PDHonline Course M226 (5 PDH)

Psychrometric Chart Fundamentals and its application to HVAC Troubleshooting

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Course Content

Introduction

If HVAC problems and challenges are to be properly diagnosed and designed, it is essential that the Psychrometric chart and psychrometrics in general be clearly understood. This course will review the essential elements of psychrometrics (the behavior of mixtures of air and water vapor under varying conditions of heat) and the chart that represents it. With this knowledge, you will be able to understand many of the HVAC challenges that are certain to arise, as well as anticipate problems before they occur and incorporate in your design.

Like many self-study courses, you will only get as much from it as you put into it. Plot each step on your own psychrometric chart. Be certain you understand the basics before studying the examples. Try to solve the examples for yourself. This is not the type of course you can just read through and take the Quiz – it will take effort. But if you do your best, you should be able to pass the Quiz with ease – whether beginner or advanced.

Disclaimer – Nothing in this course should be considered consulting engineering for your specific application – each situation requires individual analysis.

Definitions and Concepts

It is important to understand the primary concepts and definitions before we begin our study. For some of you, this will be a refresher, and for others an introduction. There are other courses that cover the fundamentals in more detail, but the following are the minimum essentials.

- HVAC – Heating, Ventilation, and Air conditioning
- Psychrometrics –The behavior of mixtures of air and water vapor under varying conditions of heat
- Enthalpy = Total heat in the air = Sensible plus Latent heat
  - Sensible Heat – Changes in temperature that do not alter the moisture content of air
  - Latent Heat – Related to level of moisture in the air
- BTU (British Thermal Unit) – The amount of heat that must be added to or subtracted from a pound of water at 60^{o}F to affect a temperature change of 1^{o}F
  - BTUH or BH – BTU's per hour
  - MBH – 1000 BTUH
- Ton
  - 1 Ton equals the amount of heat needed to melt 1 ton of ice in one day
  - 12,000 BTUH's
- Drybulb Temperature – The temperature reading given by a dry thermometer that gives a direct indication as to the sensible heat content of air
- Wetbulb Temperature – The temperature reading from a wetted bulb that gives a direct indication as to the total heat content of air
- Dew Point Temperature – Temperature at which air will begin to release moisture.
- Relative Humidity (RH)
  - The actual amount of moisture in the air expressed as a percentage of the amount of moisture the air is capable of holding.
  - More technically:
    - The amount of water vapor in the air divided by the amount of water vapor the air can hold (at the same temperature and pressure.)

        - The ratio of the air's vapor pressure to its saturation vapor pressure.
    - Example: An air sample that is at 50% RH is holding half the moisture it is capable of holding at the same temperature (at dew point or saturated.)
    - RH is inversely relational to temperature for the same moisture level (grains of moisture per pound of dry air) – warm air can hold more moisture
    - RH is what we sense
    - High RH: Sticking, mold
    - Low RH
        - Affects electronics, promotes static
        - Low RH air is seeking saturation, absorbing moisture wherever it can
- Specific Humidity or Humidity Ratio
    - The weight of the water vapor in each pound of dry air
    - Typically grains of moisture/pound of dry air
    - Grain = 1/7000 pound
- Density – Unit weight of dry air at a given temperature and moisture content, #/ft^3
- Specific Volume – Space occupied by dry air at a given temperature and moisture content (the reciprocal of density), ft^3/#

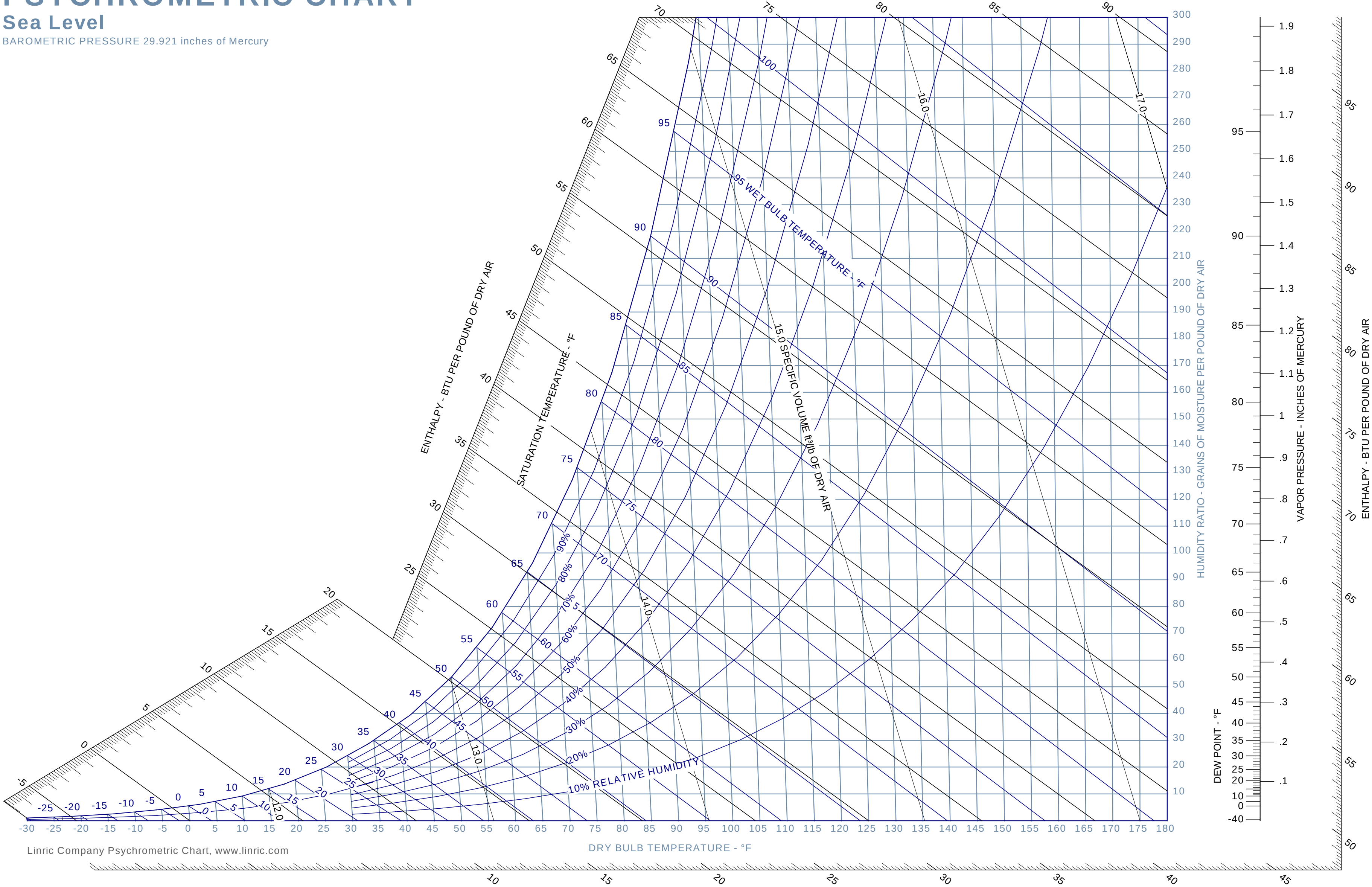
The Psychrometric Chart Template

Pause and print off the next page. Make multiple copies, as you will need them in the course. As noted previously, if you are to benefit from the course, you must plot each step for yourself. There are no shortcuts in learning this material. The smaller example charts are not intended for you to plot on, but rather instruction – use a clean larger copy to plot each example.

PSYCHROMETRIC CHART

Sea Level

BAROMETRIC PRESSURE 29.921 inches of Mercury

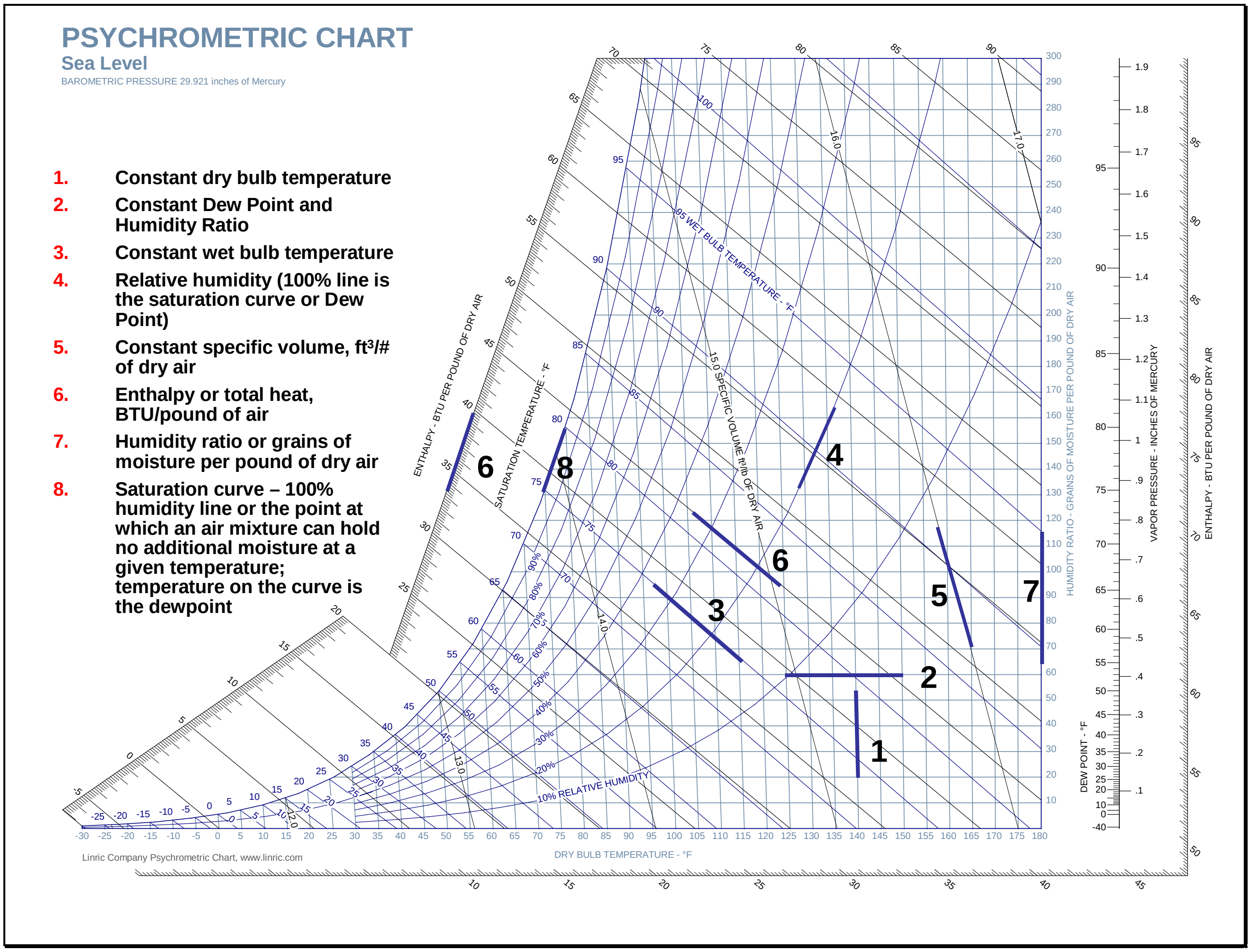


The Psychrometric Chart – an Overview

Before we proceed further in our study, let's learn or refresh regarding the Psychrometric chart. The following is a summary of the major elements on the chart. Do not continue to the next section until you can find the following on the chart.

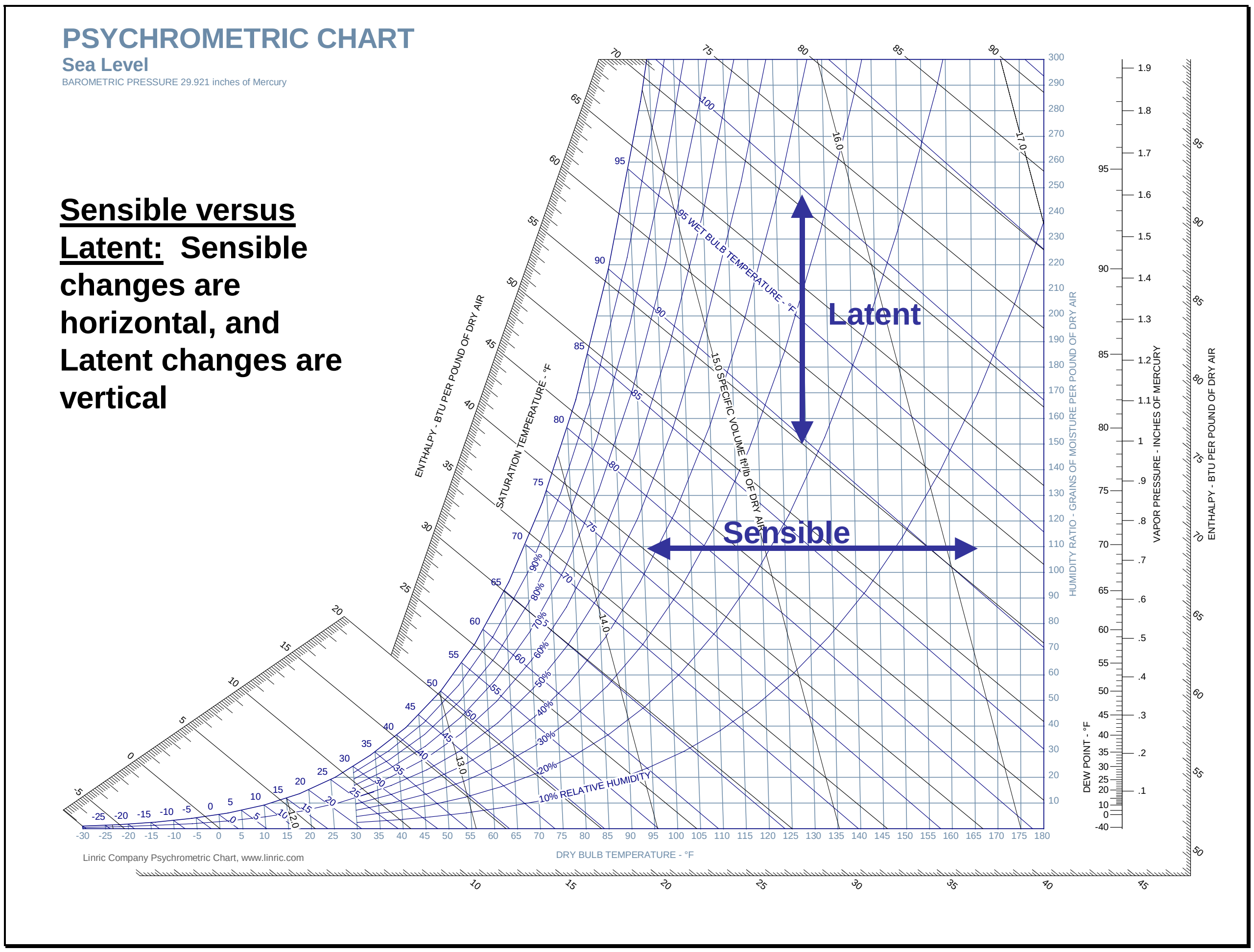
- Constant Drybulb Temperature: Vertical Lines
- Constant Dew Point and Humidity Ratio: Horizontal Lines
- Constant Wetbulb temperature: Upward left sloping lines
- Relative humidity: Curving lines (100% line is the saturation curve or correlates with Dew Point)
- Constant specific volume, ft^3/# of dry air: Nearly-vertical sloping lines
- Enthalpy or total heat, BTU/pound of air: Staggered scale left of saturation curve and left sloping lines
- Humidity Ratio: Right hand scale, grains of moisture/pound of dry air
- Saturation Curve: 100% RH Curve (or the point at which an air mixture can hold no additional moisture at a given temperature); temperature on the curve is the Dew Point

The following is a chart with the above noted (note: this is a standard curve is at Sea Level).


PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
1. Constant dry bulb temperature
2. Constant Dew Point and Humidity Ratio
3. Constant wet bulb temperature
4. Relative humidity (100% line is the saturation curve or Dew Point)
5. Constant specific volume, ft³/# of dry air
6. Enthalpy or total heat, BTU/pound of air
7. Humidity ratio or grains of moisture per pound of dry air
8. Saturation curve – 100% humidity line or the point at which an air mixture can hold no additional moisture at a given temperature; temperature on the curve is the dewpoint
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
95 WET BULB TEMPERATURE - °F
15.0 SPECIFIC VOLUME ft³/lb OF DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
VAPOR PRESSURE - INCHES OF MERCURY
DEW POINT - °F
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

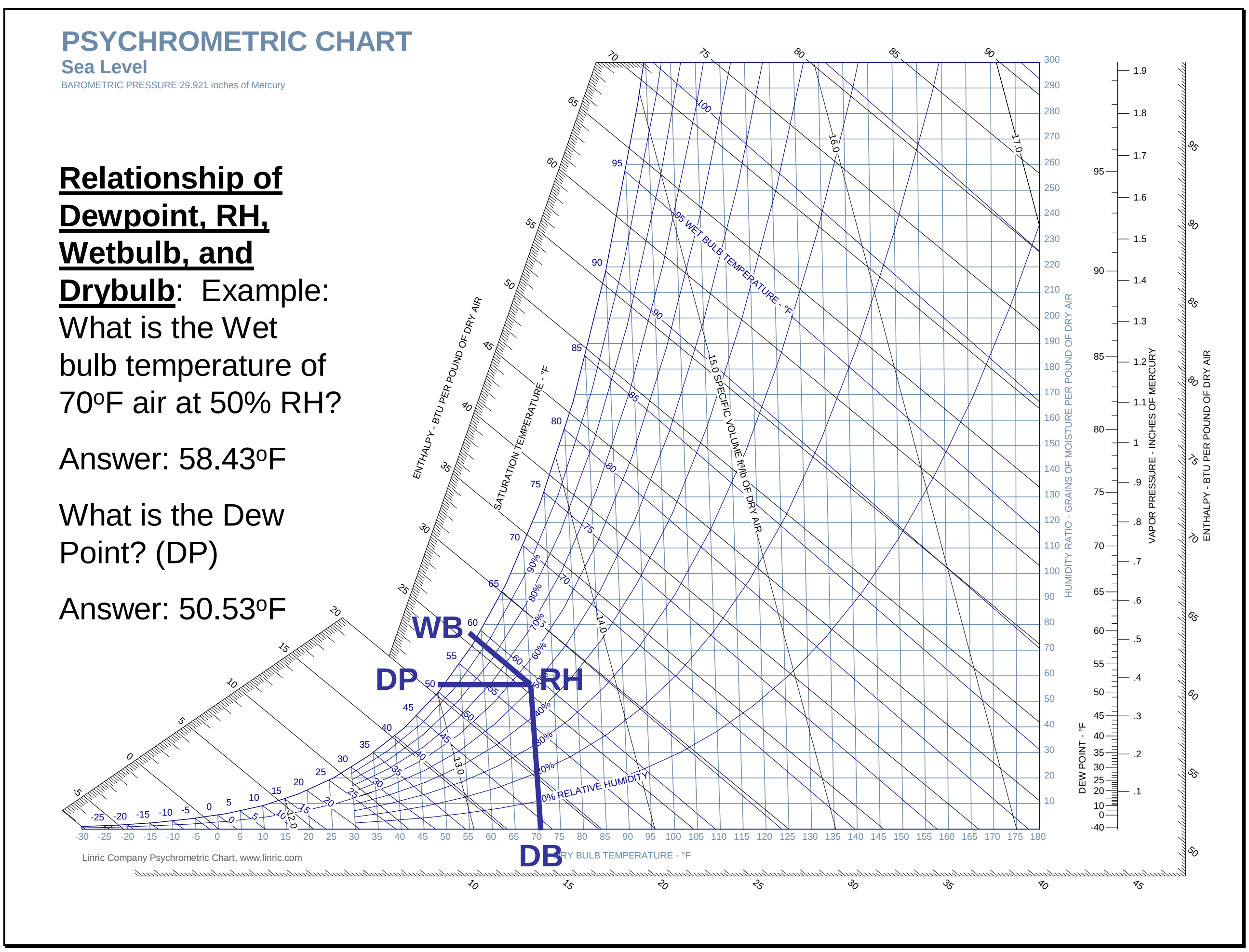
Latent versus Sensible Changes

In the next graph, let's look at changes in Latent versus Sensible changes. Latent changes move in the "Y" axis (associated with moisture content changes), and Sensible changes move in the "X" axis (associated with temperature but not moisture content changes.)



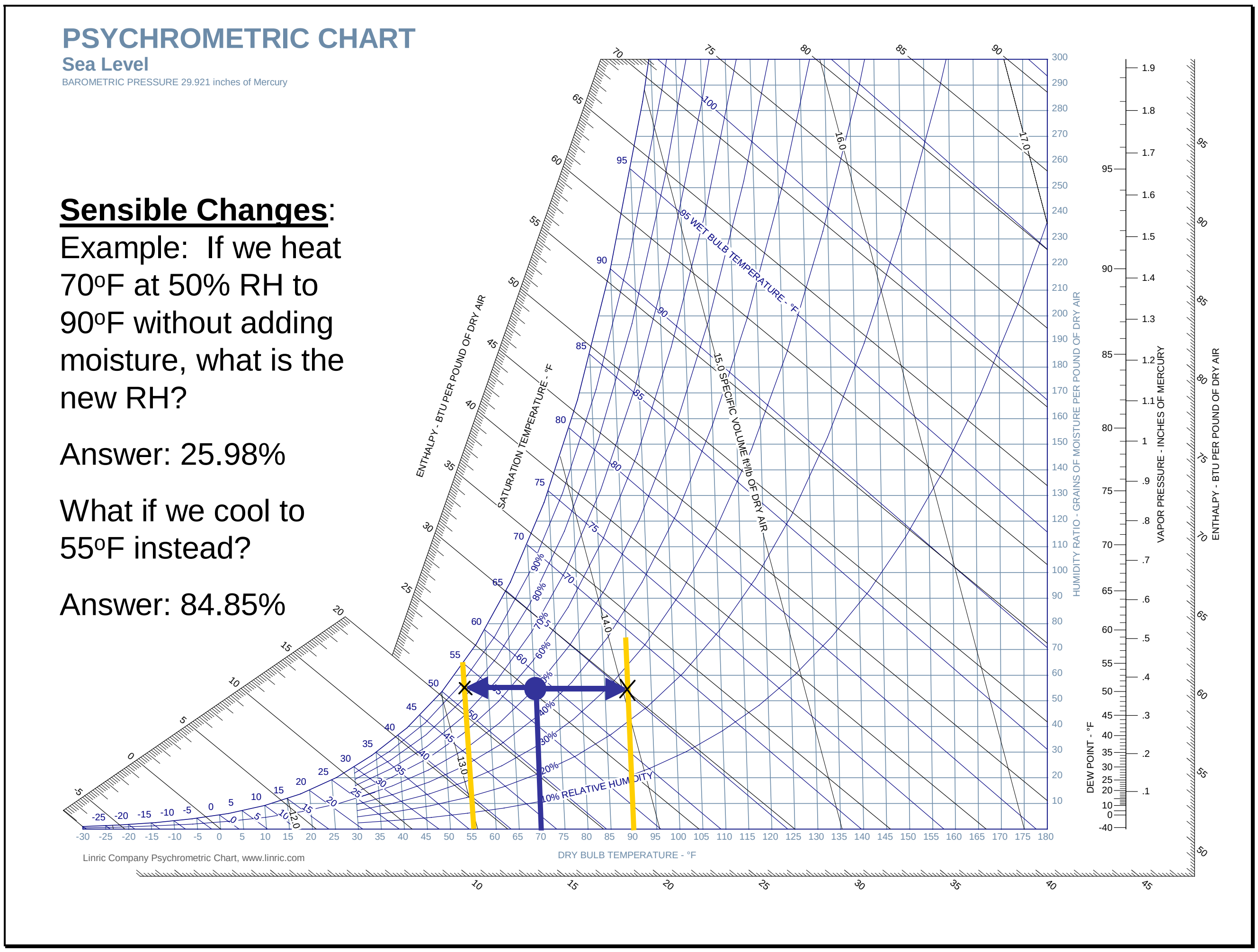
Relationship of Dewpoint, RH, Wetbulb, and Drybulb

The following chart provides an example to determine Dewpoint, RH, Wetbulb, or Drybulb if only two of the criteria are known. Drybulb is read with a typical thermometer. When I was in engineering school, we determined Wetbulb by using a sling psychrometer. In it was a Drybulb, plus another thermometer with a wet gauze. The Wetbulb reading was affected by the moisture content in the air; the lower the air moisture content, the faster the gauze evaporated and the cooler the temperature reading. Today, electronic instrumentation is generally used.



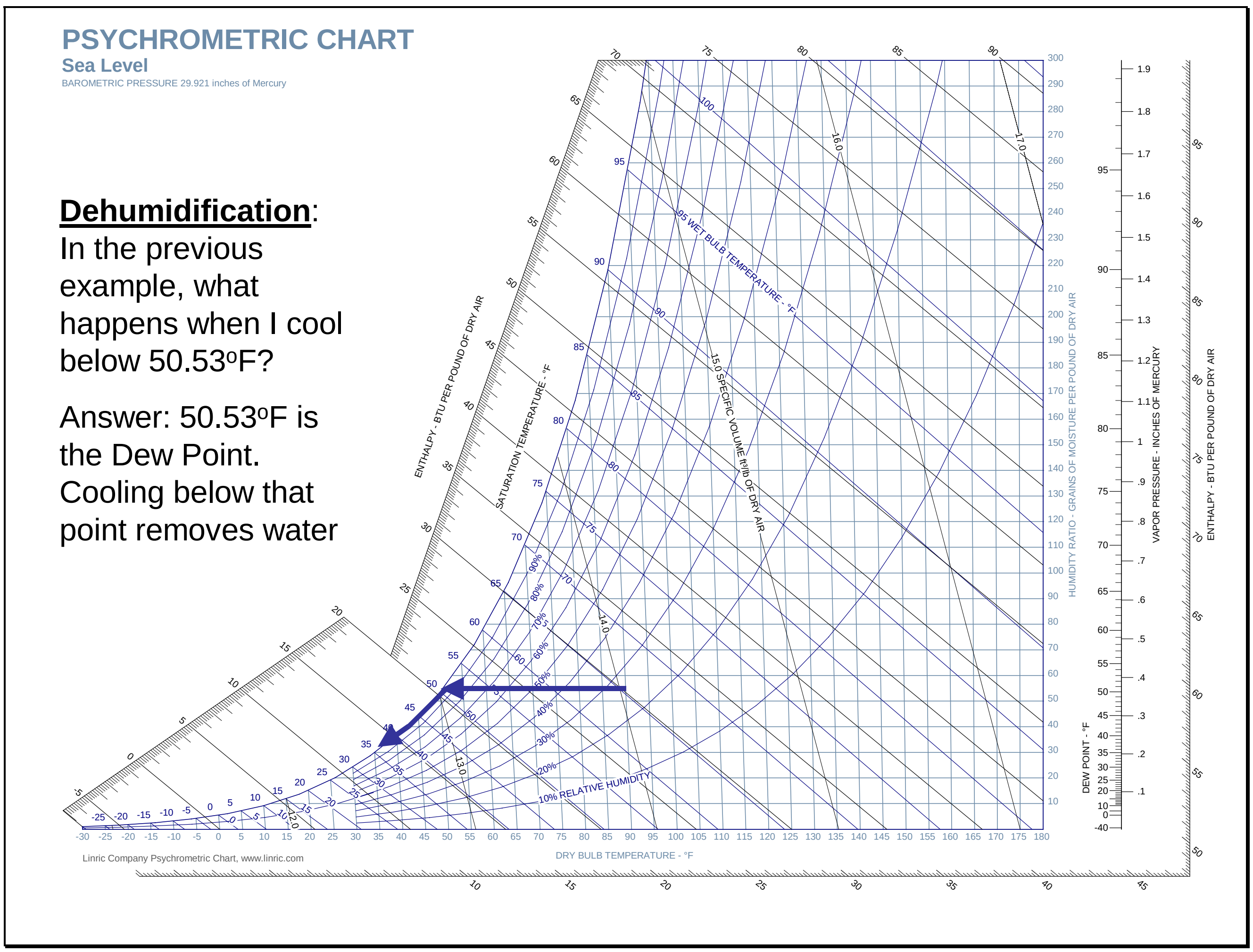
Impact to Relative Humidity from Sensible Changes

The following chart illustrates the impact to Relative Humidity from changes in temperature (when moisture content remains constant.) You will note that Temperature and Relative Humidity are inversely relational – the higher the temperature, the lower the RH. The lower the temperature, the higher the RH.



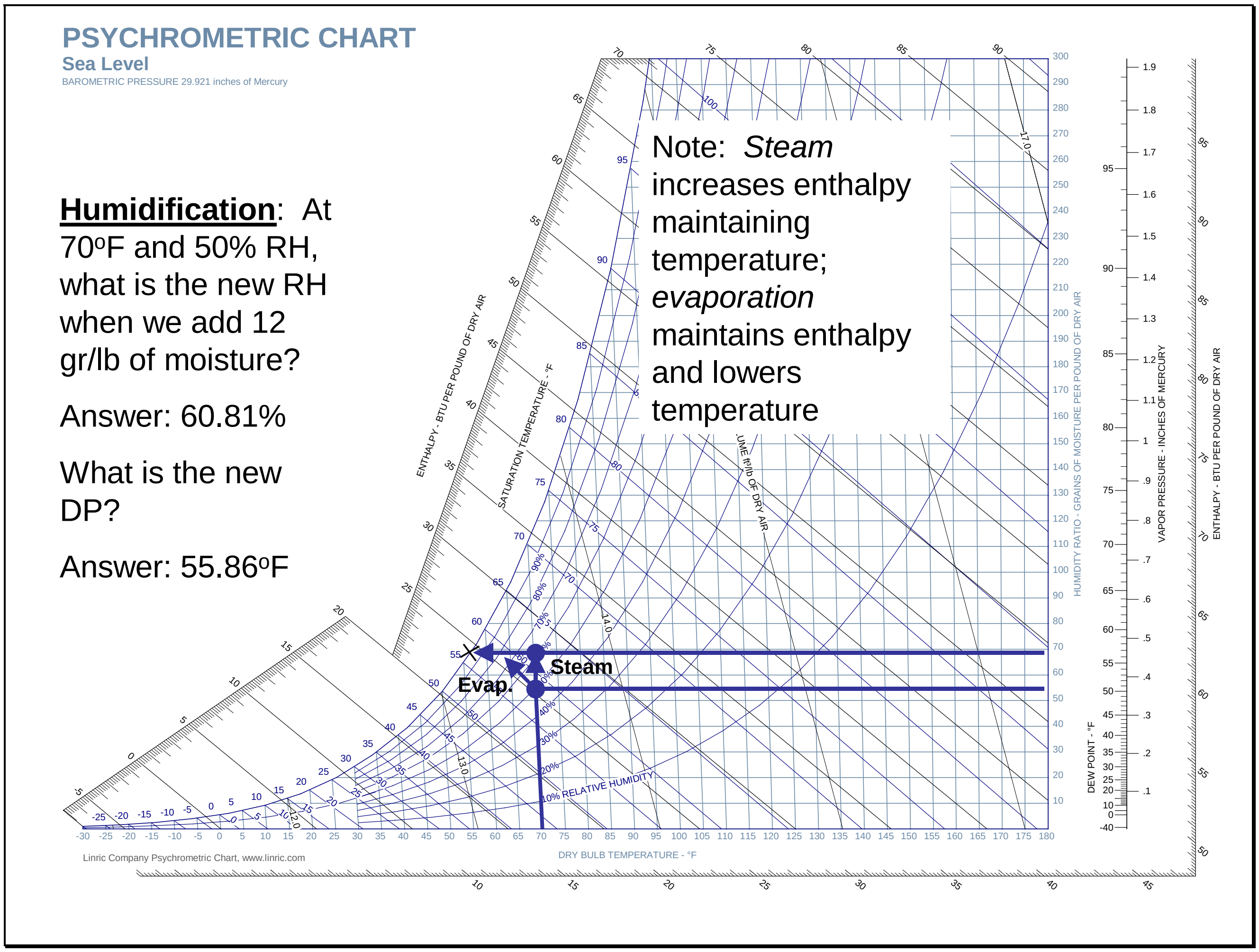
Dehumidification

As we saw in the previous section, when the temperature cools the RH increases. What happens when the RH is 100%? It rains. As cools, it eventually reaches its dewpoint and moisture begins to appear. That is what happens when you have a glass of iced tea, and there is moisture on the outside – the air in the immediate vicinity of the glass cools to the point it is fully saturated, and out comes moisture. In the following example, we continue on with the previous example to examine what happens when we continue to cool.



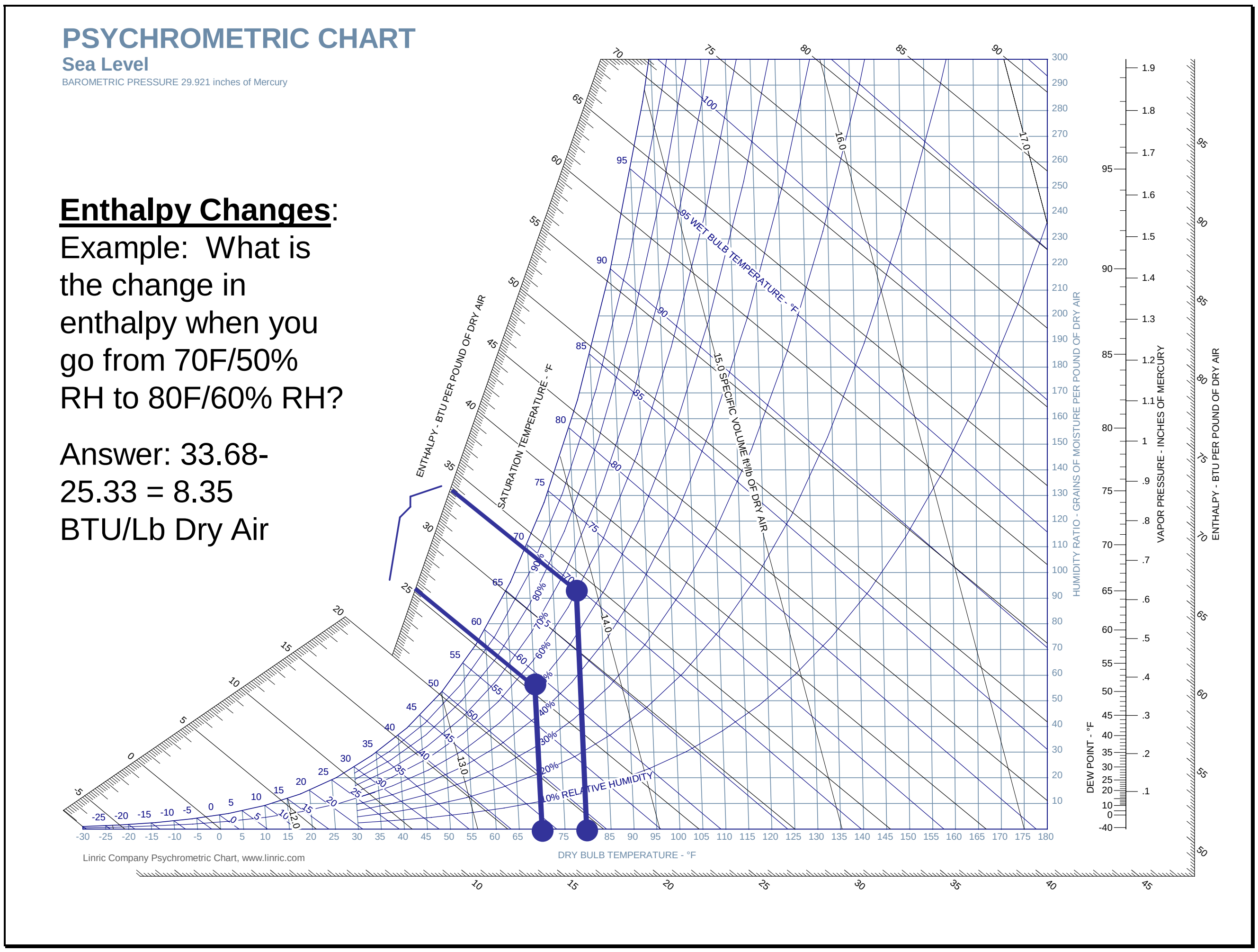
Humidification

In the previous example, we learned that we can de-humidify the air by over cooling it. But to add humidity we must have an external source of moisture. The following example illustrates that we can plot the results of adding moisture on the Psychrometric chart.



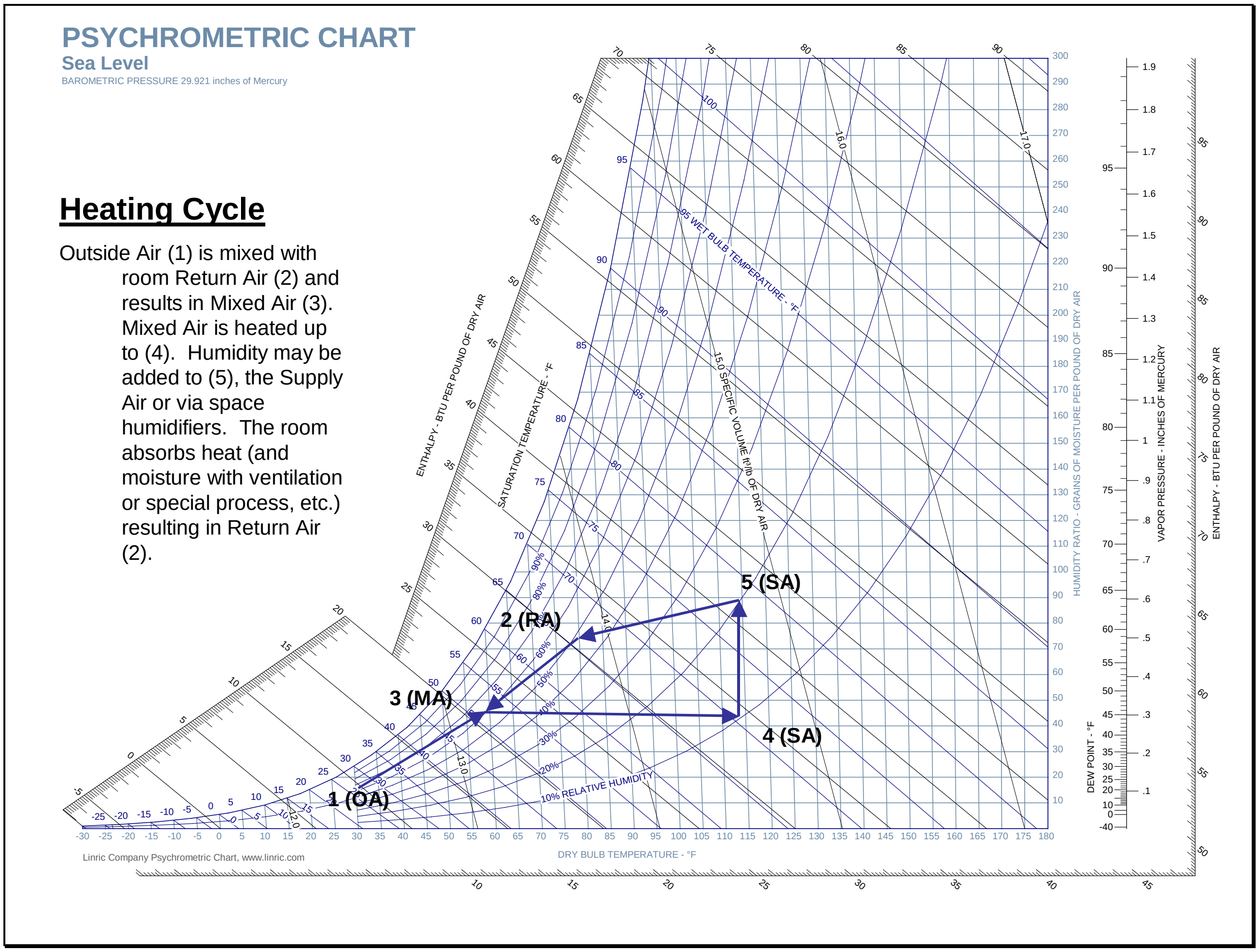
Enthalpy Changes

Enthalpy represents the total heat in the air, a summation of Sensible and Latent. Enthalpy is measured in BTU/# dry air, and can be determined if you know at least two primary chart parameters. As well, when you condition the air, there is a change in enthalpy that can be calculated. The following example illustrates how Enthalpy changes can be calculated, as well as changes to enthalpy.



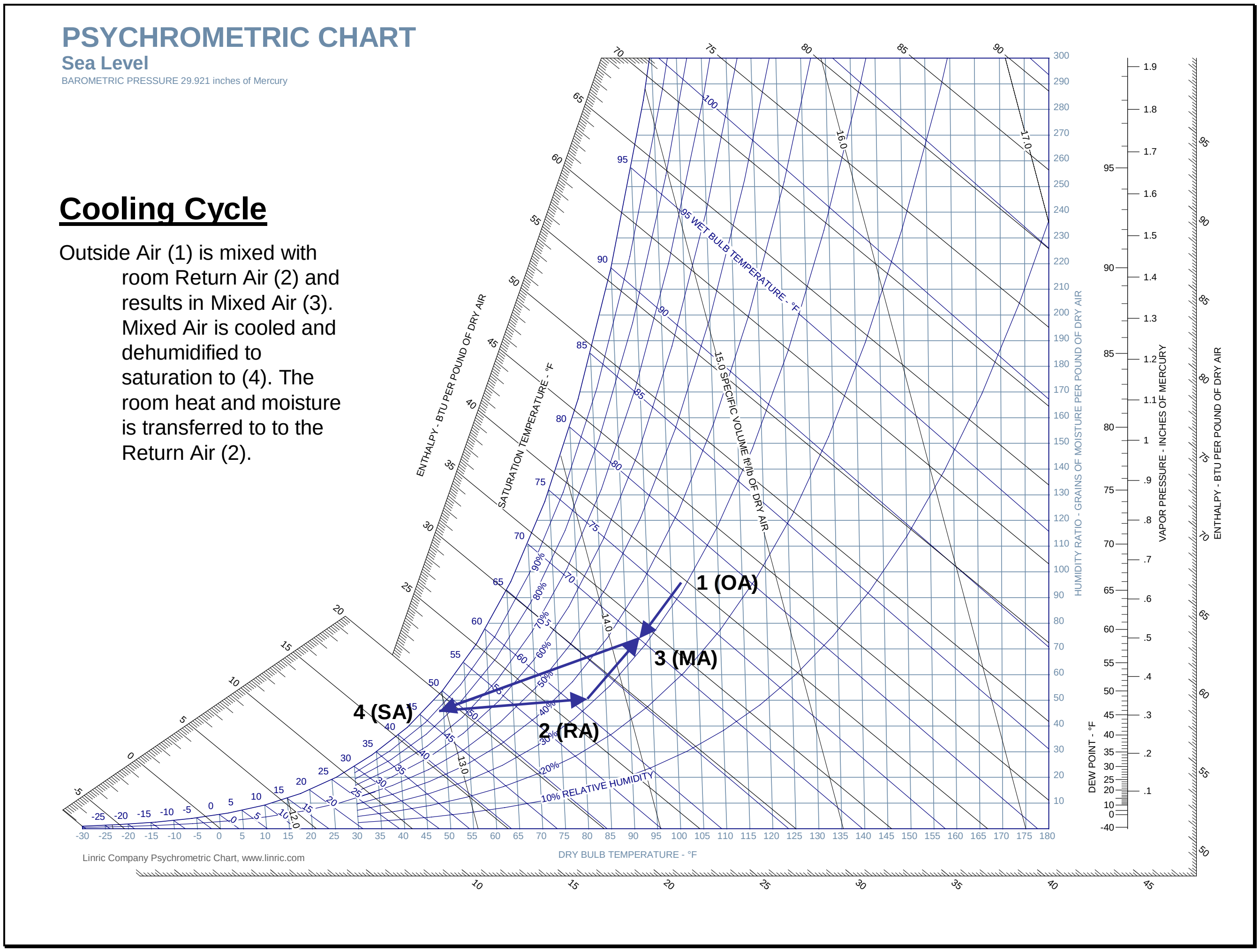
Heating Cycles

Heating cycles can be graphically illustrated on the chart. The following illustrates a typical heating cycle of an HVAC system.



Cooling Cycle

Similar to the previous example, the Cooling Cycle can also be plotted on the Chart as follows.



Try it yourself! (A Pop Quiz)

(This isn't the official course Quiz)

Now that you have reviewed (or learned) the basics of psychrometrics and the chart, give a try to answer the following (Print off this page and the Chart at the beginning of the course; circle the best answer):

For an air mixture of 74F and 45% RH, determine the following:

1.What is the dewpoint ?

a)51

b)41

c)65

2.What is the enthalpy?

a)11 BTU/# Dry Air

b)27 BTU/# Dry Air

c)31 BTU/# Dry Air

3.How many grains of moisture/# dry air?

a)33

b)40

c)56

4. What is the specific volume in cf/# dry air?

a. 13.6

b. 11.2

c. 12.1

5.What is the wetbulb temperature?

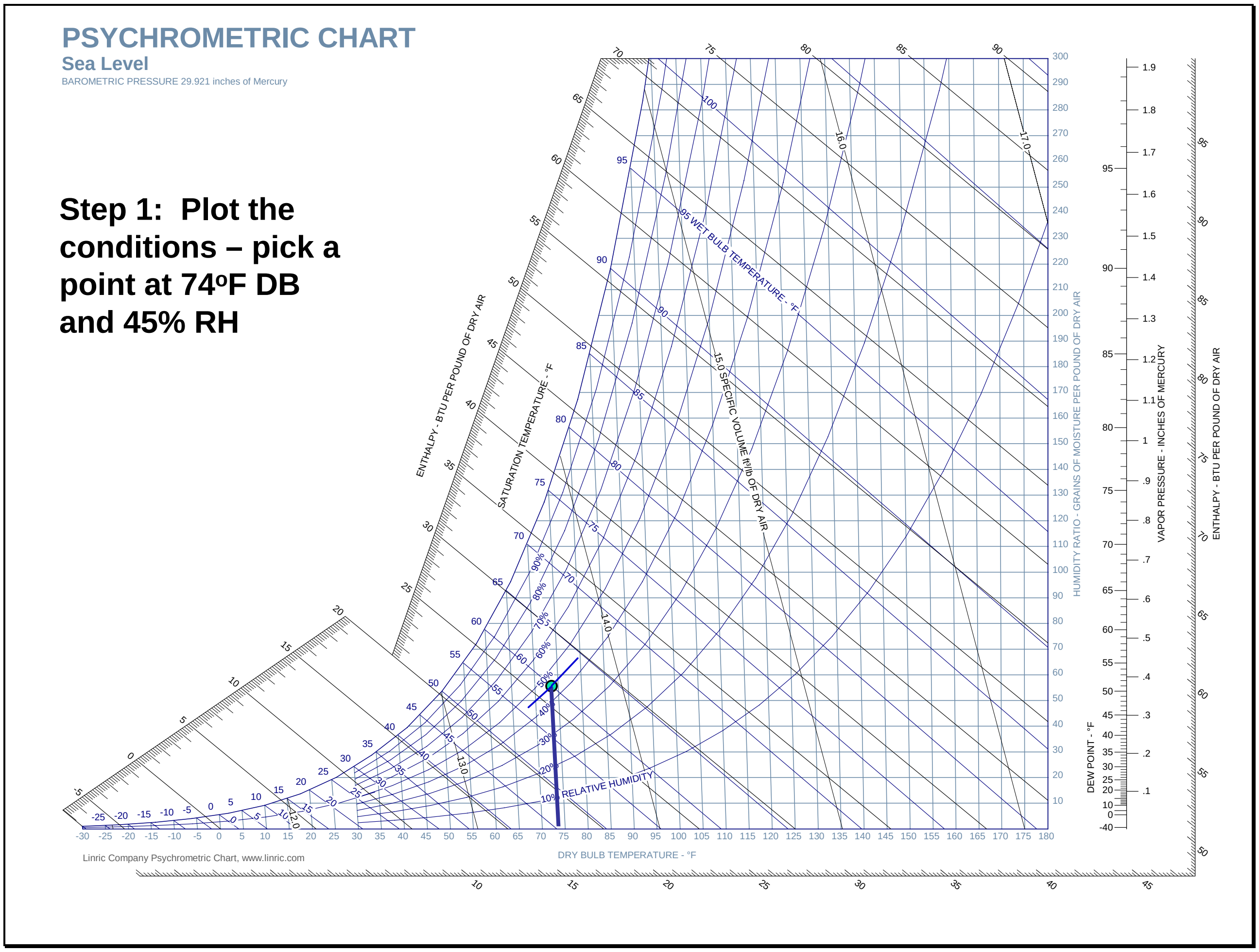
a.50

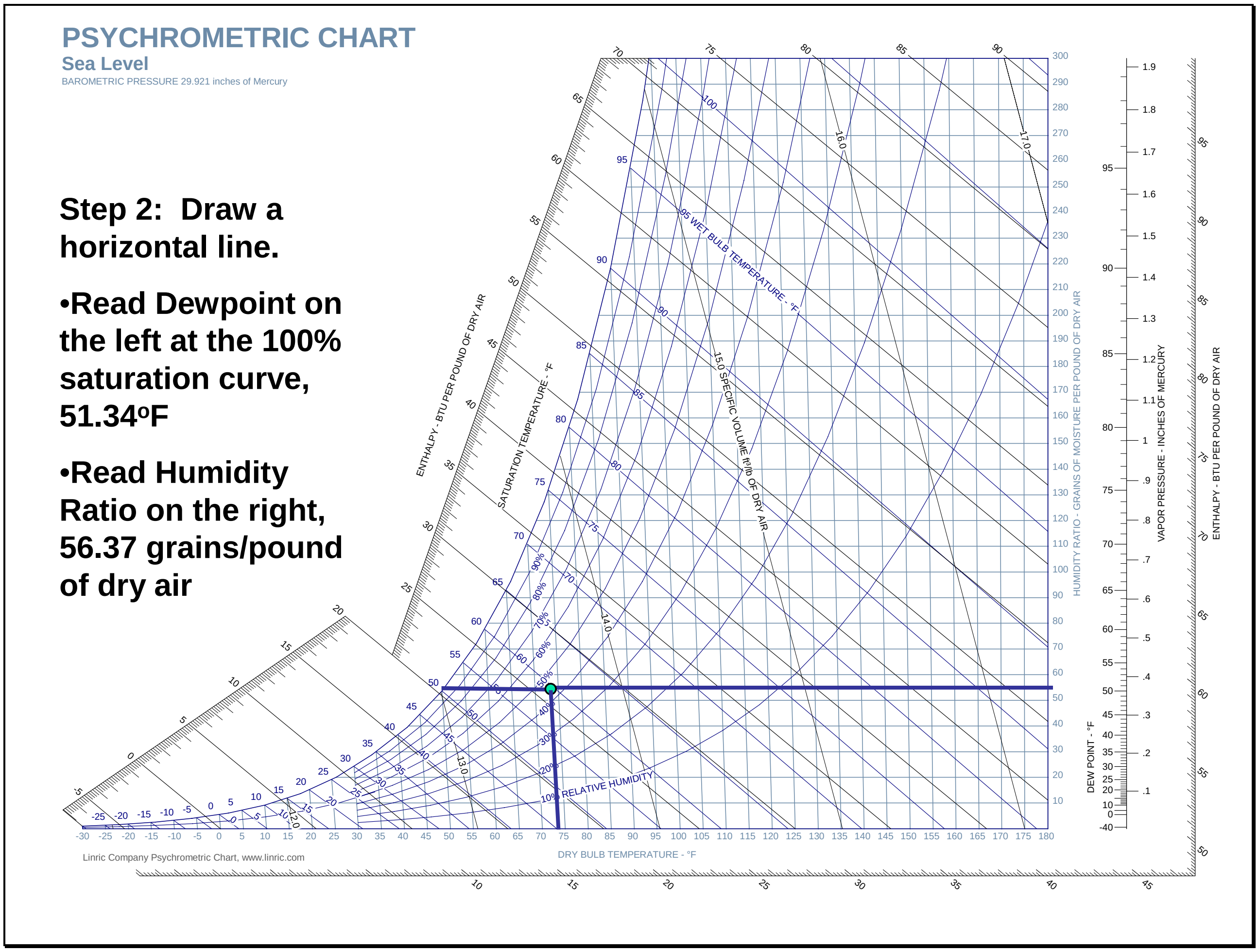
b.60

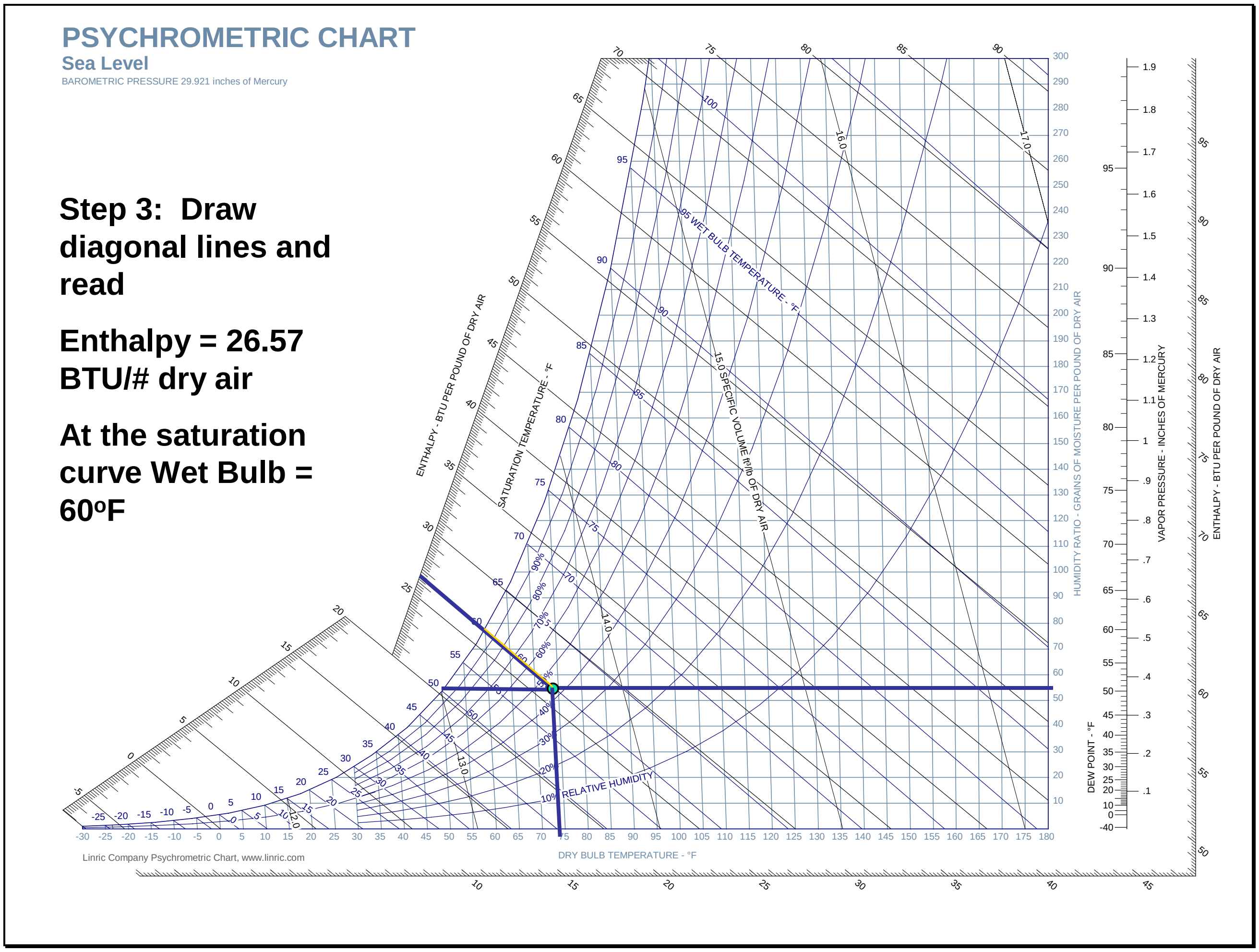
c.74

Pop Quiz Answers

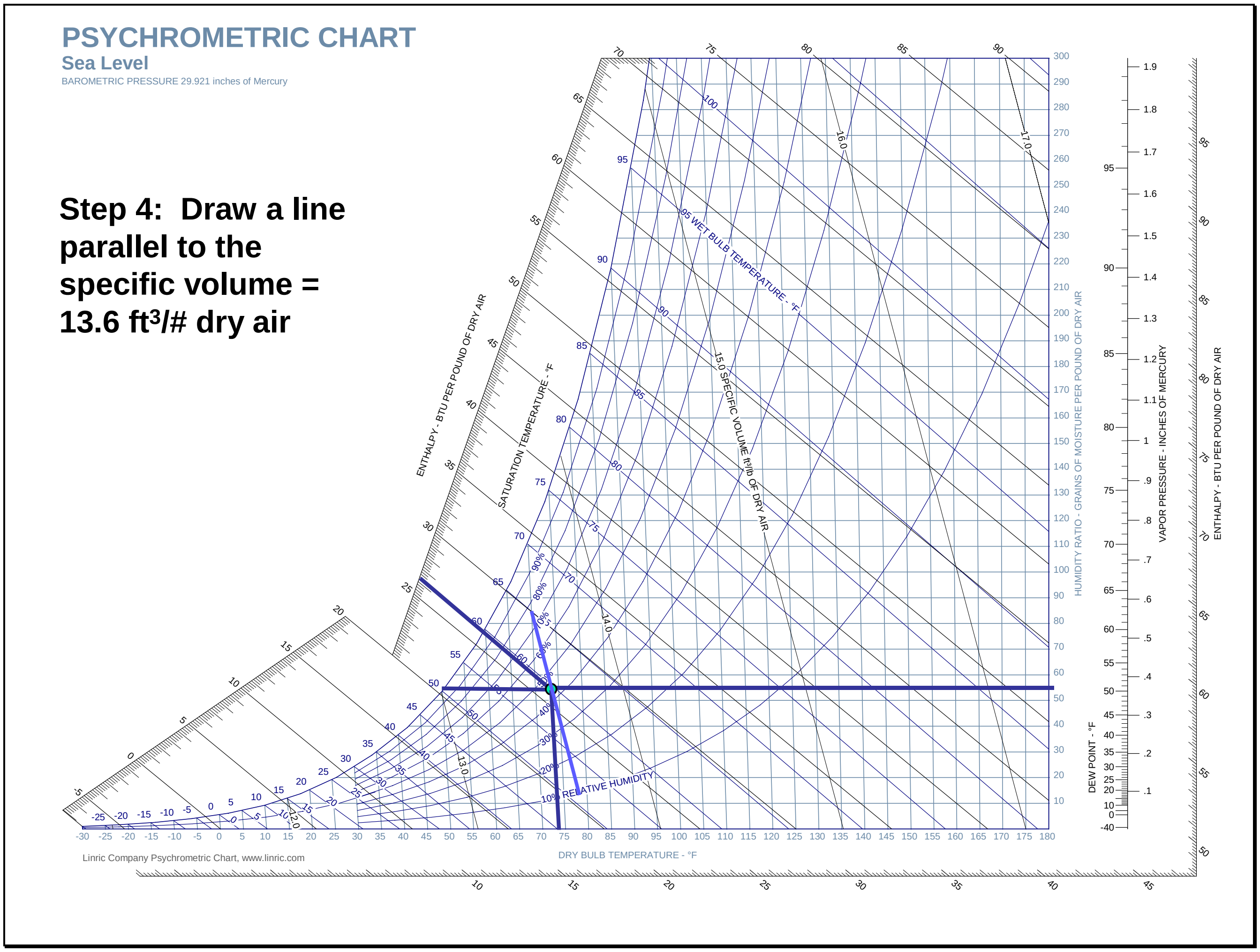
The following are the correct answers: 1-a; 2-b; 3-c; 4-a; 5-b. How well did you do? If you struggled with this, the following are the Charts that give a step-by-step illustration – compare it to your chart.




PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Step 2: Draw a horizontal line.
•Read Dewpoint on the left at the 100% saturation curve, 51.34°F
•Read Humidity Ratio on the right, 56.37 grains/pound of dry air
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
VAPOR PRESSURE - INCHES OF MERCURY
DEW POINT - °F
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com


PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Step 3: Draw diagonal lines and read
Enthalpy = 26.57 BTU/# dry air
At the saturation curve Wet Bulb = 60ºF
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

Step 4: Draw a line parallel to the specific volume = 13.6 ft³/# dry air



HVAC Troubleshooting Examples

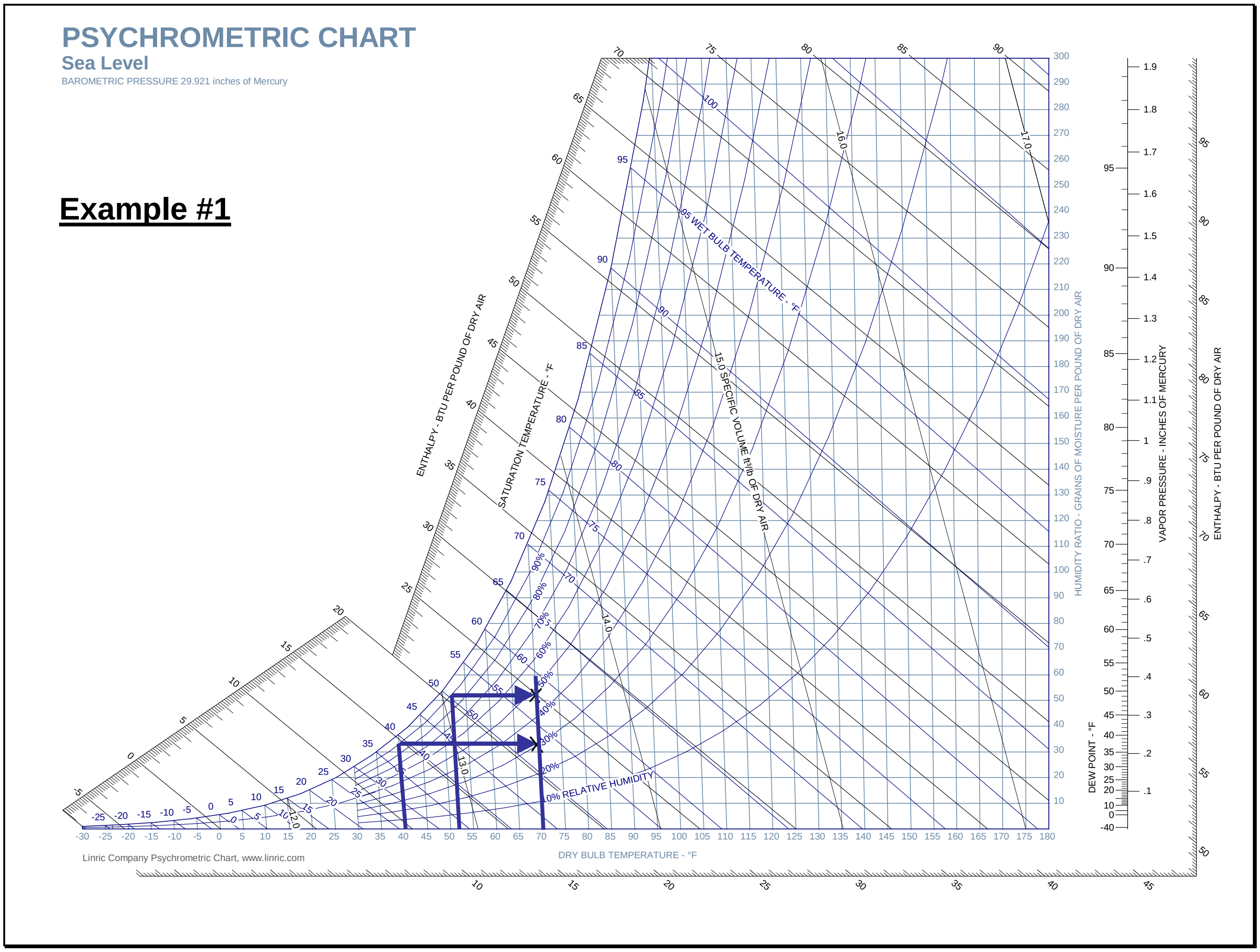
Now lets consider some specific HVAC troubleshooting examples. Before looking at the charts provided with the answers, try to plot the information yourself. If you don't do this, you will not be able to follow the examples. Some of the examples will be more challenging than others – if you don't have a HVAC background, you likely will struggle at some points. Don't be overly alarmed. If you have a strong grasp to this point, you are well on your way and passing the Quiz should be no problem. The goal for the student is to be able to use the Psychrometric chart to solve virtually any HVAC problem/challenge that involves air temperature/moisture issues.

HVAC Troubleshooting Example #1

You have a complaint of moisture condensing in a cooling chamber in a packaging line. You find you need to cool the chamber to 40^{o}F. The desired room temperature is 70^{o}F.

- A. What relative humidity in the space is needed?
  - Answer: To keep the condensation from occurring, keep the RH below 100% (say 90%) at the cooling chamber temperature (40^{o}F). Plot this condition, and draw a horizontal line that intersects 70^{o}F and read the RH, which is 30.15% (Note: This is very low and uncomfortable for occupants – consider a local environment)
- B. Answer: The lowest discharge temperature of the airhandler is 52^{o}F. Can you satisfy the conditions needed above?
  - No. Plot from 52^{o}F and 90% RH horizontally to 70^{o}F, and the minimum RH expected is 47.51% >> 30.15% - condensation will occur. (To lower further would require more expensive systems.)

Example #1

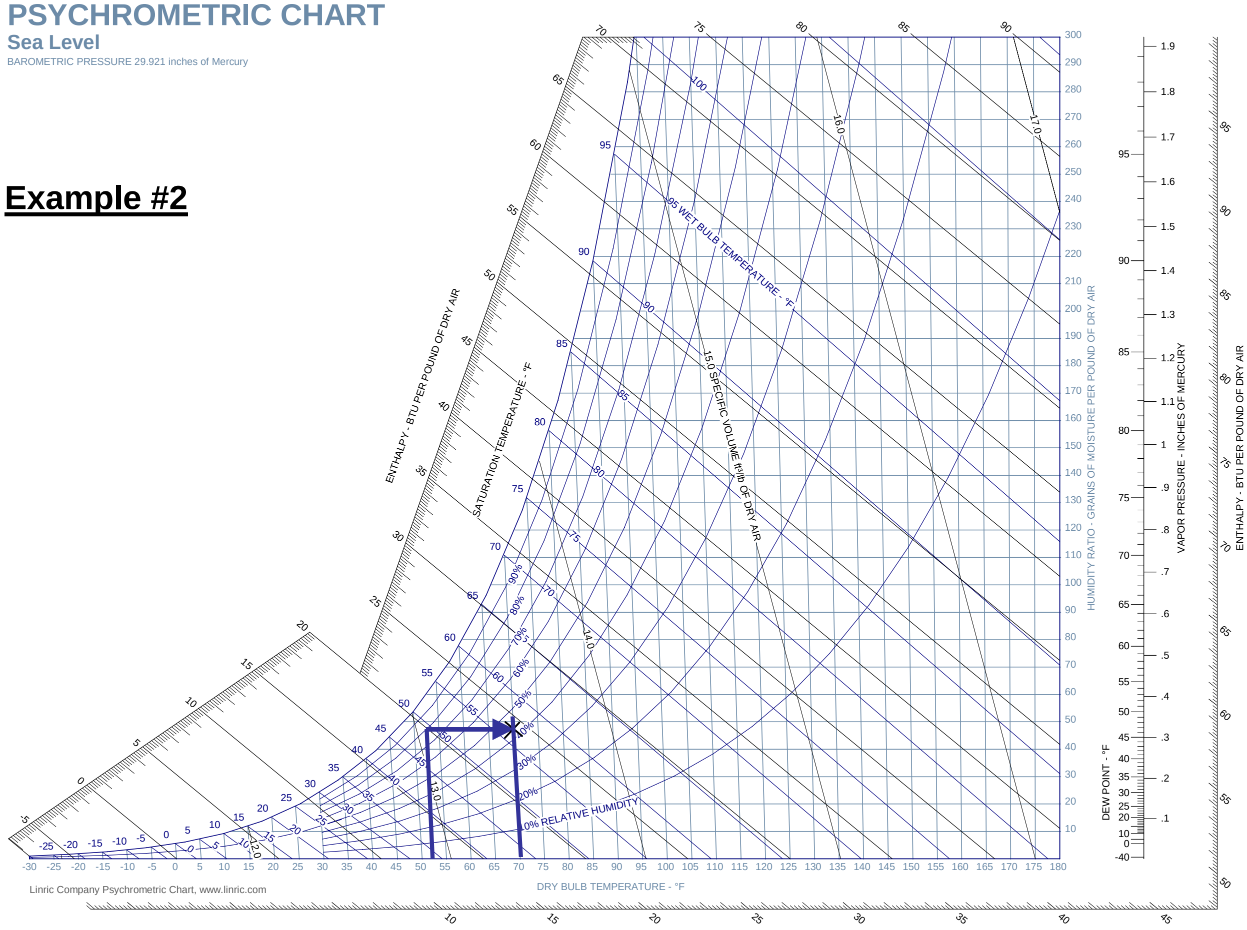

PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
ENTHALPY - BTU PER POUND OF DRY AIR
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

HVAC Troubleshooting Example #2

- You would like to humidify a space that has a 100% outside air unit to 50% RH in the winter, and would like to keep the discharge RH from exceeding 80% (ignoring any latent gains in the space). However, you get frequent low humidity alarms in the winter. Why?
  - First, check to see if the Psychrometrics are possible.
  - Plot the conditions off the coil, 52^{o}F discharge at 80%, and draw a horizontal line to 70^{o}F. The maximum RH possible is 42.23% << 50% - system will not reach conditions under some winter outside air possibilities.
  - Note: It may be possible to raise the discharge temperature to absorb more moisture and/or raise permitted RH after the coil.

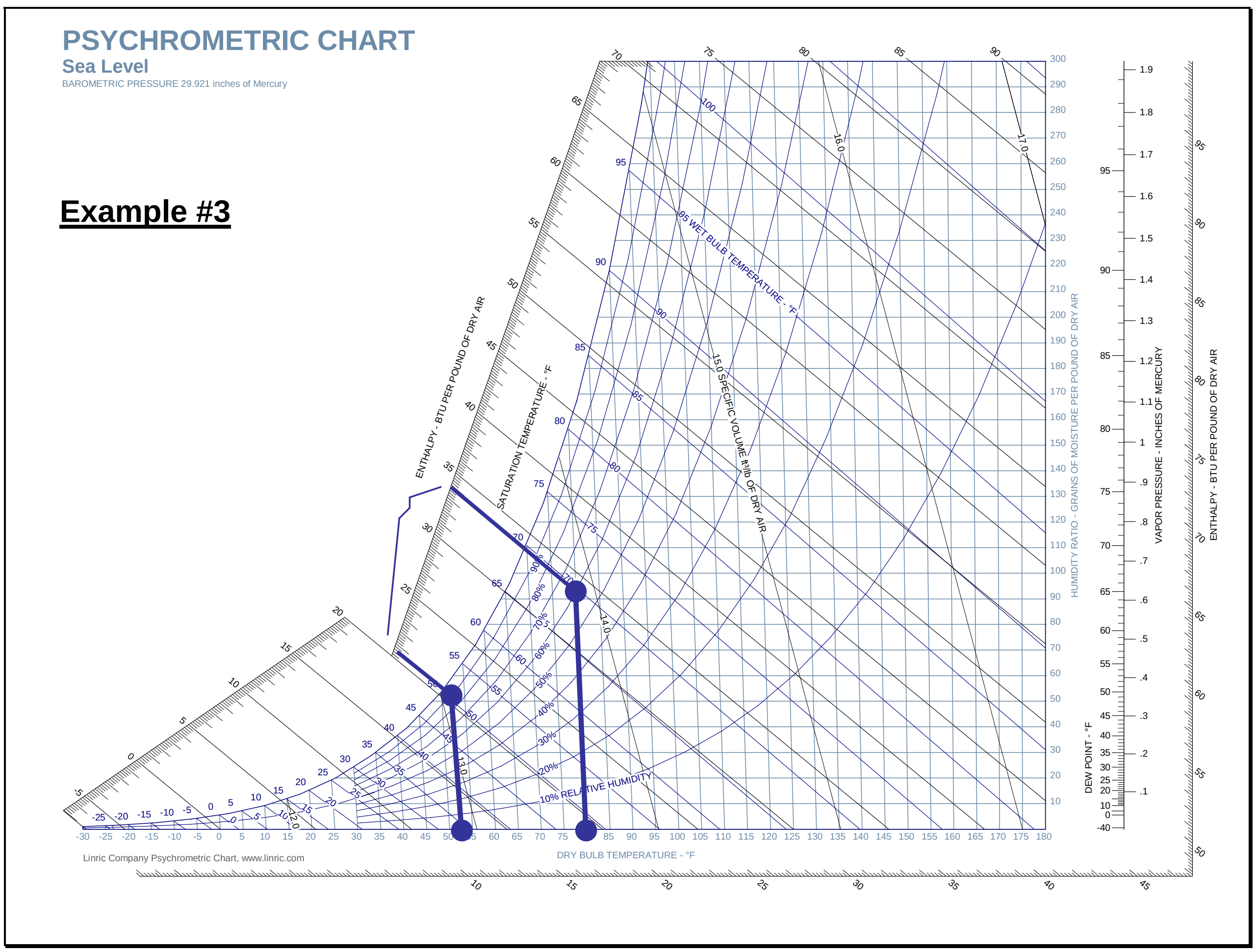
PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury

Example #2



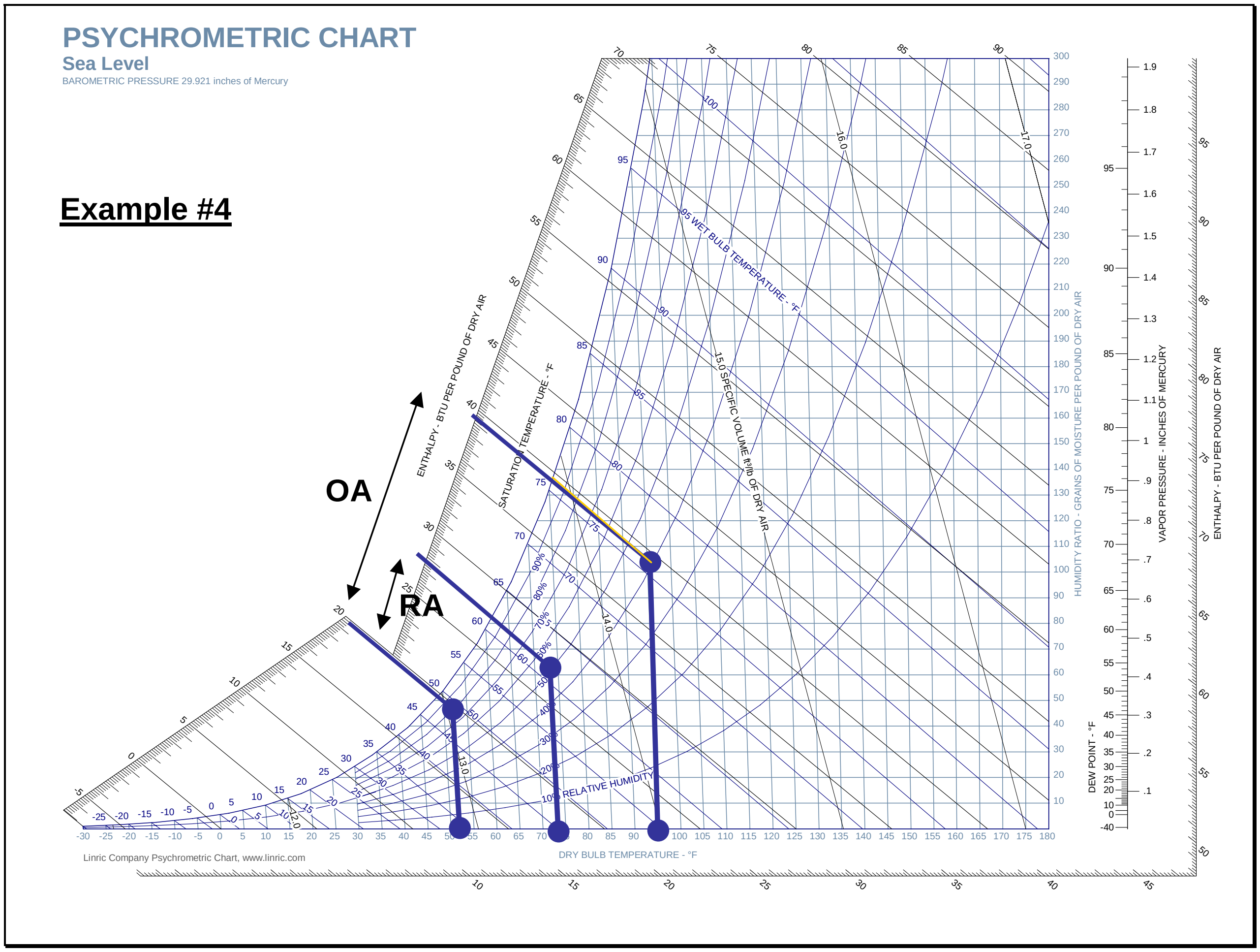
HVAC Troubleshooting Example #3

- On a day when outside air reached 80F/60RH, we noticed we were not maintaining space conditions. Assume we need 52F discharge (saturated at 90% RH) to maintain space conditions with 10,000 cfm supply air. We did not maintain space conditions that day. We installed a 25T chiller for the 100% outside air unit. Why is the system not working?
  - To diagnose the problem, first check the loads. Enthalpy needing to be removed is 33.68-20.52 = 13.16 BTU/lb dry air
  - Calculate BTUH = cfm * 4.5 * (h1 – h2) = (10000)(4.5)(13.16) = 592,200 BTUH
  - To convert to Tons of cooling, = 592,200/12,000 = 49.35 Tons >25 – chiller was undersized.



HVAC Troubleshooting Example #4

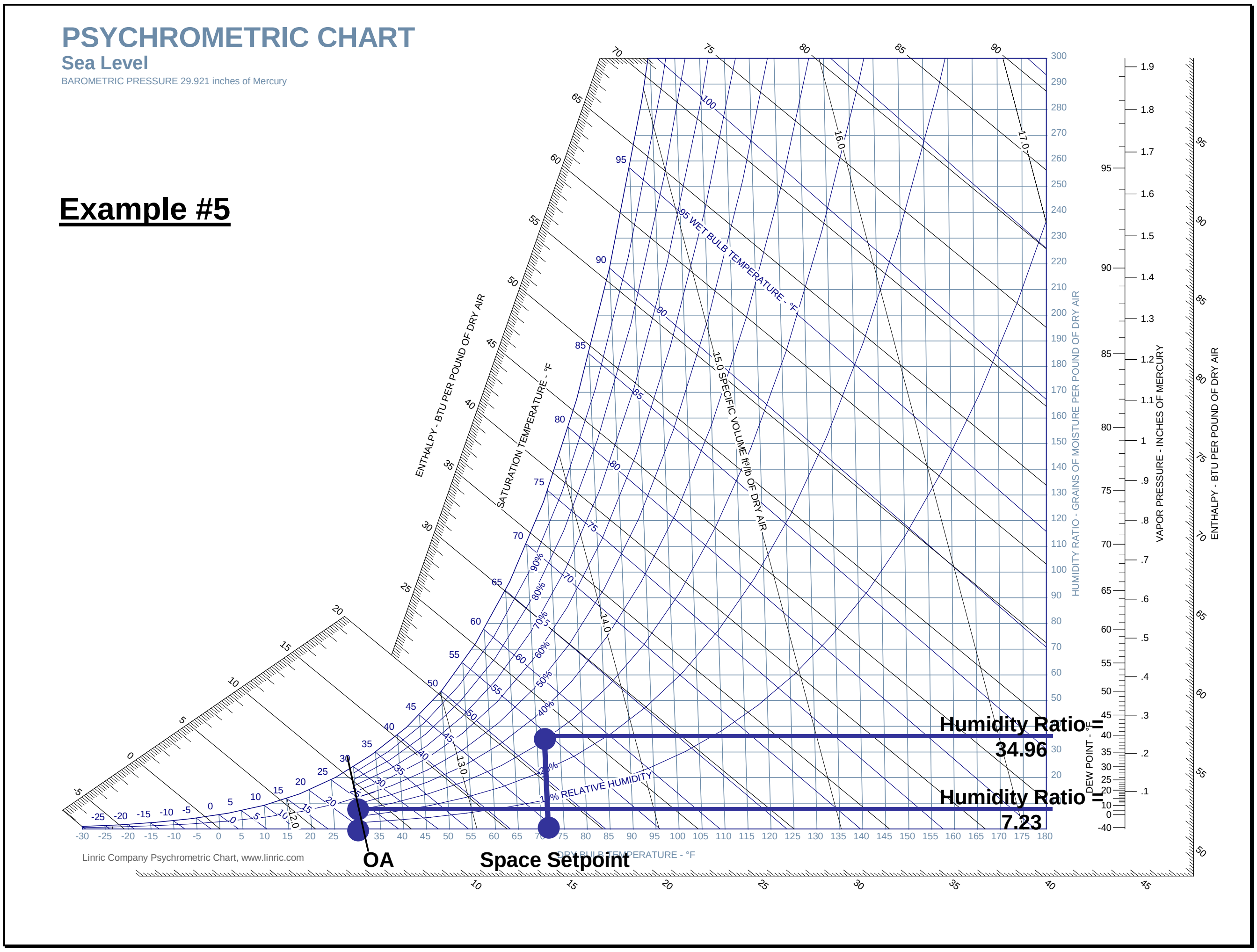
- You have an airhandler supplying 25,000 cfm. You bring in 5,000 cfm outside air (OA) and relieve the same. You know you need to return 74F/50%RH air and have the supply 52F/80% RH to maintain space conditions. However, you are getting space temperature alarms. The contractor provided a 800 MBH coil. What is the problem? What are possible solutions?
  - First, plot the conditions for the OA and RA to get the differences in enthalpy for both. Use outside design day conditions of 95F DB/76F WB.
  - Calculate the load = (5000)(4.5)(39.37-19.62) + (20000)(4.5)(27.56-19.62) = 1158975 BTUH/1000 = 1159 MBH
  - The coil can only provide 800 MBH, which is under 1159 MBH on a design day
  - To solve this, increase coil capacity or decrease outside air if possible


PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Example #4
OA
RA
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
95 WET BULB TEMPERATURE - °F
15.0 SPECIFIC VOLUME ft³/lb OF DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

HVAC Troubleshooting Example #5

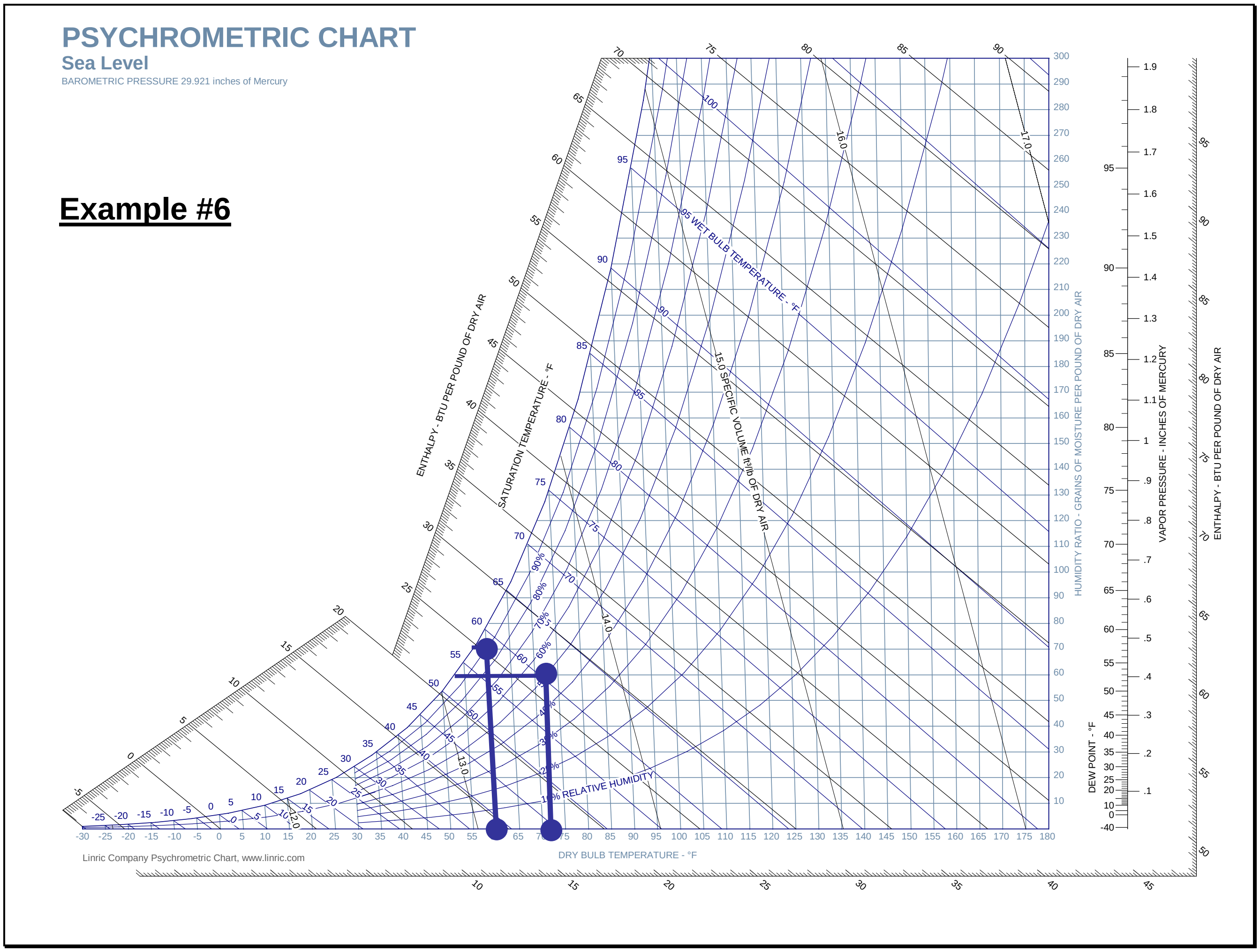
- For some reason, when outside conditions dropped to 30F/30%RH for the first time, an area fed by a 20,000 cfm 100% outside air unit went into alarm. The wintertime setpoint for RH in the space was 30% at 72F. The humidifier was designed to deliver 300 pounds of moisture per hour. What could the problem be?
  - Plot the conditions and determine the grains of moisture/# dry air for both conditions. Then, calculate the required amount of moisture.
  - Moisture needed = (g_1-g_2)*cfm*4.5/7000
  - Moisture needed = $\frac{(34.96-7.23) \text{ g/\# DA} * 20000 \text{ cfm} * 4.5}{7000 \text{ G/\#}}$

    =***<u>356 #/hour</u>***
  - Therefore, the humidifier is undersized (or slow down the fan/cfm if possible)


PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Example #5
Humidity Ratio =
34.96
Humidity Ratio =
7.23
OA
Space Setpoint
Linric Company Psychrometric Chart, www.linric.com
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
95 WET BULB TEMPERATURE - °F
15.0 SPECIFIC VOLUME ft³/lb OF DRY AIR
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
VAPOR PRESSURE - INCHES OF MERCURY
DEW POINT - °F
DRY BULB TEMPERATURE - °F
RELATIVE HUMIDITY

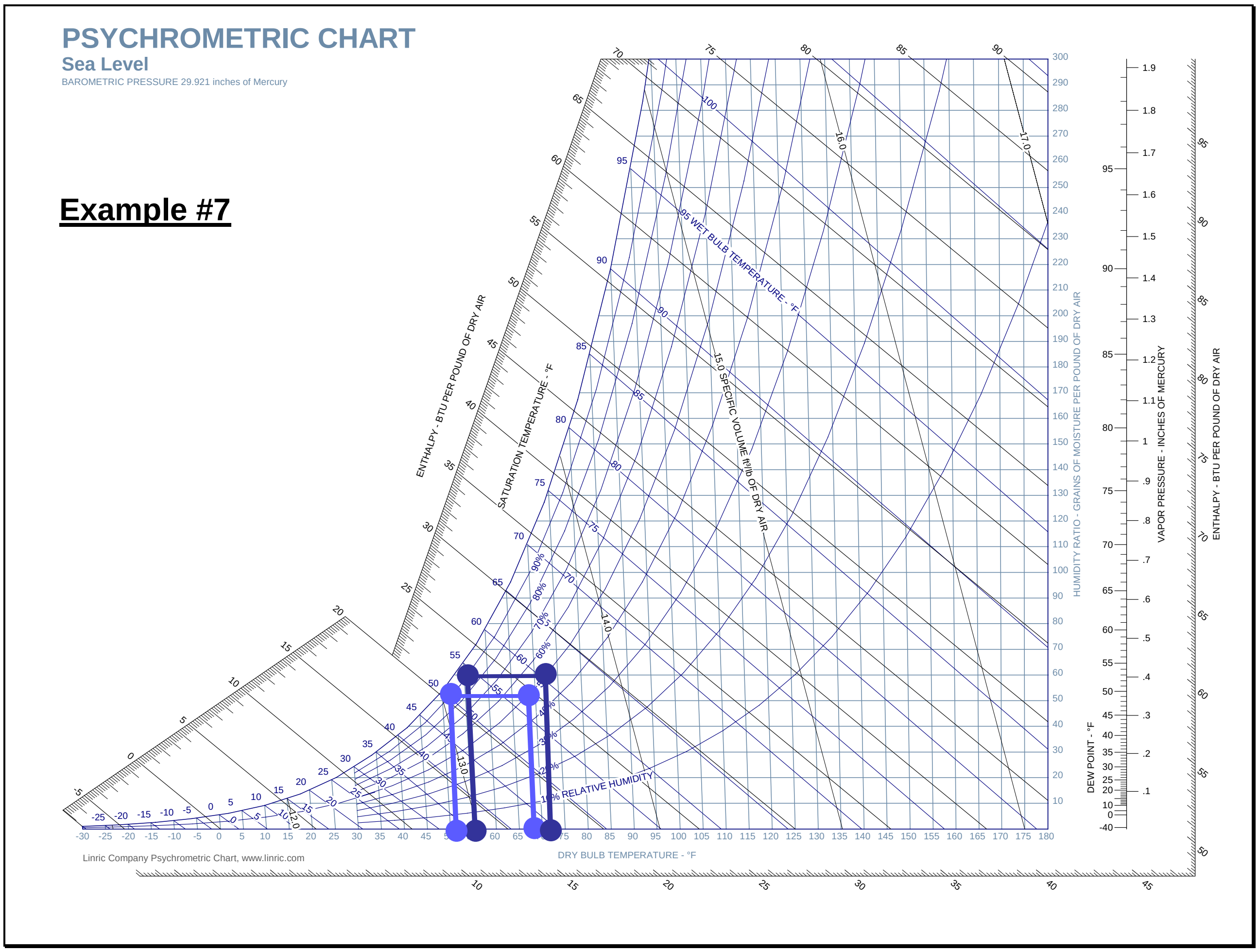
HVAC Troubleshooting Example #6

- You have a “floating” discharge temperature from 52 to 60°F. Your design space conditions are 70/50%RH. Do you need to override the “floating” discharge to control upper humidity?
  - First, plot the conditions of the highest discharge temperature and space conditions.
  - Note that the moisture content at saturation for the discharge when at 60F is higher than the room conditions. It must be lower to absorb moisture. ***Try It Yourself***: Plot for yourself (not shown) the Humidity Ratios. You will find that a lower Humidity Ratio is needed than the supply discharge conditions can supply. Obviously, that means the RH will not be maintained as desired since there will be too much moisture in the air coming into the room.
  - Therefore, an overriding dehumidification cycle is needed if space conditions are to be maintained.
  - (Note: In good practice, “floating” is typically based on outside air dew point and the above is usually not a problem.)


PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Example #6
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

HVAC Troubleshooting Example #7

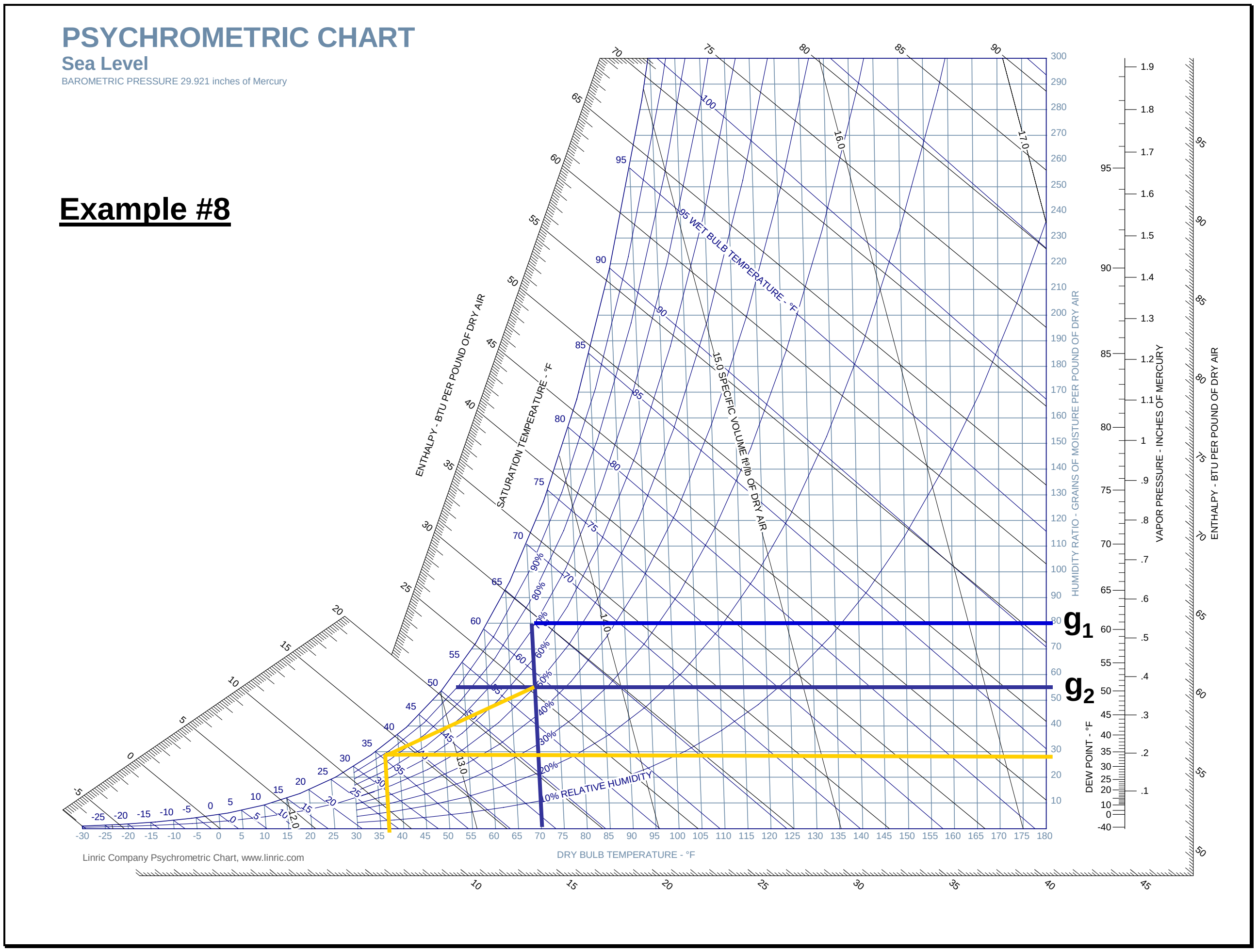
- You design a production space to 72F/50%RH. After moving in, the operators wish to lower the setpoint to 68F while maintaining the 50% RH in the summer. Is this a problem? What must be done?
  - First, plot the conditions of the original and desired conditions. Then draw a line to the 90% saturation line and drop down to see what the new discharge temperature will be .
  - Clearly, the discharge temperature must be lowered if the RH is to be maintained. Can the system handle this? Is the chilled water temperature low enough?



HVAC Troubleshooting Example #8

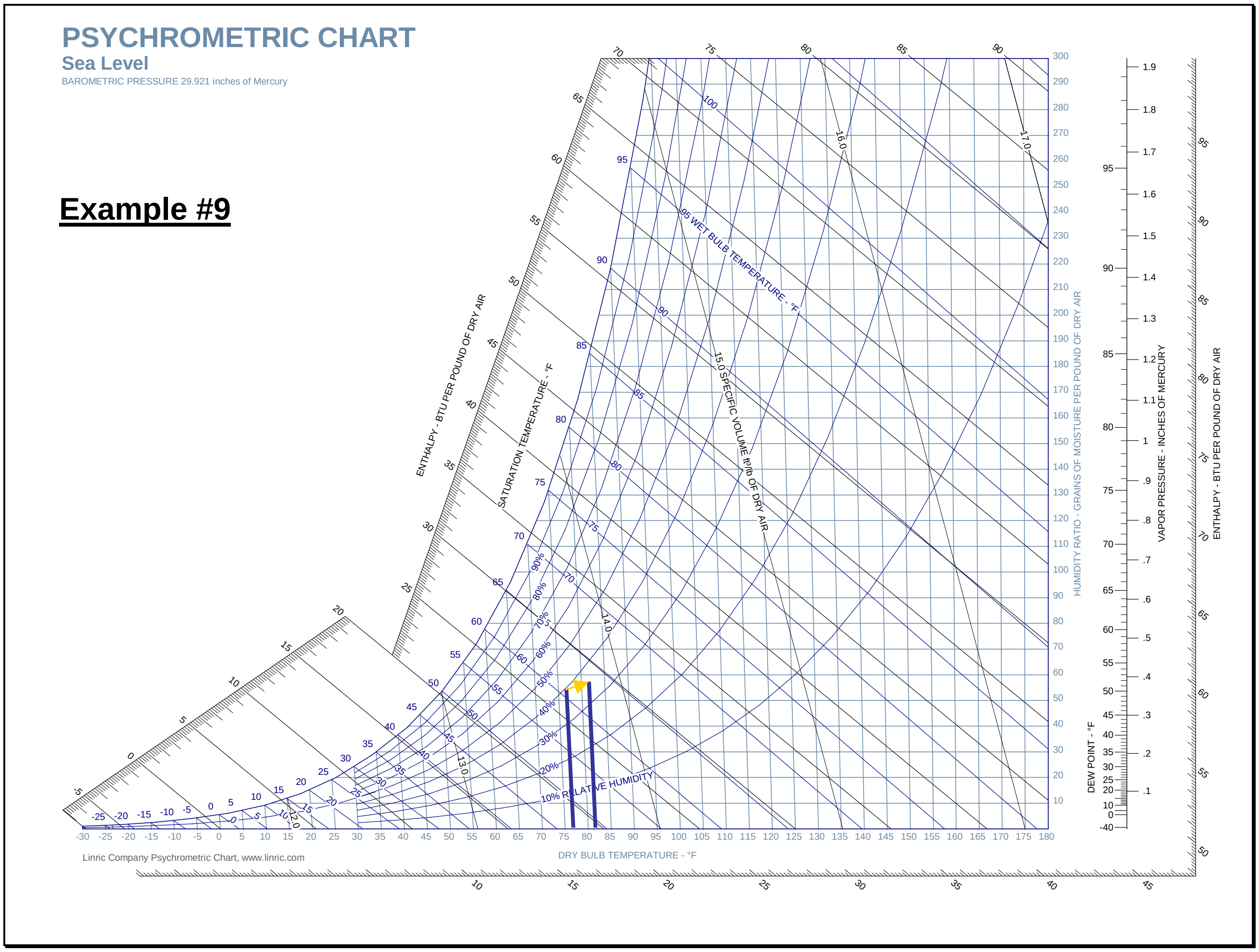
- You construct a room 20' x 30' at design conditions 70^oF/50%RH and 2800 cfm supply air. After washing the room with 100^oF water, the operators do not dry it and there are humidity alarms. Assume the evaporation rate is 0.075#/ft^2/hr (this can be determined by tables not included herein). Are there problems with the HVAC system?
  - First plot the conditions at 70^oF/50%RH (Humidity Ratio = 54.68 gr/#).
  - Then calculate the new conditions by determining the new Humidity Ratio after evaporation (you can consider it like the humidifier example earlier, where #/hr of moisture = (g_1-g_2)*cfm*4.5/7000) Solve for the unknown "g."
    - $((g_1 - 54.68)*2800*4.5)/(7000) = 0.075*30'*20'$; solving for $g_1 = 79.7$ gr/#
    - Plot the new condition from 79.7 gr/# to 70^oF and determine the new RH which is 72.47% resulting from the evaporation.
- How long before the water evaporates away?
  - Based on evaporation rates alone, you can solve for the amount of evaporation per inch/hr, or
    - Time/inch = 62.4 #/ft^3/(0.075 * 12) > 69 hours per inch, or over 4 hours for 1/16"
    - Actually much longer as water cools
- What can we do to keep from having alarms/RH above 50%?
  - Quickly dry/squeegee the space as soon as possible.
  - Lower the discharge temperature. To determine how much is required, determine the required moisture holding capacity of the discharge air. First, calculate the maximum Humidity Ratio allowed, or
    - Humidity Ratio Allowed = (Max. HR allowed) – (amount to be absorbed) = 54.68-(79.7-54.68) = 29.7gr/#

- Plot a line to the 90% saturation curve and draw line down to the DB temperature, which is 37.48°F, or the required discharge temperature. Note the line now slopes up to the new 70/50 setpoint that takes into account absorbing the evaporation. Likely, this will not be possible without changing coils and/or the chilled water system.



HVAC Troubleshooting Example #9

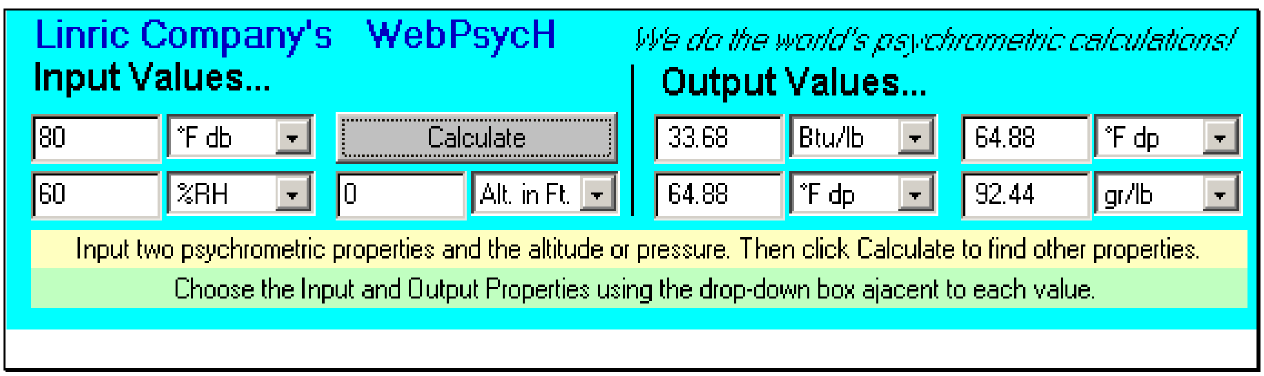
- A Stability Chamber (used in the Pharmaceutical industry to hold products at tightly controlled temperature and humidity conditions) experienced a humidity excursion – the relative humidity dropped below the setpoint of 40% to 36% RH. The conditions in the chamber are set for 25C/40% RH. At the time of the excursion, the temperature also increased to 82F. What caused the drop – could the humidifiers be malfunctioning?
  - Plot the conditions. Note that 25C = 77F.
  - Note that the rise in temperature required more capacity from humidifiers to reach same RH setpoint.
  - Therefore, the problem was a result of change in temperature versus under-sized humidifier.



PSYCHROMETRIC CHART
Sea Level
BAROMETRIC PRESSURE 29.921 inches of Mercury
Example #9
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
WET BULB TEMPERATURE - °F
SPECIFIC VOLUME ft³/lb OF DRY AIR
RELATIVE HUMIDITY
HUMIDITY RATIO - GRAINS OF MOISTURE PER POUND OF DRY AIR
DEW POINT - °F
VAPOR PRESSURE - INCHES OF MERCURY
DRY BULB TEMPERATURE - °F
Linric Company Psychrometric Chart, www.linric.com

Using on-line data or software

You might have had difficulty getting the significant figures that the examples illustrated. That is because I used software to determine the accurate values. It is often difficult to acquire the accuracy needed by plotting on the chart. Software is available, often free online, to accurately calculate various psychrometric conditions. This course utilized **linric.com** – a website providing all psychrometric tools. Using such software, we can get more accurate data and at different altitudes above sea level. As well, it avoids cumbersome conversions. However, the Psychrometric chart remains useful to understand graphically the array of parameters. The following is an example screenshot.



Course Summary

This course presented an overview of the fundamentals of psychrometrics and use of the psychrometric chart. Specific examples were provided for typical HVAC troubleshooting problems that have occurred in the Instructor's experience. It is essential that students have fundamental understanding of the subject matter if they are to successfully design to avoid problems, as well as diagnose HVAC problems when they occur.

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