Saving the Planet One Building at a Time

Technical Report
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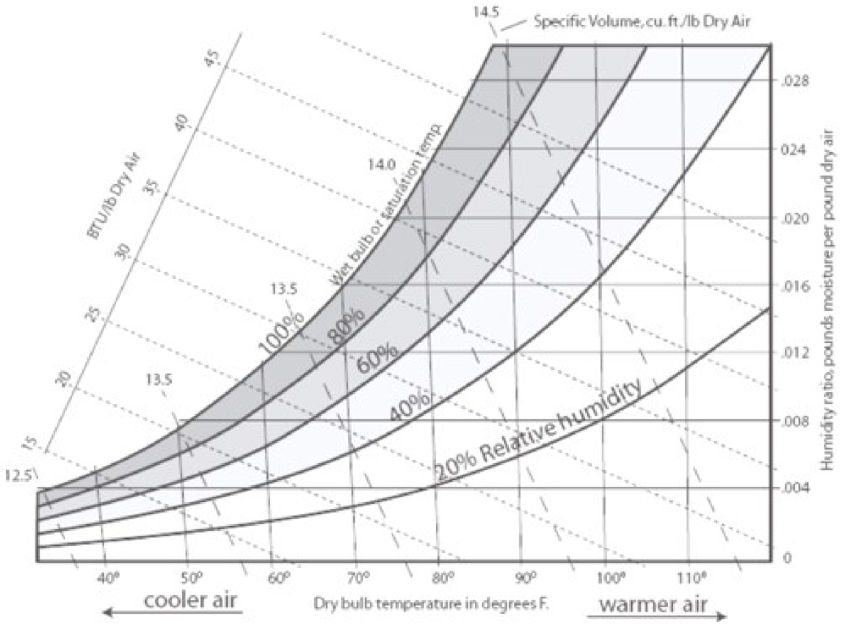
J. Pattavina

# *Introduction to Psychrometrics*



## Table of Contents

# 1. AN INTRODUCTION TO PSYCHOMETRICS

## 1.1. What is Psychometrics

*Psychometrics* in simplest terms is the science of the properties of moist air. Psychometrics is the fundamental method by which heating, cooling and humidification processes are analyzed for HVAC systems to provide comfort level for occupants in a building

The key psychrometric properties of moist air are

- Dry-bulb temperature (°F or °C)
- Wet-bulb temperature (°F or °C)
- Relative humidity (%)
- Absolute Humidity or Humidity Ratio ($grain_{WATER}$ / $lb_{AIR}$) or ($lb_{WATER}$ / $lb_{AIR}$)
- Enthalpy is the btu per pound of air ($btu/lb_A$)

Any two of these properties are sufficient to identify a state of moist air.

## 1.2. Intensities and Extensities

An ***intensive property*** or an ***intensity*** is a property whose magnitude does not depend on the amount of matter considered. Common intensities are pressure, temperature, electrical potential, density, chemical potential. An ***extensive*** property or ***extensity*** is a property whose magnitude is dependent upon the amount of matter considered. If you cut a box in half, its energy, volume, charge, and mass get cut in half. Common extensities are energy, volume, charge, mass. We can convert an extensive property to an intensive equivalent by dividing it by its mass. We denote this extensive property per unit mass by the prefix ***specific*** Common ***specific extensities*** are energy/mass, volume/mass = 1/density, temperature/mass.

## 1.3. Energy Flow

Intensive properties, when existing in unequal equal amounts, can cause an ***energy gradient*** which in turn is the driving force for the flow of energy. Therefore, intensities are sometimes termed ***effort variables.*** Extensive properties are the properties that if unconstrained, will flow if exposed to an energy gradient (intensity). Therefore, these properties are sometimes called ***flow***, ***flux***, ***current*** or ***extensities.***

*Example* - a temperature gradient causes heat flow, a pressure gradient causes fluid flow, a voltage gradient causes charge flow (current), a potential height gradient causes mass to fall.

## 1.4. Heat

*Heat Q* is a commonly misunderstood concept, even among HVAC specialist. Heat is not a static entity or even a property of state, like mass, temperature, or pressure. Heat *Q*, like its mechanical counterpart ***work W***, is a ***transient*** interaction that ***ceases to exist once the process has ended***. One can say an object has a given amount of mass, temperature, and pressure. However, ***one cannot say whether an object contains or stores an amount of heat***. An object contains or stores only ***internal energy*** *U* which is a measure of the molecular potential and kinetic energy.

***Temperature,*** however, is a measure of the molecular ***kinetic*** energy. When energy is in motion from point A to B, it becomes heat *Q* i.e., ***thermal energy in transit***. The following analogy may help. Heat is like rain and internal energy is like water. When water vapor is in a cloud its water. When the vapor condenses and falls it becomes rain (water in transit). Once the droplets hit the lake surface, they are no longer rain, but just water. Likewise, internal energy is like water and when internal energy is in transit from A to B this energy is called heat. Once the heat flow has stopped, heat ceases to exist. Thus, internal energy and temperature are properties of state while heat is a process.

## 1.5. Sensible and Latent Heat

When an object is heated, its temperature rises, due to an increase in the average molecular kinetic energy. This heat is ***sensible heat*** since it can be sensed by a temperature change. For air this heat is referred to as ***dry heat*** and is measured by ***dry-bulb*** temperature i.e., standard thermometer.

When a substance changes state from solid to liquid or liquid to vapor, the absorbed energy is used to change the molecular bonding, spreading the molecules into a larger volume; but it does not change the average molecular velocity (kinetic energy), therefore temperature does not change. The heat added to or removed from a substance during a phase change is called ***latent heat***, since the changes are ***hidden*** or ***concealed*** with respect to dry-bulb temperature. For air, latent heat represents the ***wet heat*** in the air that would be required for water to undergo a phase change to a vapor and is measured by ***wet-bulb temperature***.

The terms ***total capacity*** (sensible and latent heat) and ***sensible capacity*** are used to define a unit's cooling capacity. Sensible capacity is the capacity required to lower the temperature and latent capacity is the capacity to remove moisture from the air.

The following figure shows the phases of water which contains a total of 1,352 BTUs of energy between 0° and 300 °. Of this total, it takes a whopping 970 BTUs of latent heat to vaporize the water. This is why refrigeration systems utilize latent heat of vaporization to expel/extract heat to/from the surroundings.

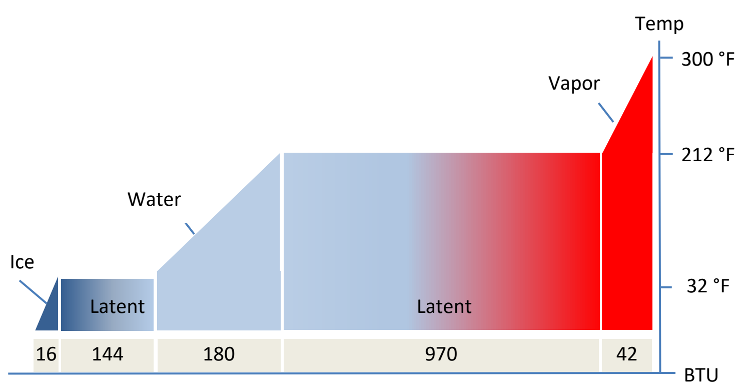



Figure 1-1 Sensible and latent heat for a pound of water (1,352 BTU/lb of water)

## 1.6. Sensible Heat Ratio

The percentage of the capacity that goes toward sensible cooling is called ***Sensible Heat Ratio*** (SHR). For example, a system that has an SHR of 70% and 10,000 Total BTUs of capacity would produce 7,000 BTUs of sensible cooling and 3,000 BTUs of latent removal.

## 1.8. Enthalpy

***Enthalpy*** of a system is defined as the summation of its ***internal energy U*** and product of the pressure and volume or ***PV work*** of the system

| | | |
|---|---|---|
| $H = U + PV\left(Joules\right)$ | *H* = Internal Energy + PV work (enthalpy) | D 1-1 |

In psychometrics we are dealing with the properties of air and can assume the pressure-volume work or *PV* work = 0. So, for air Enthalpy is equal to the internal energy

| | | |
|---|---|---|
| $H = U\left(Joules\right)$ | *H* = Internal Energy (enthalpy of air) | D 1-2 |

The following are frequently used parameters

| | | |
|---|---|---|
| $h_T\left(btu / lb\right)$ | specific enthalpy (total) | D 1-3 |
| $h_S\left(btu / lb\right)$ | specific enthalpy (sensible) | D 1-4 |
| $h_T\left(btu / lb\right)$ | specific enthalpy (latent) | D 1-5 |
| $Q_T = \left(btu\right)$ | enthalpy (total) | D 1-6 |
| $Q_S = btu$ | enthalpy (sensible) | D 1-7 |
| $Q_L = btu$ | enthalpy (latent) | D 1-8 |
| $CFM\left(ft^3 / \min\right)$ | air flow | D 1-9 |

## 1.9. Properties of Air

***Atmospheric Air*** contains nitrogen, oxygen, carbon dioxide, water vapor, other gases, and miscellaneous contaminants such as dust, pollen, and smoke. This is the air we breathe and use for ventilation. ***Dry Air*** exists when all the contaminants and water vapor have been removed from atmospheric air. Dry air is used as the reference in psychometrics. ***Moist Air*** is a mixture of dry air and water vapor. For practical purposes, ***moist air and atmospheric air can be considered the same*** thing under normal conditions encountered. The following are key properties of air

| | | |
|---|---|---|
| $c_a = 0.24\left(btu / lb - f°\right)$ | specific heat of air. Energy to raise 1 lb of air by 1°F | D 1-10 |
| $\beta = 1/7,000\left(lb_w / grains\right)$ | grains per lb of water (GPP) | D 1-11 |
| $\sigma = 0.018\left(btu / ft^3 - °F\right)$ | btu per cubic foot of air per degree | D 1-12 |
| $\rho = 0.075\left(lb_a / ft^3\right)$ | pounds per cubic feet of air (density) | D 1-13 |
| $\mu = 1,075\left(btu / lb\right)$ | enthalpy (h) of air at 32 °F for the evaporation of water | D 1-14 |

## 1.10. Psychometrics Heat Equations

The following are the fundamental psychometrics equations for heat transfer expressed in the units of btu/hour,

- $\Delta h$ = The change in enthalpy between return and supply air
- $\Delta T$ = The difference between the dry bulb temperature of the return air and the dry bulb temperature of the supply air
- $\Delta G$ = The difference between the moisture content (in grains of moisture per pound of dry air) of the return and supply air (GPP)
- $\Delta W$ = The difference between the moisture content (in pounds of moisture per pound of dry air) of the return and supply air (PPP)

**Total heat per hour**

$$q_T = 4.5\ CFM\ \Delta h\left(btu/hr\right) \qquad \text{eq 1-1}$$

*Proof*

$$q_T = \rho CFM\ \Delta h = 0.075\left(\frac{\cancel{lb}}{\cancel{ft^3}}\right)\times CFM\left(\frac{\cancel{ft^3}}{\cancel{\min}}\right)\times 60\left(\frac{\cancel{\min}}{hr}\right)\times \Delta h\left(\frac{btu}{\cancel{lb}}\right)$$

$$= 4.5 CFM\ \Delta h\left(\frac{btu}{hr}\right)$$

■

**Sensible heat per hour**

$$q_S = 1.08\ CFM\ \Delta T\left(btu/hr\right) \qquad \text{eq 1-2}$$

*Proof*

$$q_S = \sigma CFM\ \Delta T = 0.018\left(\frac{btu}{\cancel{ft^3} - \cancel{°F}}\right)\times CFM\left(\frac{\cancel{ft^3}}{\cancel{\min}}\right)\times 60\left(\frac{\cancel{\min}}{hr}\right)\times \Delta T\left(\cancel{°F}\right)$$

$$= 1.08 CFM\ \Delta T\left(\frac{btu}{hr}\right)$$

■

**Latent heat per hour** (for $\Delta G$ in GGP)

$$q_L = 0.68\ \ CFM\ \Delta G\left(btu/hr\right) \qquad \text{eq 1-3}$$

*Proof*

$$q_L = \mu\rho\beta CFM\ \Delta G$$

$$= 1{,}075\left(\frac{btu}{\cancel{lb}}\right)\times 0.075\left(\frac{\cancel{lb}}{ft^3}\right)\times CFM\left(\frac{\cancel{ft^3}}{\cancel{\min}}\right)\times 60\left(\frac{\cancel{\min}}{hr}\right)\times \frac{1}{7{,}000}\left(\frac{\cancel{lb}}{\cancel{grains}}\right)\times \Delta G\left(\frac{\cancel{grains}}{\cancel{lb}}\right)$$

$$= 0.69 CFM\ \Delta G\left(\frac{btu}{hr}\right)$$

■

**Latent heat per hour** (for $\Delta W$ *in lb/lb* )

$$q_L = 0.68\ CFM\ \Delta W\left(btu/hr\right) \qquad \text{eq 1-4}$$

*Proof*

$$\begin{aligned} q_L &= \mu\,\rho\,CFM\ \Delta W \\ &= 1{,}075\left(\frac{btu}{\cancel{lb}}\right)\times 0.075\left(\frac{\cancel{lb}}{ft^3}\right)\times CFM\left(\frac{\cancel{ft^3}}{\cancel{\min}}\right)\times 60\left(\frac{\cancel{\min}}{hr}\right)\times \Delta W\left(\frac{\cancel{lb}}{\cancel{lb}}\right) \\ &= 4.83\,CFM\ \Delta W\left(\frac{btu}{hr}\right) \end{aligned}$$

■

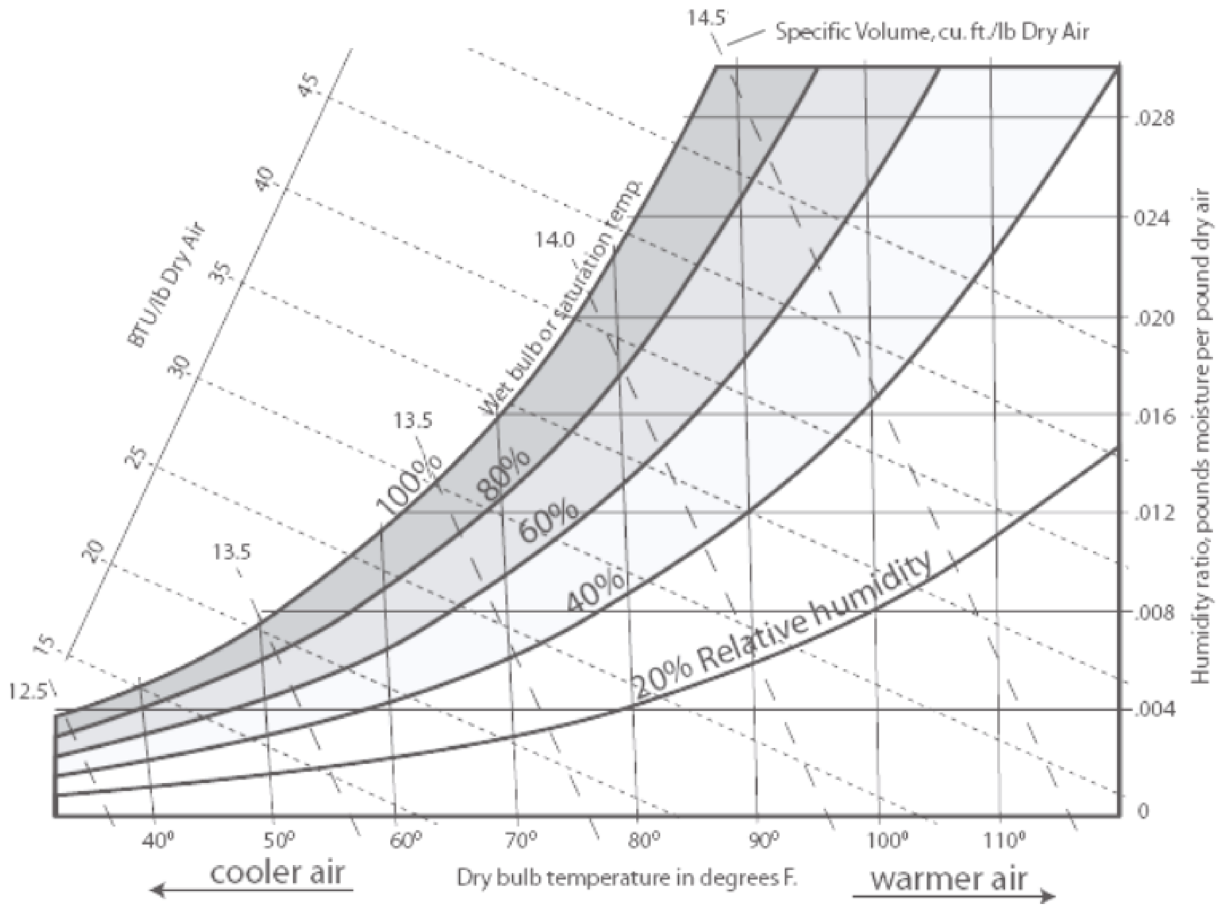
Airflow (CFM) required to condition a space can be calculated from either the total, sensible or latent heat per hour. Below we give the CFM based on the total heat or sensible heat per hour

$$CFM = \frac{q_S}{1.08\,\Delta T}\left(ft^3/\min\right)$$

$$CFM = \frac{q_T}{4.5\,\Delta h}\left(ft^3/\min\right) \qquad \text{eq 1-5}$$

## 2. CONSTRUCTING A PSYCHOMETRIC CHART

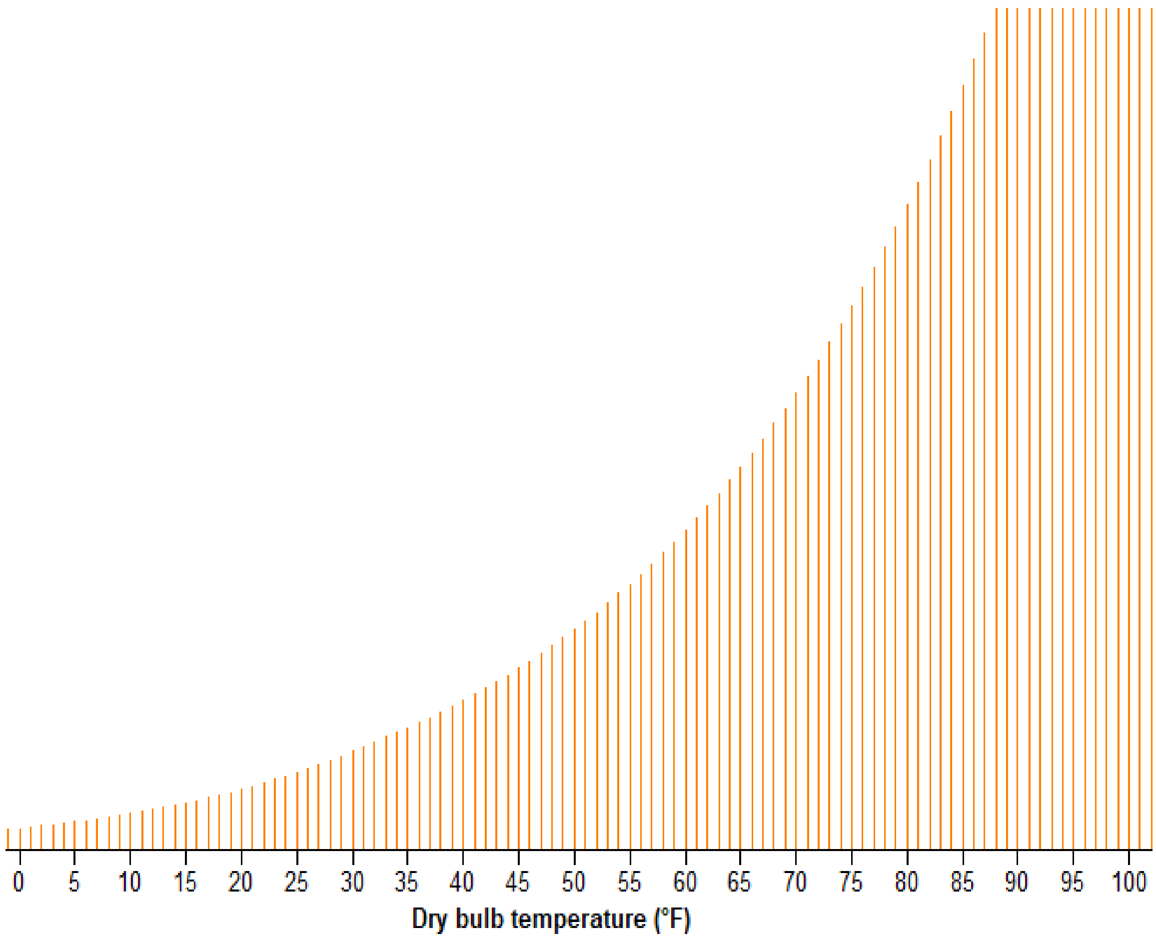
The Psychrometric Chart plots the key properties of air on a single chart



### 2.1. Dry Bulb Temperature

Dry Bulb Temperature (DBT) is the temperature that we measure with a standard thermometer that has no water on its surface.

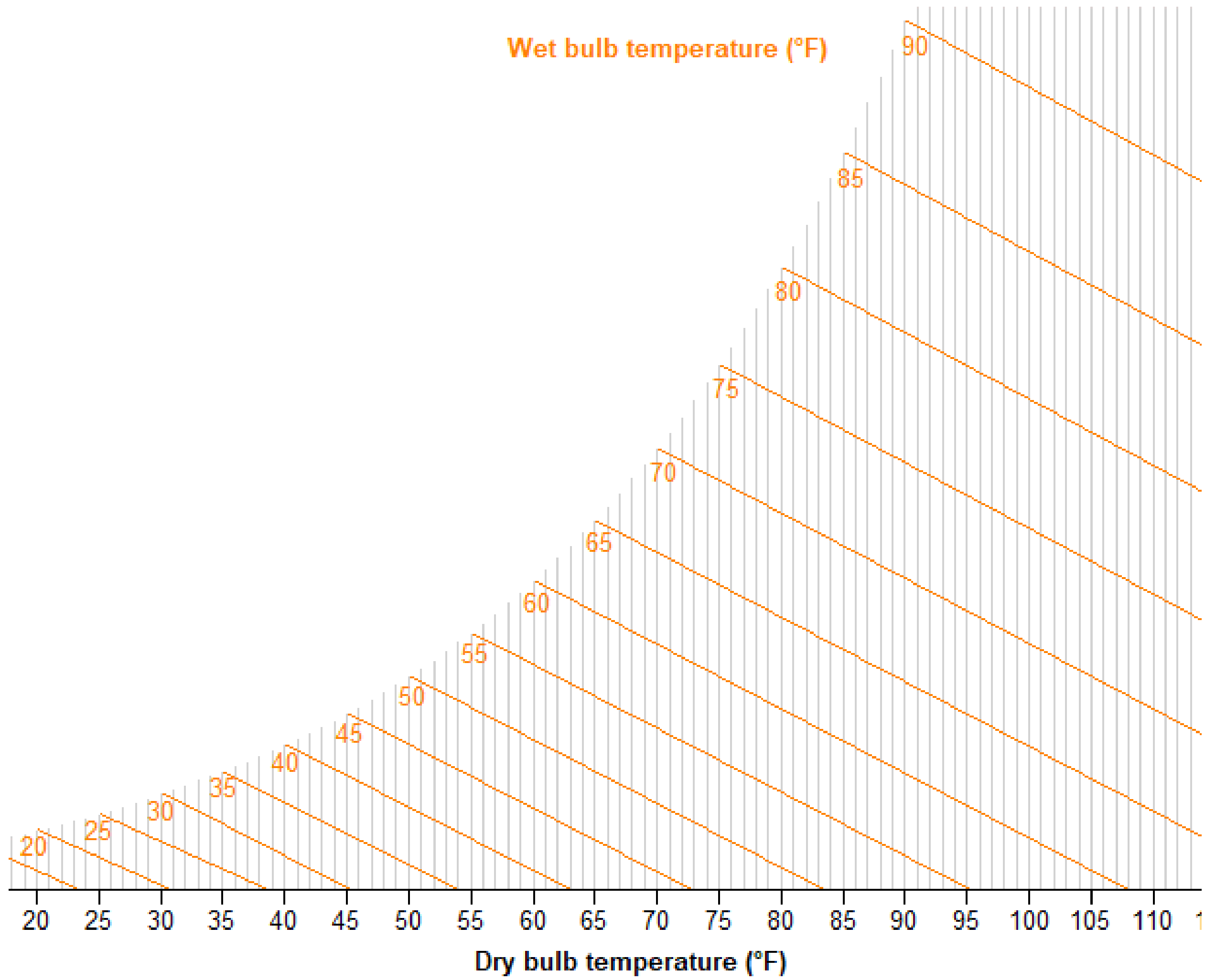
- When people refer to the temperature of the air, they are commonly referring to its dry bulb temperature (DBT).
- The unit of measure used for dry bulb temperature (DBT) is °C or °F



## 2.2. Wet Bulb Temperature

The wet bulb temperature (WBT) is a temperature associated with the moisture content of the air.

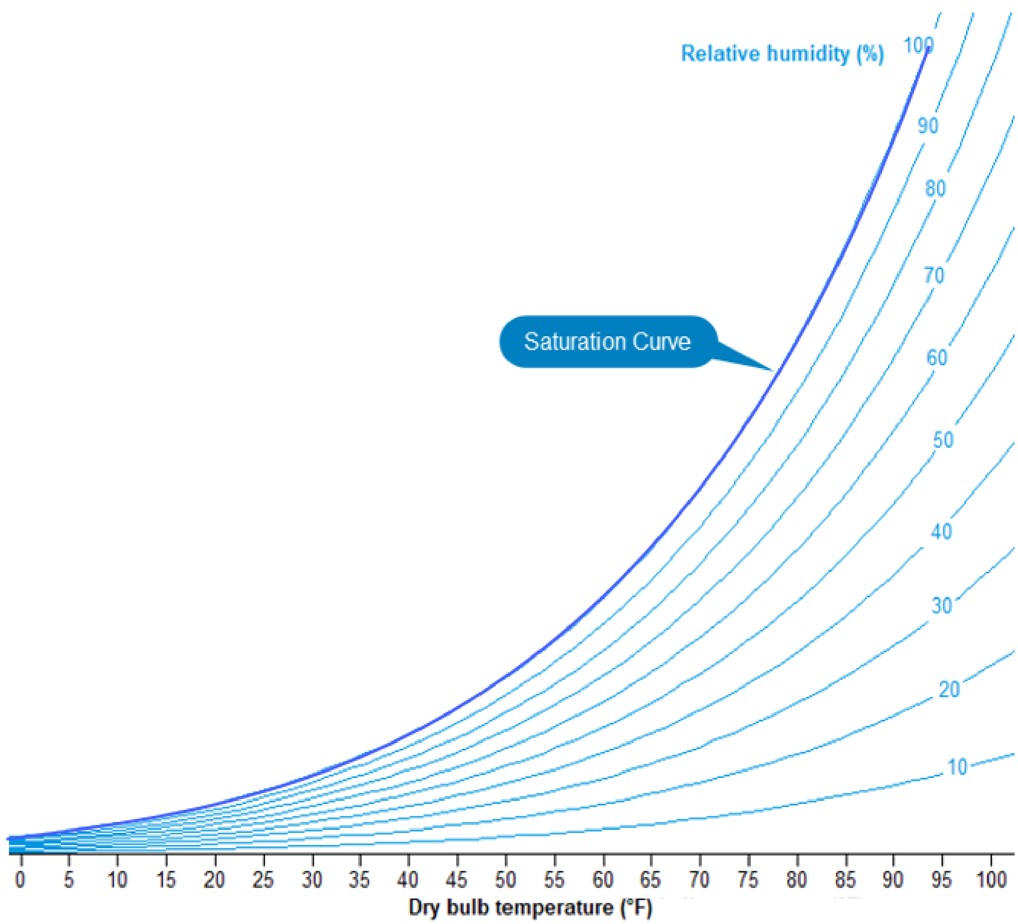
- Wet bulb temperatures are always lower than dry bulb temperatures
- The only time that they will be the same is at saturation i.e., 100% relative humidity.
- The unit of measure used for wet bulb temperature (WBT) is °C or °F



## 2.3. Relative Humidity

Relative humidity (RH) is a comparison of the percentage of moisture a given amount of air IS holding compared to the amount of moisture that the same amount of air CAN hold, at the same dry-bulb temperature.

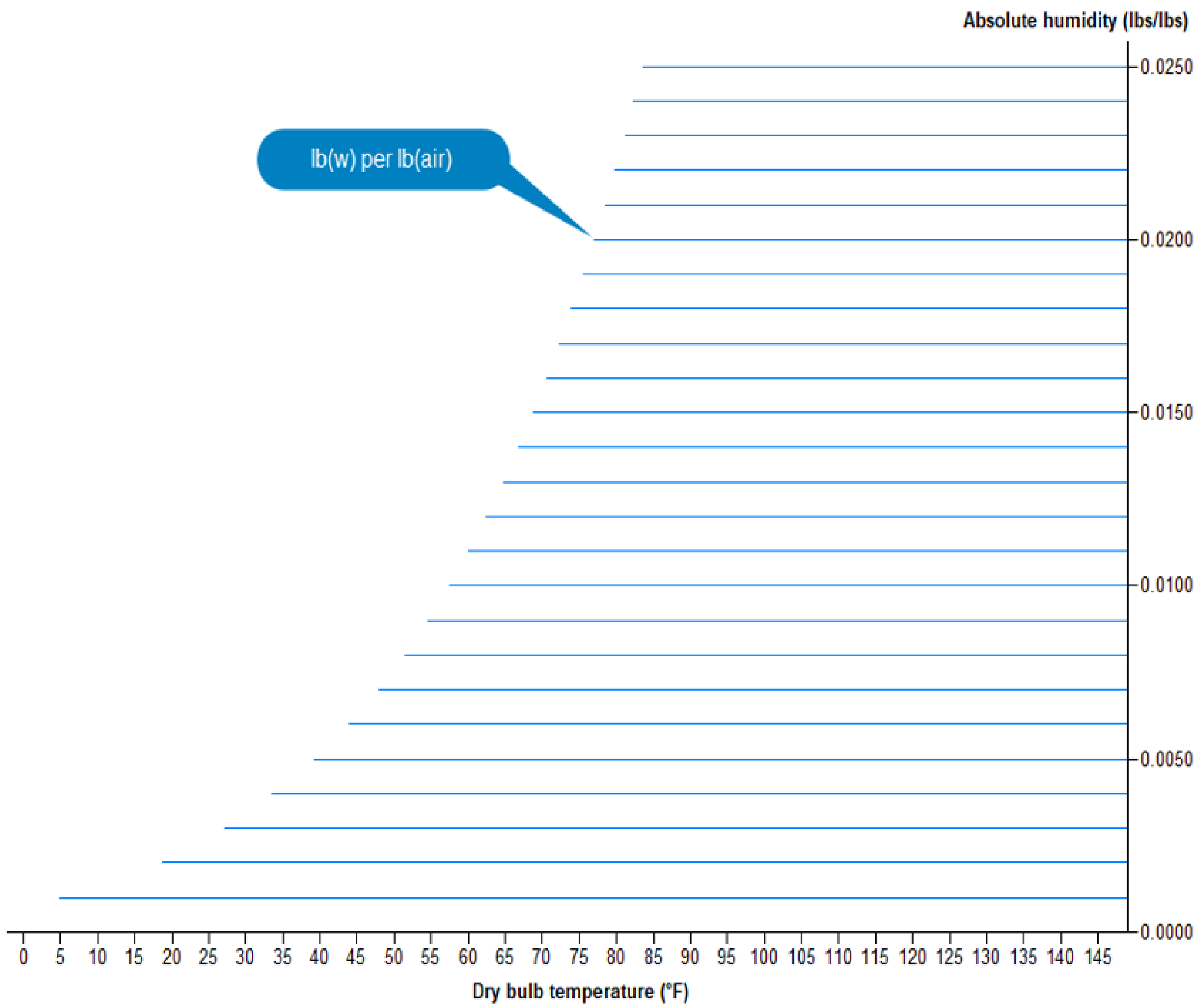
- Warmer air can hold more moisture than cold air.
- The line for 100 percent relative humidity (RH), or saturation, is the upper, left boundary of the chart. In this case the air I saturated and is holding the maximum amount of its capacity. It cannot hold or absorb an additional water.



## 2.4. Humidity Ratio (Absolute Humidity)

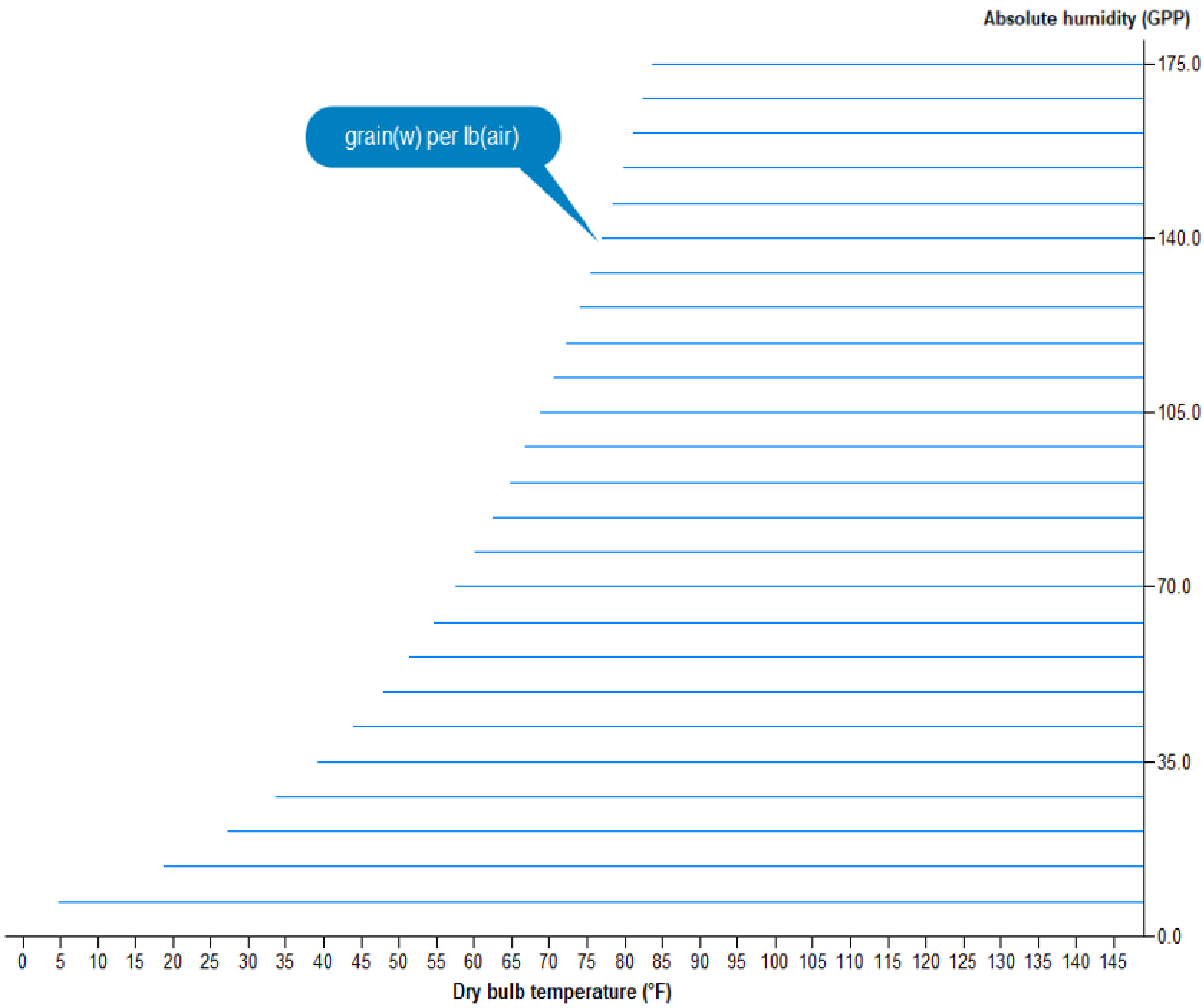
Absolute Humidity (W) or Humidity Ratio is the moisture content of air units in pounds of water per lb of dry air (PPP) or grains of water per lb of dry air.

- Humidity Ratio for lb/lb (PPP)



Absolute Humidity (W) or Humidity Ratio can also be measured in grains of water per pound of air (GPP)

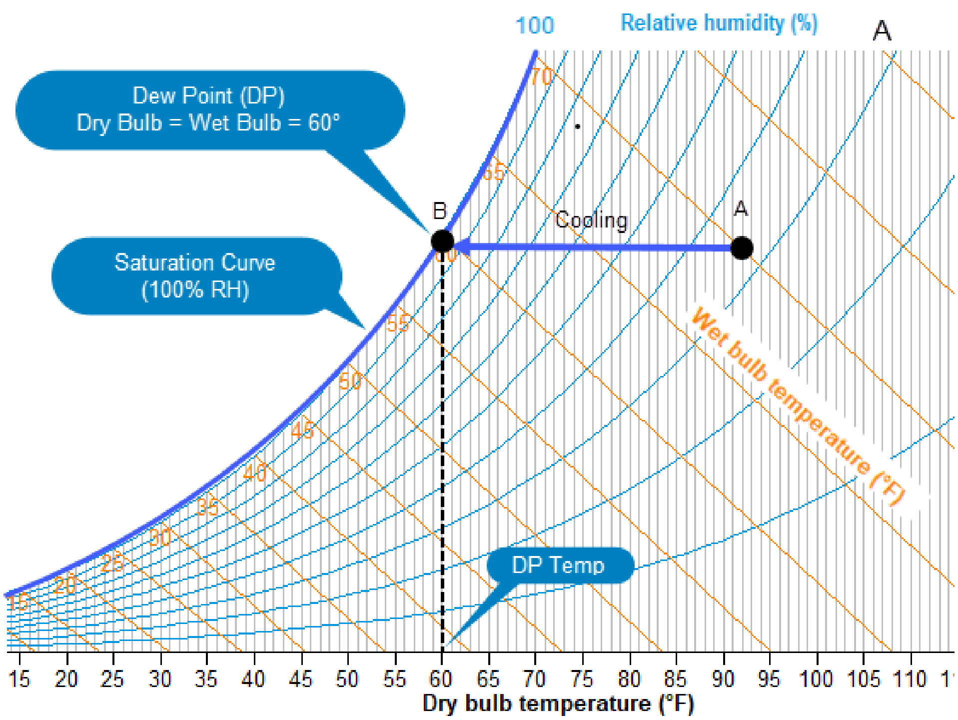
- Humidity Ratio for grains/lb (GPP)



## 2.5. Dew Point

The Dew Point temperature is the temperature at which water begins to condense out of moist air. When air is cooled (the process from A to B), the relative humidity increases until saturation (100% RH) is reached (B), and condensation occurs.

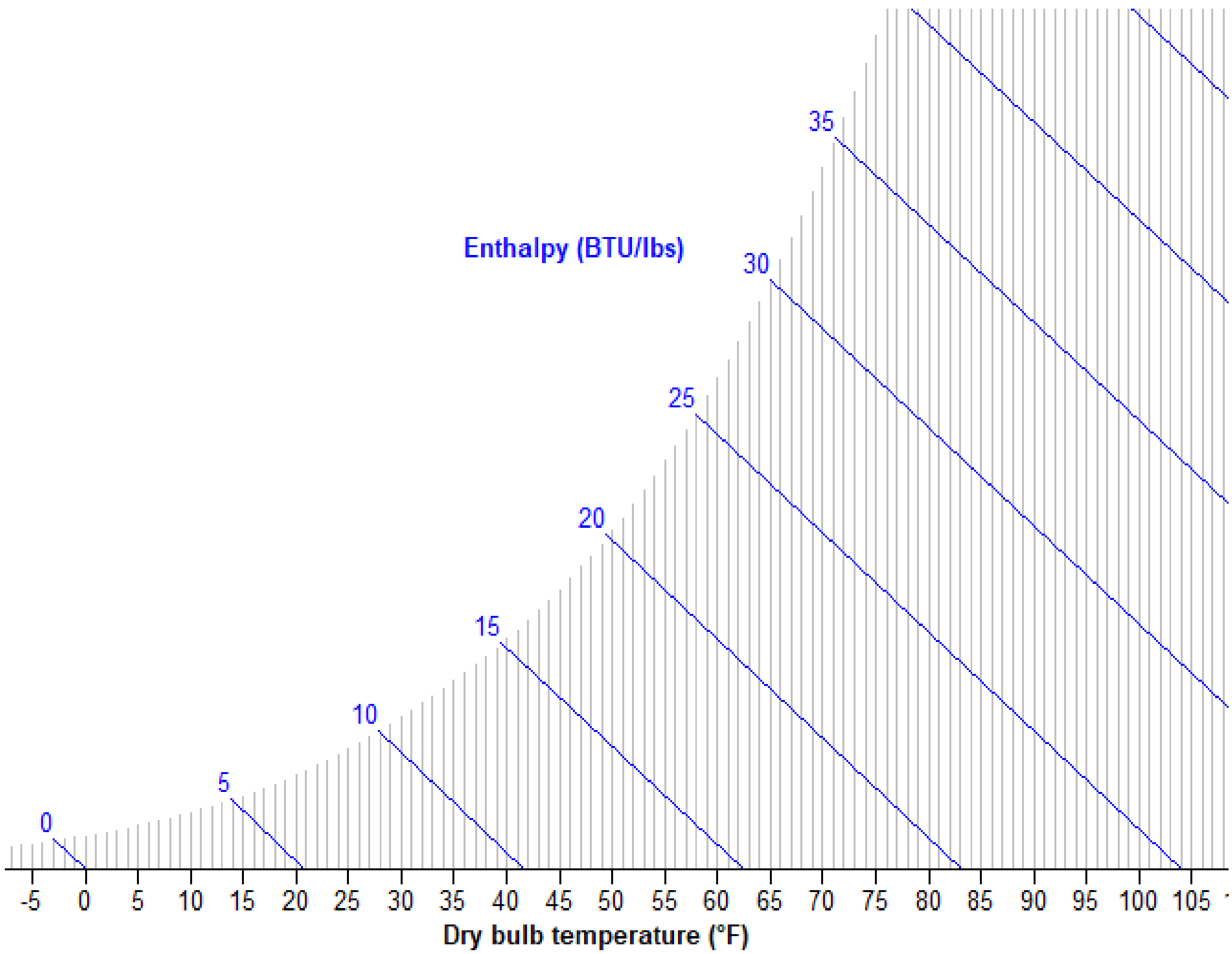
- When air is fully saturated, moisture entering the air displaces moisture within the air. The displaced moisture leaves the air in the form of fine droplets (condensation)
- Condensation occurs on surfaces which are at or below the dew point temperature.
- Dew point is represented along the 100% relative humidity line on the psychrometric chart
- At the dew point the DBT and WBT are the same. The air is saturated and there is no evaporation.



## 2.6. Enthalpy

Enthalpy is the measure of heat-energy or heat content in air due to sensible heat-energy and latent heat-energy.

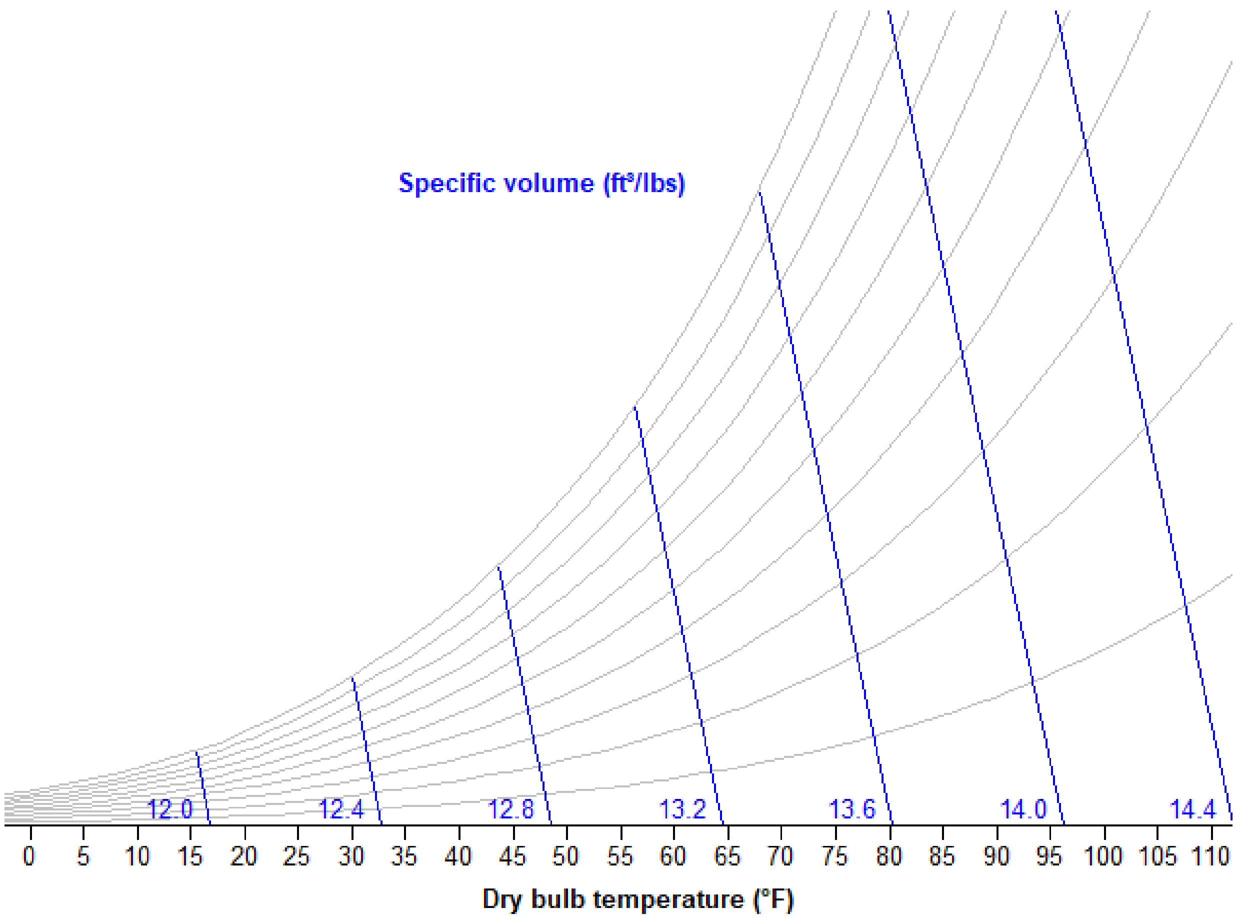
- Sensible heat is the energy in the air is due to the temperature (molecular kinetic energy) of the air
- Latent heat is the energy in the air due to the moisture of the air.
- The sum of the latent energy and the sensible energy is called the air enthalpy.
- Specific enthalpy is expressed in Btu per pound of dry air (Btu/lb of dry air) or kilojoules per kilogram (kJ/kg) of dry air.
- Note - Technically the air does not contain heat but contains thermal energy. The energy is not heat unless it is in transit (removed or added). However, the industries misuse of the term "heat" is prevalent, so we use the term heat here as well.



## 2.7. Specific Volume

Specific Volume is the volume that a certain weight of air occupies at a specific set of Conditions

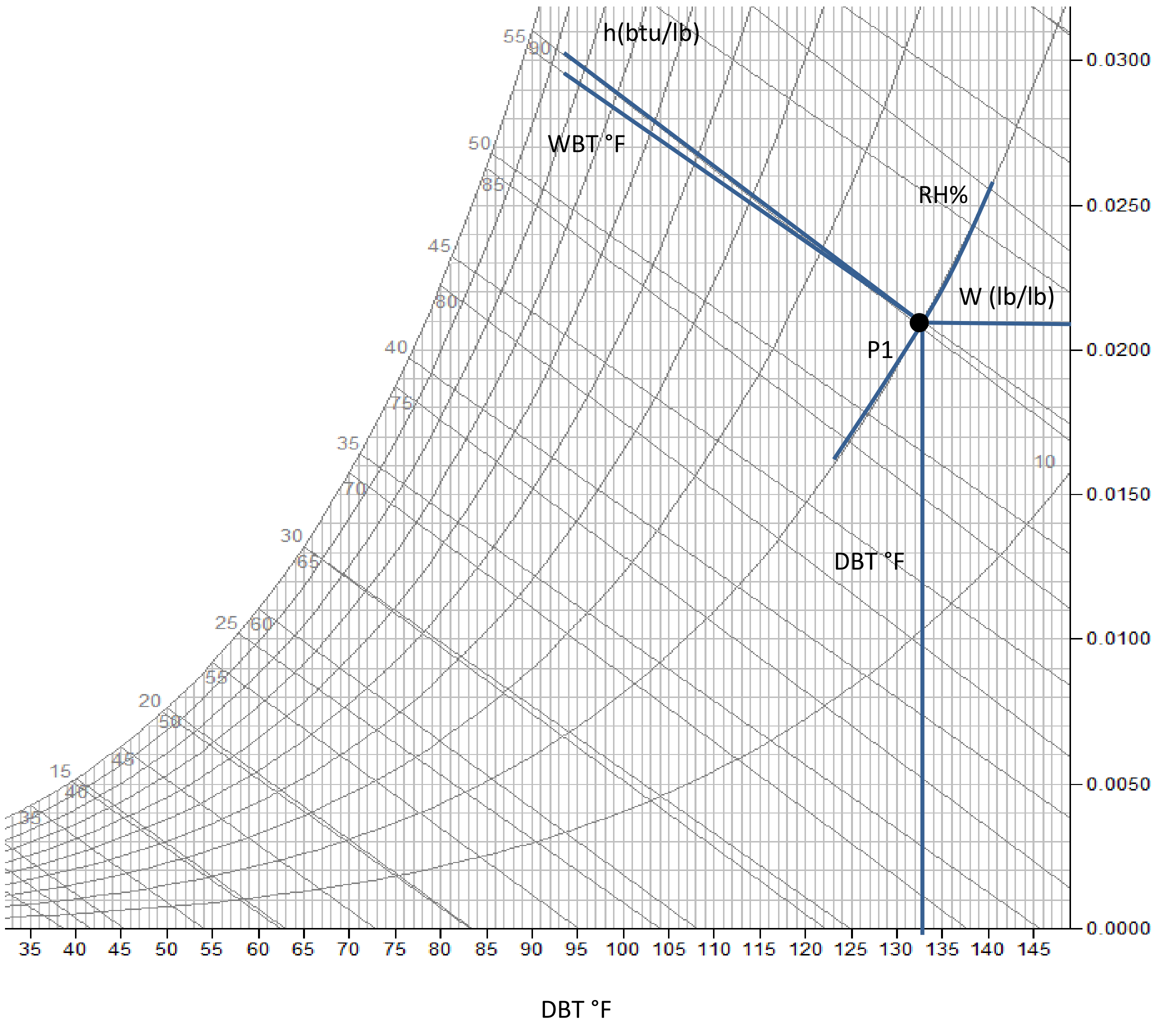
- The specific volume of air is the reciprocal of air density
- As the temperature of the air increases, its density will decrease as its molecules vibrate more and take up more space per Boyle's law.
- Thus, the specific volume will increase with increasing temperature.
- Warm air is less dense than cool air which causes warm air to rise. This phenomenon is known as thermal buoyancy.
- The unit of measure used for specific volume is cubic feet/lb of dry air.



## 3. Using the Psychrometric Chart

### 3.1. State Point

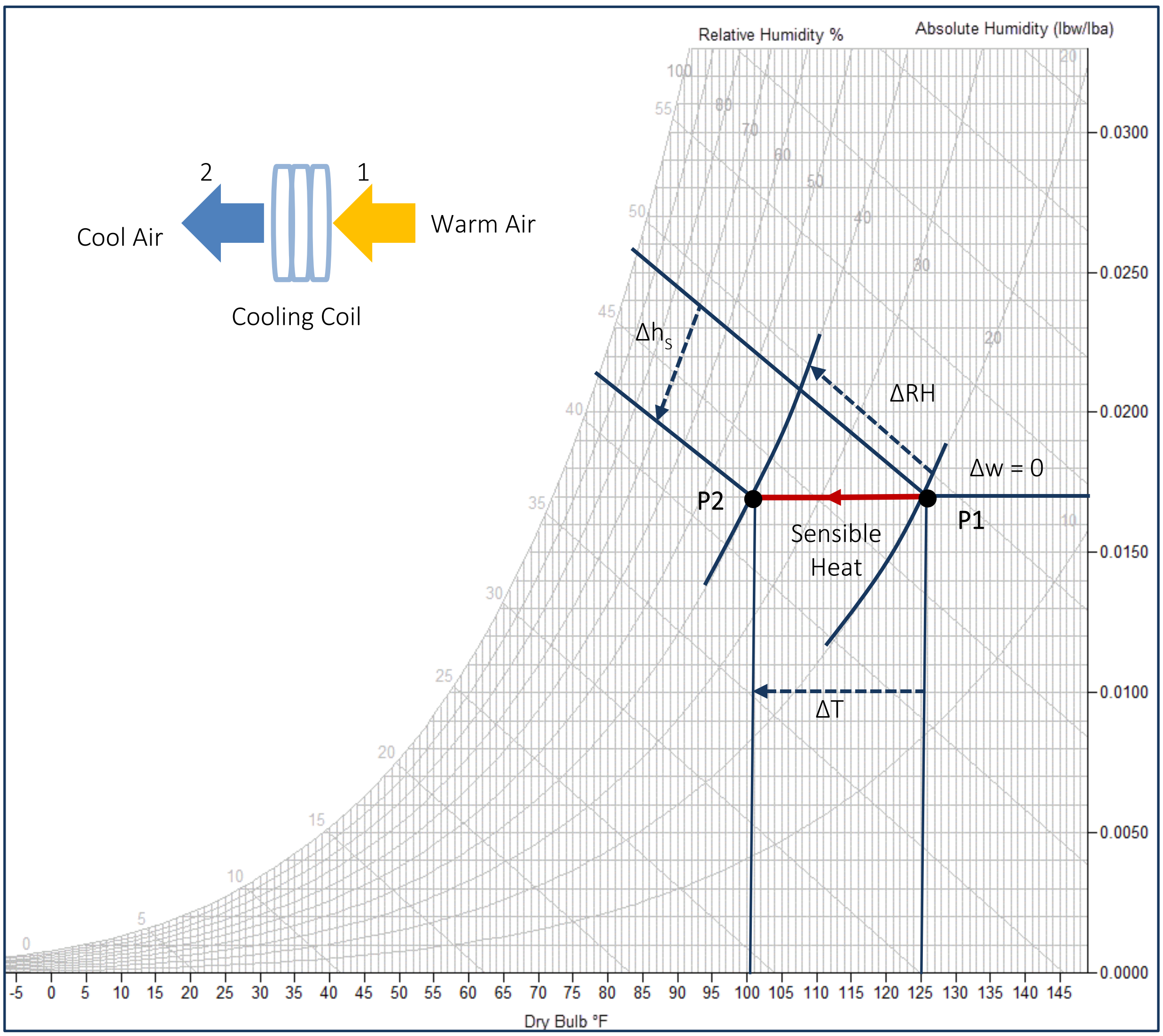
The state of air at any given point in time is represented by a single point say P1 on the psychrometric chart. You can determine the enthalpy, wet bulb temp, dry bulb temp relative humidity and absolute humidity and specific volume at that point



### 3.2. Sensible Cooling (dry cooling)

Wet air is cooled as it passes over a cooling coil.

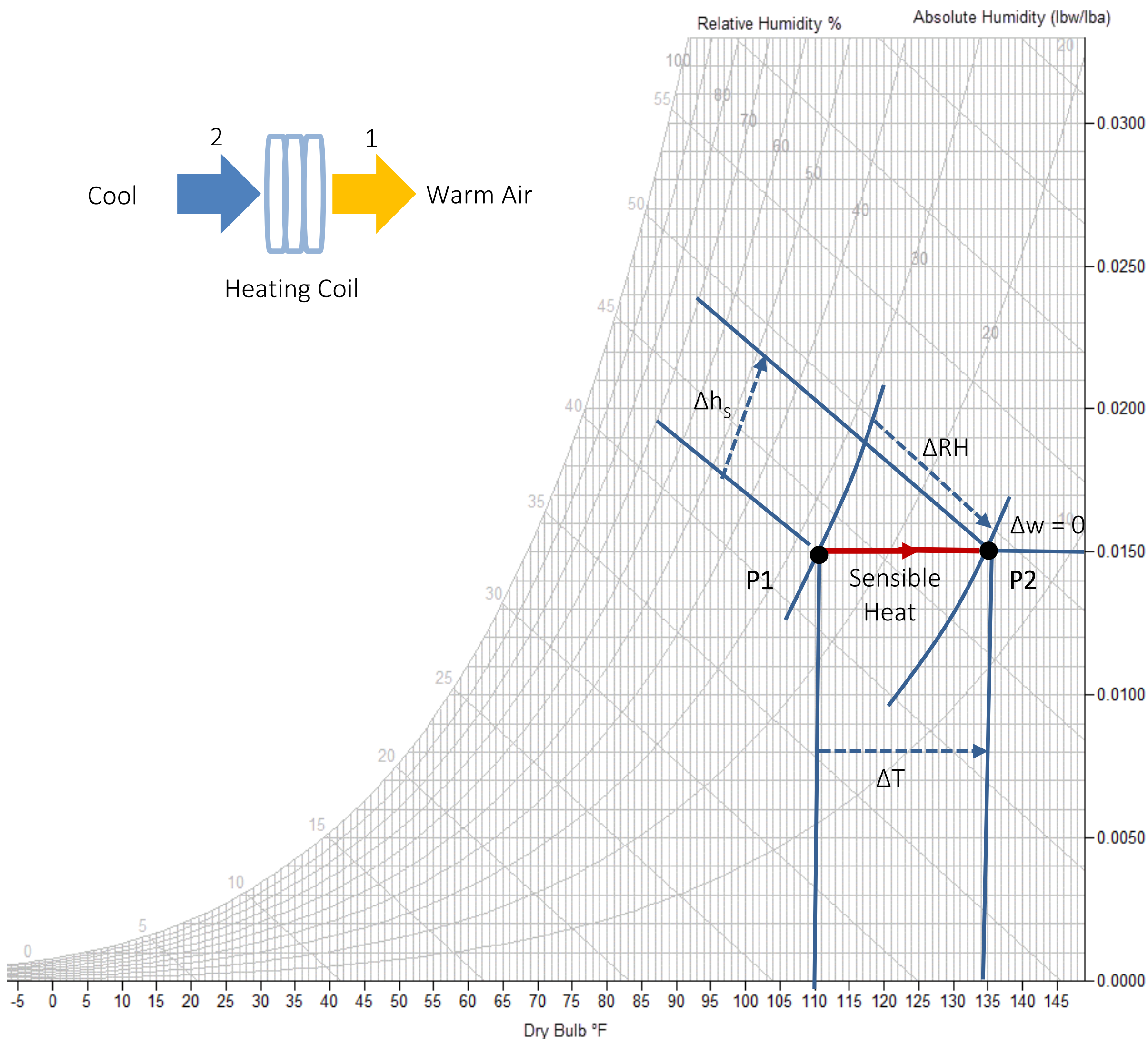
- The process travels at a constant humidity ratio (W) horizontally from P1 to P2
- Dry bulb Temperature (DBT) decreases
- Relative Humidity (RH) increases
- Enthalpy (h) decreases
- Humidity Ratio (W) remains constant ⟶ no change in absolute moisture
- There is no condensation



## 3.3. Sensible Heating (dry heating)

Wet air is heated as it passes over a heating coil

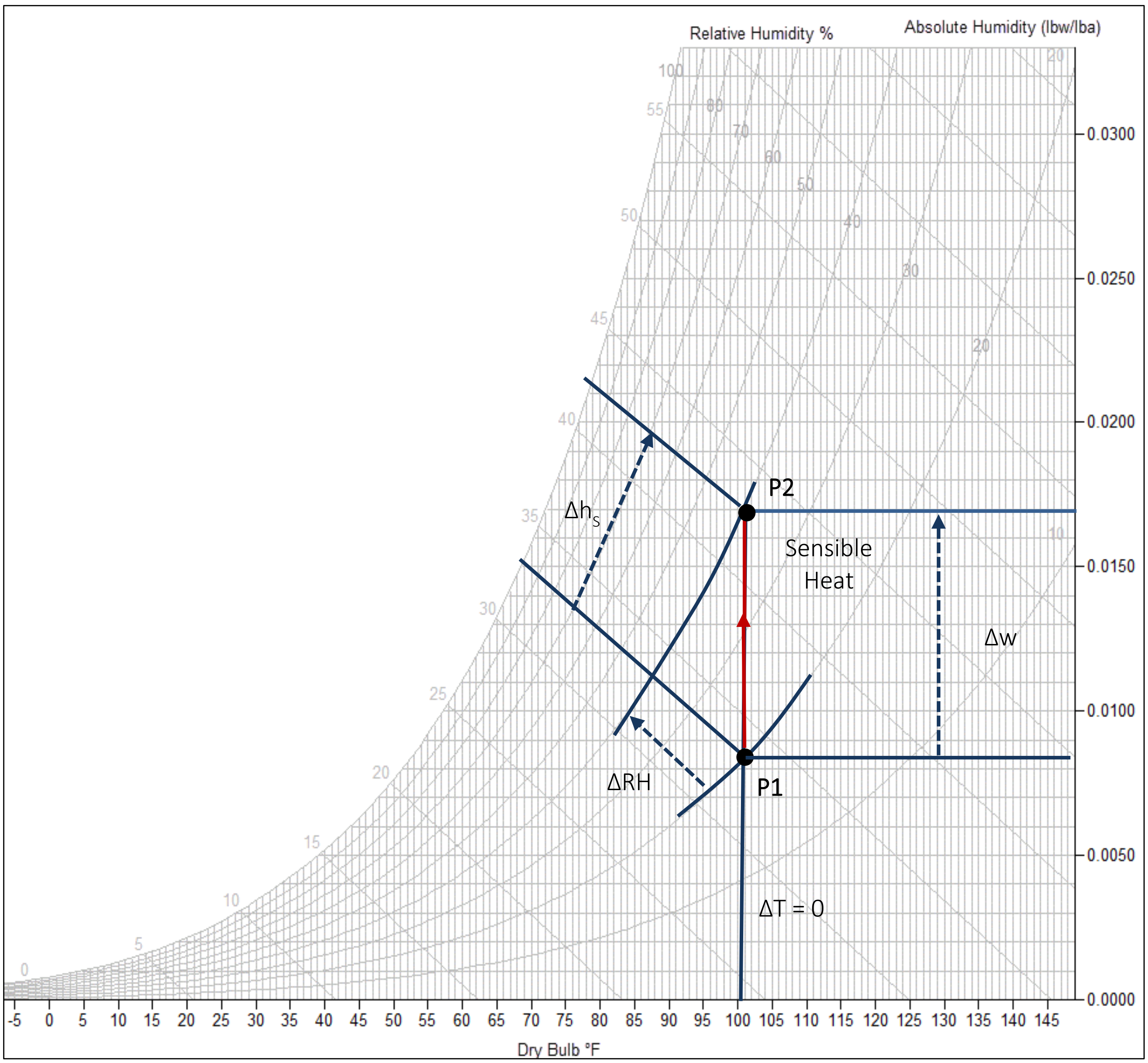
- The process travels at a constant the humidity ratio (W) horizontally from P1 to P2
- Dry bulb temperature decreases
- Relative humidity increases
- Enthalpy increases
- Humidity Ratio (W) remains constant ⟶ no change in absolute moisture
- There is no condensation



## 3.4. Pure Humidification

Moisture is added to the Air

- On a psychrometric chart at a constant DBT the process travels vertically up from P1 to P2
- Relative humidity (RH) increases
- Enthalpy (h) increases
- Humidity Ratio (W) increases ∴ absolute moisture content increases
- There is no condensation

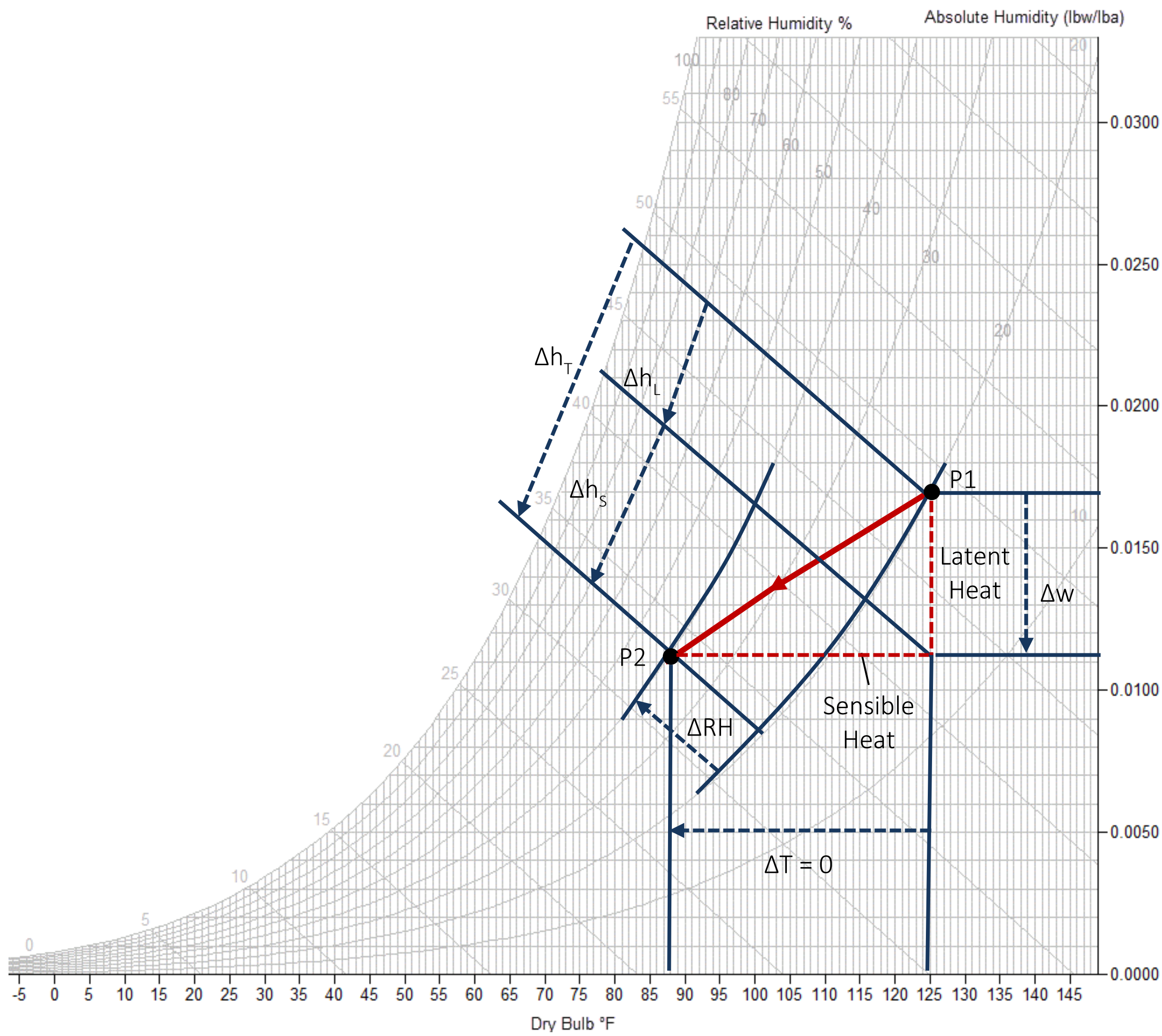


## 3.5. Cooling and Dehumidification

Air is cooled and moisture is removed from the Air

- The air is cooled and dehumidified traveling diagonally from P1 to P2
- Dry bulb temperature (DBT) decreases
- Relative Humidity (RH) increases
- Enthalpy (h) decrease
- Absolute moisture (W) decreases

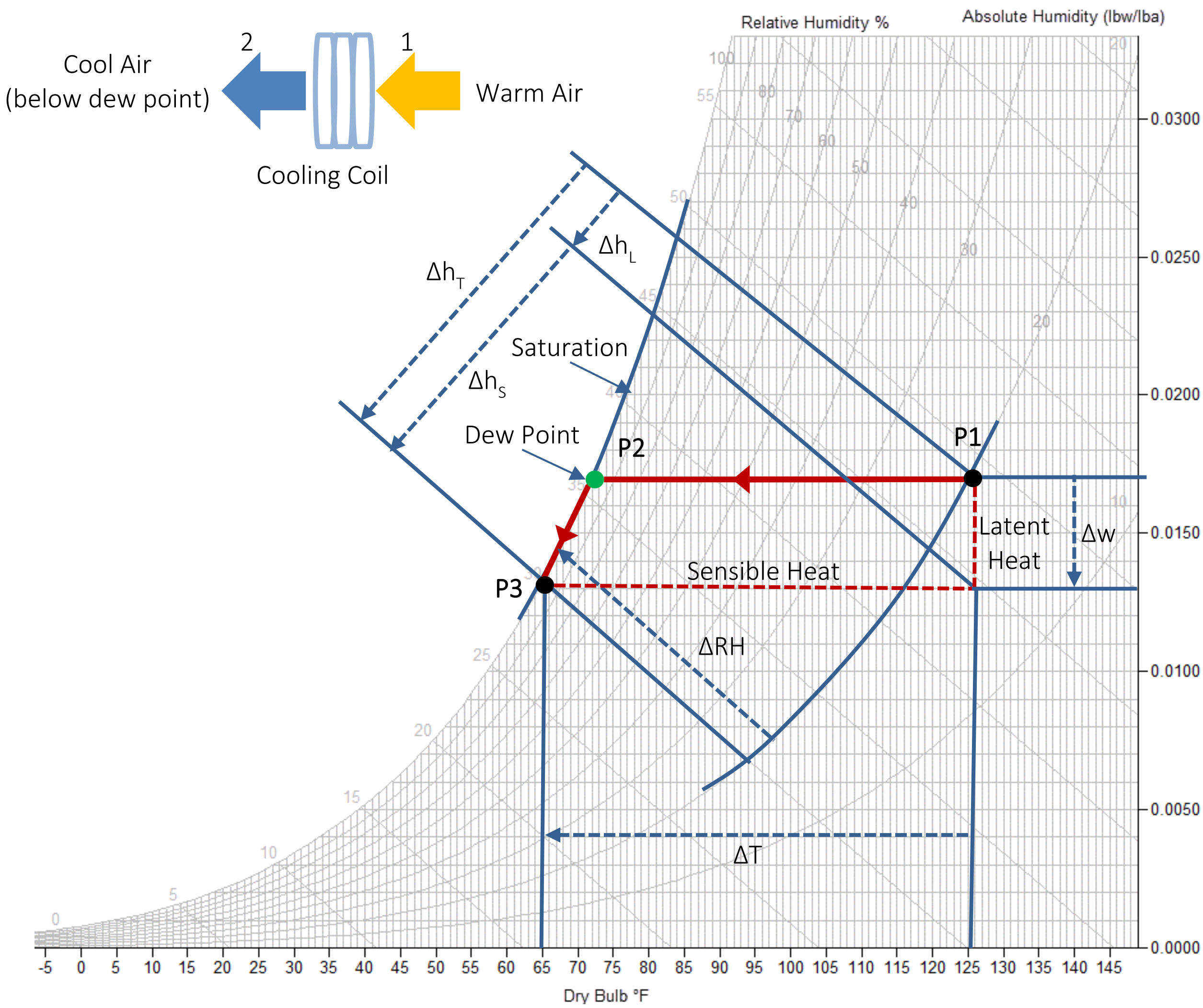
*Note* - Although the absolute moisture (W) decreases the relative humidity (RH) increases because cool air has a lower capacity to store moisture. So, the moisture at P2 represents a higher percentage relative to the capacity the air can hold at the lower temperature.



### 3.6. Cooling and Dehumidification below Dew Point

Air is cooled below Dew Point and moisture is removed from the Air. This is the most common means of cooling for an Air Conditioner.

- On a psychrometric chart at a constant the humidity ratio (W) the process travels horizontally from P1 to the dew point at P2 where RH = 100% saturated. It than travels down the saturation curve to P3
- Dry Bulb Temperature (DBT) decreases
- Relative humidity (RH) increases
- Enthalpy (h) decreases
- Humidity Ratio (W) decreases
- If the air exits the coil at P3 below its dew point at (P2) then there is condensation. Moisture is wrung out of the air by way of condensation.



# 4. Air Flow

## 4.1. Mixing Air

If $T_{OA}$ is the outside air (OA) DBT and $\sigma_{OA}$ is the % of OA air being mixed, then the OA will contribute $T_{OA} \times \sigma_{OA}$ to the DBT of the mixed air. Likewise, if $T_{RA}$ is the room air (RA) DBT and $\sigma_{RA}$ is the % of RA air being mixed, then the RA will contribute $T_{RA} \times \sigma_{RA}$ to the DBT of the mixed air (MA). So, the mixed are DBT is $T_{MA}$ given by

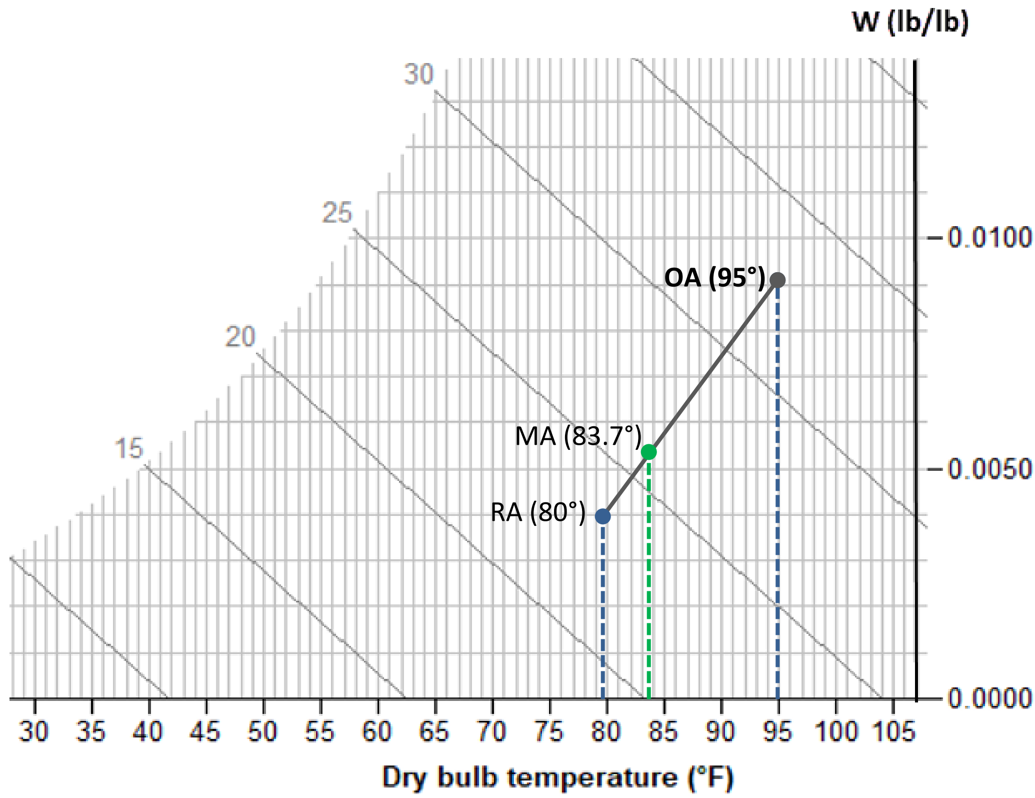
$$T_{MA} = \frac{T_{OA} \times \sigma_{OA}}{T_{RA} \times \sigma_{RA}} \qquad \text{eq 4-1}$$

Example

$$T_{OA} = 95°,\ \sigma_{OA} = 25\%$$
$$T_{RA} = 80°,\ \sigma_{RA} = 75\%$$

Then the mixed air MA dry bulb temperature is

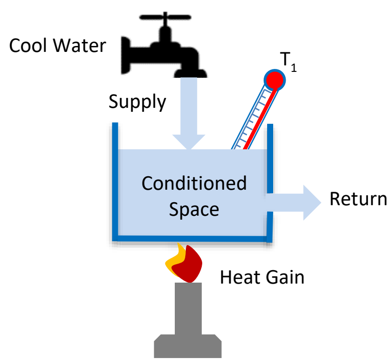
$$T_{MA} = (95 \times 25\% + 80 \times 75\%) = (23.75 \times 60.00) = 83.75$$



# 5. Sensible Heat Ratio (SHR)

This relationship between the conditions and quantity of the rate of supply air flow is described using the heated bucket analogy

- The temperature of the water in the bucket (conditioned space) is to be maintained at a constant temperature.
- The container of water is capable of absorbing heat by the flame. The amount of heat it absorbs is called ***heat gain***.
- To maintain the water temperature at a constant 75 °F, any heat gain must be offset by mixing cool water (supply) with the water already in the container.
- For a given water temperature there is a certain flow rate, measured in gallons per minute (gpm), that will offset the heat gain and maintain the desired temperature in the container.
- If the water is warm, a higher flow rate is required than if the water is very cold.

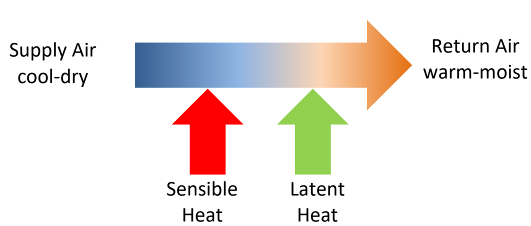



## 5.1. Sensible Heat Ratio

The ability of air to hold more moisture with rising temperature underpins the cooling and dehumidification process in HVAC systems. The Sensible Heat Ratio (SHR) represents the proportion of cooling capacity dedicated to temperature reduction (sensible cooling) versus moisture removal (latent cooling). This concept is critical in psychrometric analysis, which will be explored further with the psychrometric chart.

Conditioned supply air behaves like a sponge, absorbing heat and moisture as it enters a room. The effectiveness of this process depends on the temperature and humidity of the supply air. To manage the room's excess sensible heat and latent heat (moisture), the supply air must be sufficiently cool and dry.,

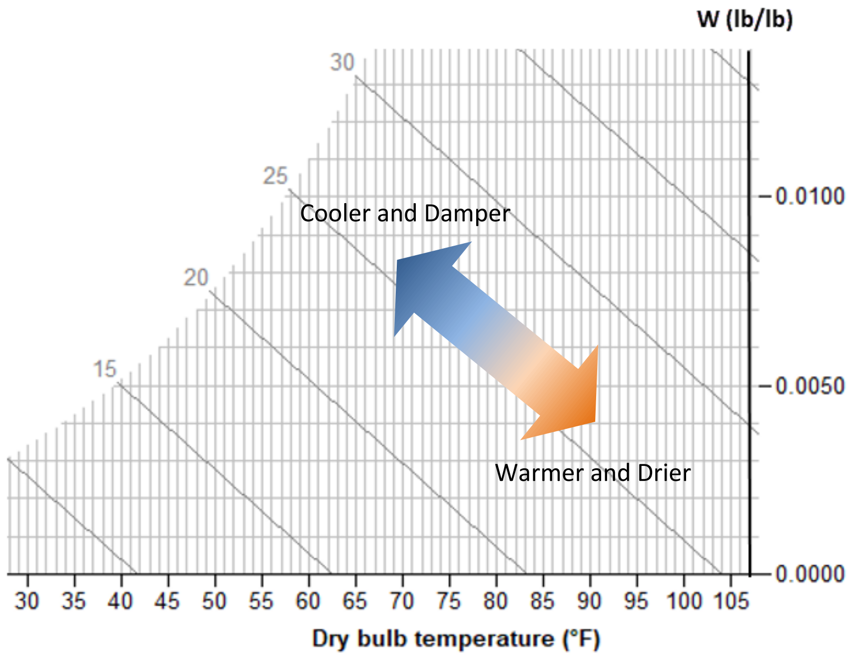
- The sensible and latent heat in the room determines the required dry-bulb and wet-bulb temperatures of that supply air.



When the required amount of sensible and latent heat is not properly removed from the room, the desired room conditions cannot be maintained. For example, if too much sensible heat and not enough latent heat are removed, the room feels cold and damp. On the psychrometric chart, room conditions move up and to the left.

On the other hand, if too much latent heat but not enough sensible heat is removed, the room feels warm and dry. On the psychrometric chart, room conditions move down and to the right. Therefore, the conditions of the supply air must be controlled accurately to ensure that both sensible and latent heat are removed in the proper proportions.

- There are several combinations of dry-bulb and wet-bulb temperatures that will produce the desired room conditions.
- Each of these combinations requires a different quantity of air.

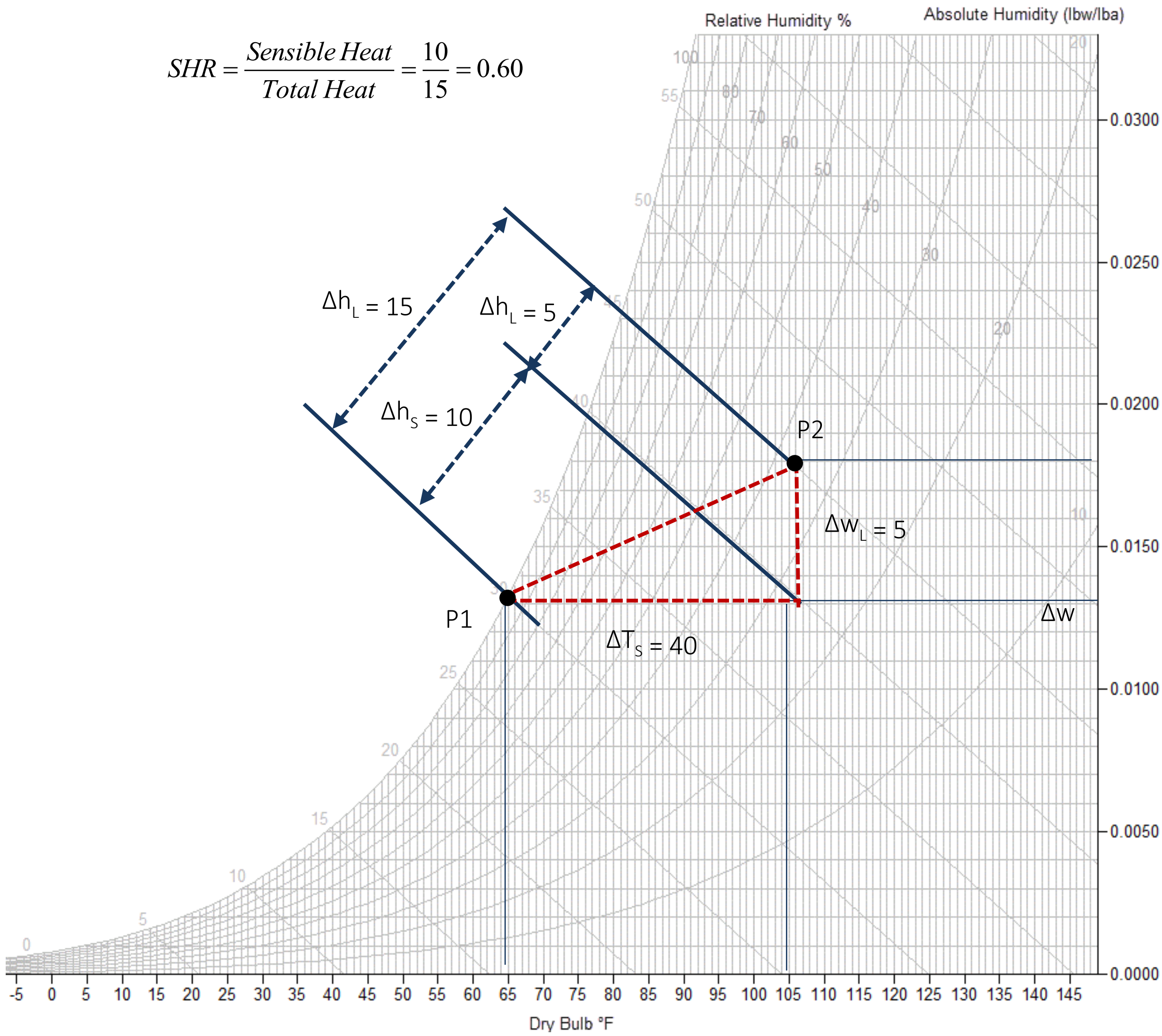



The sensible Heat Ratio is defined as:

$$SHR = \frac{Sensible\,Heat\,Gain}{Sensible\,Heat\,Gain + Latent\,Heat\,Gain} = \frac{Sensible\,Heat\,Gain}{Total\,Heat\,Gain} \qquad \text{eq 5-1}$$

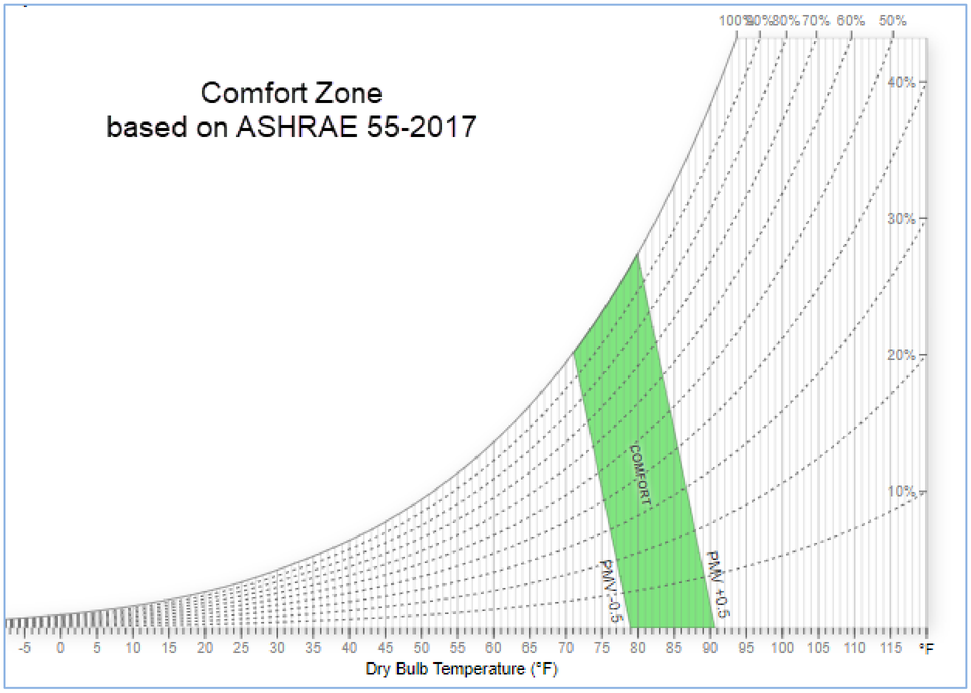
The sensible heat ratio, abbreviated as SHR, refers to the comparison of sensible heat gain to total heat gain (sensible heat plus latent heat). Once this ratio is known, an SHR line can be drawn on the psychrometric chart. Some charts provide an index point around 78 °F DB and 65 °F WB and have a line on the right-hand side marking various ratios. Simply draw a line from the index point to the desired SHR ratio. Then shift the line up or down so it runs through the room set point. If no index is provided simply plot the room set point P2 on the chart. Then move vertically down by *y* $h_L$ units and horizontally to the left by *x* $h_S$. Select *x* and *y* such that the slope of the line is the desired SHR %.

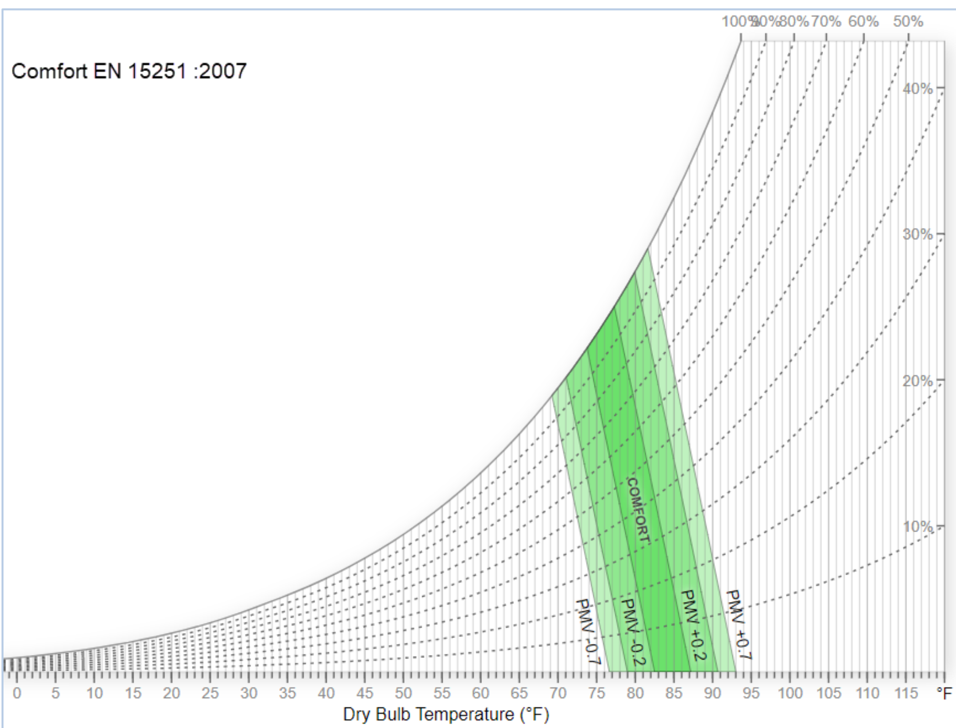
For example, to draw an SHR of 75% move down 25 *h* units and then to the right 75 *h* units. Draw a point here and connect the

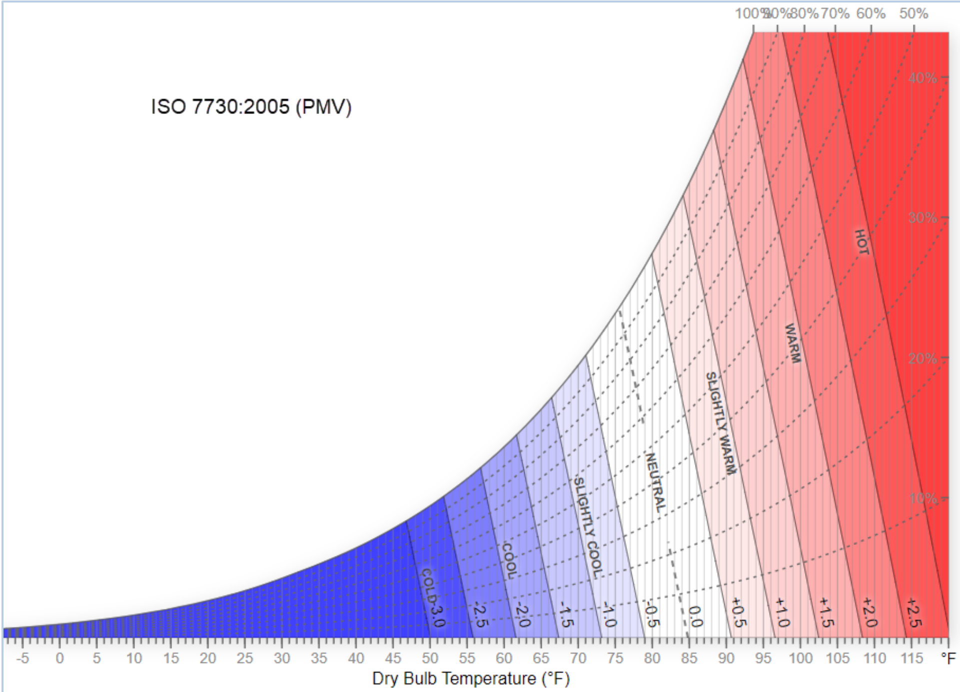


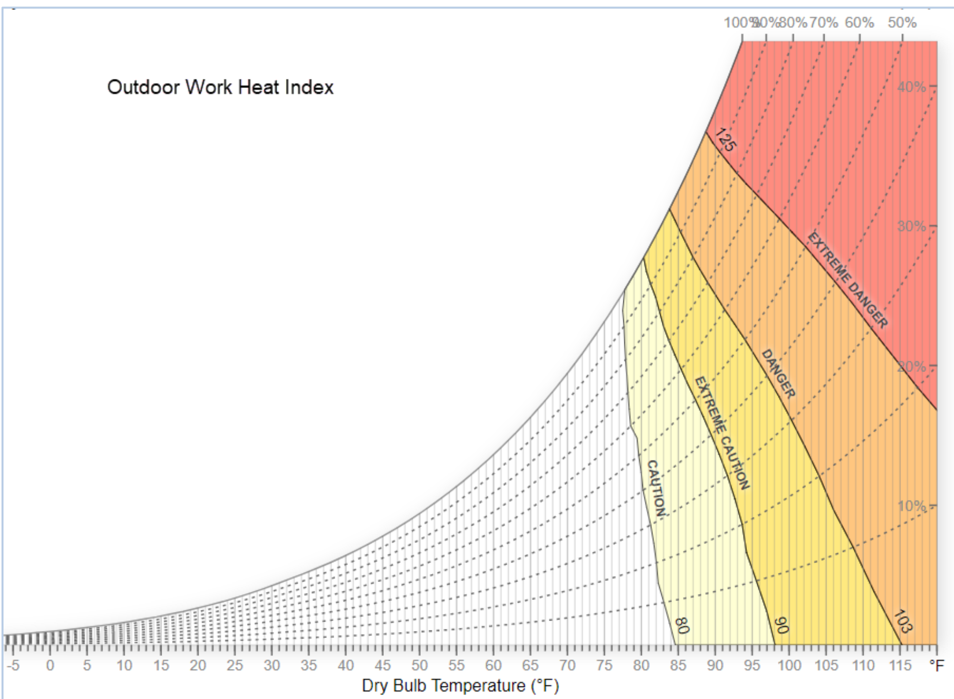
# 6. Comfort Zones

Several Comfort Zone definitions are described below




ISO 7730:2005 (PMV)
100% 90% 80% 70% 60% 50%
40% 30% 20% 10%
COLD -3.0
-2.5
COOL -2.0
-1.5
SLIGHTLY COOL -1.0
-0.5
NEUTRAL 0.0
+0.5
SLIGHTLY WARM +1.0
+1.5
WARM +2.0
+2.5
HOT
-5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 °F
Dry Bulb Temperature (°F)


Outdoor Work Heat Index
100% 90% 80% 70% 60% 50%
40% 30% 20% 10%
CAUTION 80
EXTREME CAUTION 90
DANGER 103
EXTREME DANGER 125
-5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 °F
Dry Bulb Temperature (°F)

# 7. Design Example

## 7.1. Operating Points for Outside Air (OA) and Return Air (RA)

We are to design an AC system to cool a space with the following Outside Air (OA) and Room Air (RA) parameters

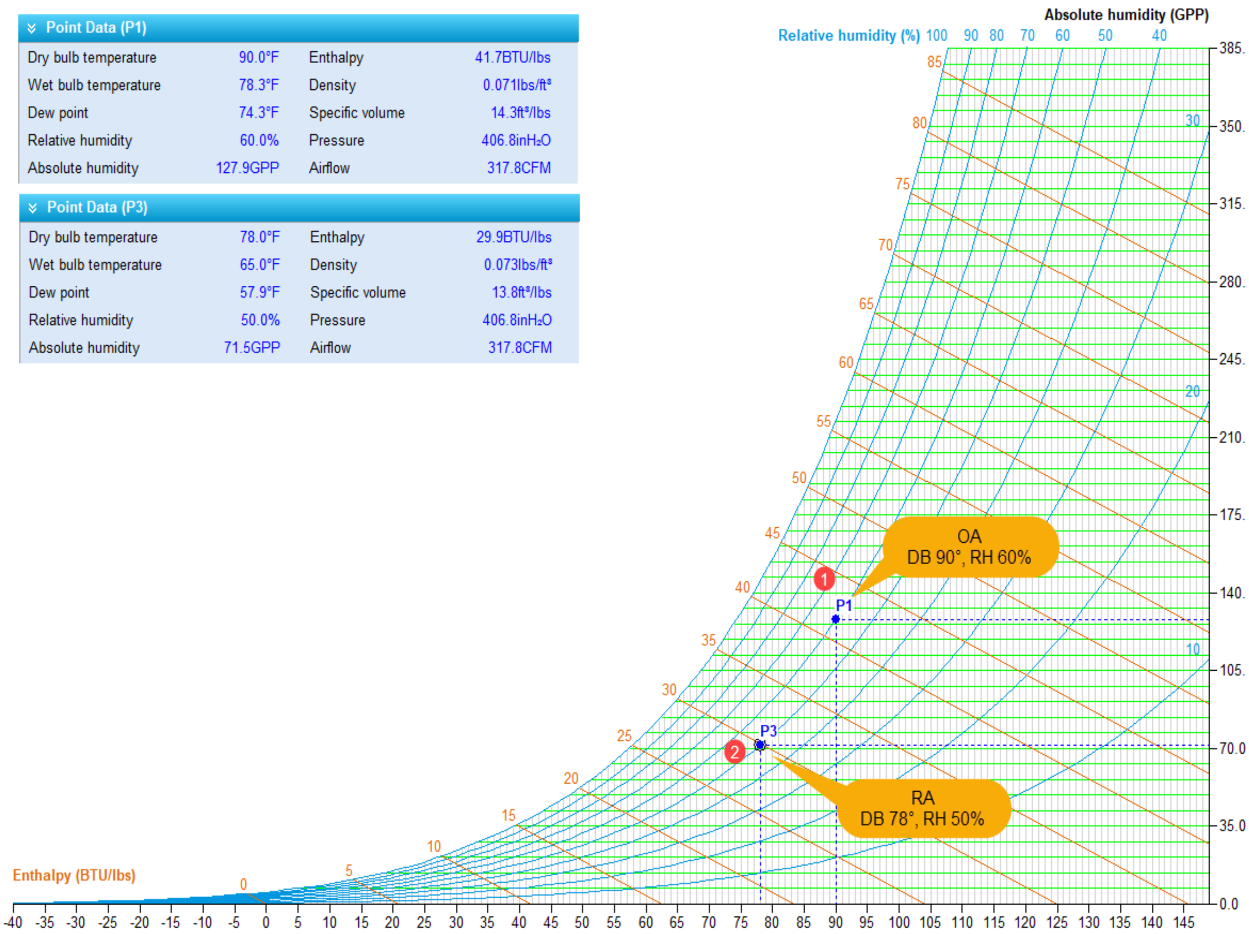
- OA = 90° F and RH = 60%.
- RA = 78° F and RH = 50%.

**Point Data (P1)**

| | | | |
|---|---|---|---|
| Dry bulb temperature | 90.0°F | Enthalpy | 41.7BTU/lbs |
| Wet bulb temperature | 78.3°F | Density | 0.071lbs/ft³ |
| Dew point | 74.3°F | Specific volume | 14.3ft³/lbs |
| Relative humidity | 60.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 127.9GPP | Airflow | 317.8CFM |

**Point Data (P3)**

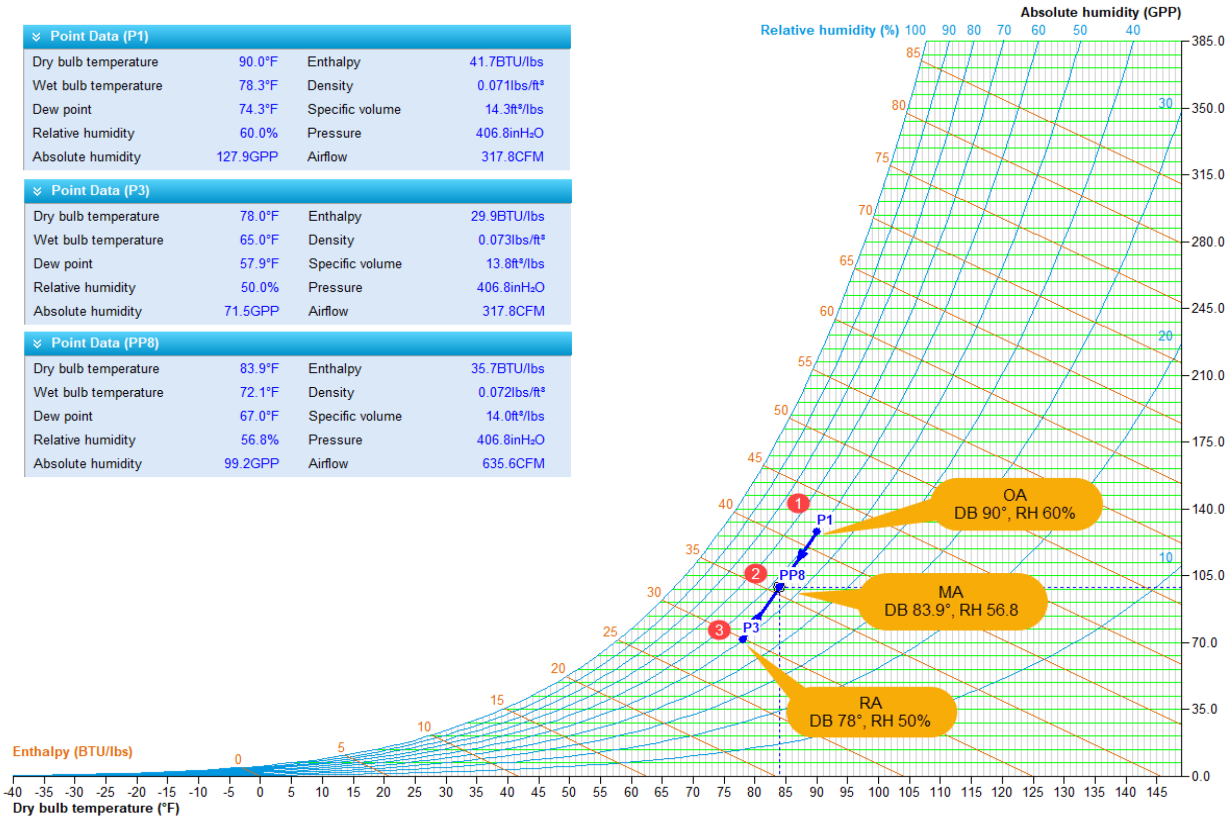
| | | | |
|---|---|---|---|
| Dry bulb temperature | 78.0°F | Enthalpy | 29.9BTU/lbs |
| Wet bulb temperature | 65.0°F | Density | 0.073lbs/ft³ |
| Dew point | 57.9°F | Specific volume | 13.8ft³/lbs |
| Relative humidity | 50.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 71.5GPP | Airflow | 317.8CFM |



## 7.2. Operating Point for Mixed Air (MA)

The return air and outside air are mixed to provide mixed air that will flow over the cooling coils

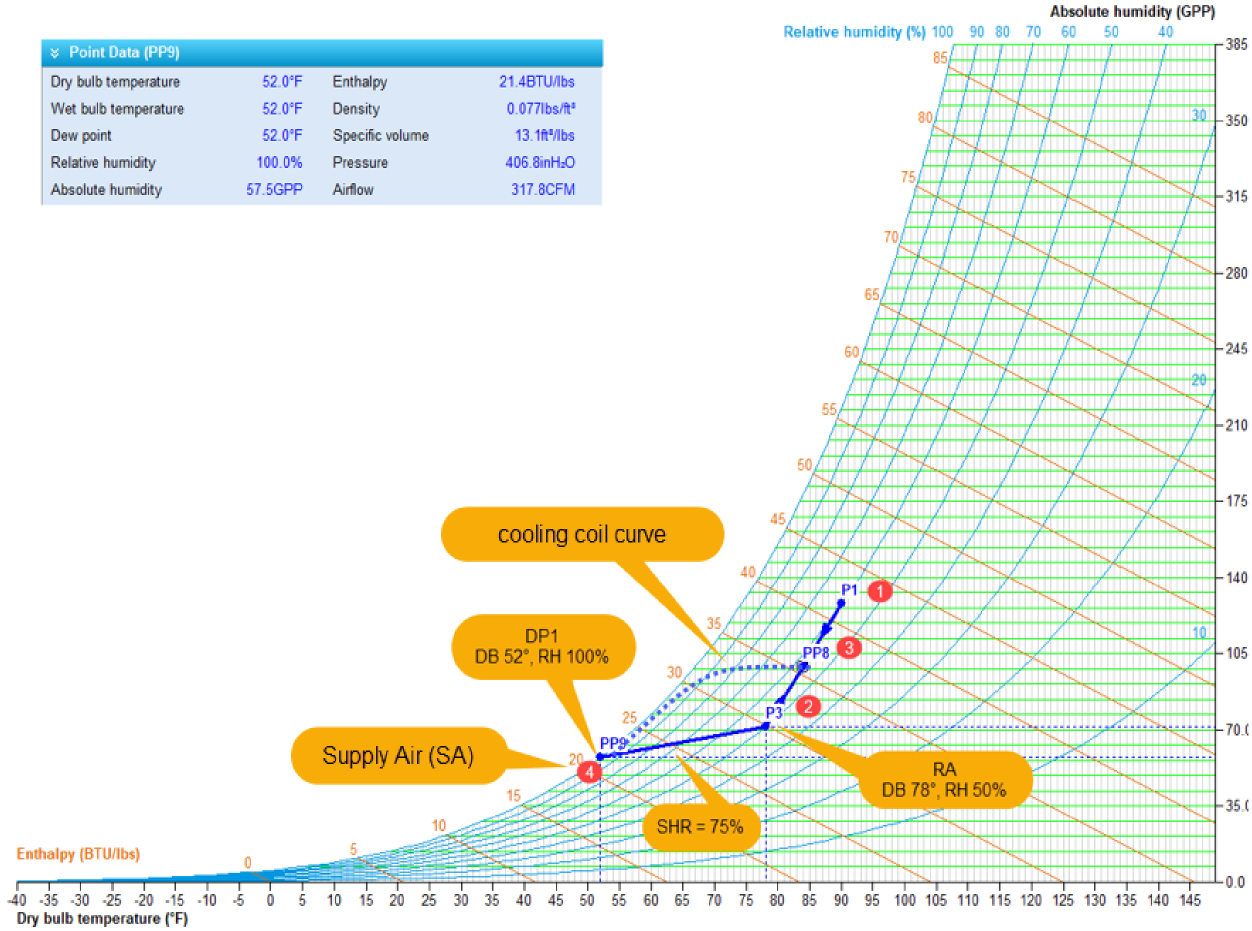
- MA = 83.9° F
- RH = 56.8%.



## 7.3. Mixed Air Discharge Point (DP)

The Mixed Air (MA) drops in DBT until it hits the saturation curve at 100% RH. It than follows the saturation curve to at Discharge Point 1 (DP1). Due to coil losses, this coil curve is bent slightly and is not quit 100% saturated. Most coils are designed for discharge points of 90%-98% RH and 50°-55°DBT

- DP = 52° F and RH = 100%.



Point Data (PP9)

| | | | |
|---|---|---|---|
| Dry bulb temperature | 52.0°F | Enthalpy | 21.4BTU/lbs |
| Wet bulb temperature | 52.0°F | Density | 0.077lbs/ft³ |
| Dew point | 52.0°F | Specific volume | 13.1ft³/lbs |
| Relative humidity | 100.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 57.5GPP | Airflow | 317.8CFM |

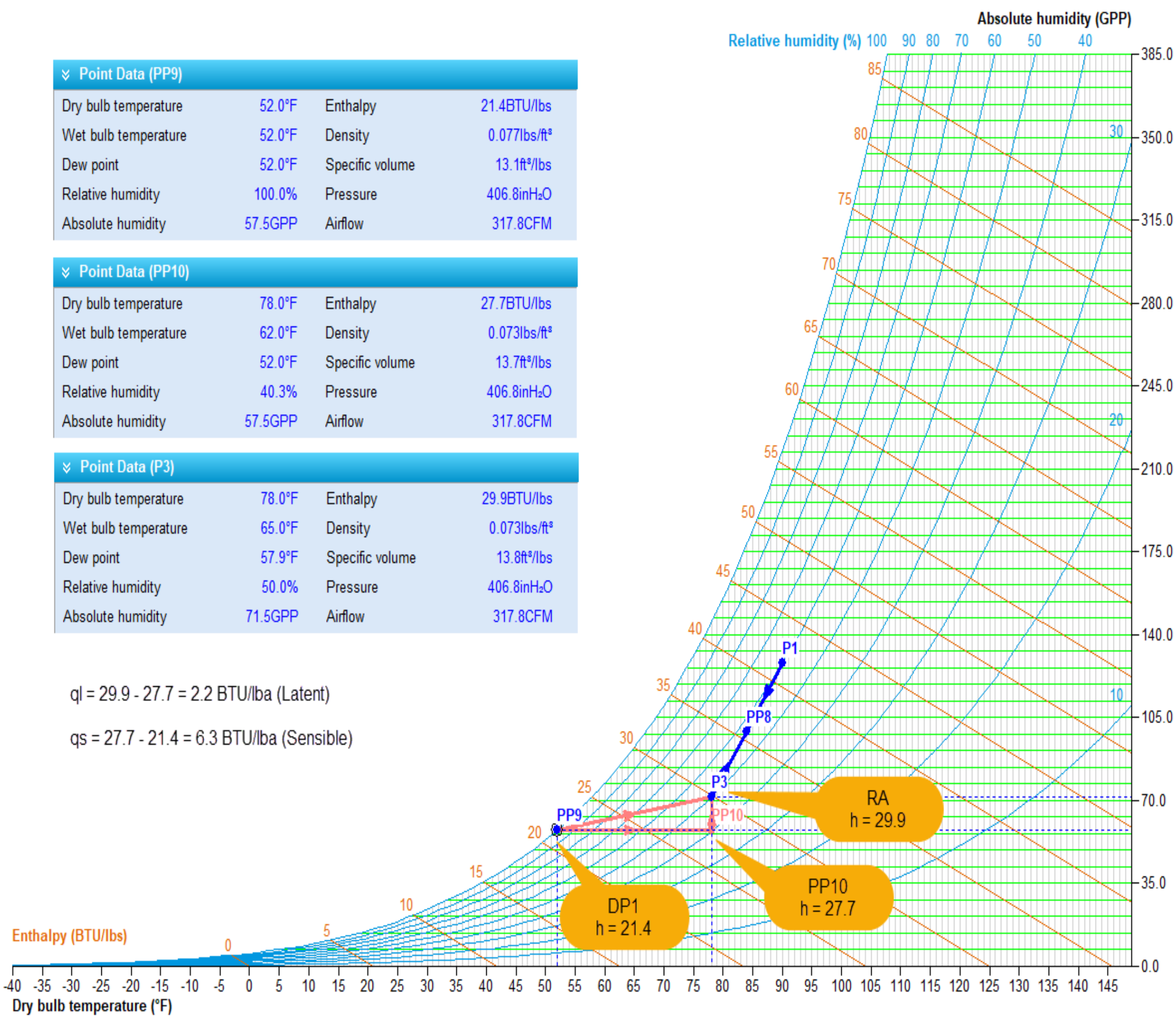
## 7.4. Calculating the SHR

The *specific enthalpy* needed to go from DP1 to RA is shown in the graph

- qS = 27.7 - 21.4 = 6.3 btu/lba (sensible)
- qL = 29.9 - 27.7 = 2.2 btu/lba (latent)
- q = 29.9 - 21.4= 8.5 btu/lba (total)

The Sensible Heat Ratio (SHR) for the room is

- SHR = 6.3 / 8.5 ≈ 75%



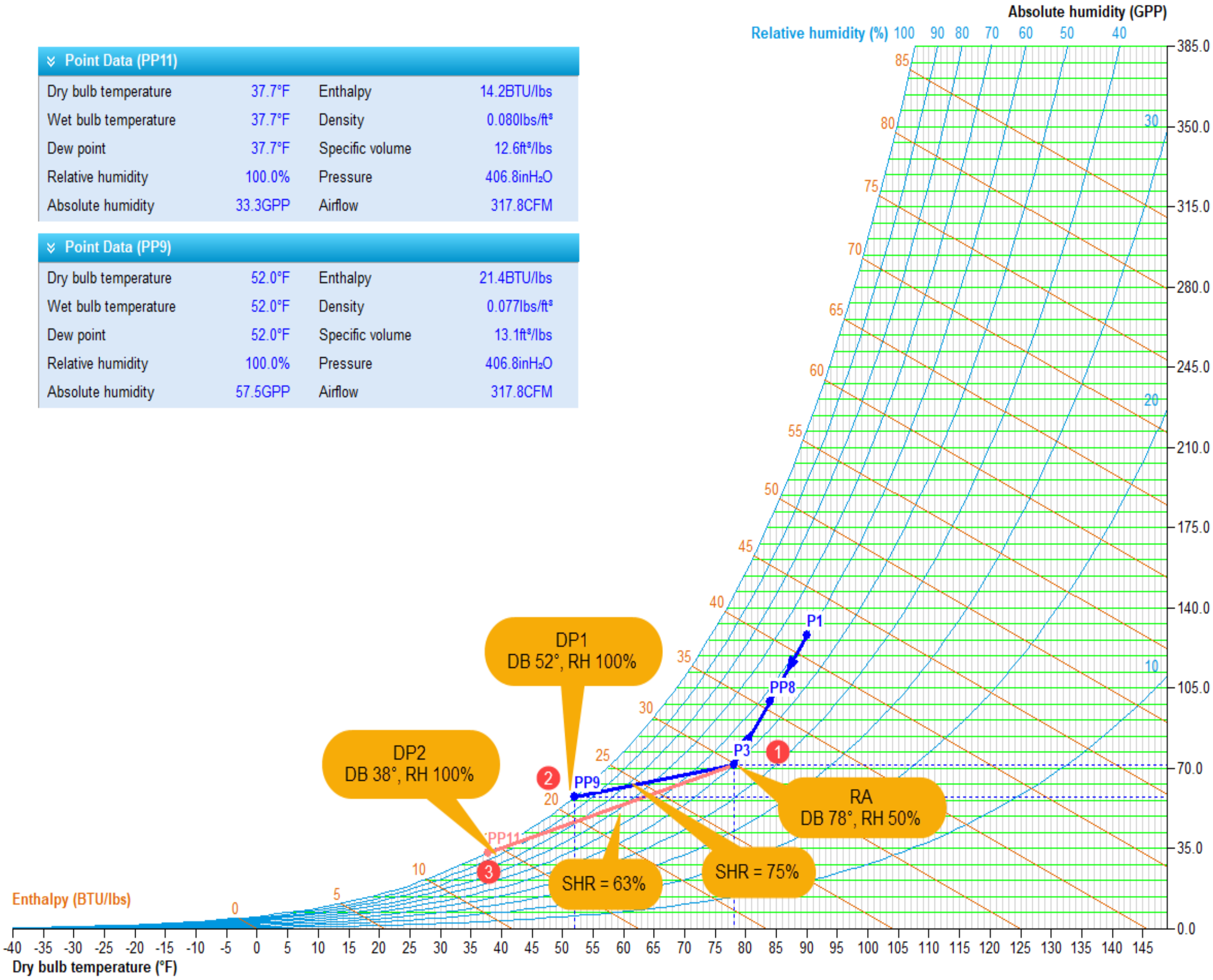
## 7.5. For an SHR of 75% the Discharge Point (DP) would be 52°

The SHR = 75% line is shown . The discharge point ❷ needs to fall anywhere on the SHR= 75% line to satisfy room conditions at ❶ of 78° and 50% RH. The difference between supply and return temperature should be

- ΔT ≈ 20°F

If ΔT much larger than 20 degrees, it might have difficulty mixing the cold supply air with room air in a way that would avoid drafts. We might also risk freezing the coil surface.

If ΔT much larger than 20 degrees, ducts, fans, etc. would become larger and more costly to run due to the increased CFM



## 7.6. A Room SHR of 63% would require DP of 34° to meet RH of 50%

If the actual room SHR = 63%. the discharge point at ❸ would need to be 33.7°.

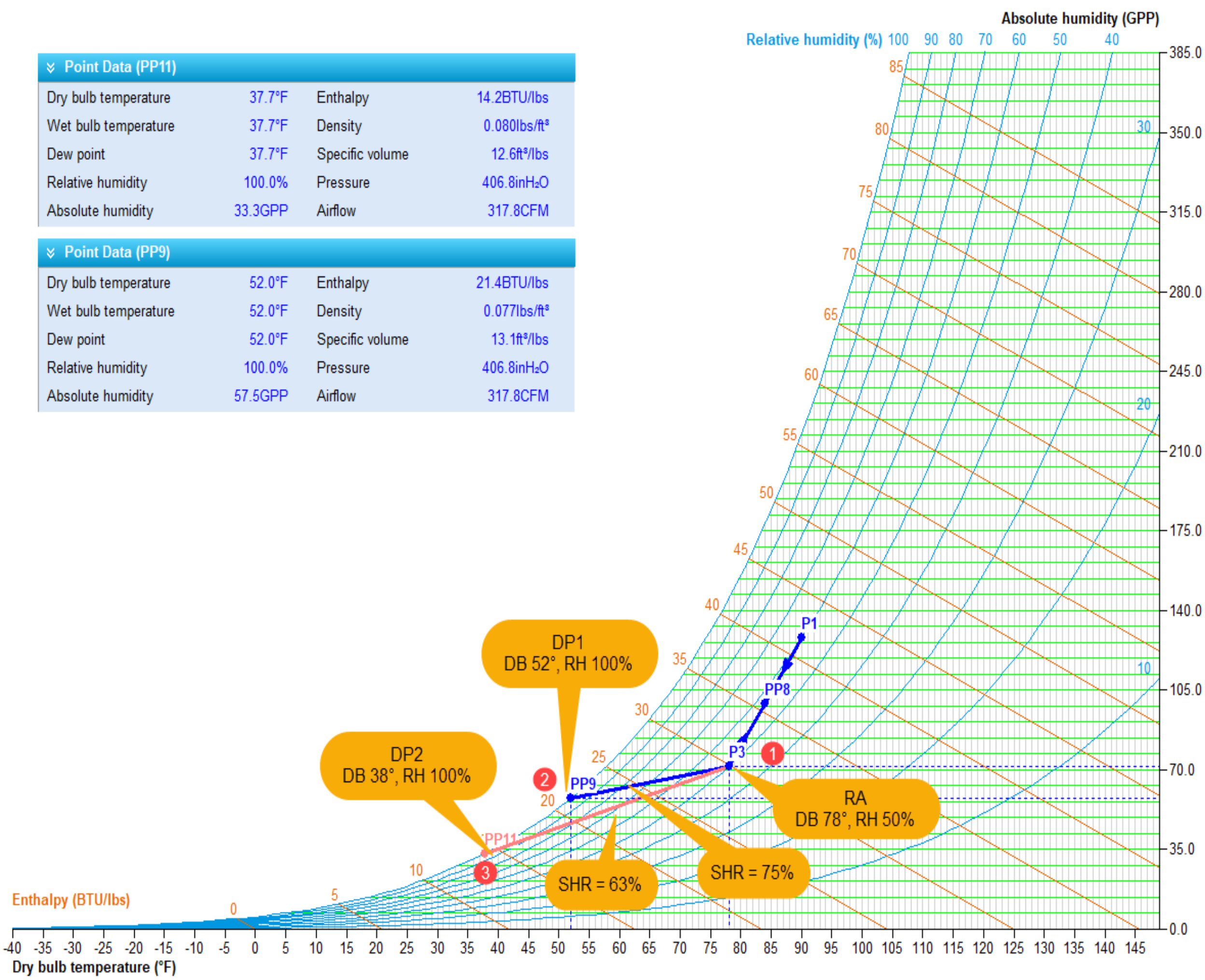
- SHR = 63% ⟶ DP = 33.7°

However

- ΔT= 78 - 38° > 20° (recommended)
- Typical coil specs are designed for DP of 50° to 55°, so we would not be able to find a coil to satisfy this.

Even if we could find a suitable coil

- Ultra cold SA mixing with RA would be susceptible to drafts and freezing of the coils



## 7.7. Room 63% SHR with 52° DP increases RH to 58%

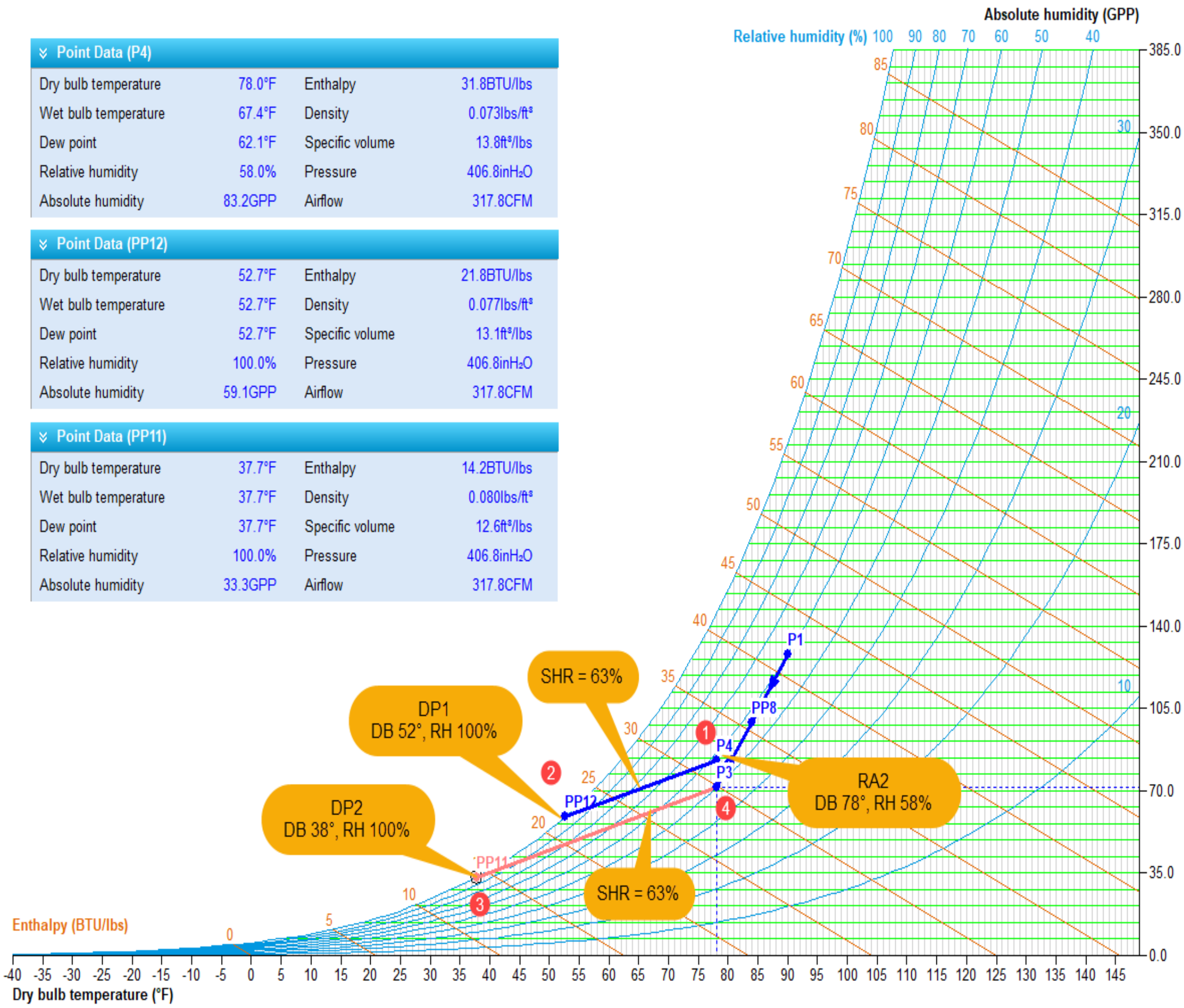
If the room SHR = 63% instead of 75% and the discharge point at ❷ is kept at 52° there will be an increase in room RH ≈ 8% higher at ❶ than the 50% design goal at ❹.

❷ ⟶ T = 52°, RH = 100%

❶ ⟶ T = 78°, RH = 58%

Consequences

- For normal comfort this would be acceptable.
- For environments like data centers, this may not be acceptable.
- We discuss methods to reduce RH next



Point Data (P4)

| | | | |
|---|---|---|---|
| Dry bulb temperature | 78.0°F | Enthalpy | 31.8BTU/lbs |
| Wet bulb temperature | 67.4°F | Density | 0.073lbs/ft³ |
| Dew point | 62.1°F | Specific volume | 13.8ft³/lbs |
| Relative humidity | 58.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 83.2GPP | Airflow | 317.8CFM |

Point Data (PP12)

| | | | |
|---|---|---|---|
| Dry bulb temperature | 52.7°F | Enthalpy | 21.8BTU/lbs |
| Wet bulb temperature | 52.7°F | Density | 0.077lbs/ft³ |
| Dew point | 52.7°F | Specific volume | 13.1ft³/lbs |
| Relative humidity | 100.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 59.1GPP | Airflow | 317.8CFM |

Point Data (PP11)

| | | | |
|---|---|---|---|
| Dry bulb temperature | 37.7°F | Enthalpy | 14.2BTU/lbs |
| Wet bulb temperature | 37.7°F | Density | 0.080lbs/ft³ |
| Dew point | 37.7°F | Specific volume | 12.6ft³/lbs |
| Relative humidity | 100.0% | Pressure | 406.8inH₂O |
| Absolute humidity | 33.3GPP | Airflow | 317.8CFM |

## 7.8. Reheat Coil to Maintain RH = 50%

Given the room SHR = 63% instead of 75% and discharge point at ❷ is 52° as before. However, we sensibly heat the air leaving the cooling-coil using a reheat-coil to 66° until it intersects with the 63% SHR line at ❹. Since the air off the reheat-coil falls on the room 63% SHR line it will be able to satisfy the original RA of 50% RH.

Final Solution for SHR = 63%

- ❷ ⟶ T = 52°, RH = 100%
- ❹ ⟶ T = 66°, RH = 62%
- ❺ ⟶ T = 78°, RH = 50%