THIS PRESENTATION STARTS FROM SLIDE-9
THE FIRST 8 ARE SLIDES FROM PART-1 FOR REFERENCE

THE PROPERTIES WE WILL STUDY

1. DRY BULB TEMPERATURE
2. VAPOR PRESSURE
   (& THE SATURATION CURVE)
3. SPECIFIC VOLUME
4. HUMIDITY RATIO
5. RELATIVE HUMIDITY
6. DEW POINT TEMPERATURE
7. WET BULB TEMPERATURE
8. SPECIFIC ENTHALPY

WHERE CAN YOU FIND MORE ABOUT THIS STUFF?

- 2013 ASHRAE HANDBOOK – Fundamentals (I-P) edition, Chapter-1

Extremely dry reading. Stay away – use it only as a reference to prove your point in case some impertinent rascal challenges your wisdom.

- Stoecker, W. F. – *Refrigeration and Air Conditioning*, *Chapter-16*, McGraw-Hill 1958

Don't let the date panic you. This is good stuff. This is where I first read about psychrometrics in college.
His Chapter-16 is where the idea of teaching psychrometrics by building your own chart comes from.

- Gatley, D. P. – *Understanding Psychrometrics*, ASHRAE 3rd Edition

Excellent book – just a little frustrating that the author chose SI Units.

- Jennings, B. H. – *Environmental Engineering*, Harper & Row Publishers

Good solid HVAC text by someone who really knew what HVAC engineers need.

- Van Wylen and Sonntag - *Fundamentals of Classical Thermodynamics*, J. Wiley and Sons, 2nd Ed., 1973

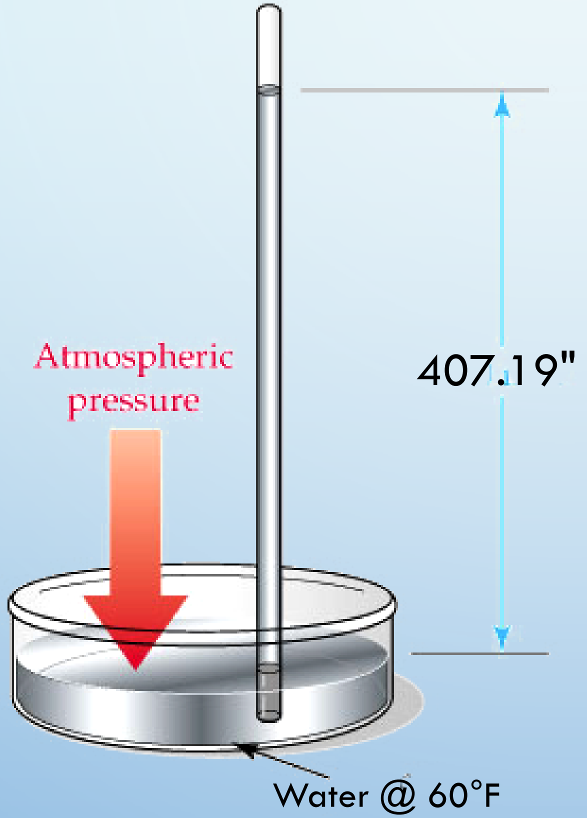
Very popular standard text from my college days. I keep this old addition as all the later additions have SI units

- Som, S.K. – *Basic Thermodynamics*, Video NPTEL, IIT Kharagpur, India

One of the best basic Thermodynamics Video tutorials on the web. However, if your ear is not tuned to the "Indian English" sounds then you might have trouble understanding what is going on.

BAROMETRIC PRESSURE

Altitude ft	Pressure psia
-1000	15.236
-500	14.966
0	14.696
500	14.430
1000	14.175
2000	13.664
3000	13.173
4000	12.682
5000	12.230



- Our chart will be based on the Standard Barometric Pressure at Sea Level, which is as follows:

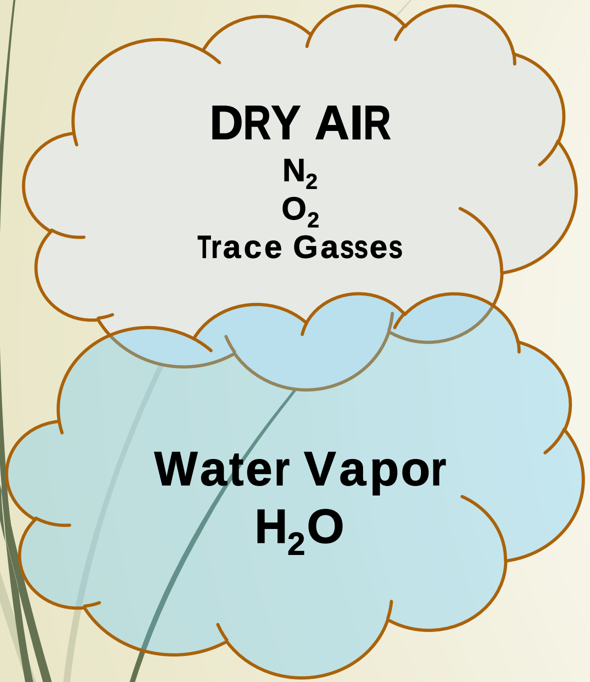
  14.696 psia

  29.921 in. Hg @ 32°F

  407.19 in W.G. @ 60°F

- ± 1000 Feet from Sea Level elevation does not produce any appreciable errors for normal commercial HVAC design.
- The table on the left shows how Standard Pressure varies with Altitude.

Key Concept Slide - 3



On a Psychrometric Chart, Moist Air is a mixture of Dry Air and Water Vapor

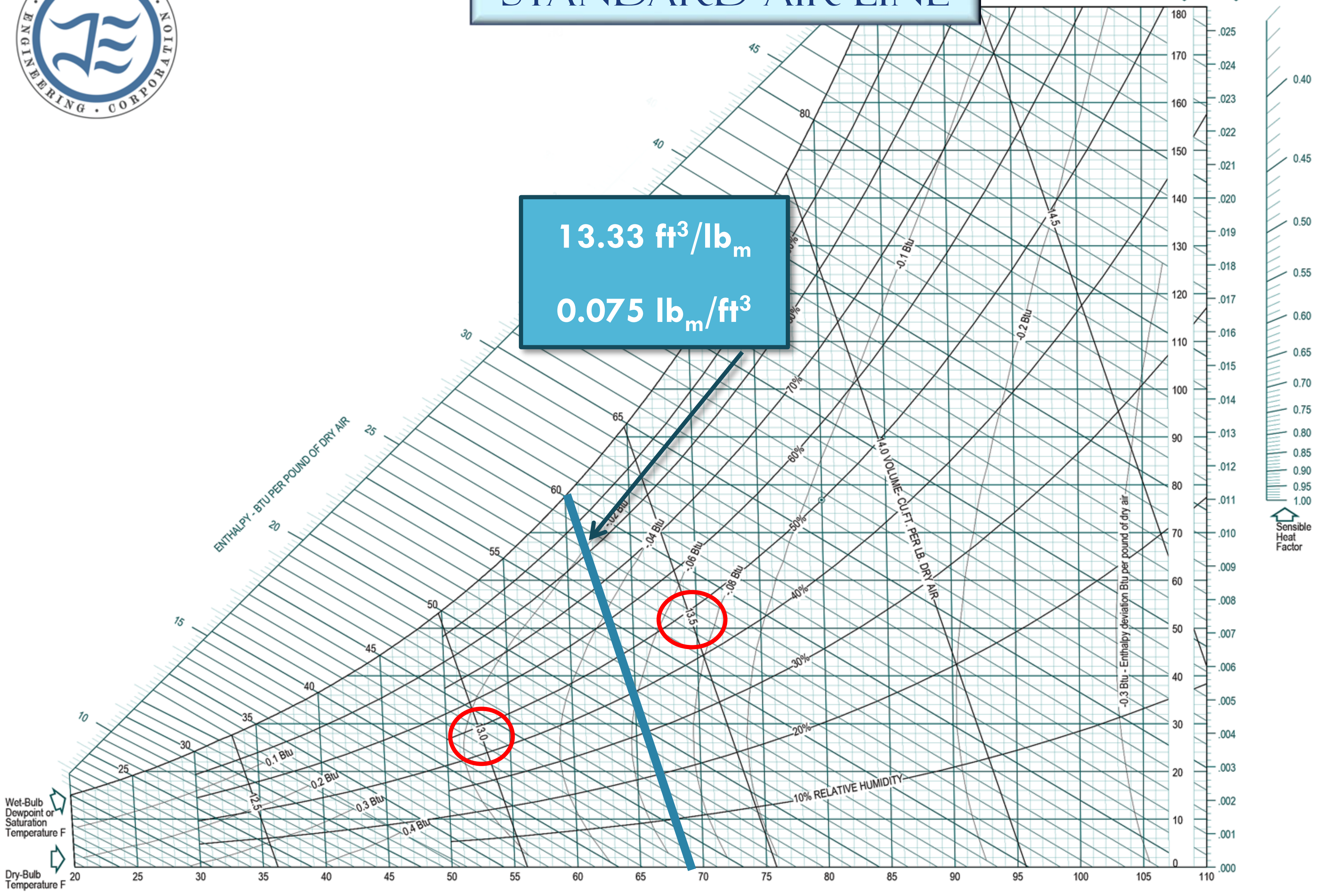
- Dry Air and Water Vapor exist totally independent of each other. They are not affected in any way by each other's presence. They both behave as ideal gasses.
- They occupy the same Volume:
  $V_{moist\ air} = V_{dry\ air} = V_{water\ vapor}$
- They have the same DRY BULB Temperature:
  $T_{moist\ air} = T_{dry\ air} = T_{water\ vapor}$
- The Total Pressure of Moist Air is always the sum of the partial pressures of the 2 components:
  $P_{moist\ air} = P_{dry\ air} + P_{water\ vapor}$ = 14.696 psia (Chart Datum)
  = 407.19 " W.G.

SEA-LEVEL CHART

STANDARD AIR LINE

13.33 ft^3/lb_m

0.075 lb_m/ft^3



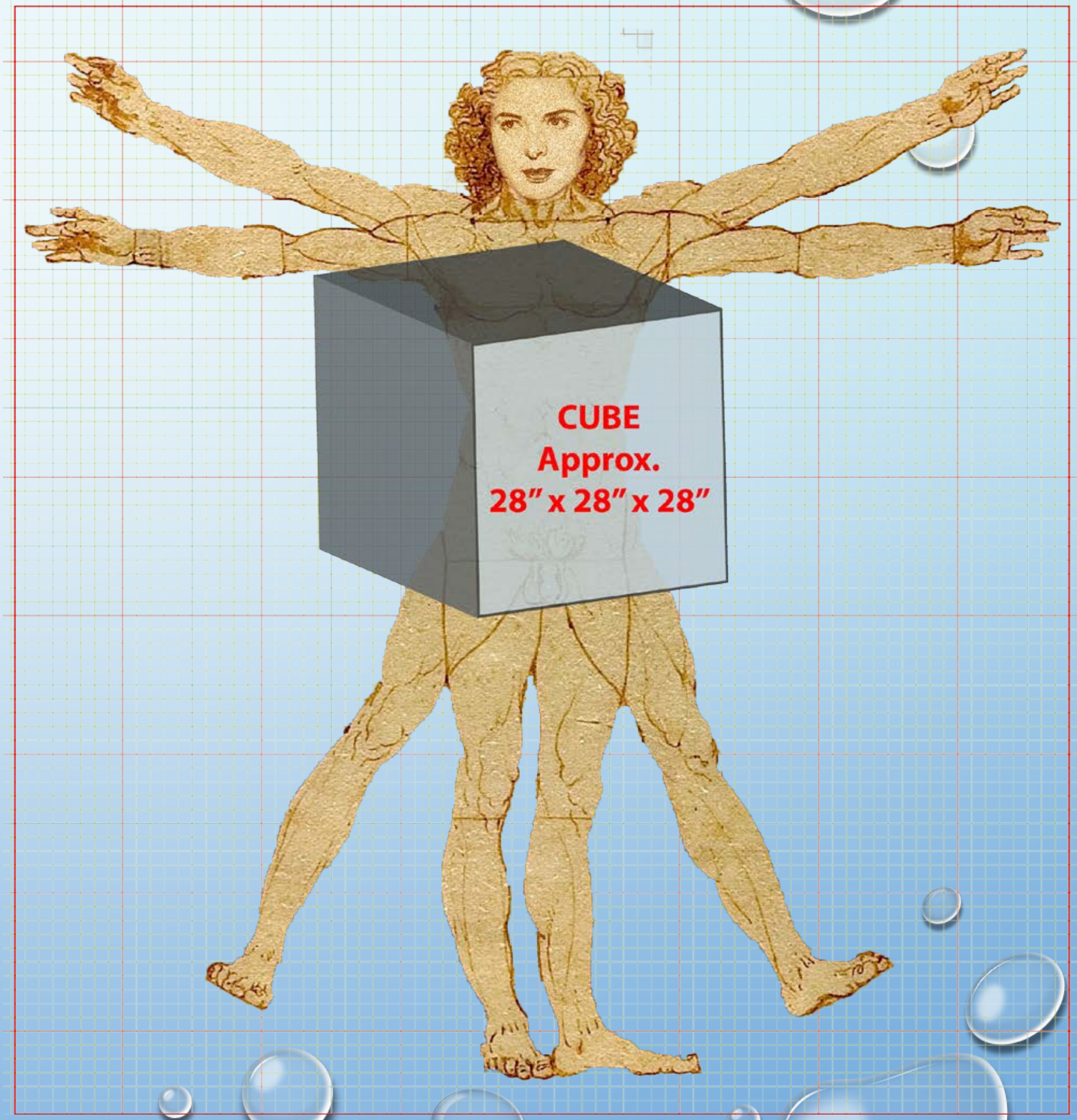
A FEW MORE PRELIMINARIES – 1

For air at Standard Density 0.075 lb_m/ft^3

HOW BIG IS A CUBE OF AIR WEIGHING 1 POUND?

$13.33\ ft^3$

About 28.45 inches each side



A FEW MORE PRELIMINARIES – 4

- All psychrometric processes that are drawn on the Psych. Chart are **CONSTANT PRESSURE PROCESSES.** For our use the Constant Pressure will be taken as the Sea-Level atmospheric pressure, 14.696 psia. (ASHRAE publishes charts for a number of different elevations and temperature ranges.)

- The atmospheric pressure 14.696 psia converts to 407.19 inches W.G.

- As an example, a fraction of an inch W.G. pressure drop through a cooling or heating coil is not going to change the density (specific volume) of the moist air to any appreciable extent and the process can be treated as occurring at a constant pressure.

- This might be helpful for those who would like to refer back to Thermodynamics text books to verify how the various formulae we use are derived.

THE END OF FACHGESPRÄCH– 5 PART-1A

See you soon for part-1B

Luke!
You must Complete
the training.

CHOOSING THE X AND Y AXES FOR OUR CHART

The chart we will construct for learning Psychrometric Concepts will have DRY BULB TEMPERATURE as the horizontal (X-Axis) coordinate and VAPOR PRESSURE as its Vertical (Y-Axis) coordinate.

This is different than the familiar ASHRAE chart which uses an oblique SPECIFIC ENTHALPY coordinate and HUMIDITY RATIO as its Vertical (Y-Axis) coordinate.

The engineers at ASHRAE have good reasons for choosing this system of coordinates. They claim that their choice of coordinate system makes for a more accurate chart.

One big difference between our approach is that ASHRAE did not think it necessary to show Vapor Pressure at all on their chart. As mentioned above they use Humidity Ratio as the vertical coordinate (which is directly related to Vapor Pressure), and chose to omit the Vapor Pressure values on the axis.

In this presentation Vapor Pressure will play a central part and will be displayed on the chart.

(Our choice of using Vapor Pressure as the Y-Axis is probably not the best for accuracy and drawing process lines. However, Part-1 of this presentation is about concepts and not accuracy. We will switch to the standard ASHRAE chart in Part-2.)

THE X AXIS – DRY BULB LINES

Thermodynamicists get all philosophical and emotional about what temperature “really” is; but we will not waste any time on that kind of nonsense. You just stick a standard (like mercury or digital) thermometer in the moist air sample and the temperature you read will be called its DRY BULB TEMPERATURE (°F).

That’s it. 1 property down, 7 more to go.

Let us start drawing the chart:

The Dry Bulb Temperature will be displayed on the X- Axis of our chart.

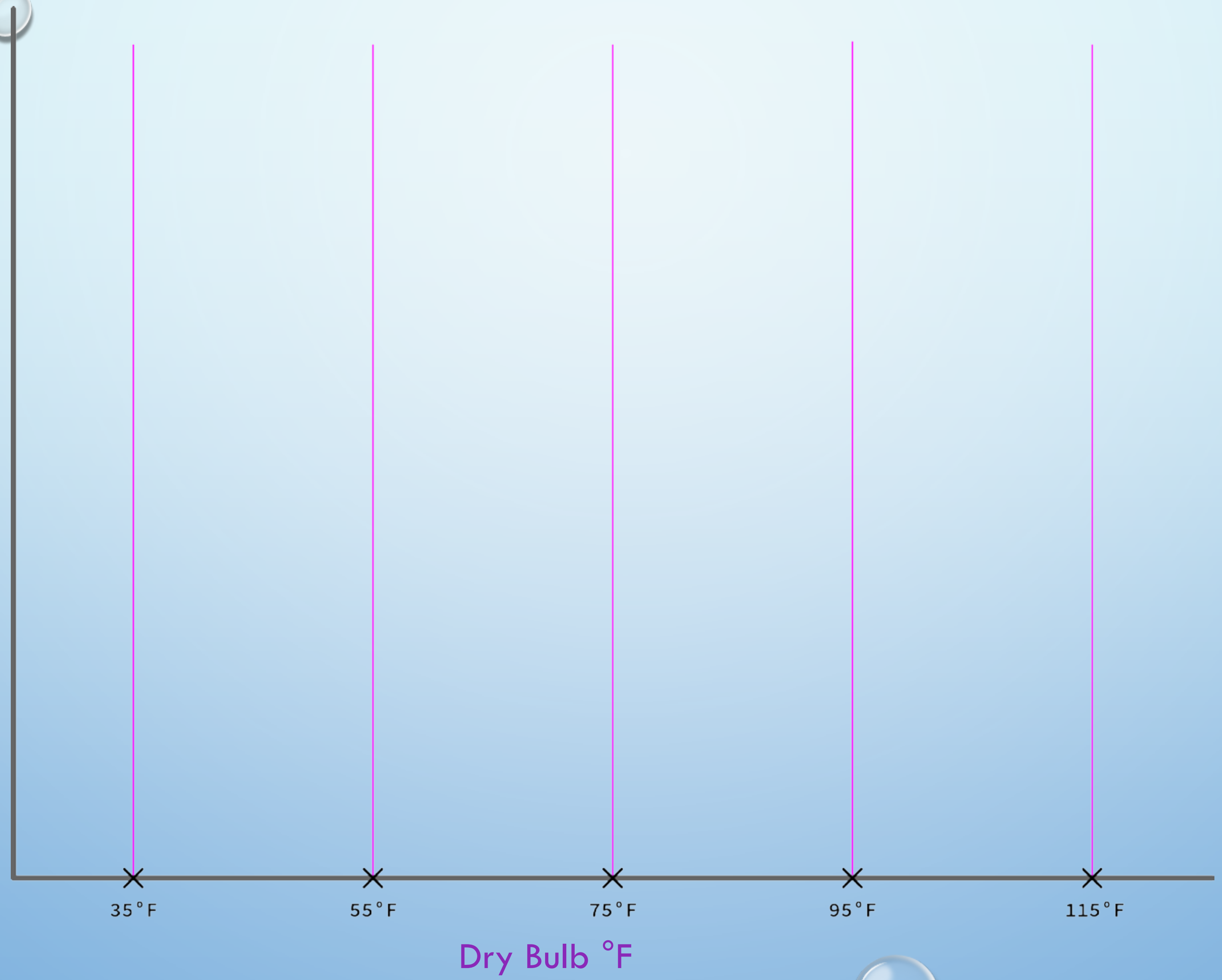
We will construct our chart for 5 Dry Bulb Temperature Points:

35°F   55°F   75°F   95°F   115°F

You have handout #1 – plot these points on the X-Axis.

CHART-1

SEA LEVEL
14.696 psia
407.19" W.G.



INFORMATION ON THE X-AXIS

Besides its function for displaying the DB Temperature, the X-Axis is also serves as the 0% Relative Humidity line.

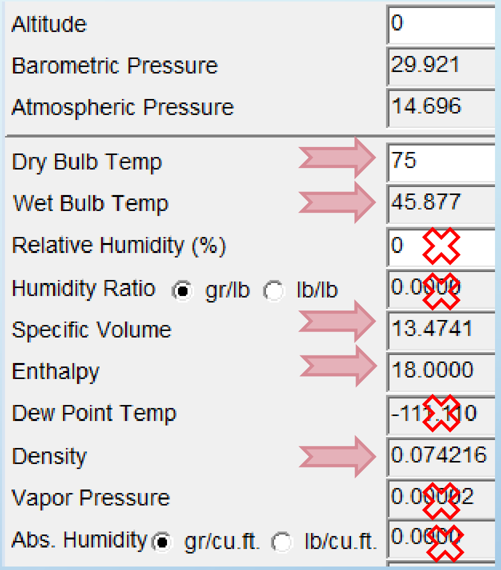
Now we have already looked at the partial pressure relationship:

$$\text{Barometric Pressure} = P_{\text{Dry Air}} + P_{\text{Water Vapor}}$$

Since, the chart is constructed for 14.696 psia Barometric Pressure and Vapor Pressure is 0 psia,
Therefore:

$$14.696 = P_{\text{Dry Air}} + 0 \quad \text{or} \quad P_{\text{Dry Air}} = 14.696 \text{ psia}$$

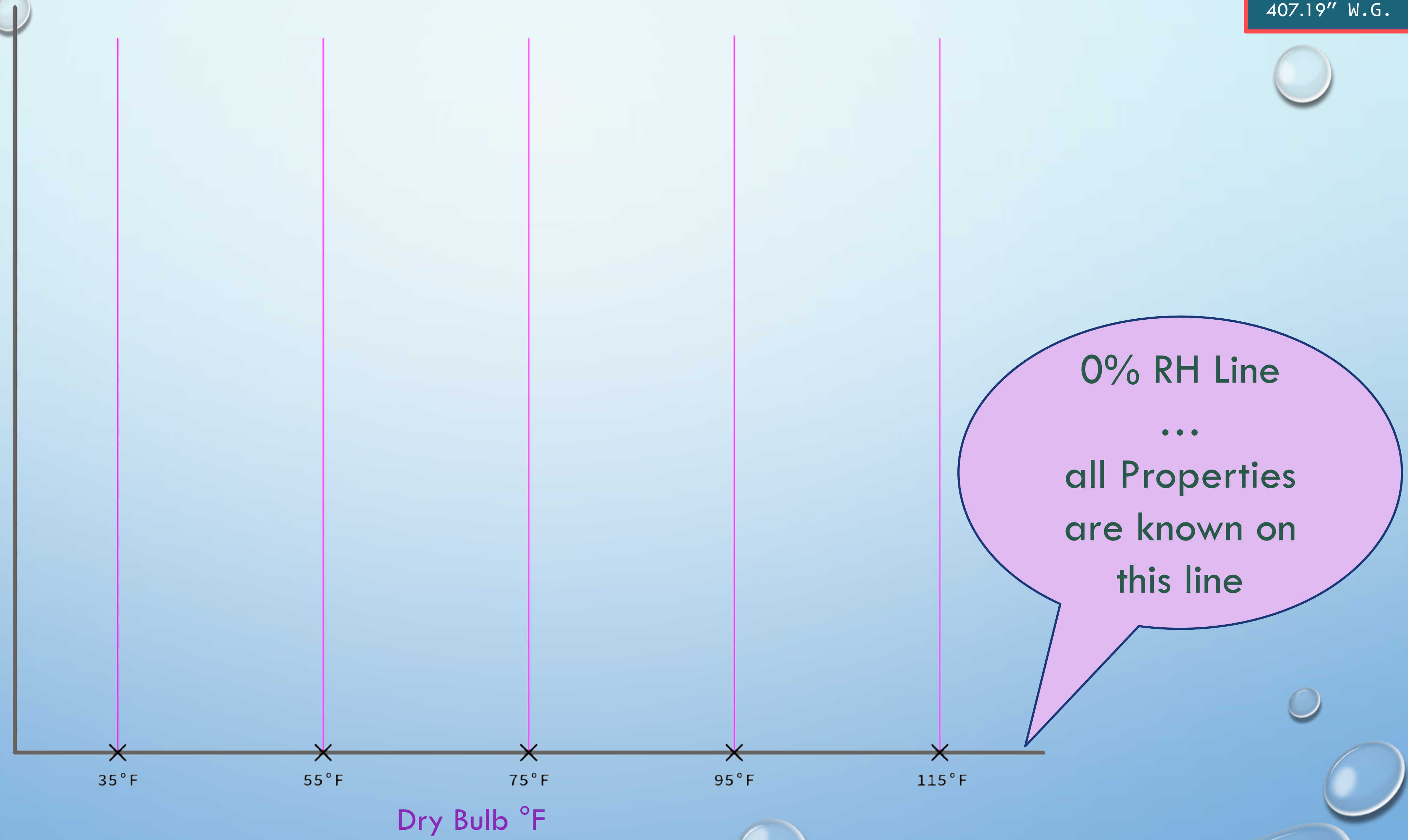
So Dry Bulb Temperature, Relative Humidity and Partial Pressure of Dry Air are all known along the X-Axis;
therefore:
all Dry Air state properties are known and fixed on the X-Axis.



For example at 75 °F Dry Bulb, you can read off the **Specific Volume**, **Specific Enthalpy** and **Wet Bulb** right off the chart. Of course the moisture related properties, Relative Humidity, Vapor Pressure, Humidity Ratio, and Dew Point Temperature are zero. We will calculate each one of these for the X-Axis while discussing the various properties.

CHART-1

SEA LEVEL
14.696 psia
407.19" W.G.



VAPOR PRESSURE

VAPOR PRESSURE AND ITS SATURATION POINT

The Partial Pressure of vapor in Moist Air is the first water side property of the air/water mixture that we will study. It will also serve as the Y-Axis variable of our Psych. Chart.

The concept of Vapor Pressure lies at the heart of Psychrometrics. If you don't understand Vapor Pressure then you don't understand Psychrometry. It is as simple as that.

Let us take a little extra time to understand what Vapor Pressure is, before we jump into empirical formulae or tabular data to look up values.

To start with:

We have already established in previous slides that at any given location:

Barometric Pressure = Partial Pressure of Dry Air + Partial Pressure of Water Vapor

This is the property we want to study next

@ Sea-Level

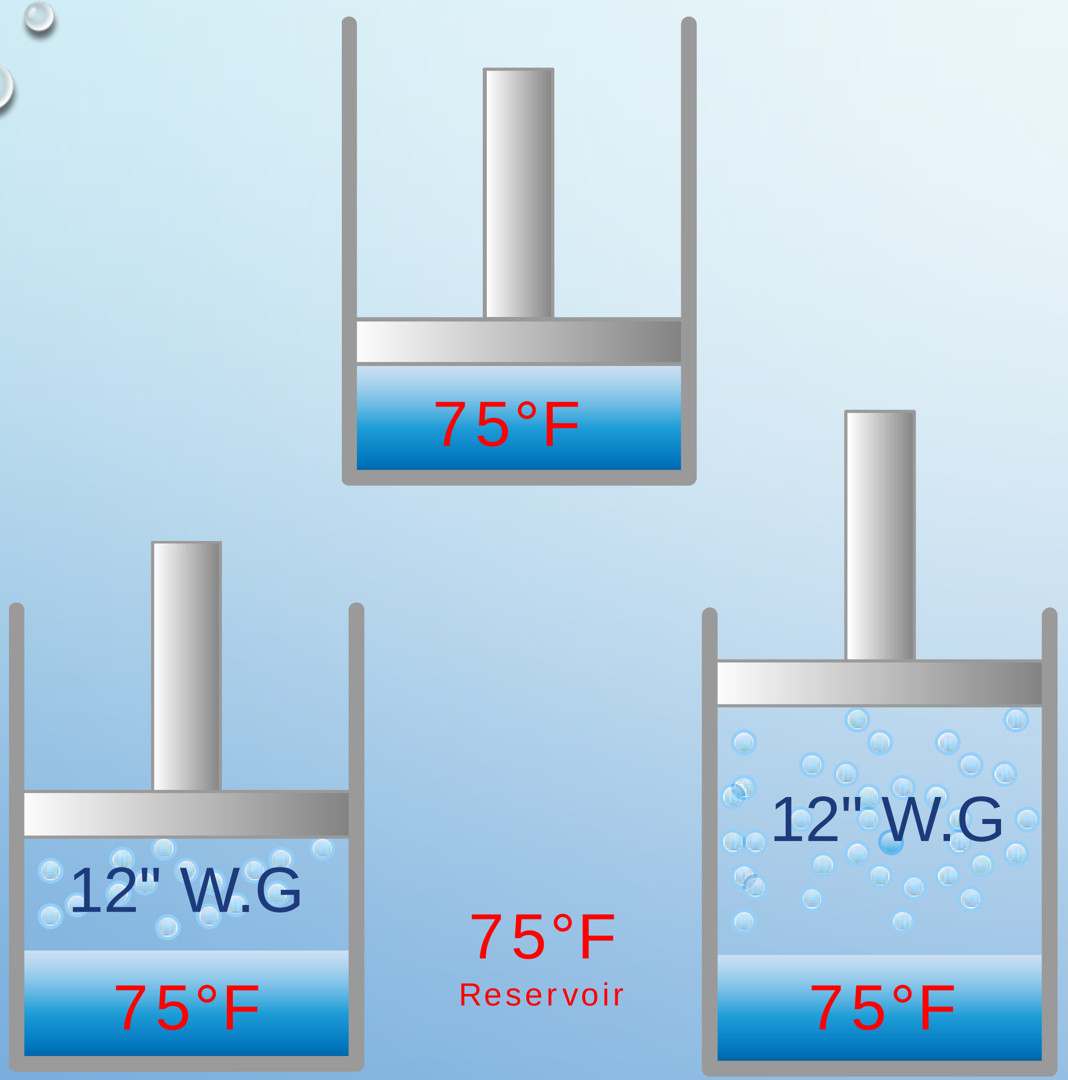
Barometric Pressure (Inches of W.G.) $407.19 = P_{dry\ air} + P_{vapor}$

Or

Barometric Pressure (psia) $14.696 = P_{dry\ air} + P_{vapor}$

In most psychrometric property calculations, the first order of business is usually to determine the Vapor Pressure and then use different formulae to determine the other properties.

OBSERVING SATURATED VAPOR PRESSURE



- A THOUGHT EXPERIMENT:
- Piston and cylinder arrangement with water at 75°F constant temperature inside and outside
- Pull piston up a little (figure on left) – for a fraction of a second there is vacuum on top of the liquid … water starts to boil and temperature drops
- Let it settle down to where everything is 75°F again – Now look at the saturated pressure column in your handout against 75°F and this is value we will find in our cylinder –
- ≈12" W.G. So this is the SATURATED value of the VAPOR PRESSURE of water at 75°F
- Pull the piston up a little more (figure on right) – the pressure drops and again the water starts to boil and temperature drops. Let it settle up to 75°F
- The pressure gage reads 12".
- If we compress it back to the left condition, the pressure is still settle at 12" W.G.
- We conclude that the Saturated Vapor Pressure is a unique property of water vapor that depends on its temperature alone.

OBSERVING SATURATED VAPOR PRESSURE

- A THOUGHT EXPERIMENT CONTINUED:
- One of our goals all through this presentation is to get a physical feel for the magnitude of many of the properties we study.
- How much is that 12" W.G. of Vapor Pressure?
- A LOT! It pushes with the same pressure (force) against vacuum as a 12" W.G. ΔP duct pressure
- If we were to toss in an evacuated and sealed soda can in the cylinder, it will be crushed easily. The total force here might be somewhere around 20 Lb-Force.
- WE HAVE TO LEARN TO RESPECT VAPOR PRESSURE.

VAPOR PRESSURE - 1

- LET US SET UP ANOTHER THOUGHT EXPERIMENT:
- LOOK AT THE FIGURE ON THE LEFT
  - The jar is under perfect vacuum to start.
  - The jar and all the contents and attachments are kept at a constant 75°F temperature by the 75°F reservoir. ALWAYS!
  - There is a pressure gage that reads vapor pressure only (don't ask how – this is a thought experiment!)
  - The vapor syringe is there to inject any amount of vapor that we want added.
  - There is a polished mirror that will fog up if there is any vapor condensation in the jar.

VAPOR PRESSURE - 2

- We start by pumping vapor into the jar using the syringe.
- We come to a point where the gage reads 6" of vapor pressure.
- The mirror is bright and shiny – no condensation. At this point it is just "Vapor Pressure". It is not "Saturated Vapor Pressure".
- The reservoir is doing its job – everything is at 75°F.
- CAUTION: As I mentioned before, water Vapor is colorless. I am just showing this light blue to show that there is something in the jar now as compared to the previous slide.

VAPOR PRESSURE - 3

- Slowly keep adding vapor through the syringe. Keep adding and waiting to see if the mirror fogs up.
- The pressure is going up as we add vapor.
- At 12" it happens – the mirror fogs up.
- NOTE: In all this discussion we will round the Vapor Pressure in inches to the nearest whole number. For example, the above number would be 11.9186 to be more precise.
- So this is the Saturation value of Vapor Pressure at 75°F. Note it is this value that we are going to plot it on our chart using the Y-Axis.
- Why is it called the Saturation Value? We will find out in the next slide.
- In the mean time just think and be awed by the magnitude of this pressure! Think of a duct with 12" static pressure!

VAPOR PRESSURE – 4

- Here is the situation that we have:
  - The mirror shows fogging (condensation).
  - The pressure is 12" W.G.
  - The temperature is held constant by the reservoir at 75°F
- Let us inject more vapor. The pressure gage reading does NOT change. The extra water injected simply condenses out and collects at the bottom of the jar.
- How can we increase this Saturation point of Vapor Pressure without changing the Temperature?
- Let us try a sneaky trick. We know that one of the gas laws (Boyle) says that, if temperature is kept constant, then if we reduce the volume of an ideal gas the pressure must increase in the same proportion. Let us try this in the next slide.

VAPOR PRESSURE – 5

- Let us use the syringe to flood the jar with water. Everything still at 75°F.
- There is no place for the vapor to go, the jar is airtight. We would expect the water level to act as a piston driving up to pressurize the vapor in the top of the jar. Surely the pressure in the small volume now will get above where it has been stuck – at 12" W.G.?
- RESULT? No change! Still 12" W.G.
- What happened to all that compressed vapor?
- It condensed out. A large number of H_2O molecules were squeezed out of the vapor space and went into the liquid space. This condensation of molecules kept going on till the pressure was back to 12" W.G. and the water/vapor interface at equilibrium.
- (BTW that is why Boyles law does not apply. We are not comparing the same number of molecules.)
- So the saturation pressure level (or point) does not change with a change in volume as long as the temperature does not change.

VAPOR PRESSURE – 6

- So what did we learn?
- Careful: Remember there are 2 separate concepts here. One is the property Vapor Pressure and it can be any value depending on temperature and volume.
- The second concept is that of the SATURATION level of Vapor Pressure with the symbol $P_{sat\ vapor}$ and it is a function of temperature only. This is the 12" W.G. value in our experiment. This is the highest value that Vapor Pressure can have for a given temperature.

VAPOR PRESSURE – 7

- If the Saturation Vapor Pressure level is a function of Temperature (only) then we can assume that if we change the Temperature the Saturation Vapor Pressure will also change.
- If we change the reservoir temperature to 55°F and repeat the experiment, we will observe the following:
  - The mirror fogs at 6" W.G.
  - Injection of any more vapor after that simply collects at the bottom as condensate.
- Therefore the Saturated Vapor Pressure at 55°F is 6" W.G.

VAPOR PRESSURE – 8

- If we change the reservoir temperature to 95°F and repeat the experiment, we will observe the following:
  - The mirror fogs at 23" W.G.
  - Injection of any more vapor after that simply collects at the bottom as condensate.
- Therefore the Saturated Vapor Pressure at 95°F is 23" W.G.

Key Concept Slide - 4

The Vapor Pressure Of Air In A Room Can Go Up Or Down Because Of Many Different Reasons

BUT

The Saturation Point (Or Level) Of Vapor Pressure Depends Only On The Temperature Of The Vapor

VAPOR PRESSURE – 9

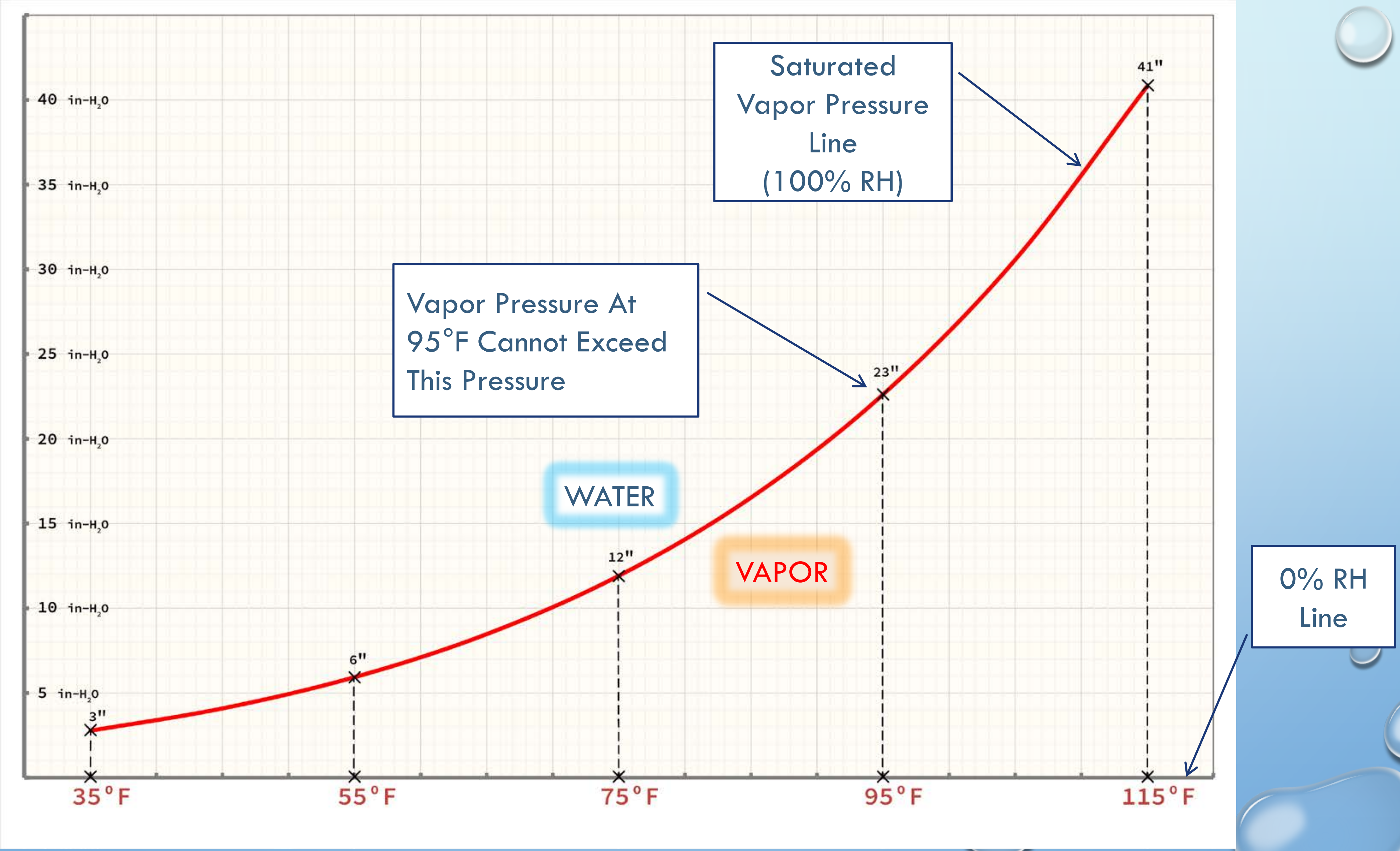
Temp. °F	Saturated Vapor Pressure psia	Saturated Vapor Pressure inches W.G.
35	0.09998	**2.770**
55	0.21414	**5.933**
75	0.43015	**11.919**
95	0.81636	**22.620**
115	1.47304	**40.815**

- Of course there is no need to do this kind of experiment.
- Saturation Vapor Pressure of water is available in tables in many reference books.
- On the left are values to 3 places of decimal that we will round to the nearest integer and use for our chart.

PLOT THE DATA ON YOUR CHART

- Your handout shows a vertical scale in inches of water gage for plotting the vapor pressure
- Using the Table from the previous slide (also part of handout) plot the Saturated Vapor Pressure for the 5 Dry Bulb points on the x-Axis
- This is the 100% RH line. Since we know 2 properties on this line (Dry Bulb and Vapor Pressure) every thing else can either be calculated or looked up. Same for the X-Axis or the 0% Humidity line.
- Everything to the LEFT of this Saturation line is water. Everything to the RIGHT is vapor. Exactly on the line (and only there) it can exist as water and vapor combination. (Let us ignore the fog region for now.)
- ASHRAE Table - 3 Properties of Water at Saturation (Fundamentals 2013) is also part of the handout. This is the source where all these numbers have been adapted from
- Use whatever precision you feel justified. The Pressure numbers in the graph on the next slide have been rounded to the nearest integer. We are just talking concepts – not calculating anything in particular.

PLOT THE DATA ON YOUR CHART



VAPOR PRESSURE – 10

- WE ARE NOT DONE YET!
- Up to this time the jar in our experiment had vapor only. But moist air is a combination of dry air and water vapor. The question now is: how does the presence of dry air change what we have been observing?
- And the answer is: absolutely no difference! Now that is very lucky for us that (within the ideal gas behavior limits) nature chose to behave that way.
- Let us start with where we were a few slides back. The figure on the left shows this state:
  - The Temperature is held at 75 °F
  - We have injected enough vapor to raise the Vapor Pressure to 6" W.G.
  - There is no fogging of the mirror as we are well below the Saturated Vapor Pressure of 12" W.G.
- Now let us bring an air pump of some kind and start pumping dry air in the jar.

VAPOR PRESSURE – 11

- The red bicycle pump, pumps DRY AIR only
- The dry air gage reads the pressure of DRY AIR only
- We got carried away and pumped the jar to 30 psig!
- What will the vapor pressure gage now read? Won't the vapor get squeezed by the air and increase its pressure?
- NO … It still reads 6" W.G. ❢
- Remember, Dalton said it would be like this!

The Vapor is unaware of the Dry Air

The Dry Air is unaware of the Vapor

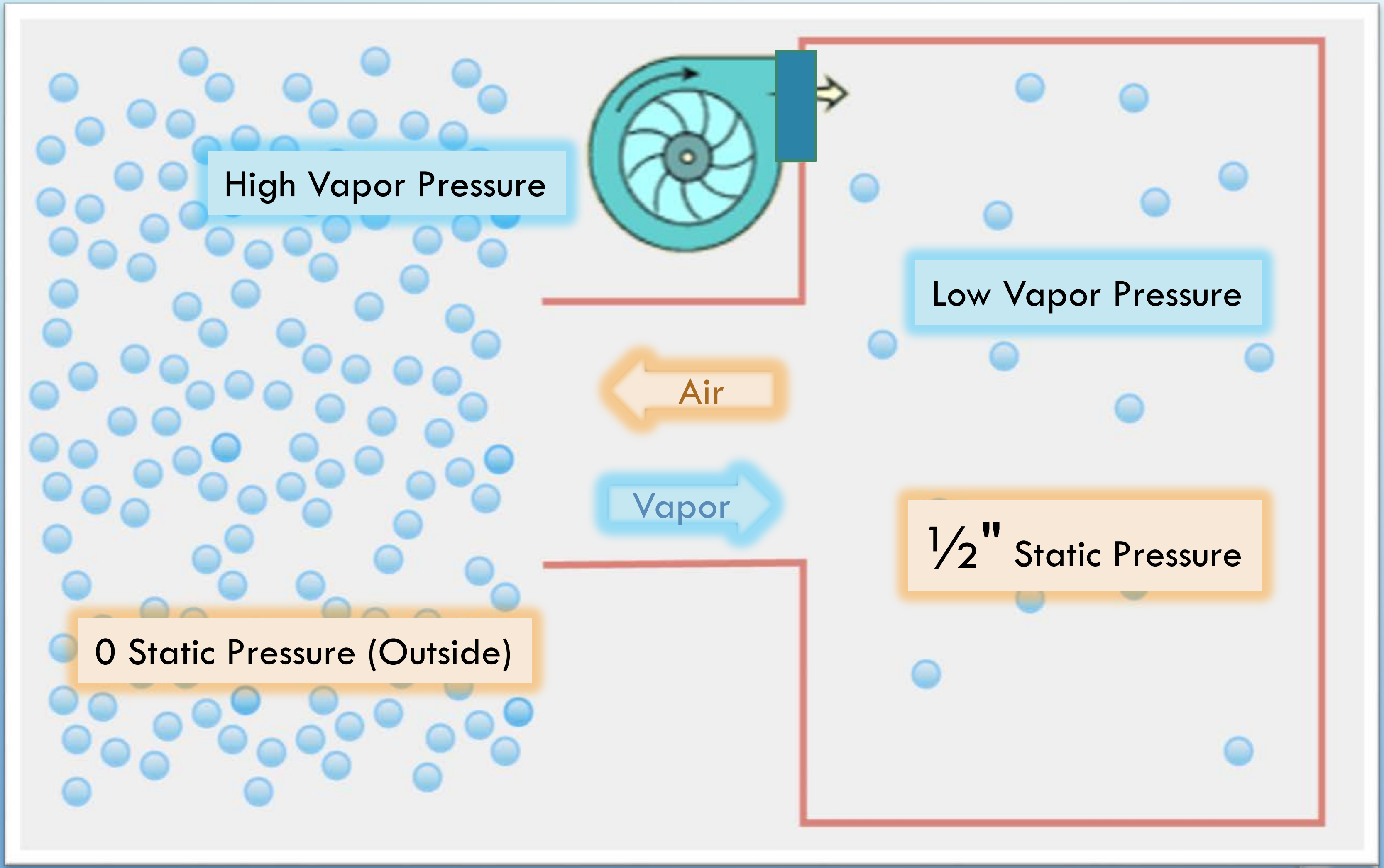
Key Concept Slide - 5

The independence of moisture and dry air

- What have we learned?
- The vapor pressure and its saturation point have nothing to do with dry air.
- So all the following statements are technically not quite correct: (Not a big deal, because we all understand what is meant - but still, not quite correct.)
  - The air is saturated
  - Dry air sucks out the moisture from ….
  - The capacity of air to hold moisture increases with rise in temperature …
  - The relative humidity of air is ….
  - The dew point of air is ….

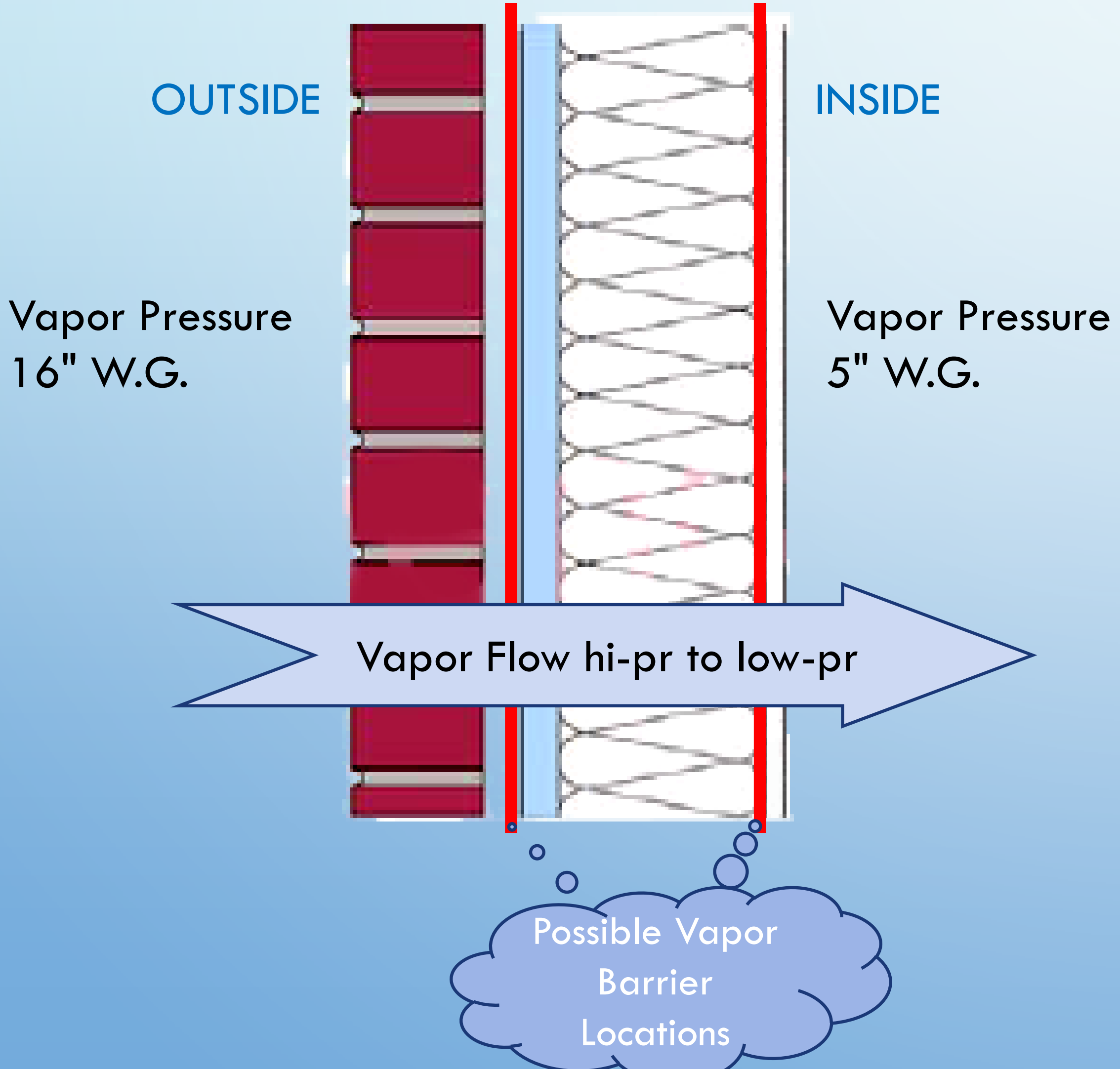
One Last Time:
Dry Air in this room has no relationship with the Vapor in this room.
The two are totally unaware of each other's presence.

VAPOR PRESSURE IN ACTION



Water Vapor will always try to equalize its own pressure, AND IF IT HAS TO, it will fly UPSTREAM AGAINST air pressure to seek it equilibrium pressure level.

VAPOR PRESSURE IN ACTION



LOOK AT THE 2 POSSIBLE LOCATIONS SHOWN IN THE SKETCH FOR THE VAPOR BARRIER

QUESTION: ON WHICH SIDE SHOULD THE VAPOR BARRIER GO?

ANSWER: ALWAYS PLACE THE BARRIER ON THE HIGH VAPOR PRESSURE SIDE

CAUTION: LOCATING VAPOR BARRIERS IS A COMPLEX DECISION. TALK TO AN EXPERT. THIS SLIDE IS ONLY HERE TO SHOW YOU THE GENERAL PRINCIPLE.

VAPOR PRESSURE IN ACTION

1 atm = 407″ W.G. ≈ 15 psia

Air Entering
95°F DB
55%RH
P_{vapor} ≈ 12″
P_{dryair} = 395″

Supply

Condensate
To Auto-Drain

What happens when air is compressed? Look at the picture on the left (With everything going to DDC, these guys are disappearing fast.)

Let us do some rough and simple arithmetic:

Moist Air @ 95°F DB 55%RH and 407" W.G. (≈15 psia) enters the compressor

Here are the Partial pressures
407 = $P_{dry\ air}$ + P_{vapor} = 395 +12 (all inches of W.G.)

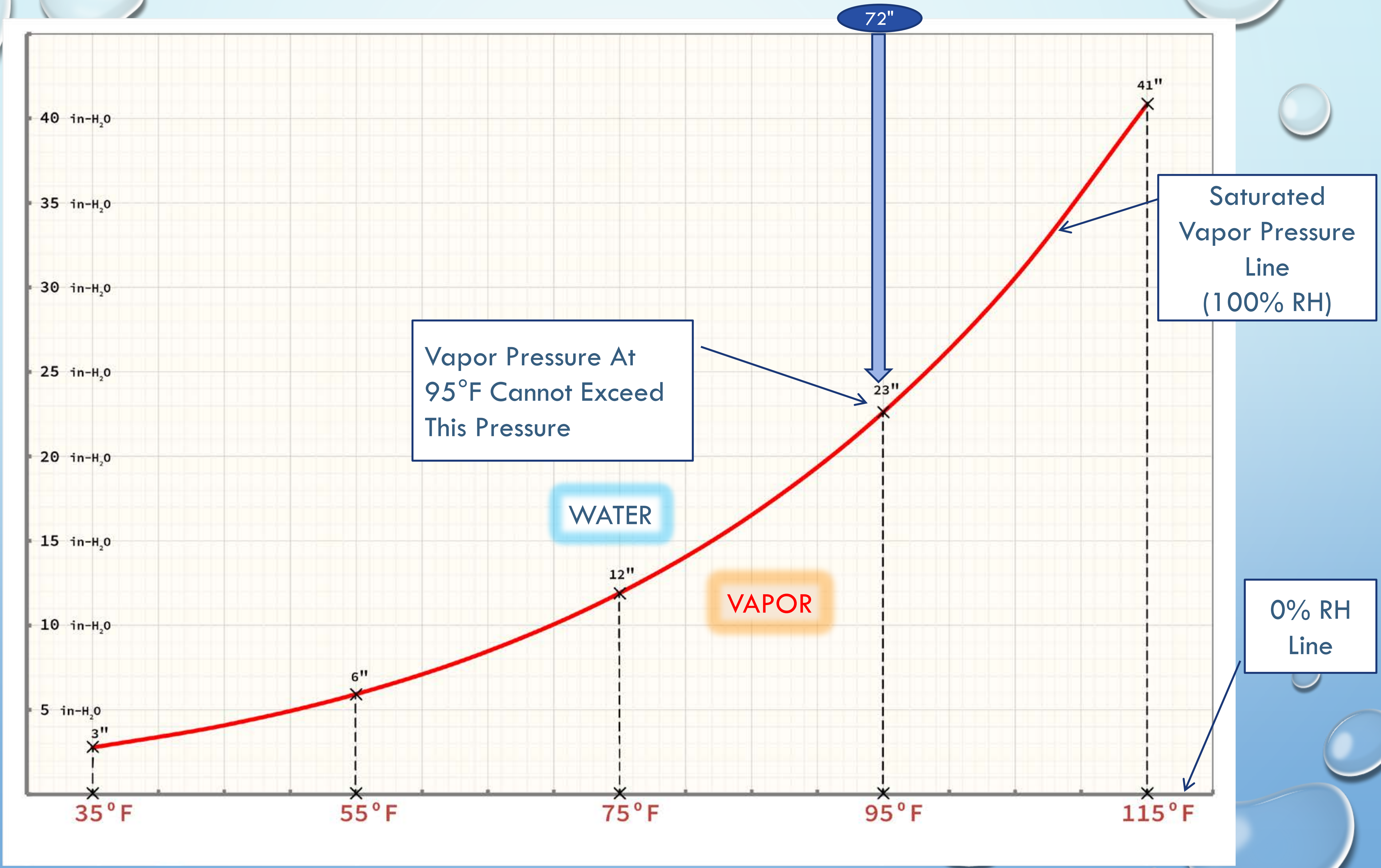
The compressor compresses the air to 75 psig (90 psia). This is roughly 6 times the free air atmospheric pressure of 15 psia or 407" W.G.

Here is what it looks like in the tank right after the compressor discharge:
6 x 407 = 6 x 395 + 6 x 12
i.e. the vapor is compressed to 72" of W.G.

Now look at the chart you have made and note that at the tank temperature of 95°F the saturated level is ≈23" W.G. - so this cannot happen for long.

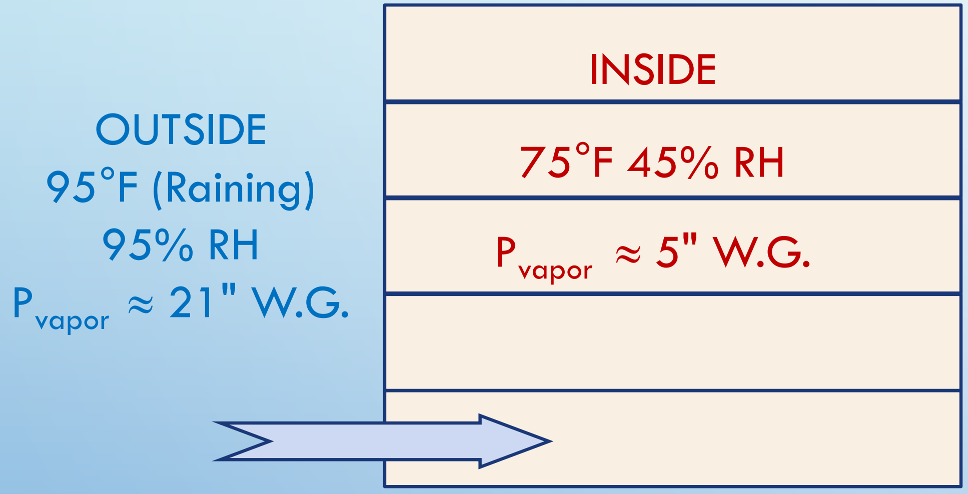
MOISTURE WILL CONDENSE OUT TILL ONLY ENOUGH IS LEFT TO MAINTAIN 23" W.G. IN THE TANK.

Note also that the air in tank is now fully saturated at 95°F and any further cooling along the piping will further shed water.


72"
41"
40 in-H_2O
35 in-H_2O
30 in-H_2O
25 in-H_2O
20 in-H_2O
15 in-H_2O
10 in-H_2O
5 in-H_2O
Saturated Vapor Pressure Line (100% RH)
Vapor Pressure At 95°F Cannot Exceed This Pressure
23"
WATER
12"
VAPOR
6"
3"
0% RH Line
35°F
55°F
75°F
95°F
115°F

VAPOR PRESSURE IN ACTION

- A TYPICAL MULTI-STORY OFFICE BUILDING:



Δ P = 16" W.G.

(Negative with respect to OUTSIDE)

On the ASHRAE Chart this would show as:
0.0348 $lbm_{vapor}/lbm_{dry\ air}$ outside and 0.0083 $lbm_{vapor}/lbm_{dry\ air}$ inside

Would that mean much to you?

THE MAGNITUDE OF THE PROBLEM IN VAPOR SEALING COMMERCIAL BUILDINGS STRUCTURES

- The sketch on the left show very clearly why it is almost impossible to hold moisture out.

(Use your charts to see if the Vapor Pressure values are correct.)

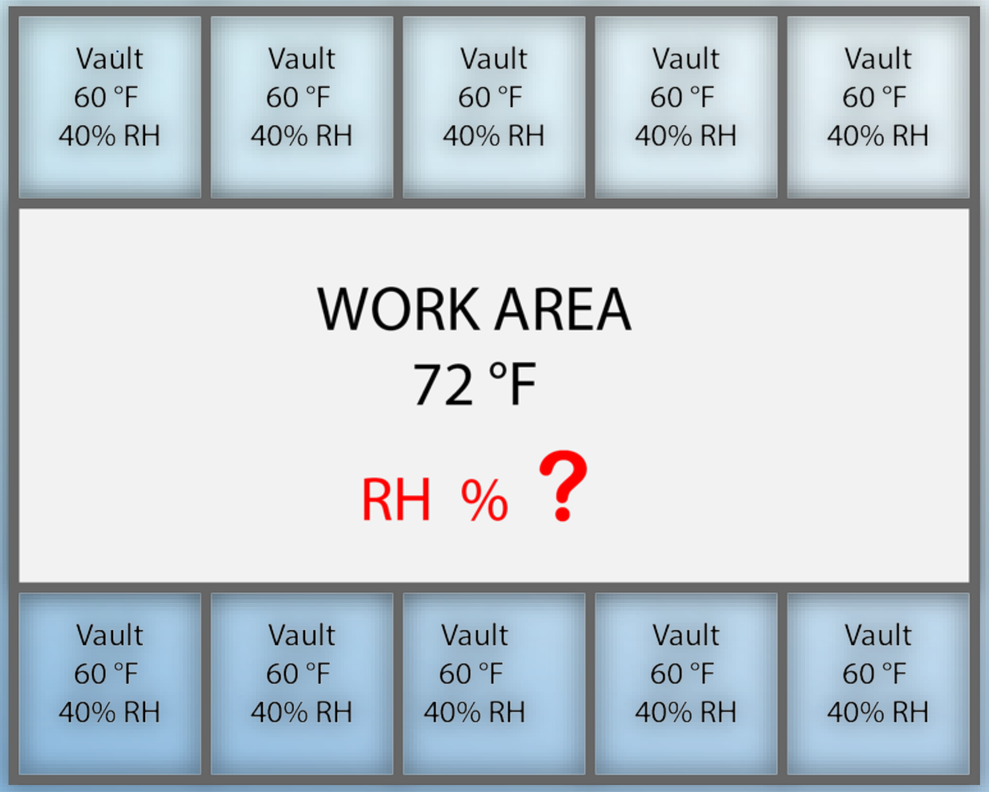
- Let us ignore the DIFFUSION through the porous building materials. Just sealing the cracks against a 16" negative static – is that even possible?
- Your only hope is that you can wring out the moisture in your a/c system faster than it can come in.
- Note that when energy codes require ducts to be sealed at a few tenths of an inch static, many installations fail the test.
- And this is why I chose to use inches of W.G. for Vapor Pressure – because I knew I can get the "now I get it" reaction from you guys.

VAPOR PRESSURE IN ACTION

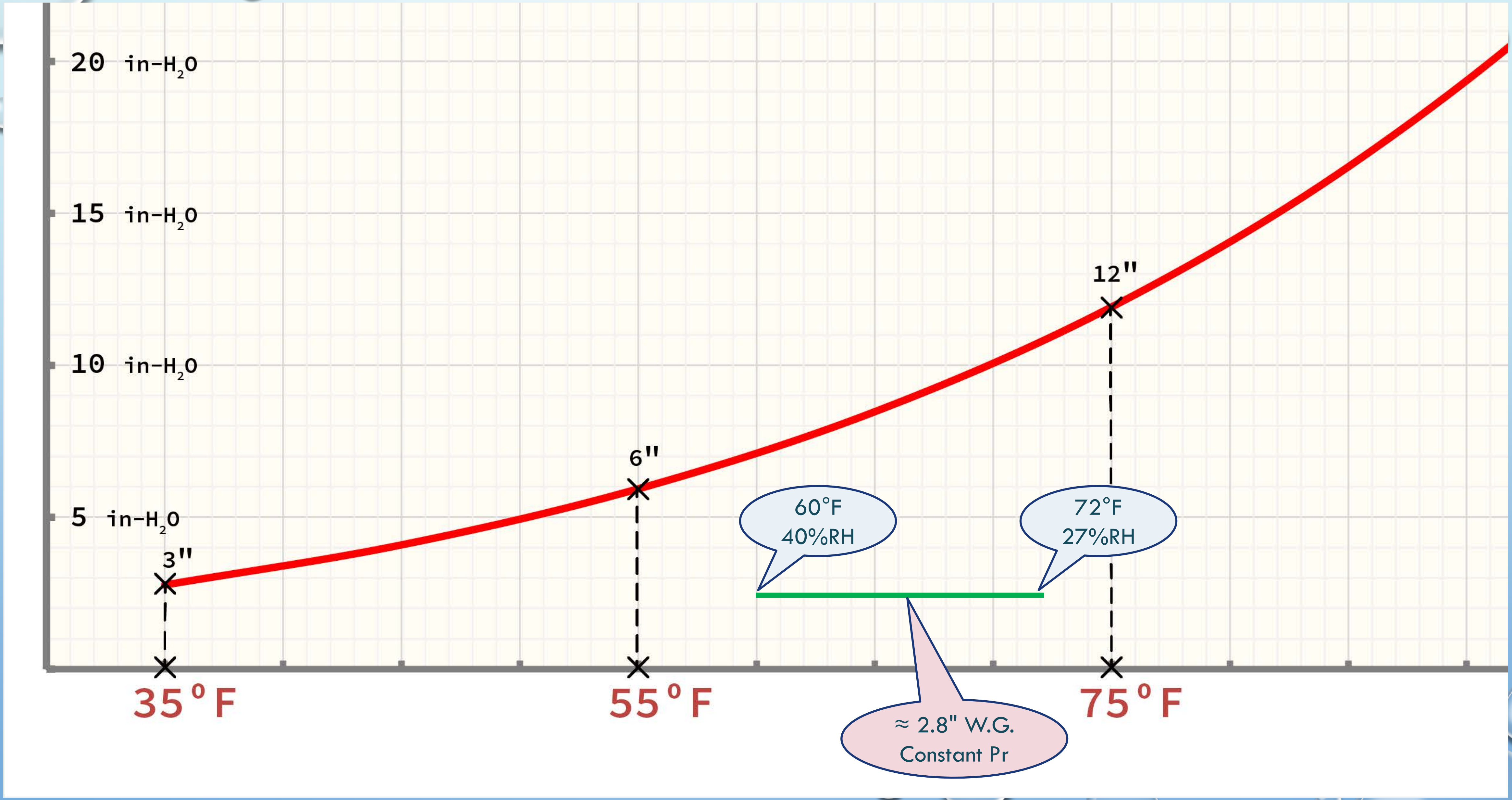
- EXOTIC HARDWOOD BEING ACCLIMATED BEFORE INSTALLATION.
- WOOD BEING HYGROSCOPIC WILL ABSORB OR REJECT MOISTURE BASED ON VAPOR PRESSURE DIFFERENCE BETWEEN ITSELF AND THE SURROUNDING. THIS IN TURN WILL CHANGE ITS DIMENSIONS.
- THIS MANUFACTURER REQUIRES 72 HOURS IN THE SPACE AT THE TEMPERATURE AND HUMIDITY (VAPOR PRESSURE?) THAT IS GOING TO BE NORMAL FOR THE SPACE
- NOTE THE STACKING FOR MAXIMUM AIR CIRCULATION AROUND THE PLANKS
- EQUALIZE WOOD'S INTERNAL VAPOR PRESSURE TO THE ROOM'S VAPOR PRESSURE.

VAPOR PRESSURE IN ACTION

Paper ART Storage Vaults



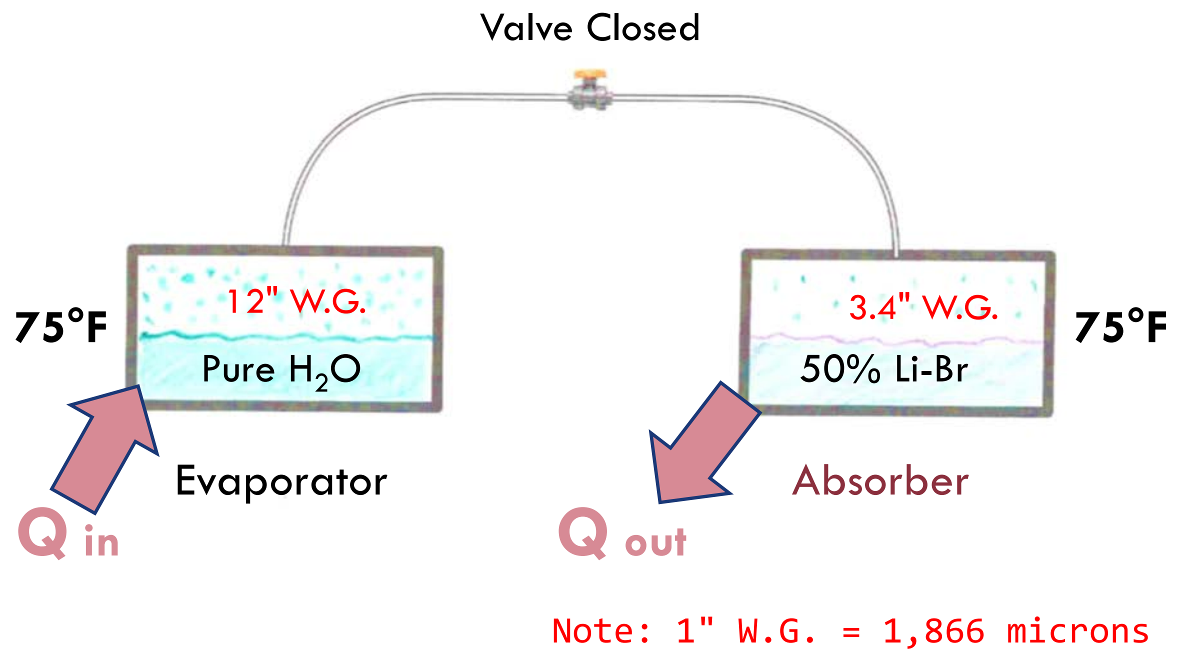
- HERE IS A REAL WORLD EXAMPLE OF THE USE OF VAPOR PRESSURE
- The sketch on the left shows a bank of vaults for paper drawings archive.
- The vault storage was specified as 60°F and 40% RH by the Owner. The drawings were being brought out in the work area to be inspected and digitized by the staff. The work area Dry Bulb temperature was specified as 72°F.
- The question was – what humidity level should be maintained in the work area so as not to stress the paper by drying or moisture absorption when it is brought out into the Work Area?
- The answer of course is to keep the Vapor Pressure identical in both locations. This comes up to about 27% RH at 72°F.
- ☹☹The Owner decided that the implementation to hold the Work Area humidity 27% RH was too expensive … nothing was done except standard office air conditioning with no special humidity control. ☹☹



20 in-H_2O
15 in-H_2O
10 in-H_2O
5 in-H_2O
3"
6"
12"
60°F
40%RH
72°F
27%RH
≈ 2.8" W.G.
Constant Pr
35 °F
55 °F
75 °F

VAPOR PRESSURE IN ACTION

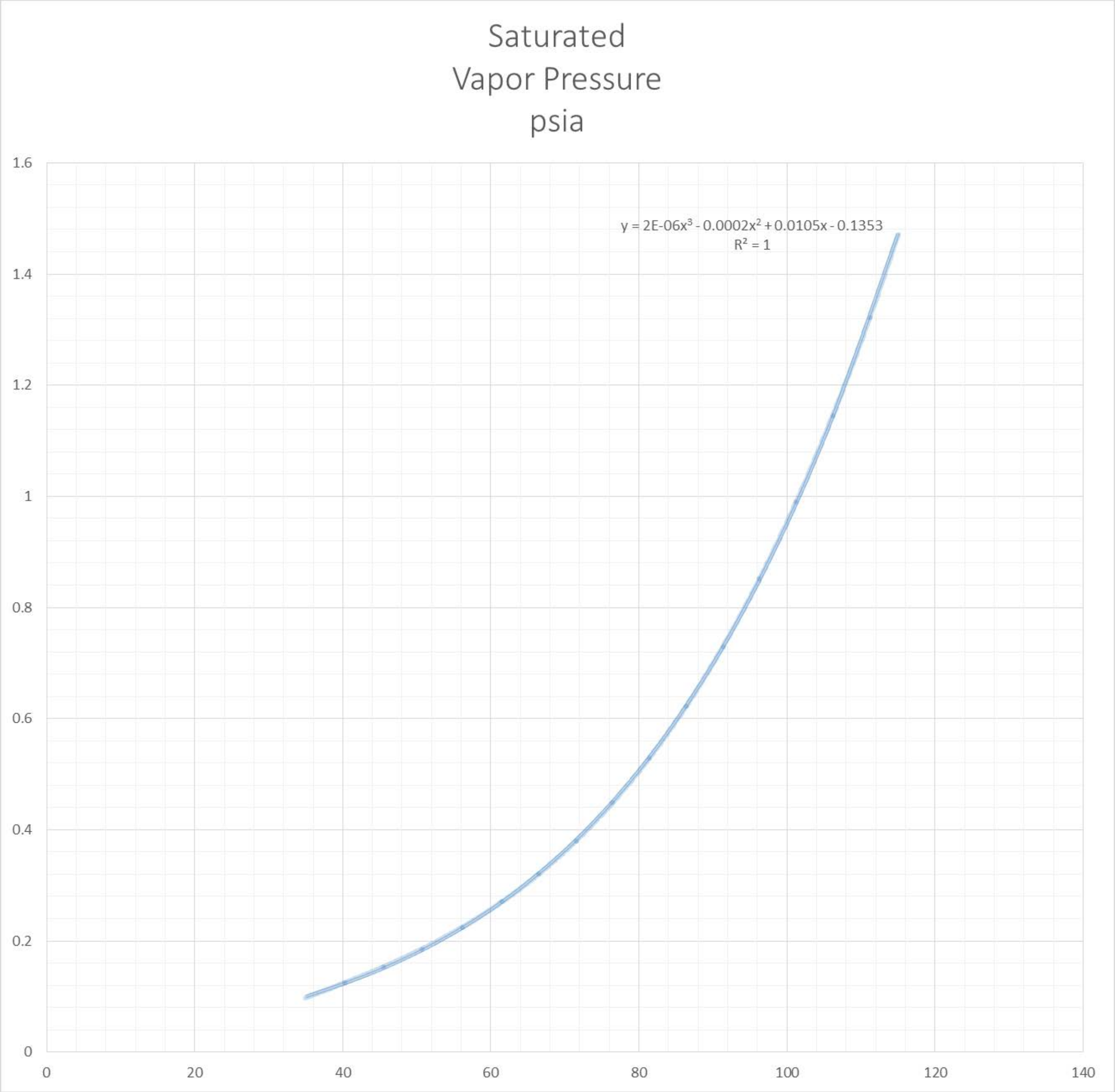
ONE-SHOT ABSORPTION COOLER



Absorber ⇒ Generator ⇒ Condenser ⇒ Evaporator

- Absorption Refrigeration systems take advantage of the fact that when salt is dissolved in water, the vapor pressure of the mixture is lower than the vapor pressure above the pure water. (Note: Actually not just "salt and water" but any solute/solvent.)
- On the left are 2 vessels, one with pure distilled water and the other with a 50% Lithium Bromide solution in water.
- The system was evacuated close to vacuum before filling them with liquids.
- The valve in the middle is closed. Everything has settled at 75°F. Both vessels settle at the respective SATURATED vapor pressures. The absorber has less pressure because of the natural property of salt solutions to have lower vapor pressure.
- If we open the valve, the vapor will rush from the evaporator into the absorber due to the delta-P and the pressure in the evaporator will drop suddenly. This will cause the water to boil and act as a refrigerant absorbing heat from the surroundings.
- Note the extremely low working pressures. Almost at the vacuum evacuation levels. This is why sealing absorption systems is such a headache.

SOURCES FOR VAPOR PRESSURE DATA

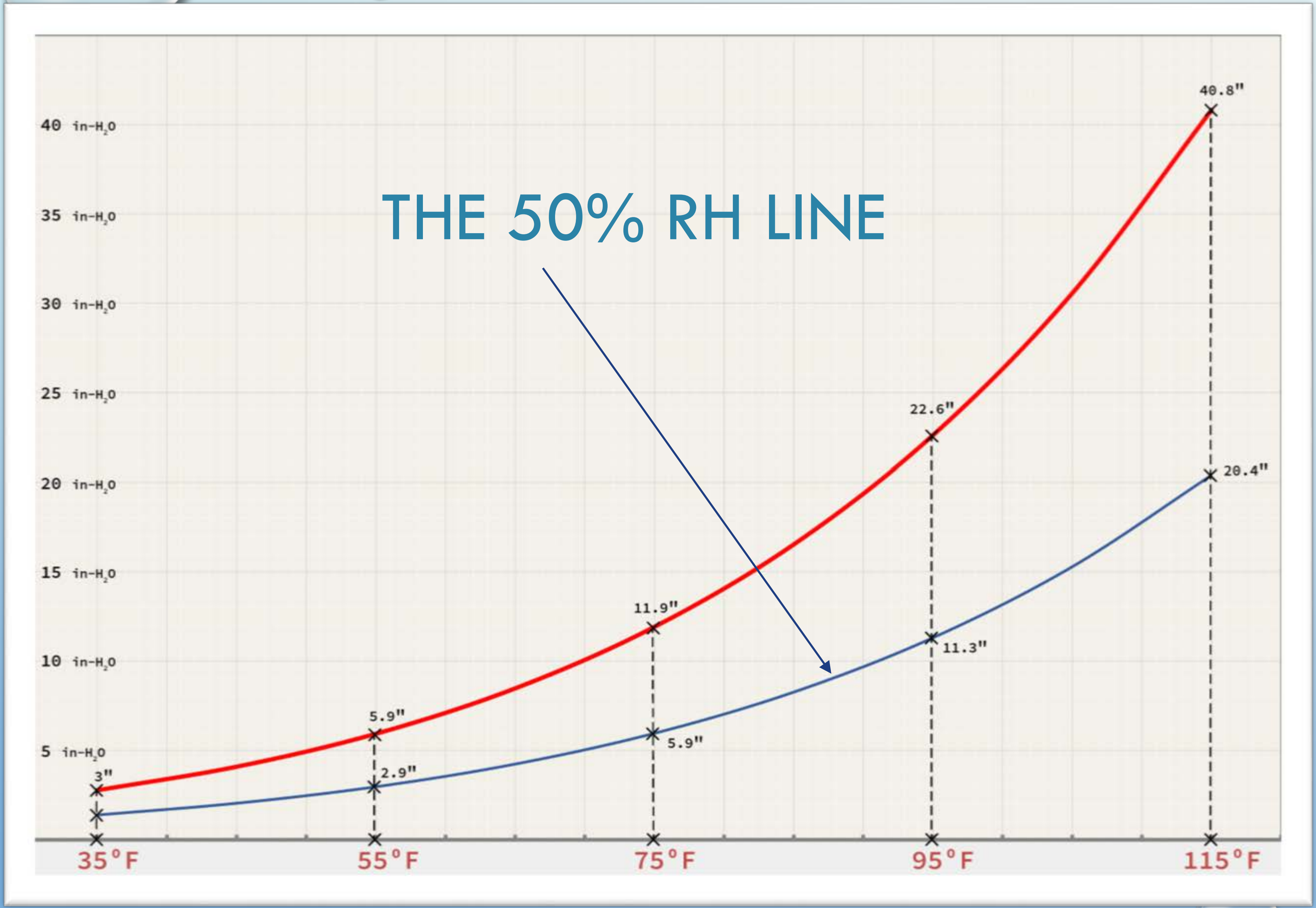


- You can get Vapor Pressure data from tables available in many handbooks. See handout from ASHRAE 2013 Fundamentals Chapter-1 Table 3 THERMODYNAMIC PROPERTIES OF WATER AT SATURATION
- ASHRAE also gives empirical equations (long, complex and tedious) for Vapor Pressure in the Chapter on Psychrometrics. You may want to look at these if you are writing DDC programs. The Vapor Pressure is usually the first property to be calculated, as it forms the basis of determining many other properties.
- Within the temperature range we are talking about in this presentation, a simple 3rd order polynomial regression equation generated by the click of a key in Excel can provide an almost perfectly ($R^2 = 1$) correlated equation.

A PEEK AHEAD – RELATIVE HUMIDITY

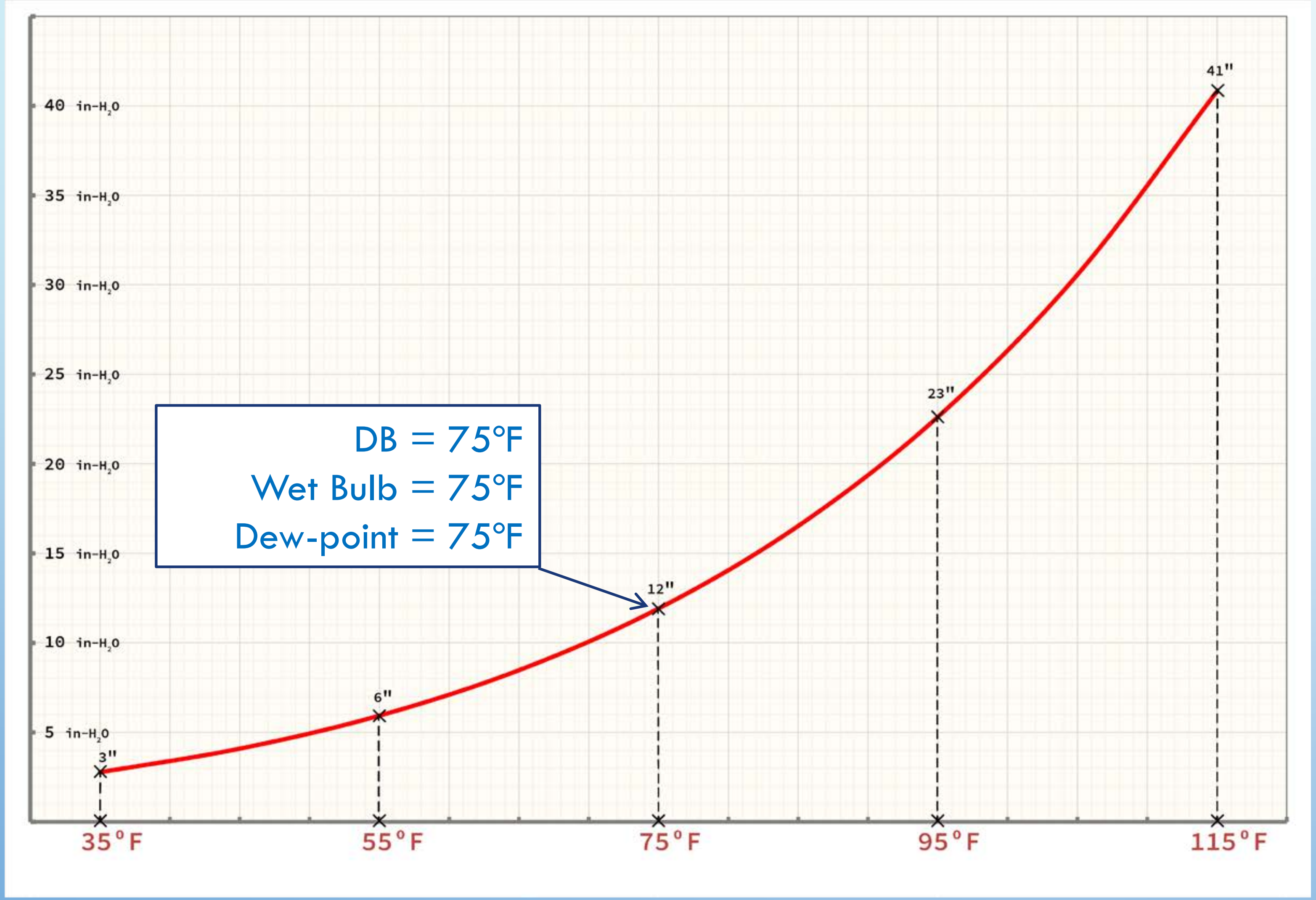
- The next property we are going to study is SPECIFIC VOLUME; however, since we have spent so much time on Vapor Pressure, and there is such a strong connection between RH and Vapor Pressure, let us take a quick peek at RH here, before we discuss it in detail later on.
- The usual symbol for Relative Humidity is Φ (fee or fie) . In this presentation we will use both "RH" and "Φ"
- RH is always expressed as a percentage. Say 50% RH. So the natural question is: "What is 50% of what?" There are at least 3 correct answers to this question (and a couple of wrong ones floating around). We will get into details later.
- For the purpose of our discussion we will call Relative Humidity simply an indicator of Vapor Pressure. It describes what the relationship of water Vapor Pressure is at any point to what it can be at Saturation at the same Temperature. So when someone is talking about RH at a location, you would be correct in assuming that he is describing the state of Water Vapor Pressure at that location.
- $\Phi = \dfrac{P_{vapor}}{P_{sat\ vapor}}$ (At the same Dry Bulb Temperature.)
- Just a ratio therefore dimensionless and expressed as a percentage.
- Looking at our Chart under construction: If RH is 50% at 95°F, then the Vapor Pressure must be (22.6" x 0.5) or 11.3" W.G.
- Based on this definition it is easy to plot %RH lines on the chart. So let us plot the 50% RH line on our Chart by marking halfway points between the saturation curve and the X-Axis.

THE 50% RH LINE



- The blue 50% RH line has been added.
- The points on the blue line are exactly 50% of the points on the red Saturation Curve. (I have added another decimal point to get a smooth curve.)
- This should convince you that RH is simply another way of calling out the Vapor Pressure.
- And it is very obvious that 50% means different Vapor Pressures (and moisture content as we shall soon see) when the DB Temperatures are different. Although very obvious on Vapor Pressure Y-Axis Chart, this simple fact has caused endless confusion among people not familiar with Psychrometry.
- RH value without the underlying Dry Bulb Temperature is meaningless.

A PEEK AHEAD – Dew-point & Wet Bulb Temperature

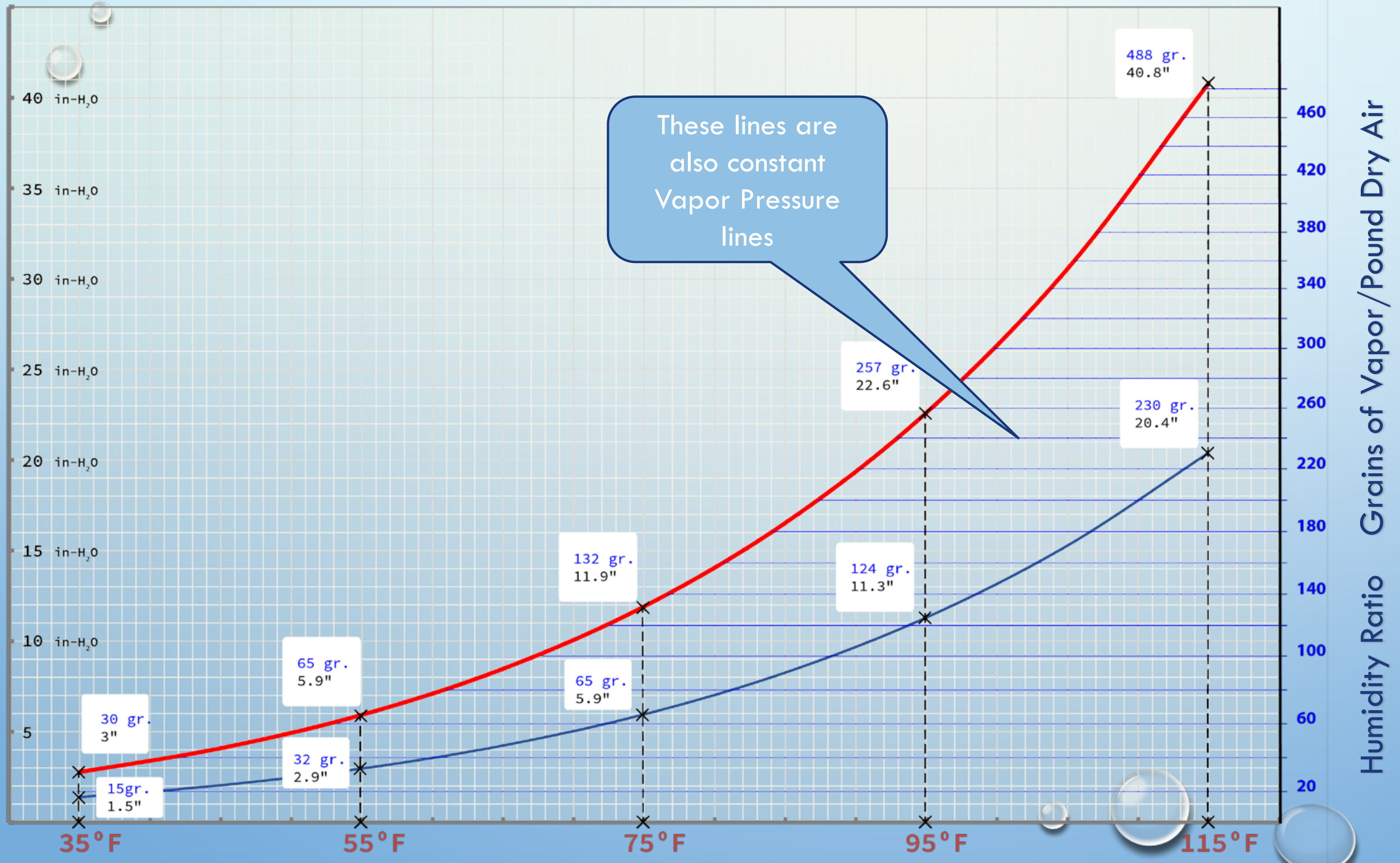


- We will deal both these properties in detail later on. But while we have the saturation curve fresh in our mind, let us make note of the following:

(Remember in our previous experiment the mirror always fogged at the saturation vapor pressure for a given dry bulb temperature.)

  - The Dew-point Temperature is the same as the Dry Bulb Temperature on the Saturation Line
  - The Wet Bulb Temperature is the same as the Dry Bulb Temperature on the Saturation Line

MANY CHARTS DO NOT SHOW VAPOR PRESSURE



USE HUMIDITY RATIO LINES AS CONSTANT VAPOR PRESSURE LINES

THE END OF FACHGESPRÄCH – 5 PART-1B

See you soon for Part-1C

Luke!
You must Complete
the training.

SPECIFIC VOLUME

v (lower-case "v")

SPECIFIC VOLUME DEFINITION

Volume (ft^3) of AIR per Pound Mass of DRY AIR.

Question: Volume of which air? Dry Air? Moist Air Mixture? Water Vapor?

Answer: It doesn't matter. They are all the same. (Remember the slide on Dalton's Law.)

$V_{\text{moist air}} = V_{\text{dry air}} = V_{\text{vapor}}$ (We will just say "air".)

Formula:

$$\frac{Volume\ of\ sample}{Mass\ of\ DRY\ AIR\ in\ the\ sample} = \frac{ft^3}{lbm_{\ DRY\ AIR}}$$

Specific Volume Of Standard Air

For air at Standard

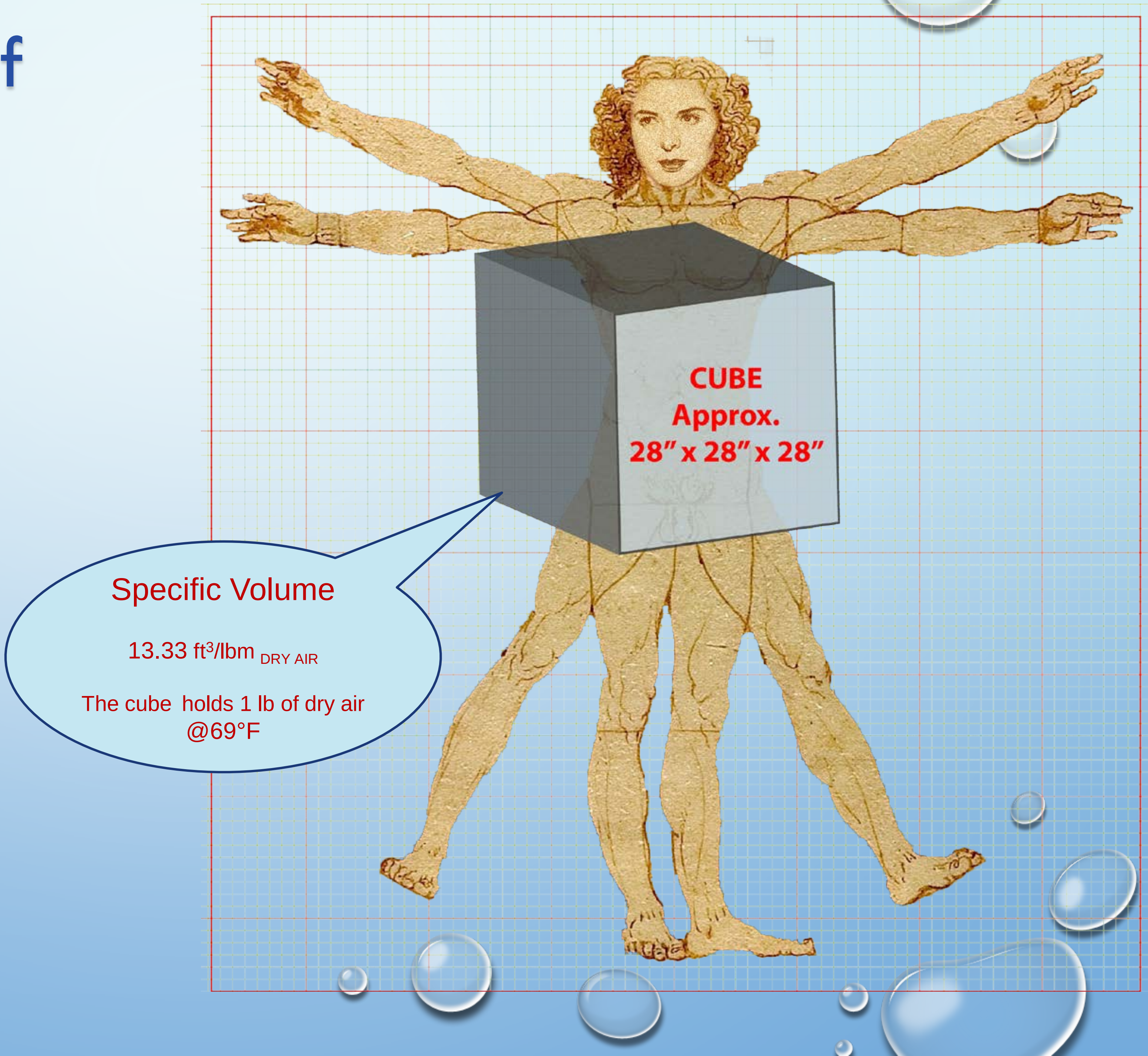
Density(ρ) 0.075 lb_m/ft^3

Specific Volume (v) is:

13.33 ft^3/lbm DRY AIR

$$v = \frac{1}{\rho}$$

A cube with ≈ 28.45" sides



CALCULATING SPECIFIC VOLUME - 1

- TO CLEAR UP THE CONCEPT LET US DO AN EXAMPLE:
  - Suppose we wanted to find the SPECIFIC VOLUME of Air in this room.
    - The room is at 75°F and 50%RH and Volume = 20' wide x 40' long x 8' high = 6,400 ft^3
    - The weight of Water Vapor in the room is 4.3 lb_m [P V = m R T]
    - The weight of Dry Air in this room is 467.8 lb_m [P V = m R T]
    - And the TOTAL weight of Moist Air is 4.3 + 467.8 = 472.1 lb_m
    - So by definition,

      Specific Volume = 6400/467.8 = 13.68 $ft^3/lbm_{\text{Dry Air}}$
  - Notice that we DID NOT divide by the total mass of Moist Air which is 472.1 lb_m above. If we had done that it would have given us a slightly lower answer.

CALCULATING SPECIFIC VOLUME - 2

Volume ft^3

Mass = 1 lb_m

$$P \; V = 1 \times 53.35 \times T$$

Absolute Temperature °R

Absolute Pressure lb_f/ft^2

P_{DRY} = 407.19" - P_{VAPOR}

Gas Constant $ft \cdot lb_f/lb_m \cdot °R$

For **plotting** Specific Volume lines on the chart we have to use the above equation.

CALCULATING SPECIFIC VOLUME - 3

Using the Ideal Gas Equation PV = mRT to find Specific Volume:
Air at 75°F and 50% RH

We know that the vapor pressure at 75F and 50%RH is 5.933" W.G.

$$(407.19'' - 5.933'') \times 5.19 \times V = 1 \times 53.35 \times (459.67 + 75)$$

$$V = 13.69 \ ft^3/lbm_{\text{DRY AIR}}$$

Let us plot the Specific Volume lines passing through all five 50% RH Points on the chart we are building. But 2 points are needed to plot a line and we have only 1. (The 50%RH points for 55, 75, 95°F Temps.) How do we find a second point which will lie on the 13.69 $ft^3/lbm_{\text{DRY AIR}}$ line?

CALCULATING SPECIFIC VOLUME - 4

Volume
ft^3

Mass = 1 lb_m

On the X axis
Vapor Pressure is 0

Absolute
Temperature
°R

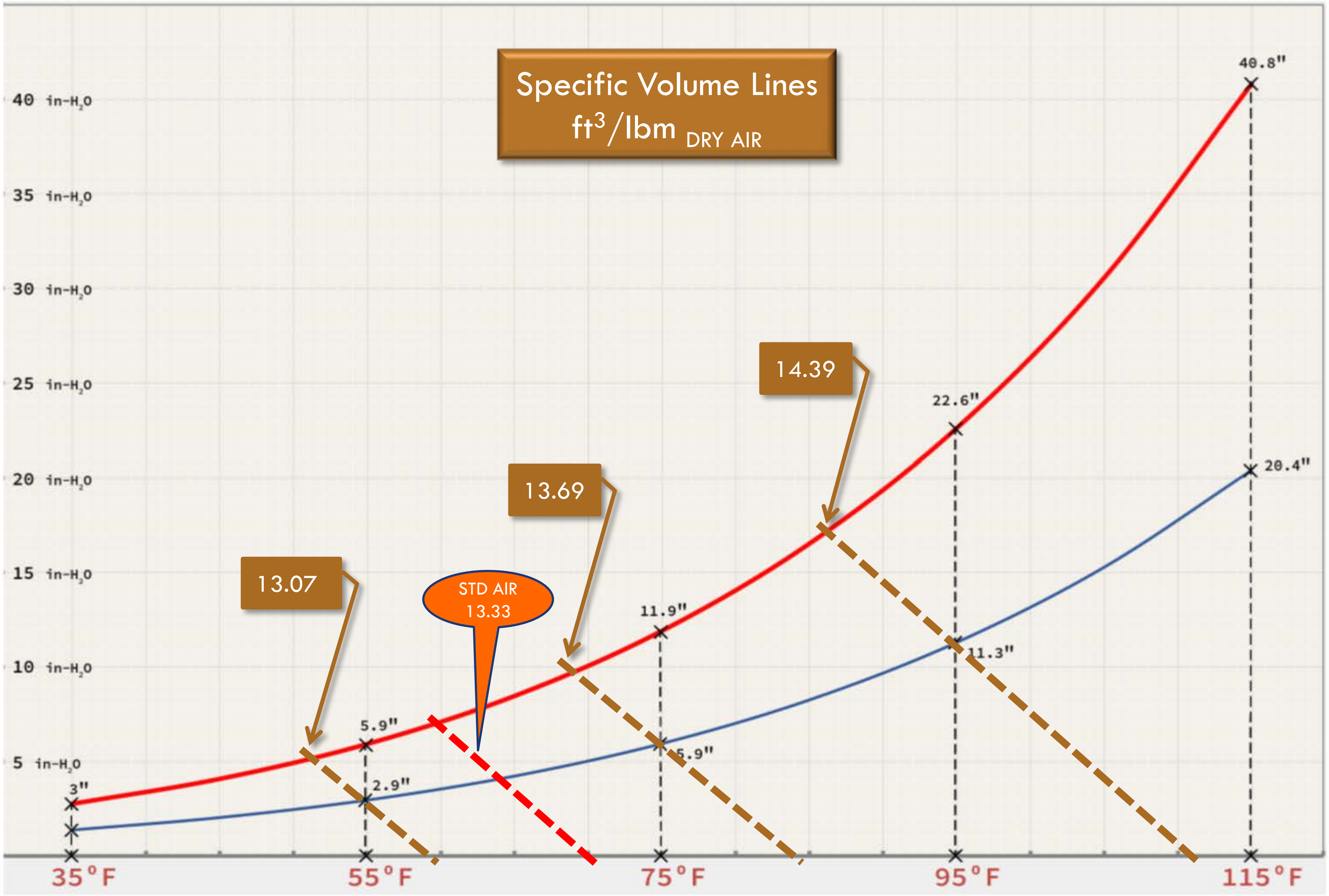
407.19" x 5.19 x 13.69 = 1 x 53.35 x T

Absolute Pressure lb_f/ft^2

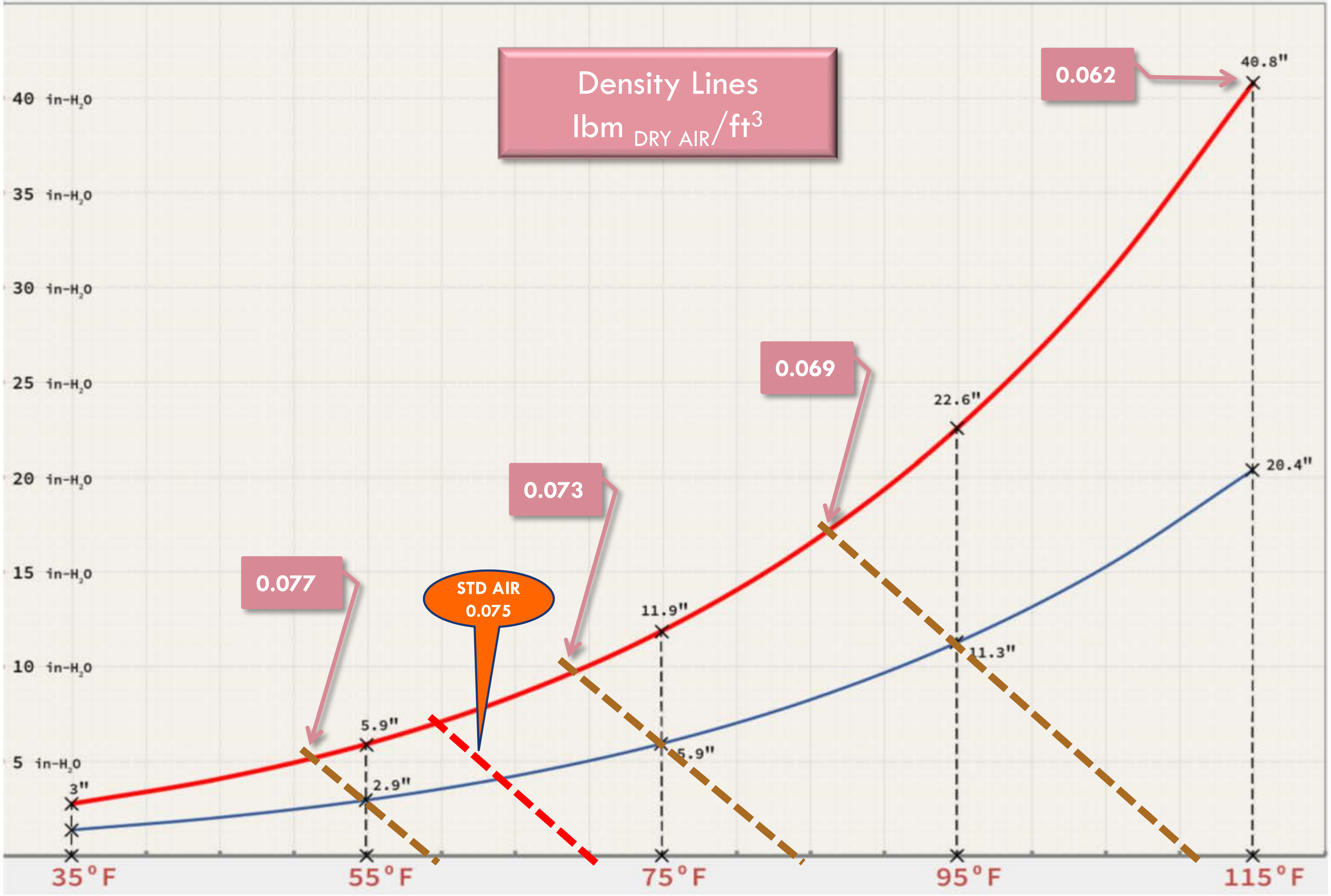
P_{DRY} = 407.19" - 0

Gas Constant
$ft \cdot lb_f/lb_m \cdot {}^\circ R$

T = 83.6°F



Specific Volume Lines
ft³/lbm DRY AIR
40 in-H2O
35 in-H2O
30 in-H2O
25 in-H2O
20 in-H2O
15 in-H2O
10 in-H2O
5 in-H2O
40.8"
22.6"
20.4"
11.9"
11.3"
5.9"
5.9"
2.9"
3"
14.39
13.69
13.07
STD AIR
13.33
35°F
55°F
75°F
95°F
115°F



Density Lines
lbm DRY AIR/ft3
0.062
40.8"
40 in-H2O
35 in-H2O
30 in-H2O
25 in-H2O
20 in-H2O
15 in-H2O
10 in-H2O
5 in-H2O
0.069
22.6"
0.073
20.4"
0.077
STD AIR
0.075
11.9"
11.3"
5.9"
5.9"
2.9"
3"
35°F
55°F
75°F
95°F
115°F

"STANDARD AIR" IN HVAC CALCULATION CONSTANTS - 1

TOTAL BTUH = 4.5 x CFM x Δh (Ignoring water "down the drain". ☺)

Base Formula:

TOTAL BTUH = m x Δh

Where,

m = mass flow rate in $lbm_{DRY\ AIR}/hr$

h = Specific Enthalpy $BTU/lbm_{DRY\ AIR}$

To change CFM into mass lbm/hr

$$\frac{ft^3}{min} \times \frac{60\ min}{hr} \times \frac{0.075\ lbm}{ft^3} = 4.5\ \frac{lbm}{hr}$$

Note the use of "Standard" Density

"STANDARD AIR" IN HVAC CALCULATION CONSTANTS - 2

SENSIBLE BTUH = 1.1 x CFM x ΔT

Base Formula:

SENSIBLE BTUH = m x C_p x ΔT

Where,

m = mass flow rate in $lbm_{DRY\ AIR}/hr$

C_p = Constant Pressure Specific heat BTU/lbm-°F

For bone dry air
Cp = 0.24 BTU/lbm-°F

4.5 x 0.24 = **1.08**

Moist air will probably have a little higher Specific Heat and Per ASHRAE closer to 0.25 BTU/lbm-°F

4.5 x 0.25 = **1.1**

So 1.1 is recommended.

Note the use of "Standard" Density

$$\frac{\cancel{ft}^3}{\cancel{min}} \times \frac{60\ \cancel{min}}{hr} \times \frac{0.075\ lbm}{\cancel{ft}^3} = 4.5\ \frac{lbm}{hr}$$

Note:
If the density assumption is wrong, then there is not much point in worrying about 1.1 and 1.08

"STANDARD AIR" IN HVAC CALCULATION CONSTANTS - 3

LATENT BTUH = 4.5 x CFM x ΔW x 1076

= 4840 x CFM x ΔW (W is in pounds mass)

= 0.69 x CFM x ΔW (W is in grains)

Base Formula:

LATENT BTUH = m x ΔW x 1076

Where,

m = mass flow rate in $lbm_{DRY\ AIR}/hr$

W = Humidity Ratio $lbm_{VAPOR}/lbm_{DRY\ AIR}$

1076 = heat content of VAPOR @ 70°F and 50% RH less sensible heat of water 50°F

(ASHRAE 2013 Fundamentals 18.13)

Note the use of "Standard" Density

$$\frac{\cancel{ft}^3}{\cancel{min}} \times \frac{60\ \cancel{min}}{hr} \times \frac{0.075\ lbm}{\cancel{ft}^3} = 4.5\ \frac{lbm}{hr}$$

"STANDARD AIR" IN HVAC CALCULATION CONSTANTS - 4

Air Velocity (FPM) = 4004 $\sqrt{\text{VP Inches of } H_2O}$

Base Formula:

$VP = 0.075 \times V^2/2g$

Where

V = Velocity FPS

VP = Velocity Pressure lbf/ft^2

V^2 (fpm) = 3600 x 2 x 32.17 x 5.19/0.075 x VP"

Note the use of "Standard" Density

FLOW OVER A COOLING/HEATING COIL

QUIZ

1,000	lbm/hr Dry Air
80°F	Dry Bulb
67°F	Wet Bulb
$v = 13.85\ ft^3/lbm_{DRY\ AIR}$	

→ Cooling Coil →

1,000	lbm/hr Dry Air
55°F	Dry Bulb
54°F	Wet Bulb
$v = 13.16\ ft^3/lbm_{DRY\ AIR}$	

WTF !
where did the
CFM go ?

$$\frac{1,000\ lbm}{hr} \times \frac{1\ hr}{60\ min} \times \frac{13.85\ ft^3}{1\ lbm} = \frac{231\ ft^3}{min}$$

$$\frac{1,000\ lbm}{hr} \times \frac{1\ hr}{60\ min} \times \frac{13.16\ ft^3}{1\ lbm} = \frac{219\ ft^3}{min}$$

☺ **Does this mean that our Air Balance Techs should read upstream of the cooling coil when short of air and downstream when too much air?**

Hint: Use Std. air on both sides and see what happens! Instruments read Std. air.

Key Concept Slide - 6

Specific Volume is the Volume (ft^3) of AIR per Pound Mass of DRY AIR.

$V_{moist\ air} = V_{dry\ air} = V_{vapor}$ (We will just say "air".)

$$v = \frac{Volume\ of\ sample}{Mass\ of\ DRY\ AIR\ in\ the\ sample} = \frac{ft^3}{lbm\ Dry\ Air}$$