27 – 0.40 | 0.10 – 0.23 | | |
| 4 | 0.19 – 0.30 | 0.05 – 0.14 | 0.12 – 0.22 | 0.03 – 0.10 |
| 5 | 0.12 - 0.23 | 0.02- 0.09 | 0.08 – 0.14 | 0.01 – 0.08 |
| 6 | 0.08 – 0.18 | 0.01 – 0.06 | 0.06 – 0.11 | 0.01 – 0.05 |
| 8 | 0.03 – 0.08 | | 0.02 – 0.05 | |



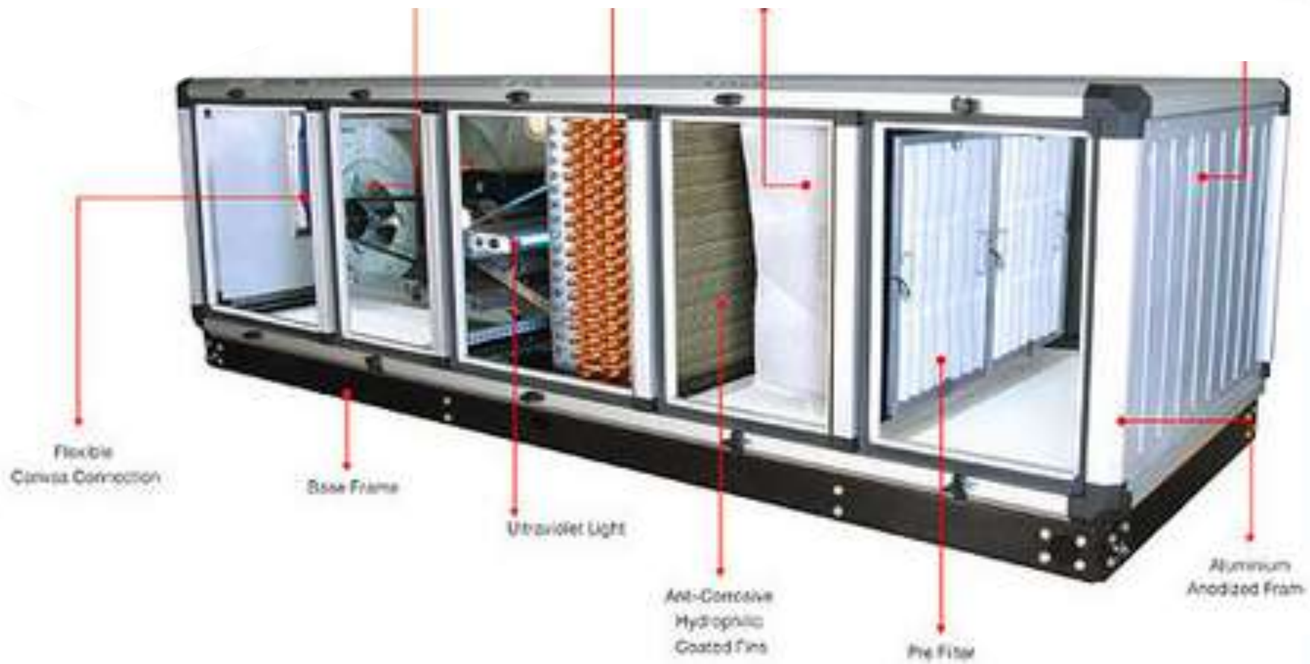
# Applications

| Coil bypass factor | Type of application | Example |
|---|---|---|
| 0.30 to 0.50 | A small total load or a load that is somewhat larger with a low sensible heat factor (high latent load) | Residence |
| 0.20 to 0.30 | Typical comfort application with a relatively small total load or a low sensible heat factor with a somewhat larger load | Residence, small retail shop, Factory |
| 0.10 to 0.20 | Typical comfort application | Department store, Bank, Factory |
| 0.05 to 0.10 | Applications with high internal sensible loads or requiring a large amount of out door air for ventilation | Department store, restaurant, Factory |
| 0 to 0.10 | All outdoor air application | Hospital operating theatre, Factory |

# Specifications of Air Conditioner

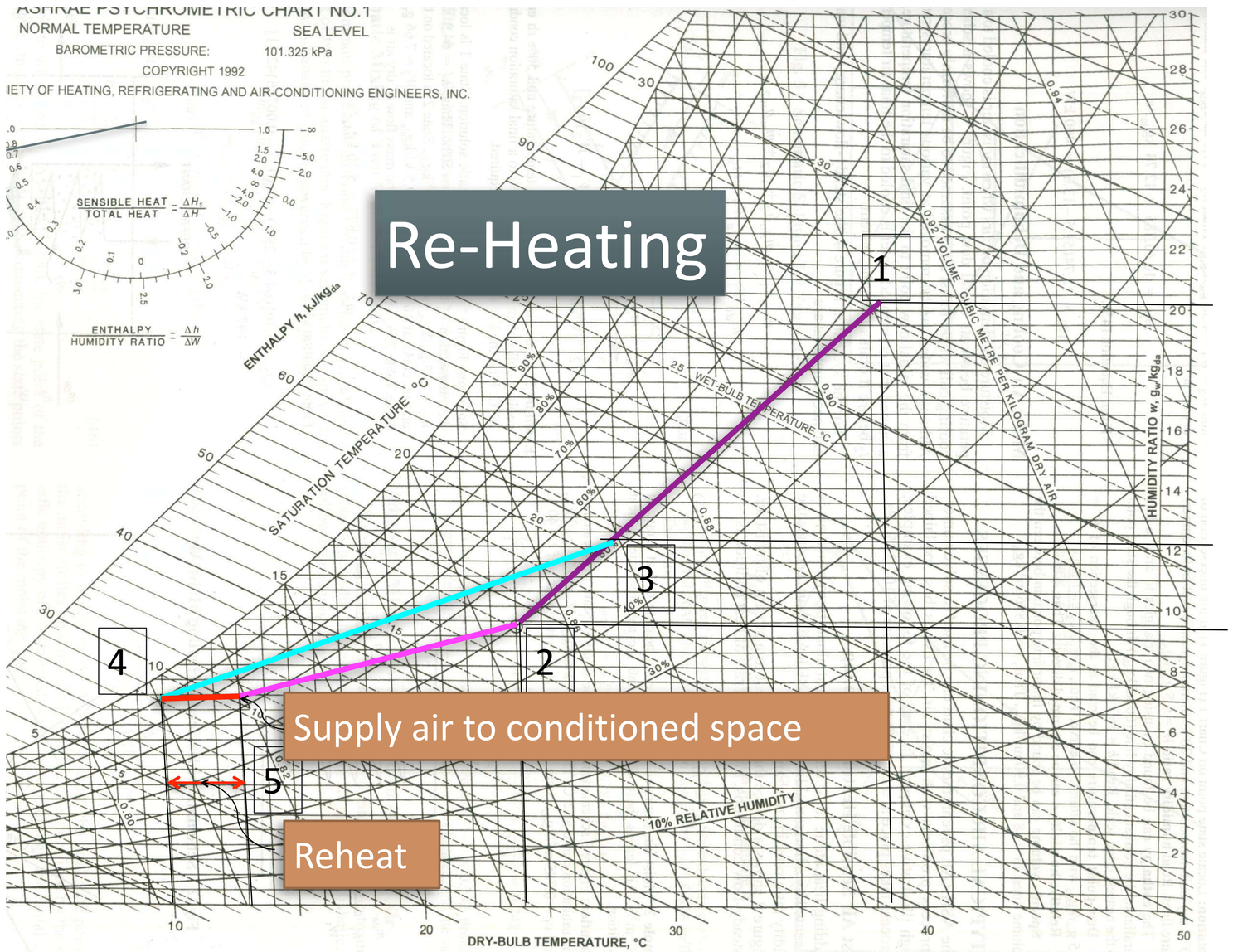
Specifications of the Air conditioner is;

1. Total cooling capacity kW
2. Sensible cooling capacity kW
3. Sensible Heat Ratio SHR
4. Coil conditions ON coil / OFF coil temperature
5. Supply air volume L/s
6. Outdoor fresh air volume L/s



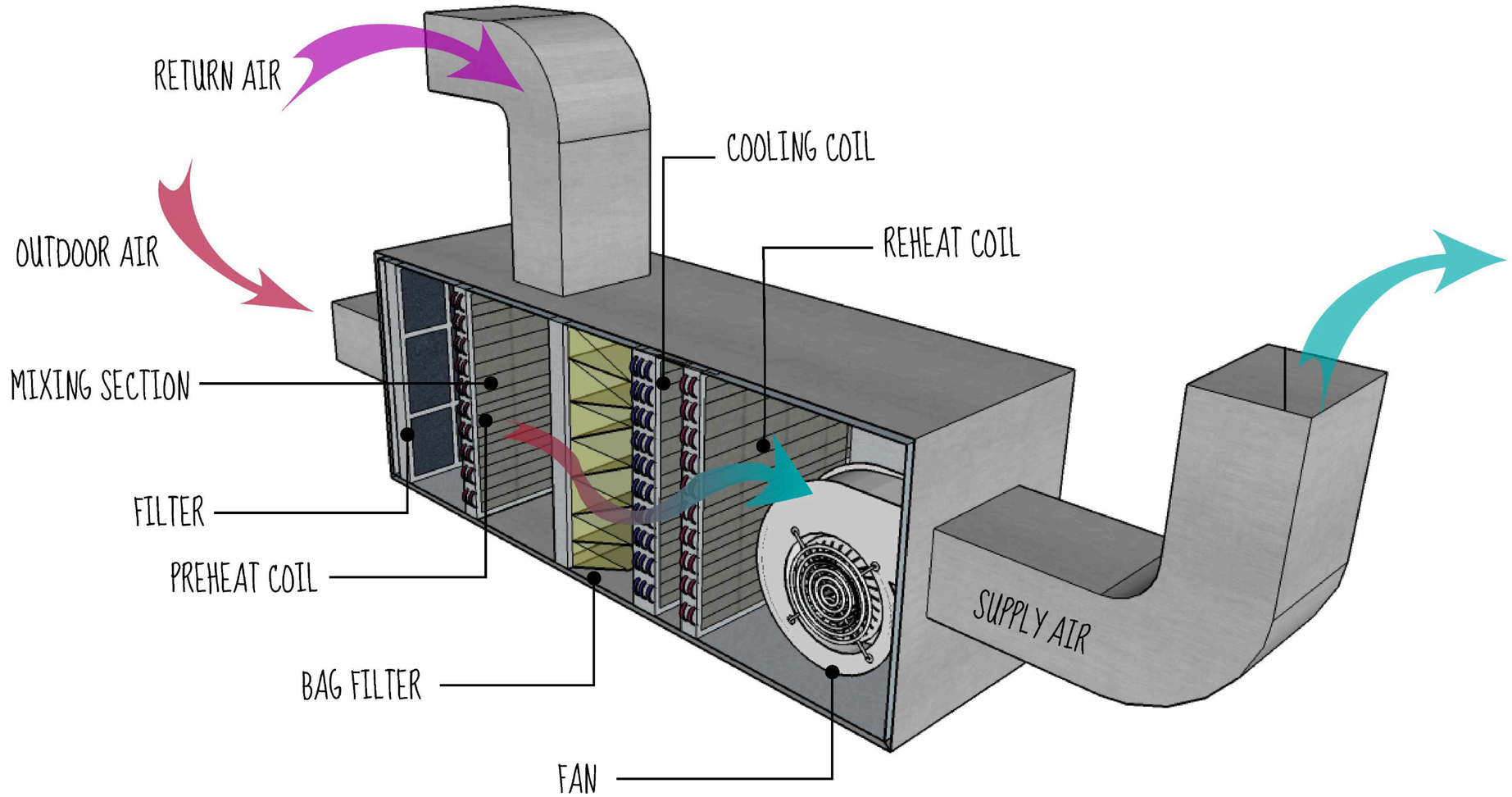
# High Latent Load

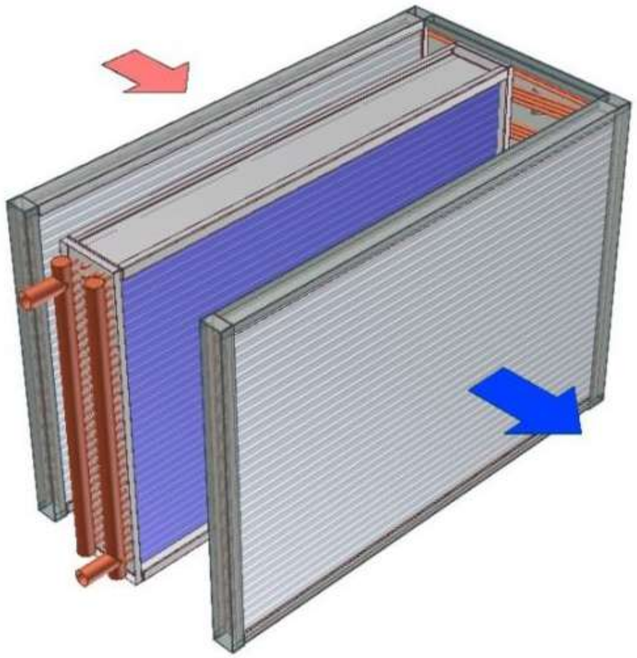
When high occupancy prevails such as **Auditorium** or **Banquet Hall**, psychrometric Process become **High Latent load application**.
When the latent load increases, Room SHR line do not intersect with coil ratio line, which is the coil leaving conditions. From the leaving conditions, a horizontal line has to Draw, until Room SHR line intersects. This horizontal line represent the **reheat** required after the coil outlet.
This re-heating wood be an energy waste, hence heat exchangers such as Heat pipe or face-bypass is used Without electrical energy being used.



# Electric Heaters use for Re-Heating

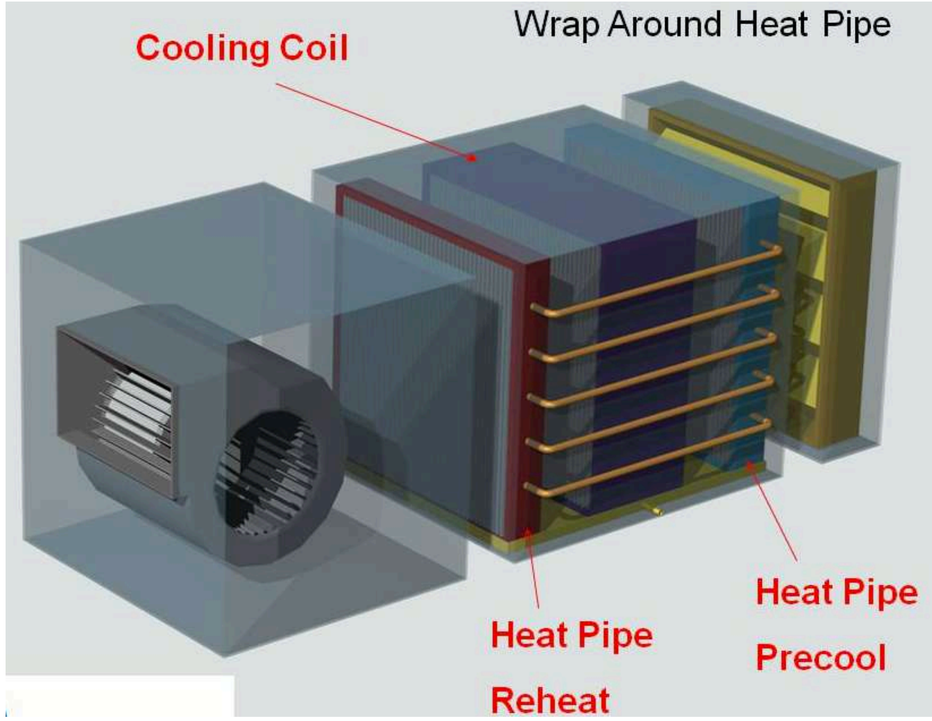
Electric re-heating coils are placed downstream of the cooling coil for de-humidification of supply air in high latent load applications.
Usually these are 3-staged electric heaters working on 3-phase electricity.
With increasing electric costs usage of electric heating is discouraged by ASHRAE Standards





# Heat Pipe use for Re-Heating with Zero Energy Input

Wrap-around, de-humidification, non controlled heat pipe (DHP) use for re-heating the air leaving evaporator for de-humidification with zero energy input.

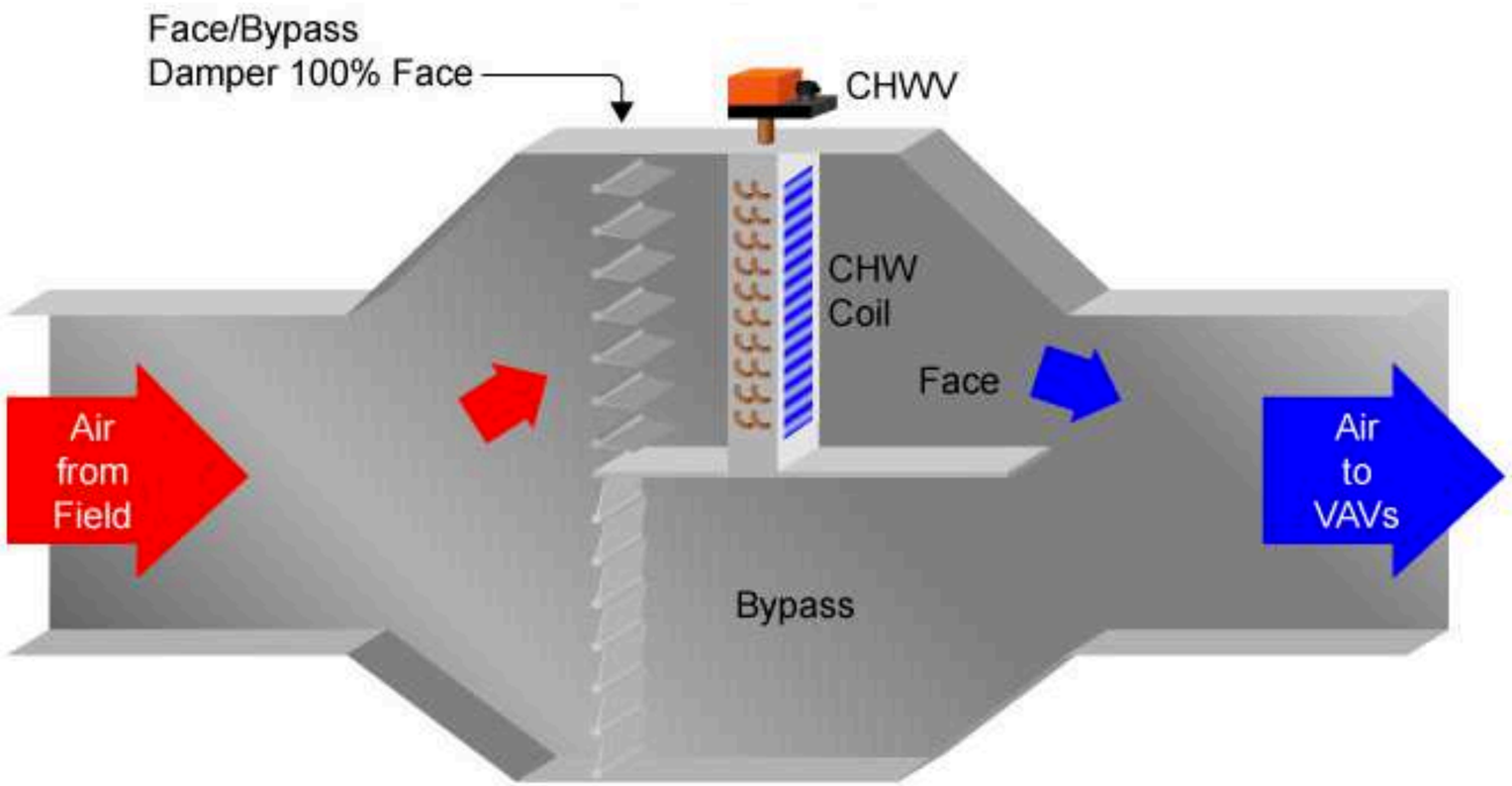



Heat from return air picked up by upstream heat pipe coil and transfer it to the downstream heat pipe coil placed after the cooling coil, which re-heats the air to achieve further de-humidification required.

These were successfully used in world's second Passive House Rated building in Sri Lanka, to maintain relative humidity down to 52~54% without control.

# Face & Bypass Dampers for Re-Heating with Zero Energy Input

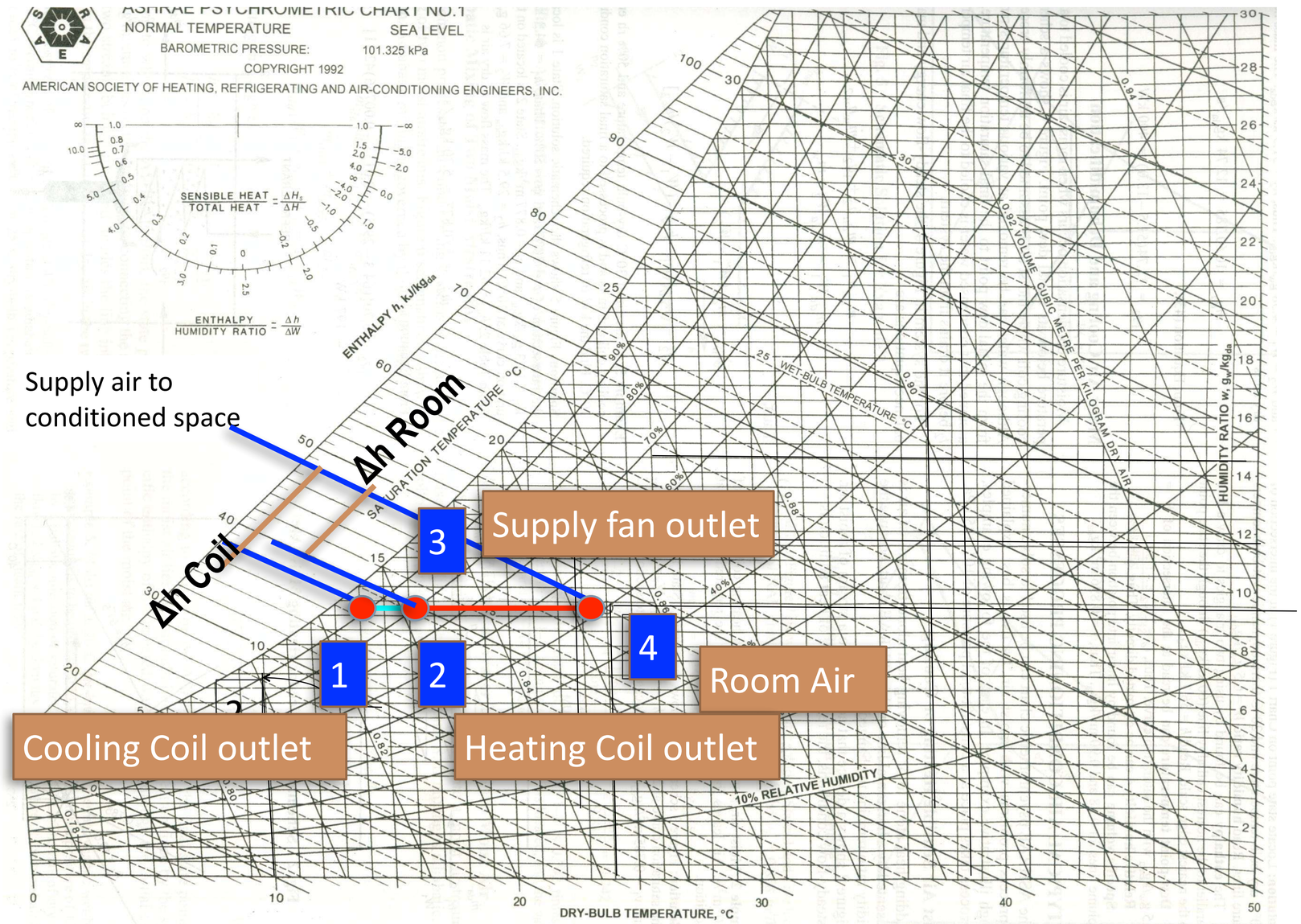
There are set of phase and bypass dampers are installed upstream of the cooling coil. Normal operation air passes through face dampers and enter the cooling coil, where bypass dampers are closed. When you need extra de-humidification for high latent lands, by pass dampers opens and some of the return air by passes the coil and enters supply air stream thus adding more heating to air.



# High Sensible Heat Applications

Server room Cooling Loads comprises of Sensible heating only and room SHR = 0.9 may be 1.00. No latent load so room ratio and coil ratio lines are horizontal. Moisture content of air is constant. Coil load is from 4 to 1 and the room load is 4 to 3.

Such application is Server Room air conditioning. Deference between server room & comfort cooling is heat density; 5000 W/m² vs 250 W/m² . High density heat and close control of temperature /relative humidity are the Design targets of IT cooling.



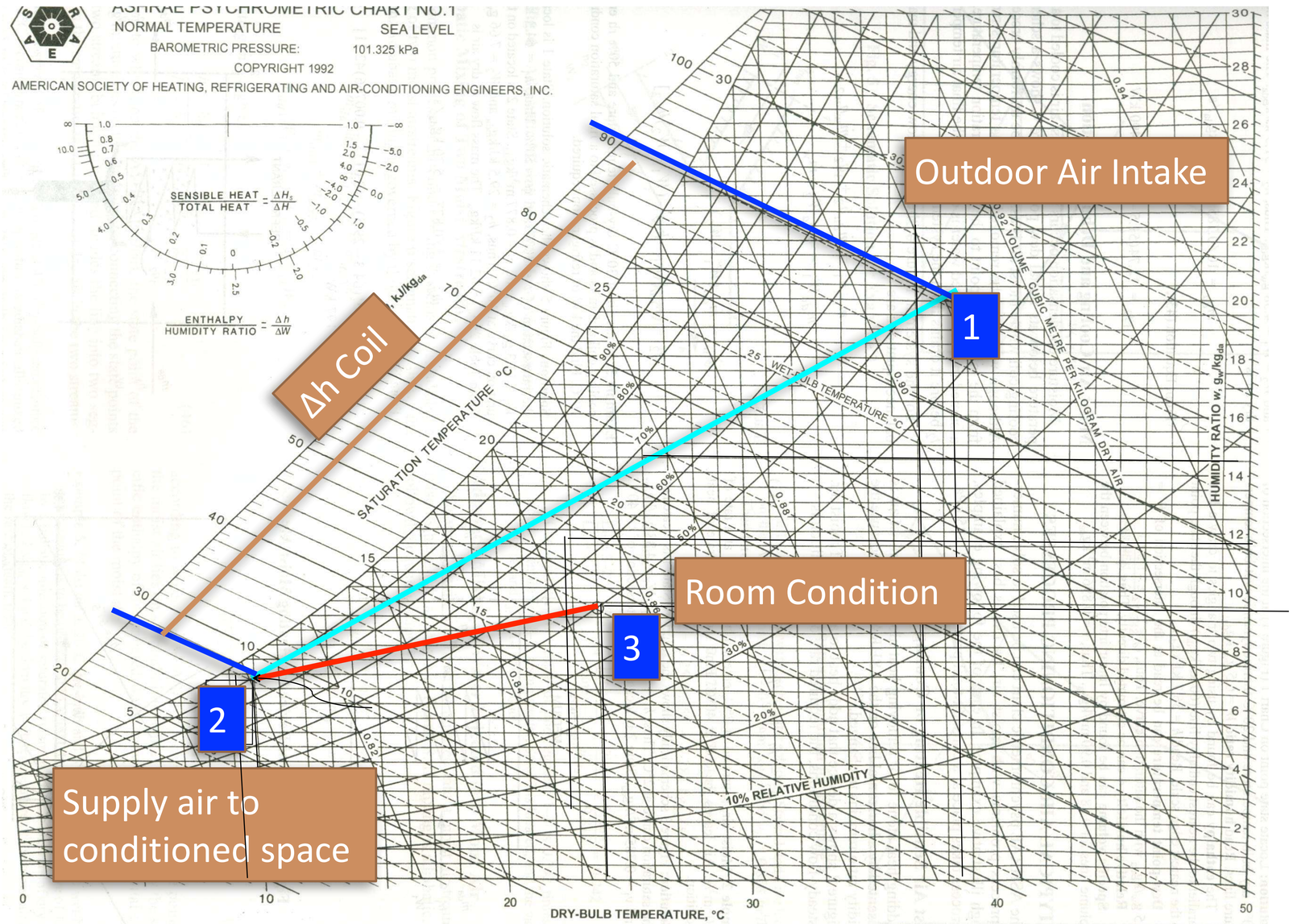
# IT Cooling & Server Room Applications

Server room or IT cooling require close control of Temperature & Humidity. Indoor conditions as per 1999 ASHRAE Applications; 22℃ ±1 ℃ and 50 ± 5% RH. Typical supply air temperature 14 ℃ and return air temperature is 24 ℃ & 45%RH.

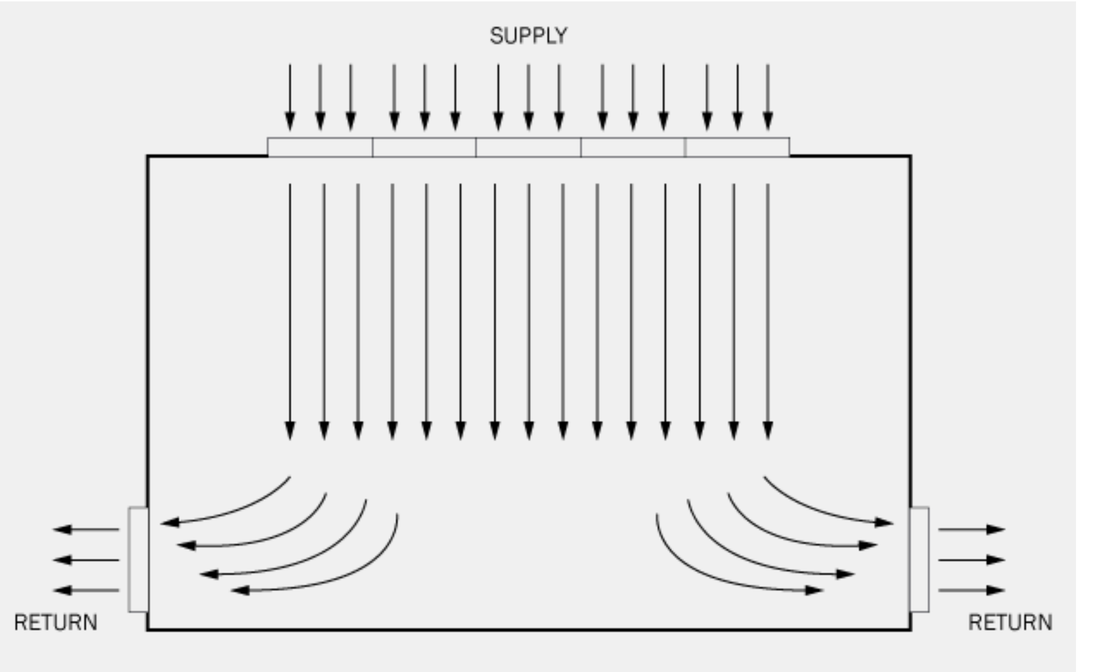
# ALL Outdoor Air Applications

Coil needs to handle large latent load, coil depth up to 8 to 10 rows may require. Evaporator capacity control required with freezing protection. Usually coil loads are 2.5 to 3.0 times larger than comfort AC systems. Applications are Operating Rooms, ICU, CCR etc.

Outdoor air Directly passthrough the cooling coil and Cooled & De-humidified to coil leaving conditions and enters the room. No air will be circulated, all air is exhausted while keeping space positively pressurised.



# All Fresh Air Applications for Operating Theatres




100% fresh air from outdoors, filtered and cooled & de-humidified before entering the OT. All room air exhausted, creating positive pressure in the OT. Supply air Uni-directional flow (*laminar flow*) is created and return air (*exhaust air*) picked up by wall extract grills at floor level.

# Q & A