Building Hydronic Systems Pressure Profile

For HVAC Project Managers

Fachgesprach 6-B

☺ WTF Institute of Higher Learning ☺

Part -2

Actual Building Pressure Profile

1 All Results Rounded To Whole Number In This Presentation

2 Velocity Head is ignored. (As we discussed in Part-1)

The Basic Hydrostatic Formula

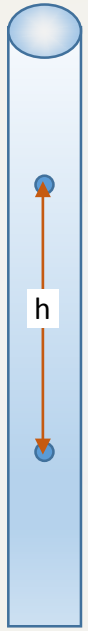
For Water (only)
$\gamma = 62.4 lb_f/ft^3$

Vertical distance between the 2 points in Feet

$$\Delta p \text{ (psi)} = \frac{h}{2.31}$$

Press. Diff. between any 2 points in a water column

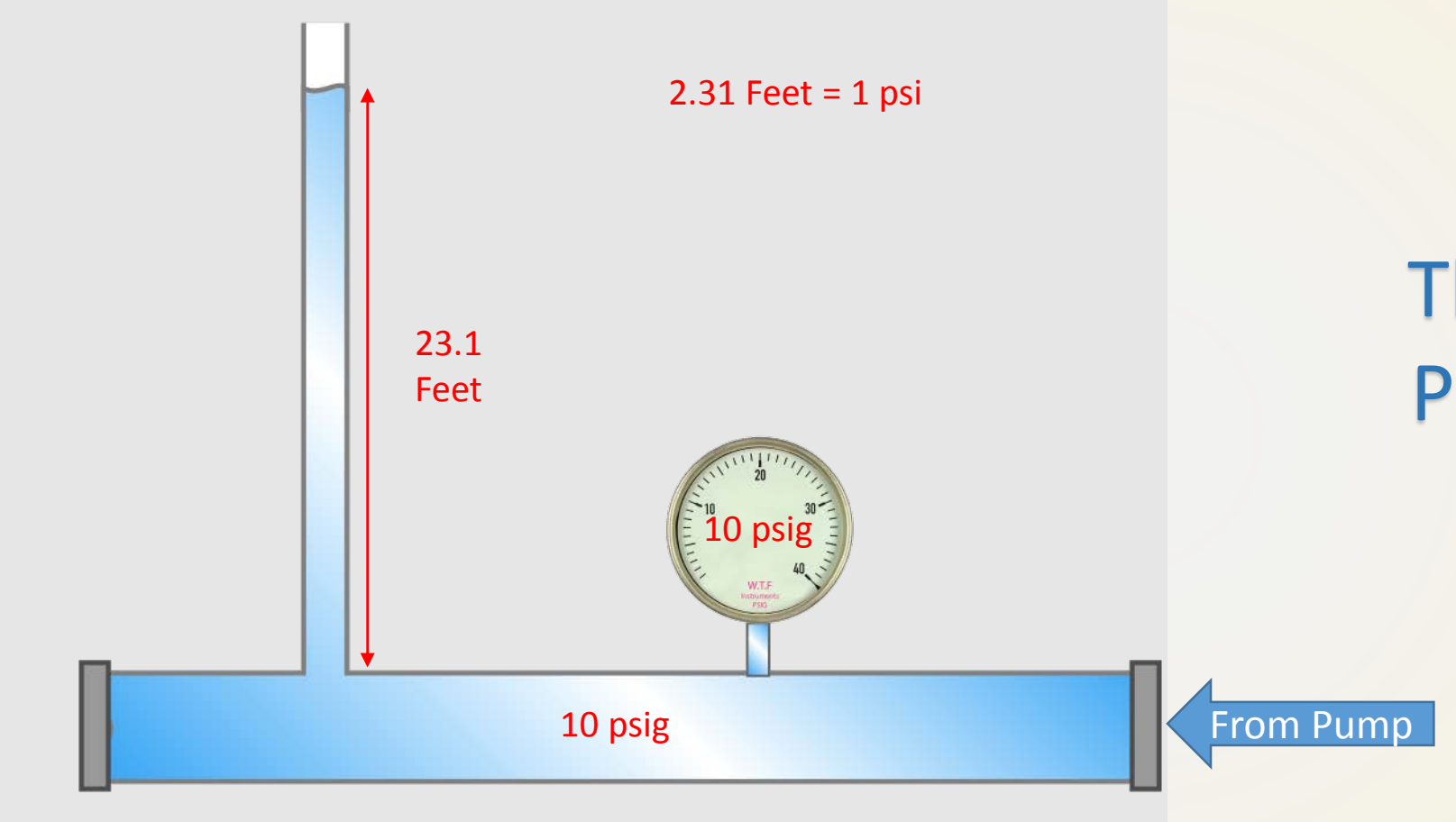
Constant



- 2.31 comes from dividing 144/62.4
- You may choose to remember 0.433, the reciprocal of 2.31. Or Both. Your choice.
- All it is saying is that every 2.31 feet of a water column will exert 1 psi pressure at the base.
- You need to remember this Constant!

Note: For hydronic systems using glycol, correct the gamma (γ) value by multiplying by the specific gravity of the glycol mixture.

The Basic Hydrostatic Formula

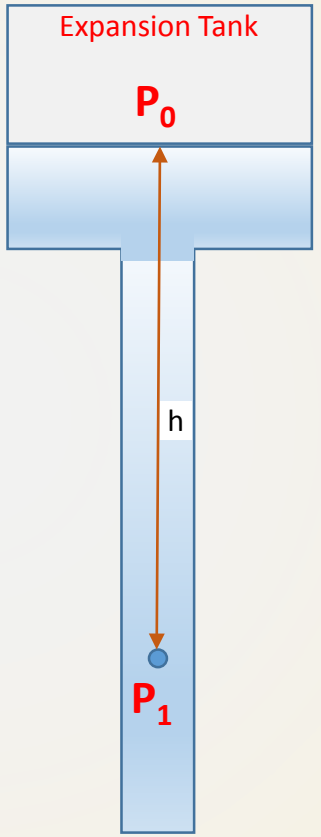


The Equivalence Of Pressure And Head

The Basic Hydrostatic Formula

$$P_1 = \frac{h}{2.31} + P_0$$

Where P_0 is the Air Pressure in the Expansion Tank



Bernoulli's Equation – The Final Form We Will Use

Velocity Head Ignored

Pump TDH feet

Friction & Dynamic Loss feet

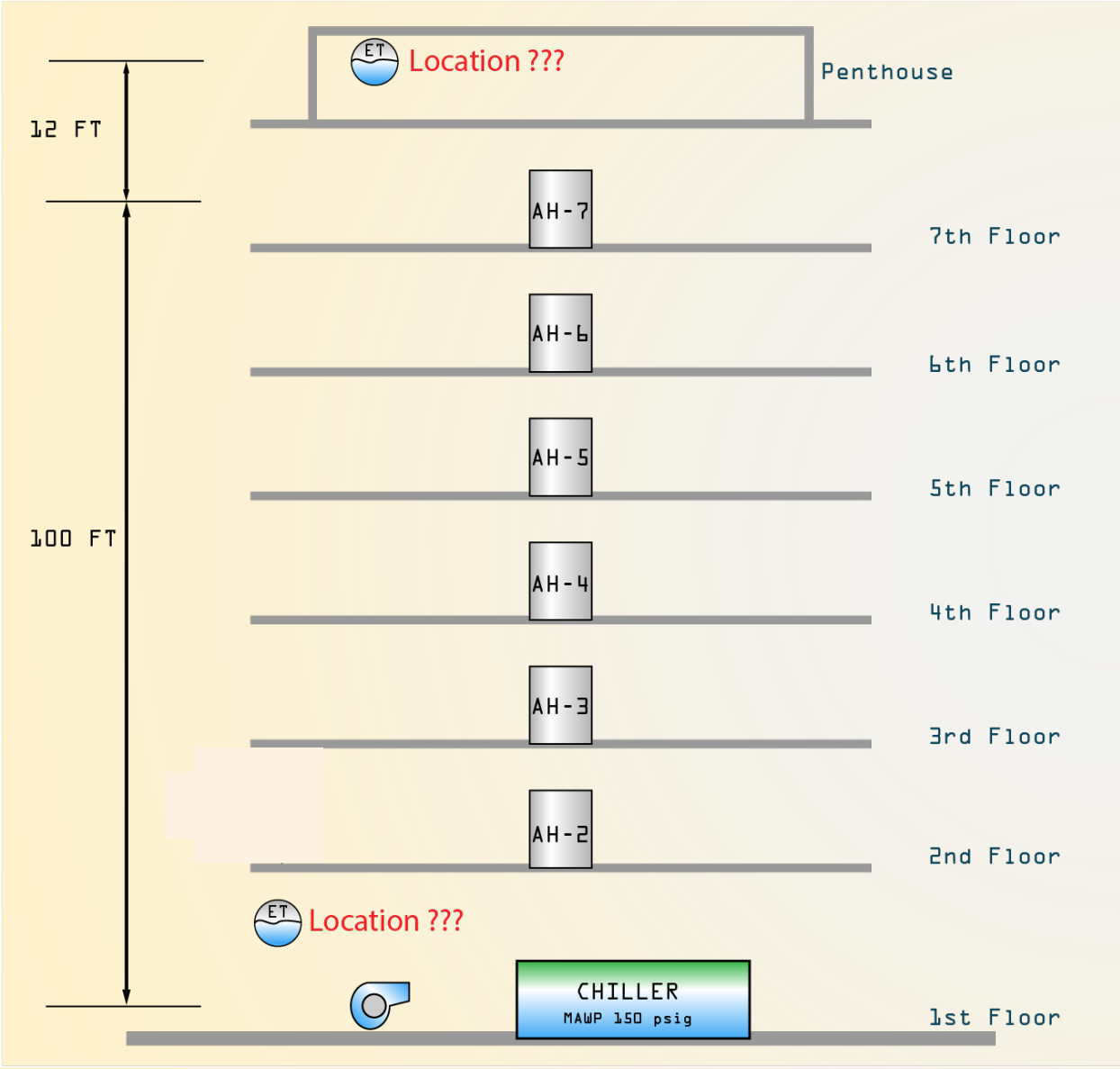
$$2.31\ P_1 + Z_1 + H_{PUMP} = 2.31\ P_2 + Z_2 + H_{LOSS}$$

Pressure Head (feet) Elevation Head (feet)	Pump Head (feet)	=	Pressure Head (feet) Elevation Head (feet)	LOSS (feet)

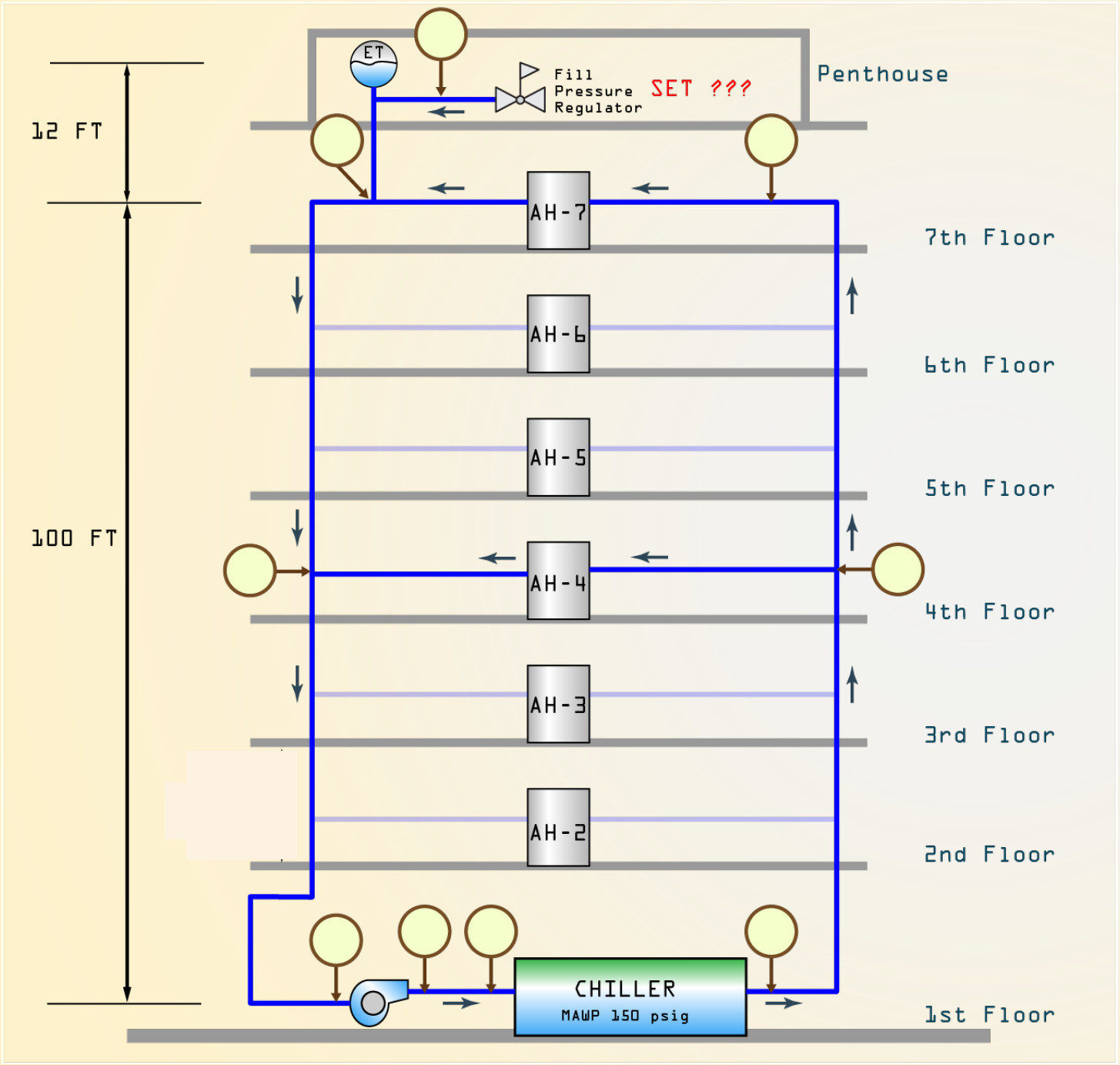
$$\text{Head at Point 2} = \text{Head at Point 1} + H_{PUMP}\ \text{Added} - H_{LOSS}\ \text{Lost}$$

Summary

- The Total Head at any point consists of the sum of:
  - The Pressure Head
  - The Velocity Head
  - The Elevation Head
- This Total Head remains constant at ALL points in the system, except when:
  - A pump adds Head
  - Frictional and Dynamic Losses subtract (dissipate) Head
- THIS IS THE PRINCIPLE THAT WE WILL KEEP IN MIND AND IGNORE THE EQUATIONS



Equipment Layout



What is this all about?

For design-build bidding and estimating, it is useful to know the system pressures at all points in the proposed system for many reasons,

for example:

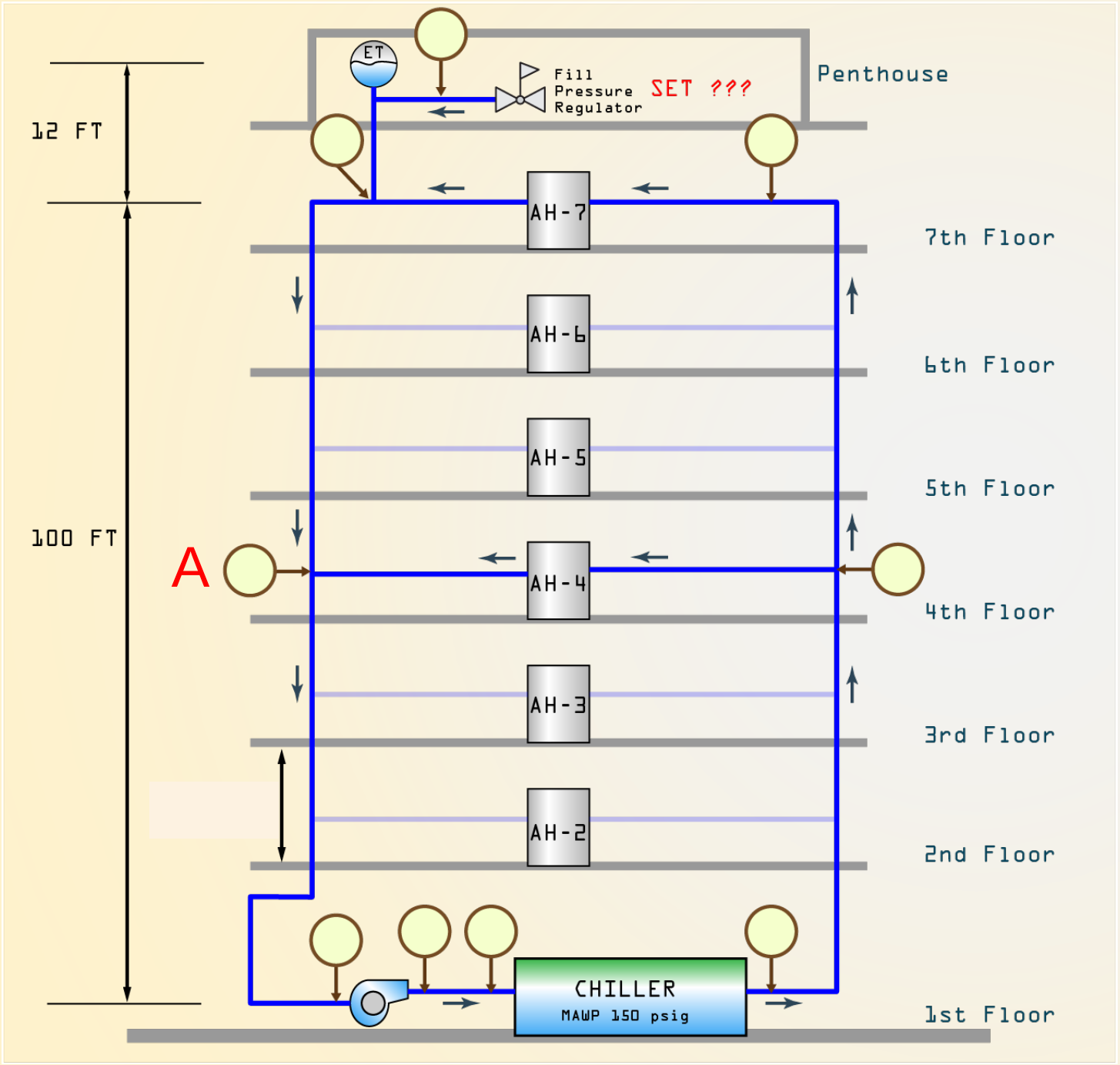
1. We need to know if any of the proposed piping materials, accessories, sensors, and instruments need to be special

2. Can the boiler be located on the lower floors without exceeding its relief valve setting

3. Most chiller evaporators have a 150 psig standard MAWP – is that OK?

4. If our start-up tech claims that at some location the pressure reading is abnormal - then we need to know enough to agree with, or contradict his opinion.

5. Etc. etc. And so having a good feel for what the pressures are in your system is always helpful



Pressures Expected:

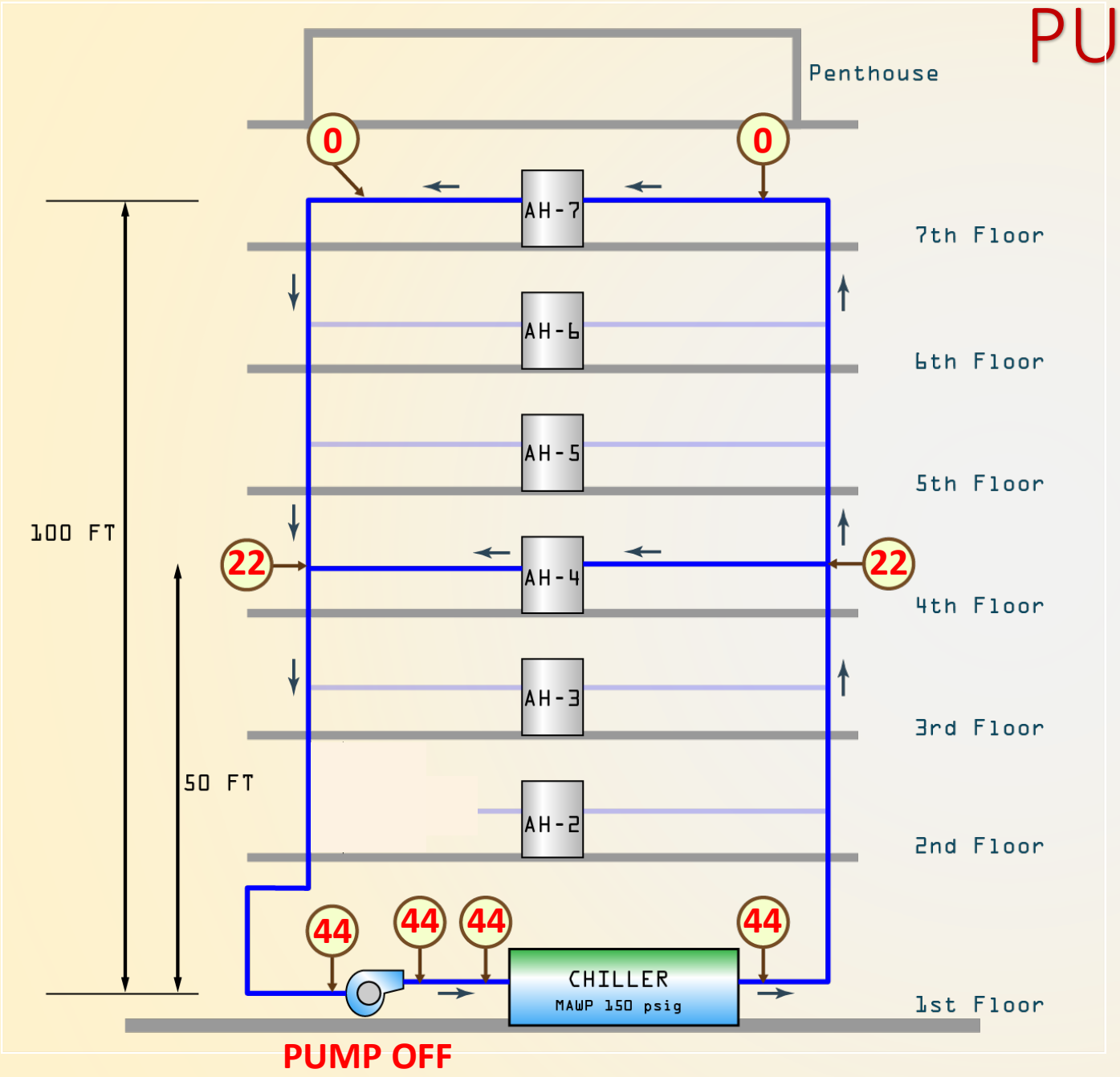
What will pressure gage A read with the pump OFF?

Will it increase or decrease when the pump is turned ON?

Where (and when) is the highest pressure that the system will experience?

These are fairly easy questions to answer – once you understand the basics of hydrostatics and the Bernoulli's Equation. So let us take a look at the theory.

PUMP OFF – Static Pressures



With the pump off and no expansion tank, the only formula needed is:

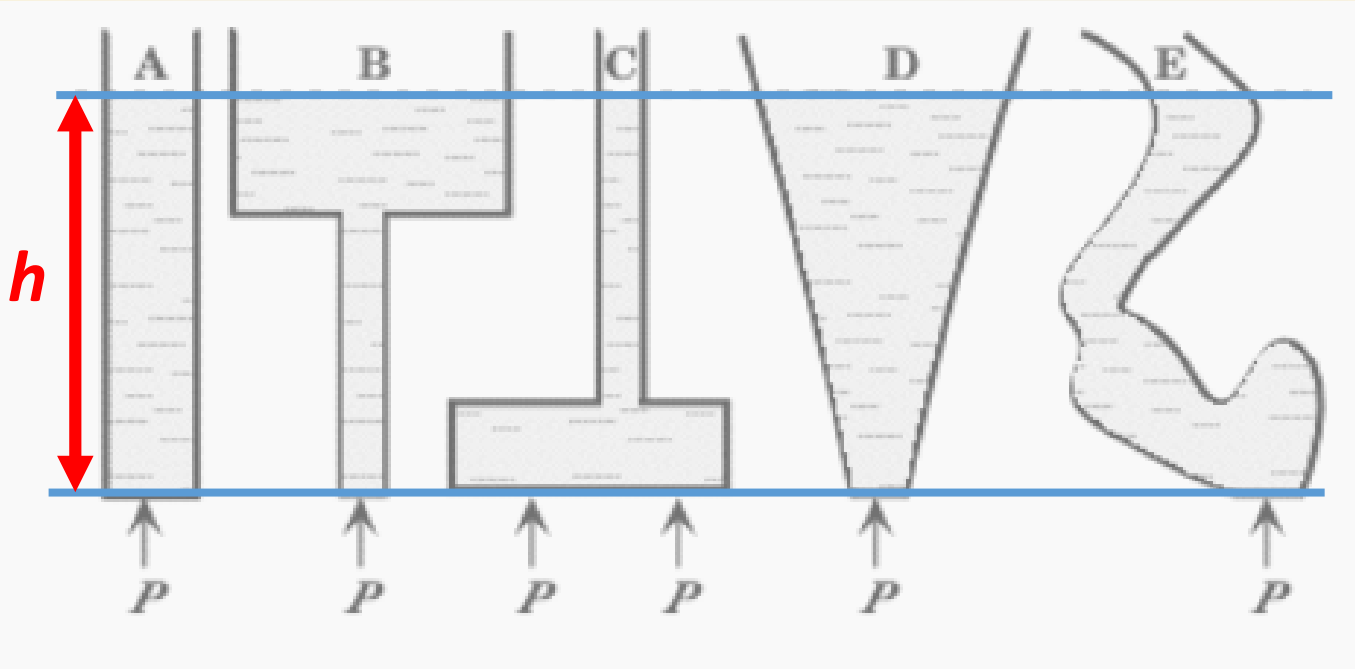
$$\Delta p \text{ (psi)} = \frac{h}{2.31}$$

- So the top 2 gages will read 0 psi-gage
- The middle gages will read (50 ÷ 2.31) = 22 psig
- The bottom gages will read (100 ÷ 2.31) = 44 psig

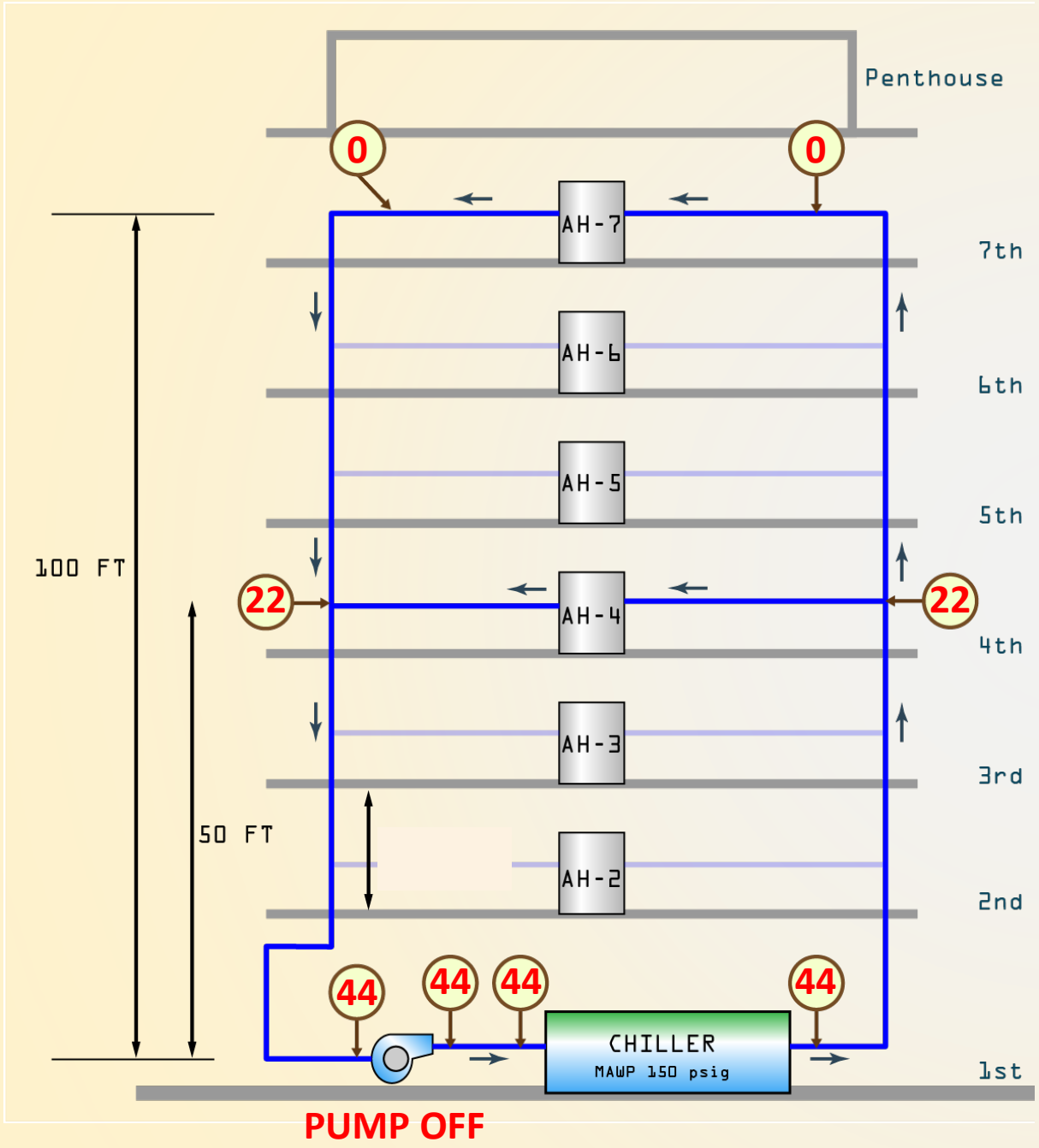
NOTE-1: It is only the vertical column height above a point that matters. The horizontal offset in the pipe does not matter. So, for example, all gages located at the level 100' below the top will read the same.

NOTE-2: The above formula is not an approximation - it is fairly exact if you know the specific gravity of the fluid and can trust your gages. (Within rounding limits.)

All Pressures At The Bottom (P) Are Equal, Because They Are The Same Vertical Distance Below The Water Line.



The Lowest Pressure Point "LPP" in the System



1. Where does the LPP occur? There are no hard and fast rules. Luckily it is not very hard to guess LPP when a flow schematic with elevations is available.

2. For high-rise buildings, usually at the top of return riser. This is the location we will assume in our example. For flat systems, usually at the inlet of the pump.

3. We will also discuss what happens if we change the location to ground level near the pump.

The Expansion Tank – What Does It Do?

3 Things: (Diaphragm/Bladder Tanks)

1. The obvious - it absorbs the expanded water volume and prevents the system pressure from getting to dangerous levels. You cannot compress water. ☺

2. When properly designed, it maintains all parts of the piping loop above atmospheric pressure to avoid drawing air in.

3. It maintains the low pressure points of a system safely above the vapor flash point so that we are always pumping water and never steam. When properly designed and located, it also guarantees that the system pump always sees the NPSH required.

Water Vapor Pressure Table

Temperature	Pressure	Pressure	Pressure
°F	Ft H_2O (Abs)	PSIA	PSIG
32	0.20	0.0885	-14.6015
40	0.28	0.1217	-14.5683
50	0.41	0.1781	-14.5119
60	0.59	0.2563	-14.4337
70	0.84	0.3631	-14.3269
80	1.17	0.5069	-14.1831
90	1.61	0.6979	-13.9921
100	2.19	0.9493	-13.7407
120	3.91	1.6920	-12.9980
140	6.67	2.8880	-11.8020
160	10.94	4.7360	-9.9540
180	17.34	7.5070	-7.1830
200	26.61	11.5200	-3.1700
212	33.93	14.6900	0.0000

As you can see, chilled water systems will not flash very easily but hot water systems will. High temperature water systems need extra care in design.

The Expansion Tank – Location?

1. Always on the suction side of the pump. Preferably on the "Lowest Pressure Point" (LPP) of the system.

2. If not located at the LPP due to practical reasons, then it is the designers job to set the Expansion Tank Pressure such that the remote LPP will be safely above the vapor flash point and above atmospheric pressure. Note that for flat systems the LPP can be inside the pump. You then check the NPSHR and set the Tank pressure accordingly.

The Expansion Tank – What is special about the point where the tank is located in the loop?

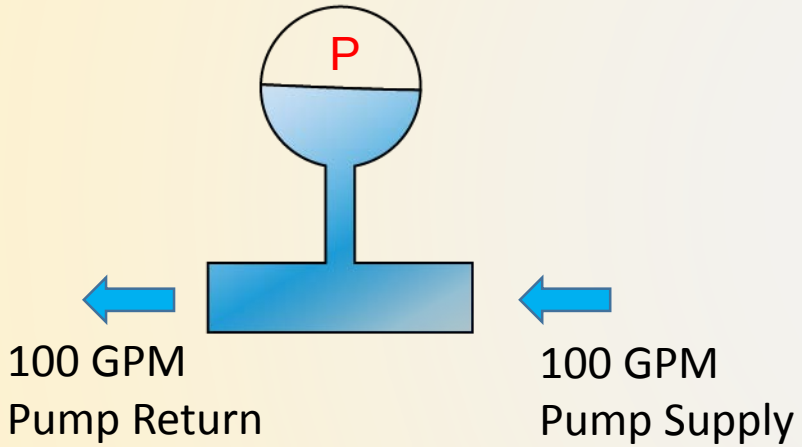
1. It is very special indeed. It is the only point in the loop where starting or stopping the system pump does not change the pressure.

2. In other words if you locate a pressure gage very near where the expansion tank ties into a system, you will not see any appreciable difference in the pressure with the pump ON or OFF.

3.

There is a common misconception that this is a point of "no pressure change". It is not. As the temperature of the water and expansion volume changes – this pressure will change, (within limits of your tank pressure min./max. design). All I am saying is that it does not change because of the system PUMP starting or stopping.

The Expansion Tank Pressure – Tee Law



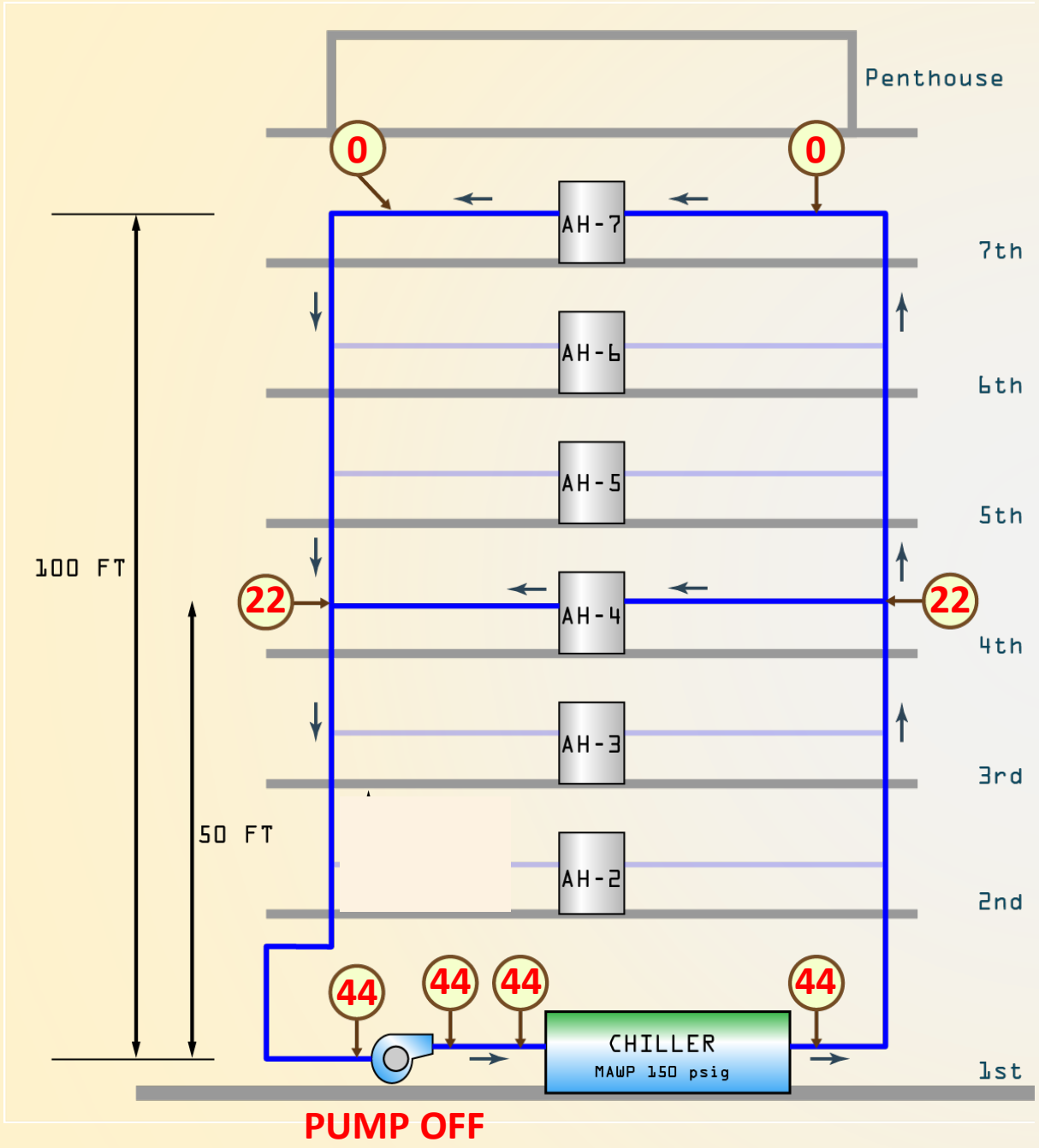
- In pipe flow theory, the "Law" of the Tee states that the flow going into a Tee must equal flow leaving the Tee.
- Also for steady state flow, what leaves the pump must enter the pump.
- As the graphic on the left illustrates, the pump supply must match the pump return.
- The only way the pressure "P" can increase is if extra water is pushed up into the expansion tank.
- Since the pump cannot do that it cannot change the pressure "P" in the tank.
- Note that the water level in the tank WILL rise when the system water expands and the pressure "P" WILL go up.

The Expansion Tank – Serves As Our Reference

1. To analyze loop system pressures you need a reference start point. The expansion tank connection point serves as that base.

2. For open systems (no ET), we use the open water surface as our reference (0 gage) and work from there.

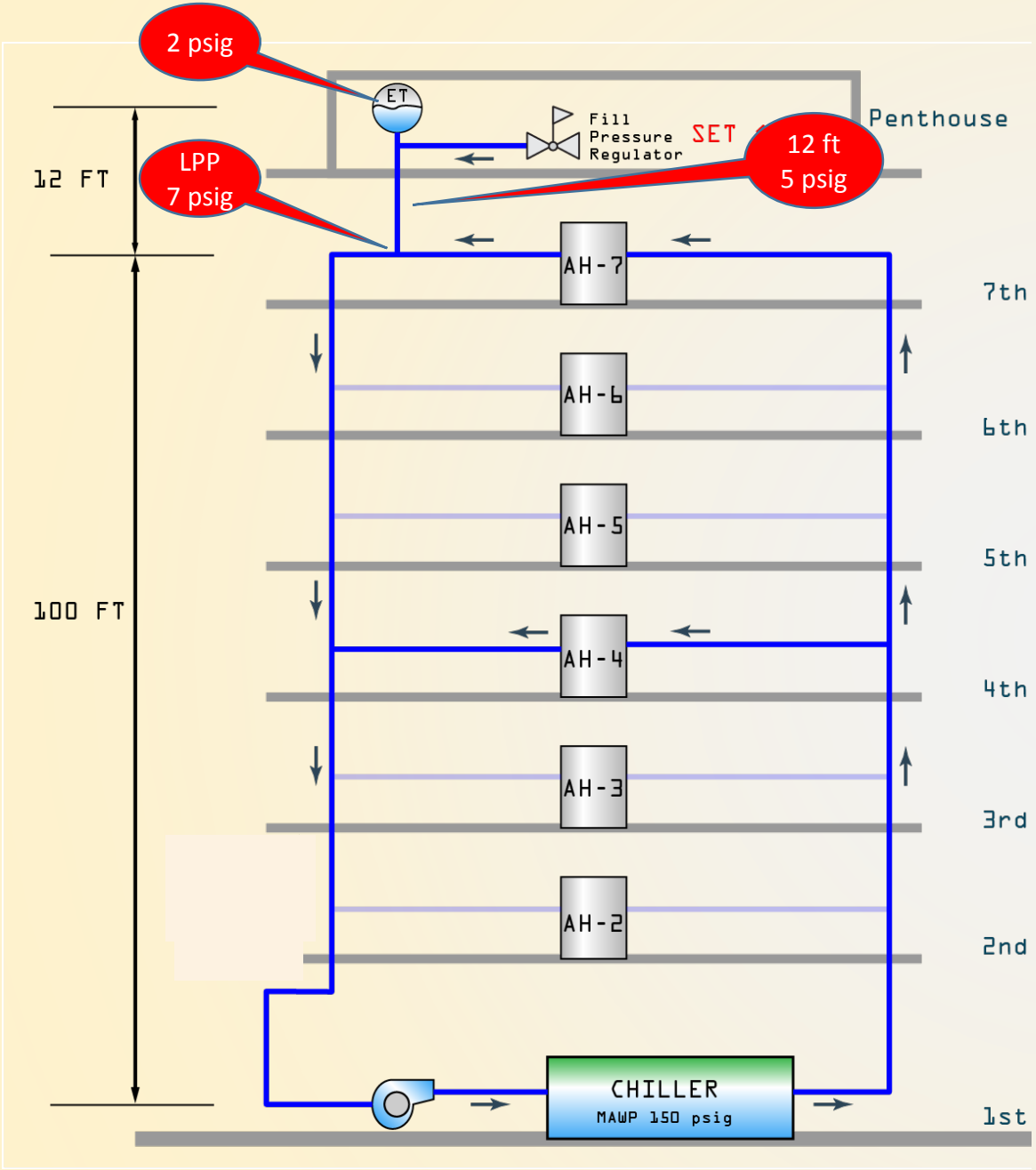
We will not get a chance to discuss expansion tank sizing in this presentation. Maybe another Fachgesprach some day.



Pressures With No Expansion Tank

$$\Delta p \text{ (psi)} = \frac{h}{2.31}$$

FILL Pressures

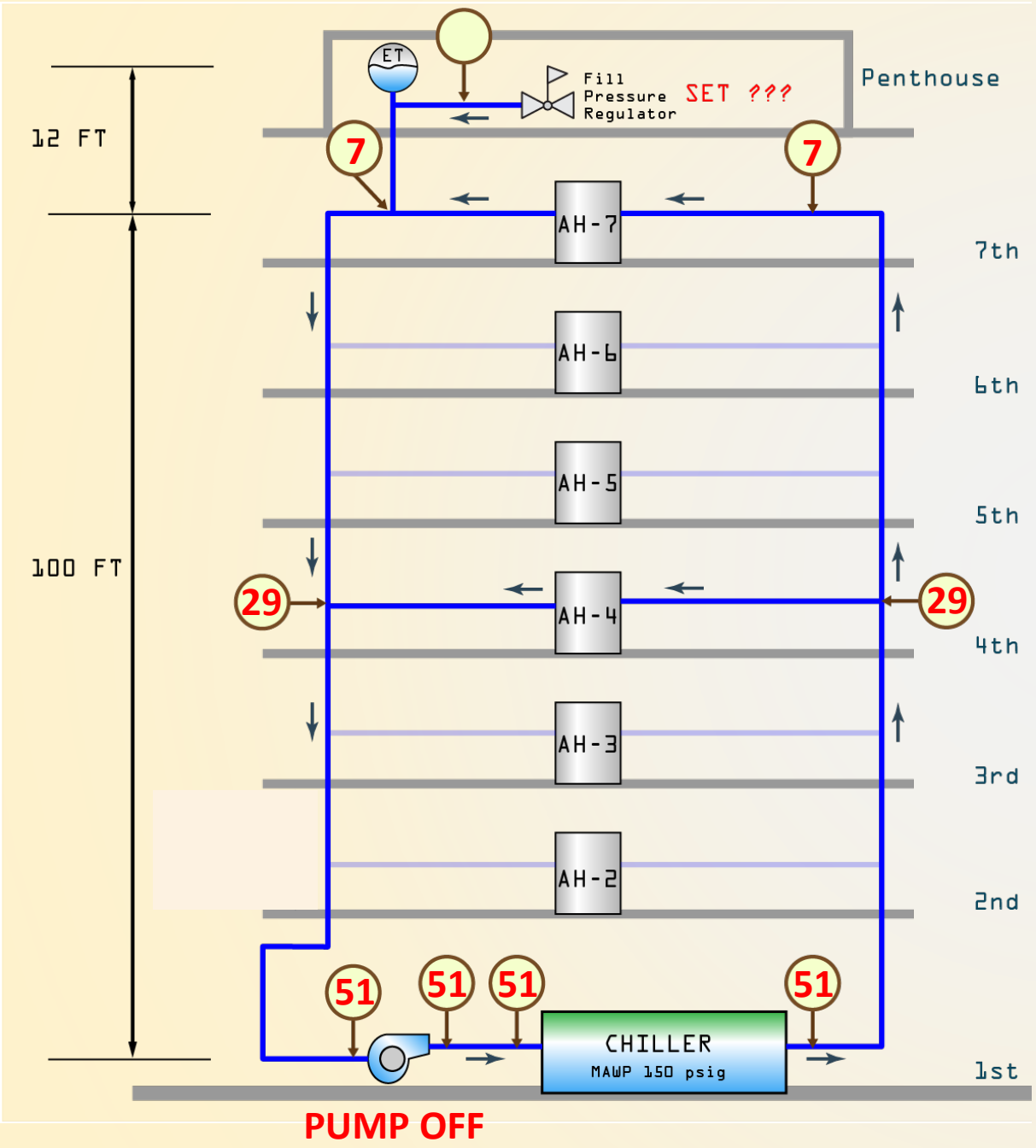


PUMP OFF

- Let us locate the expansion tank as shown at the LPP
- The chiller range is 55°F to 45°F. So the minimum temperature for the system is 45°F. Let us assume that the fill water temperature at startup is 65°F.
- Most engineers use a minimum pressure value of 5 psig for LPP. This would occur when the water is 45°F. Since our fill water is at 65°F, let us use 7 psig for the LPP pressure at the time of filling. (Allowing for a little drop as the chilled water cools.)
- The top of water surface is 12 feet above LPP and therefore will exert a (12 ÷ 2.31) = 5 psig on the LPP.
- To get 7 psig on the LPP we need to pressurize the tank another 2 psig. (This is P_{min} for tank sizing.)
- That sets the bottom static pressure limit for the entire system.

Let us ignore the fill regulator setting for the moment. We will come back to that later.

Pump OFF - FILL Pressures



$$P_1 = \frac{h}{2.31} + P_0$$

Critical Sizing - Expansion

System Volume

Volume must be numeric

1000 Gallons

Fluid Type

Water

Low Temperature

Temperature must be numeric

60 F

High Temperature

Temperature must be numeric

90 F

Initial Pressure

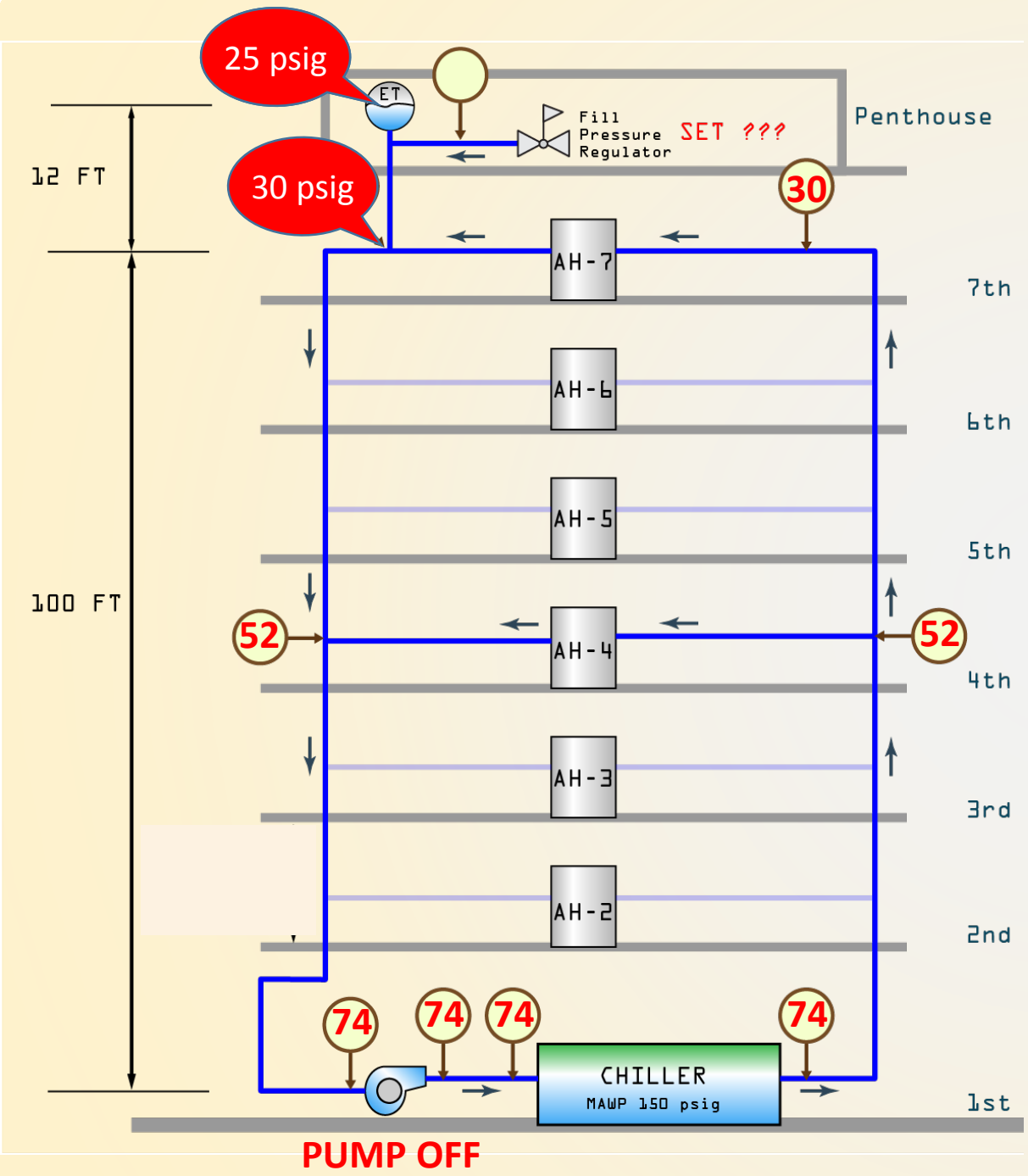
2 psig

Final Pressure

This program was designed to size product at or below a typical ASME tank rated pressure of 125 psi. Your pressure input exceeds this value. Please consult factory - 317-888-9800

25 psig

Pump Off - Warm System - 90 ^{o}F



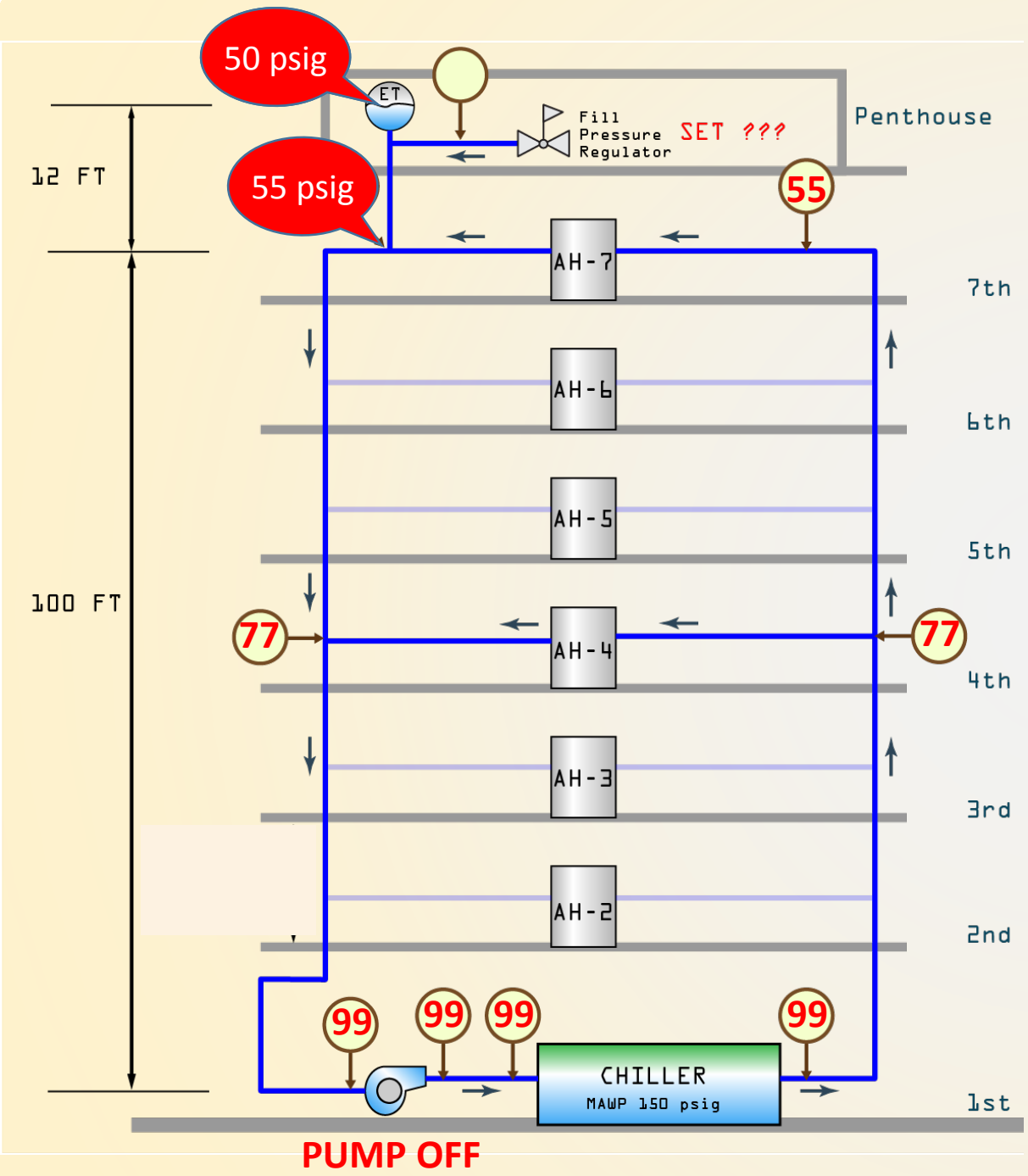
When sizing an expansion tank, one of the key selection parameters you enter is the maximum allowable pressure P_{max} at the tank when the water is at its highest expected temperature, T_{max}.

Let us assume that the designer had selected 90 ^{o}F as the maximum chilled water system temperature and sized the tank so it maximum pressure (at 90 ^{o}F) will not exceed 25psig. Since this is the condition right now, the tank pressure will rise to 25 psig. (Note how the tank pressure is NOT constant.)

There is 12 feet or 5 psig head above the LPP. Therefore the LPP gage will read 30 psig.

Note how your selection of P_{max} at the expansion tank directly effects the inlet to the chiller. A lower P_{max} means a bigger expansion tank but lower pressure at the chiller. A lot of engineers are confused about what to plug in for P_{max}. Always be aware of what it happening to the “Maximum System Pressure” when you increase P_{max}.

Pump Off - Warm System - 90 ºF



Cheaper Tank Selection:

Let P_{max} go to 50 psig

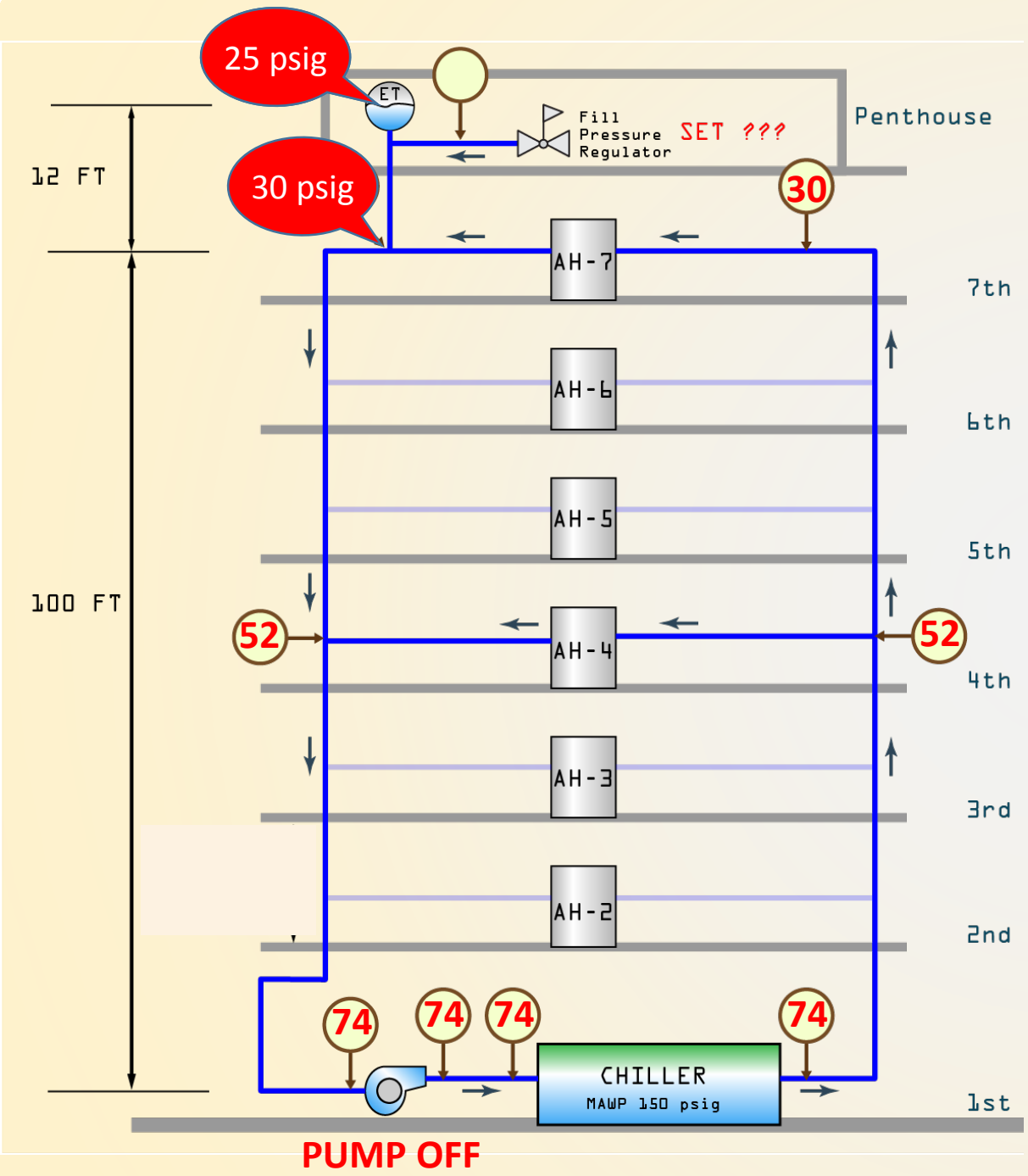
Standard Relief Valve on Copper Finned Tube Boilers

Options

OPTION	HEAT EXCHANGER	PRESSURE RELIEF VALVE			
	A-3	A-10	A-11	A-12	A-14
	CUPRO-NICKEL	30 PSIG	45 PSIG	60 PSIG	75 PSIG
MODEL	ALL	H	H	H	H
503A/504A	$342	$34	$35	Standard on H units	$70
753A/754A	$490				
1003A/1104A	$693	$650 *See Note 1*	*Size 2003 See Note 1*		
1253A/1504A	$858				
1503A	$985				
1753A/2004A	$1,201				
2003A	$1,373				
2503	$2,250	$248	N/A		N/A
3003	$2,579				
3503	$2,908	$608			
4003	$3,236				

RayPak
Higher Relief Settings
Available as add Option

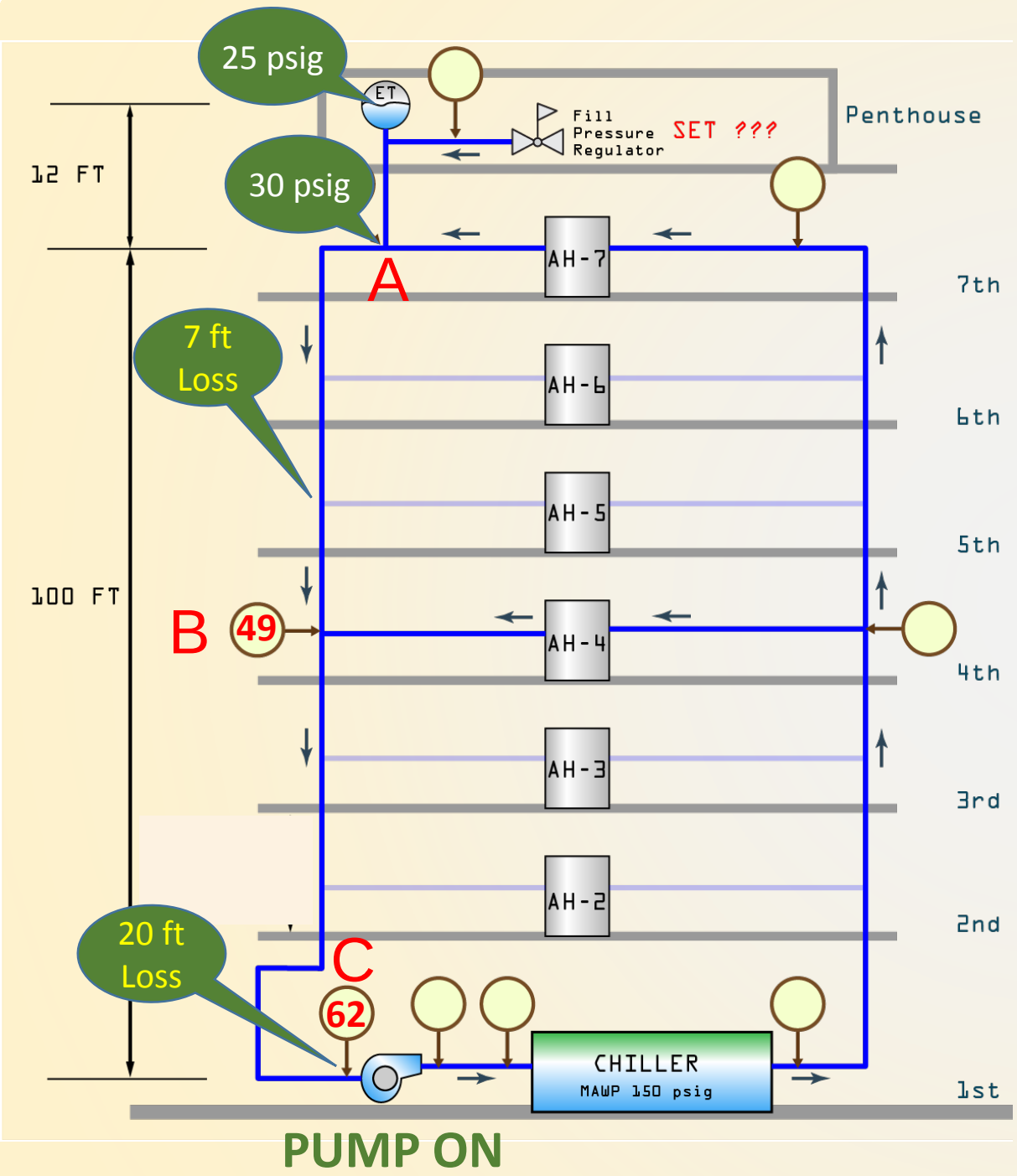
Pump Off - Warm System - 90 ºF



Back to the normal selection.

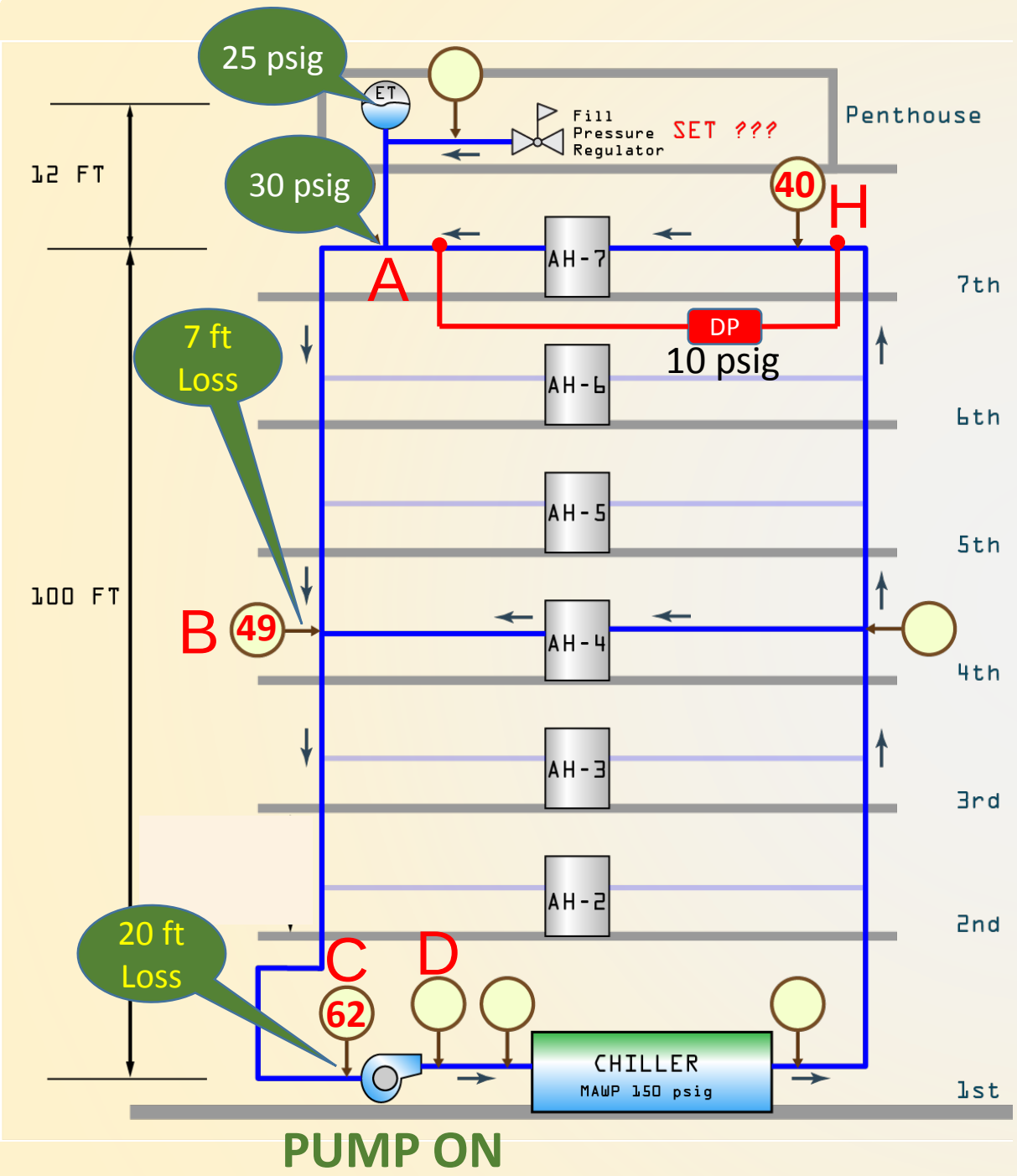
Ready to turn ON the pump.

Turn **ON** The Pump
Warm System - 90 °F



- Where do we start? We can ONLY start at a known pressure point.
- The only "known pressure point" is where the expansion tank ties in. Remember the hydronic law that the pump cannot change the pressure at the point where the expansion tank ties in? So we know the pressure at "A" is still 30 psig.
- The next gage in the direction of flow ("B") read 52 psig before the pump was started. But now there is a head loss of 3 psig (7 feet) due to friction between "A" and "B" so it will read:
  - 52 – 3 = 49 psig
- If you didn't know the pressure at B before starting the pump, then:
  - $P_B = P_A$ + Elev. Head – Head loss
  - $P_B = 30 + (50/2.31) – (7/2.31)$
  - $P_B = 30 + 22 – 3 = 49$ psig
- In a similar way the pressure at point "C" is:
  - 74 – 12 = 62 psig [27 feet ≈ 12 psig]

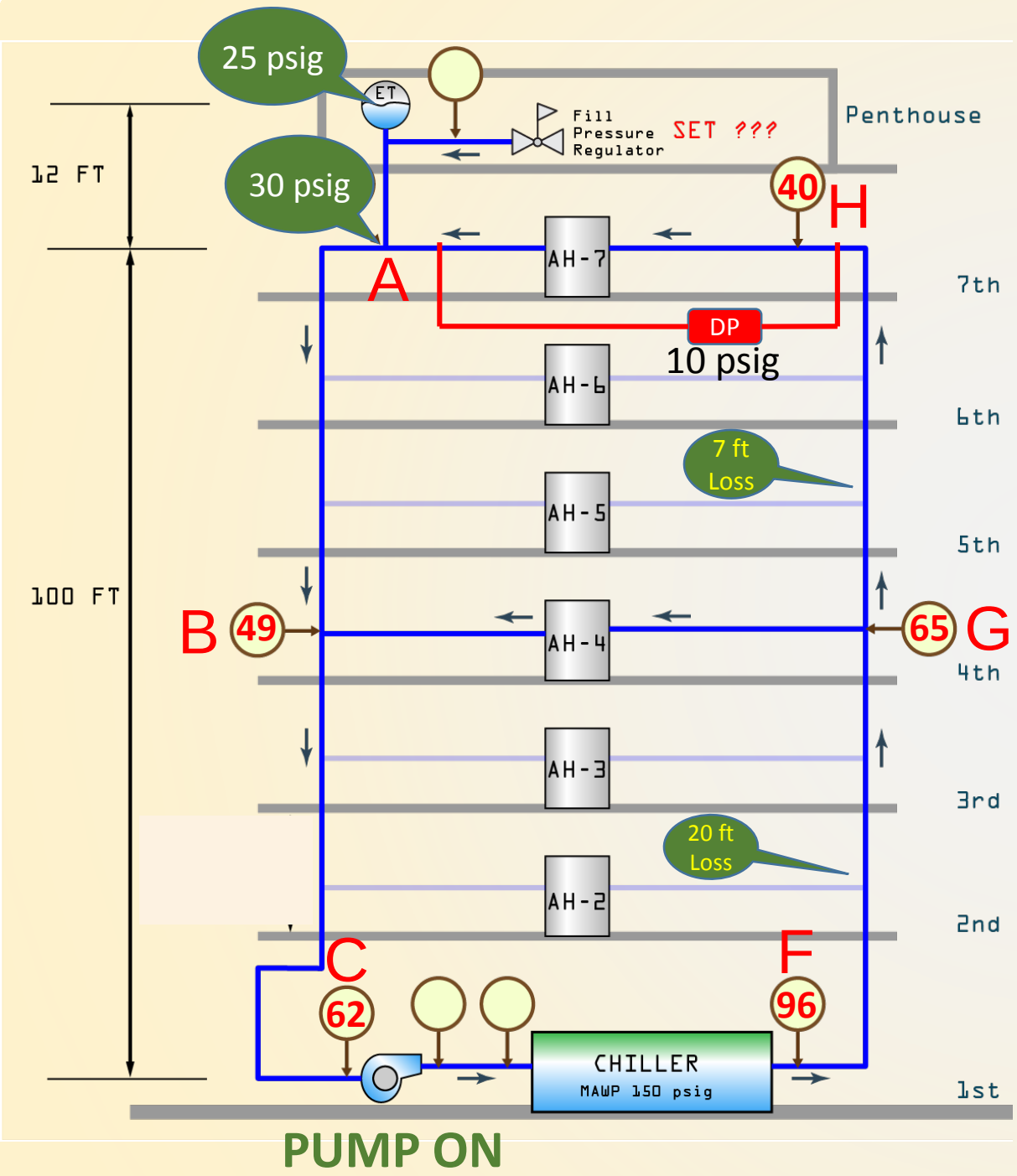
Turn **ON** The Pump
Warm System - 90 ºF



- Point D is simple if you know the head the pump is operating at. For e.g. if the TDH for the pump is 80 feet then point "D" is at:
  - $P_D = P_C$ + Pump Head
  - P_D = 62psig + 80/2.31 = 97 psig

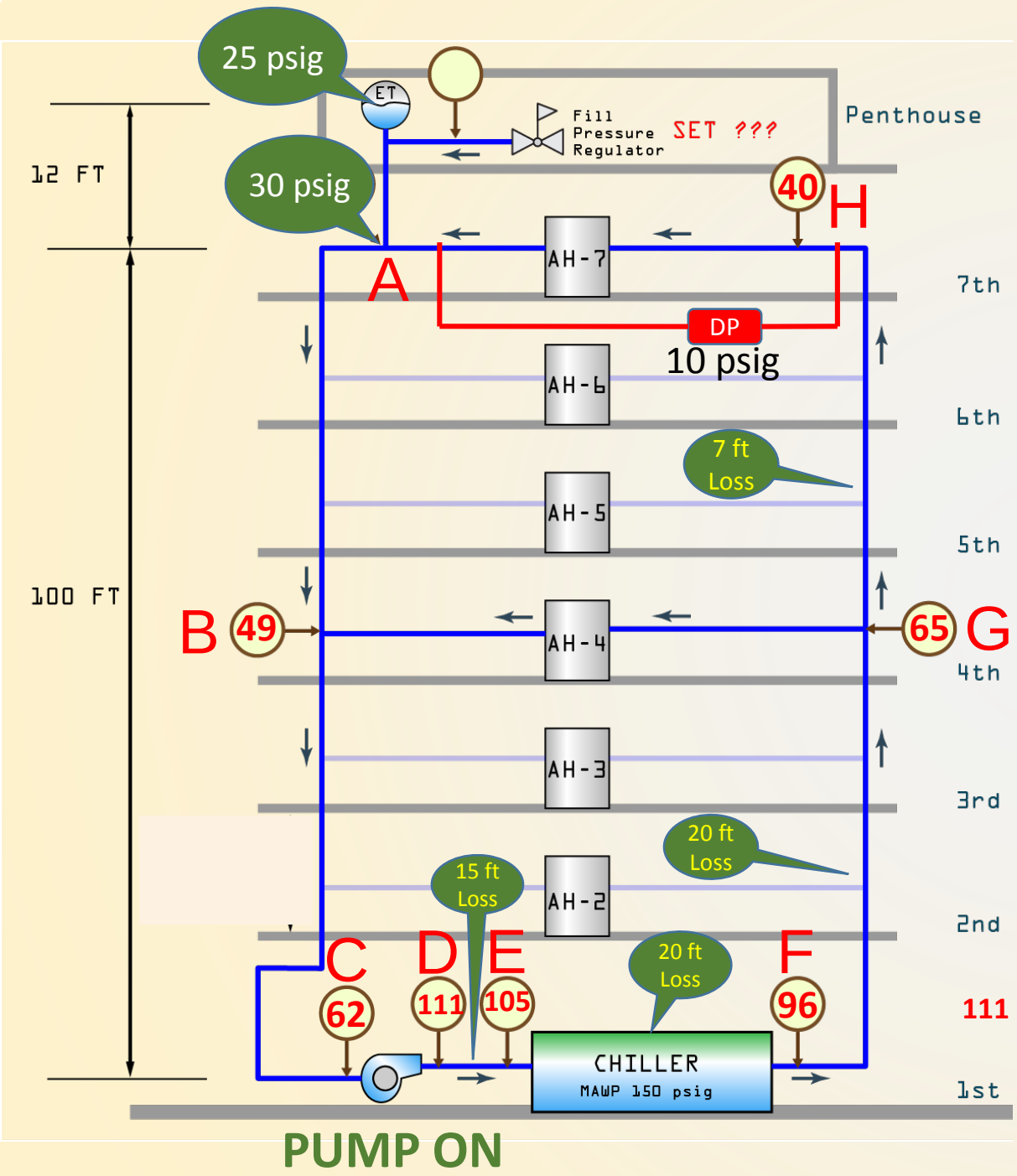
  So the gage at "D" (pump discharge) will read 97 psig.
- But there is a catch in reasoning this way. Just because the engineer selected the pump for 80'TDH doesn't mean that the system head matches 80'. And therefore the pump might not be producing 80 feet TDH.
- So let us go back to the top. Point H is also a known pressure. WHY? Because the chilled water pump VFD is modulated to this pressure a fixed amount above point "A". Say 10 psig.
- They (our DDC programmers) will modulate the pump VFD to keep the 10 psig difference between the supply and return headers.
- Therefore pressure at "H" is (30 + 10) or 40 psig.
- So let us work backward from "H" and see if we can find the real pump TDH required and in the process also verify the pump selection.

Turn **ON** The Pump
Warm System - 90 ºF



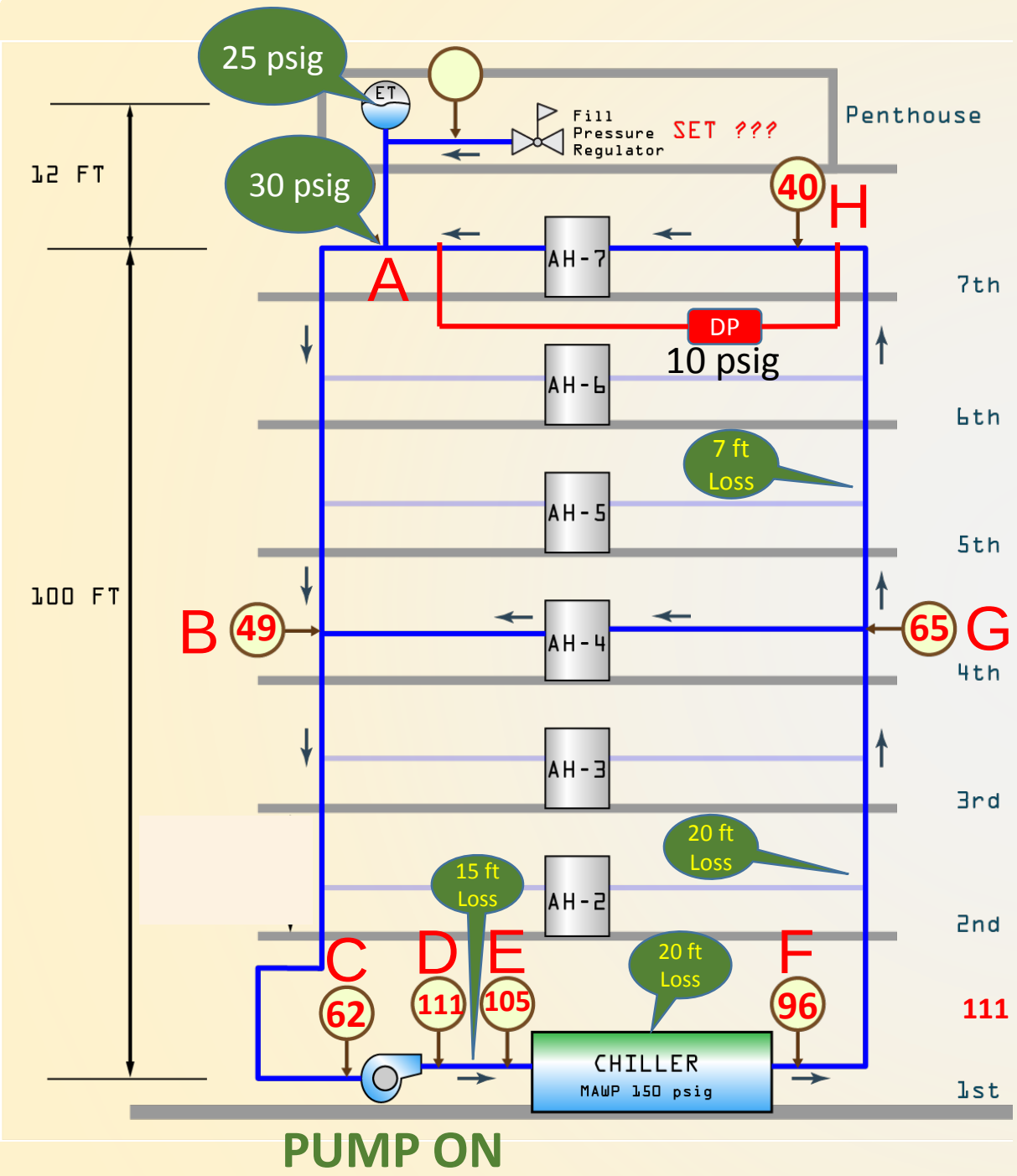
- At G you can use the Bernoulli's equation or just use simple reasoning that G will be 50 ft (22 psig) higher than H but has to source the 7 feet pressure loss also:
  - $P_G = P_H + 50/2.31 + 7/2.31$
  - $P_G = 40 + 22 + 3 = 65$ psig
- Notice something very important (and interesting)! The Δp across AH-4 is higher (16 psig) than the Δp across AH-7, which is being controlled at 10 psig. In general the lower floors will always have a higher Δp, than the upper floors. (This is what the PIV peddlers are talking about in their "lunch and learn" seminars.) Let us not discuss this here.
- Using similar reasoning as for point G above we get for F:
  - $P_F = P_G + 50/2.31 + 20/2.31$
  - $P_F = 65 + 22 + 9 = 96$ psig

Turn **ON** The Pump
Warm System - 90 ºF



- Between E and F there is only the chiller (evaporator) tube bundle pressure drop of 20 feet:
  - $P_E = P_F + 20/2.31$
  - $P_E = 96 + 9 = 105$ psig
- Between D and E, there is the pump discharge trim and the chiller inlet trim, say 15 feet:
  - $P_D = P_E + 15/2.31$
  - $P_D = 105 + 6 = 111$ psig
- If all our pressure drops estimated are correct than this pump must be selected for
  - $P_D - P_C = 111$ psig $- 62$ psig $= 49$ psig
  - $P_D - P_C = 49 \times 2.31 = 113$ feet pump TDH

Turn **ON** The Pump
Warm System - 90 ºF



- Look what we have accomplished
- The pressure profile of the whole system is known and published before it is installed and before our start-up technicians go out to start the system
- This can be so handy when troubleshooting flow problems during start-up that you wonder why this pressure profile is not a *required* document from the design engineer on every job

THE END

Closing Discussion & Questions

1. Why is the fill always located at (or close) to the expansion tank?
2. What happens if the expansion tank is located in the basement with the pump?
3. What happens if the expansion is located on the discharge side of the pump?
4. Where would you locate the relief valve for this system?