Energy & Store Development Conference

E+SD 2015

Refrigeration 401 – A High Side Exploration

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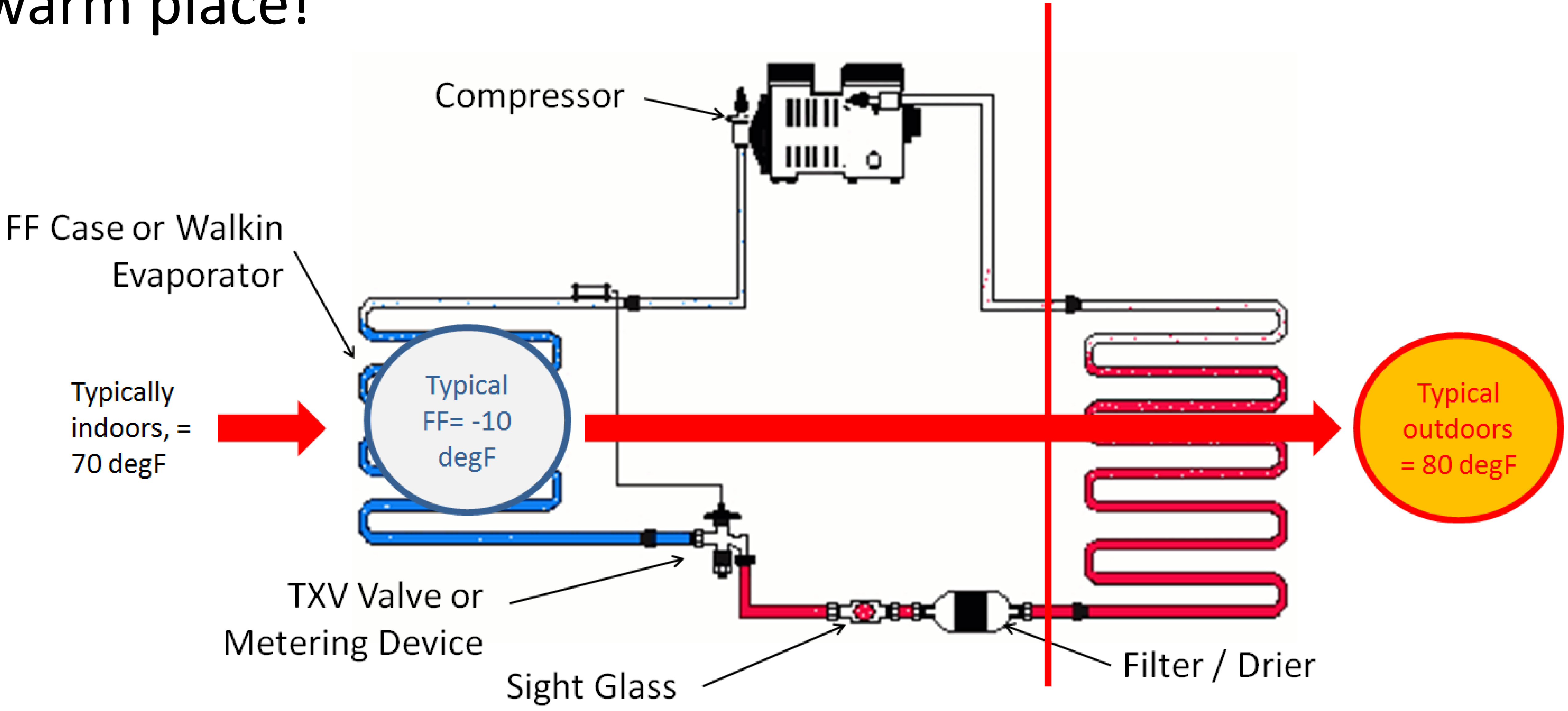
BaselineES

Heat Transfer:

Heat transfer always occurs (can only occur) from a region of high temperature to another region of lower temperature.

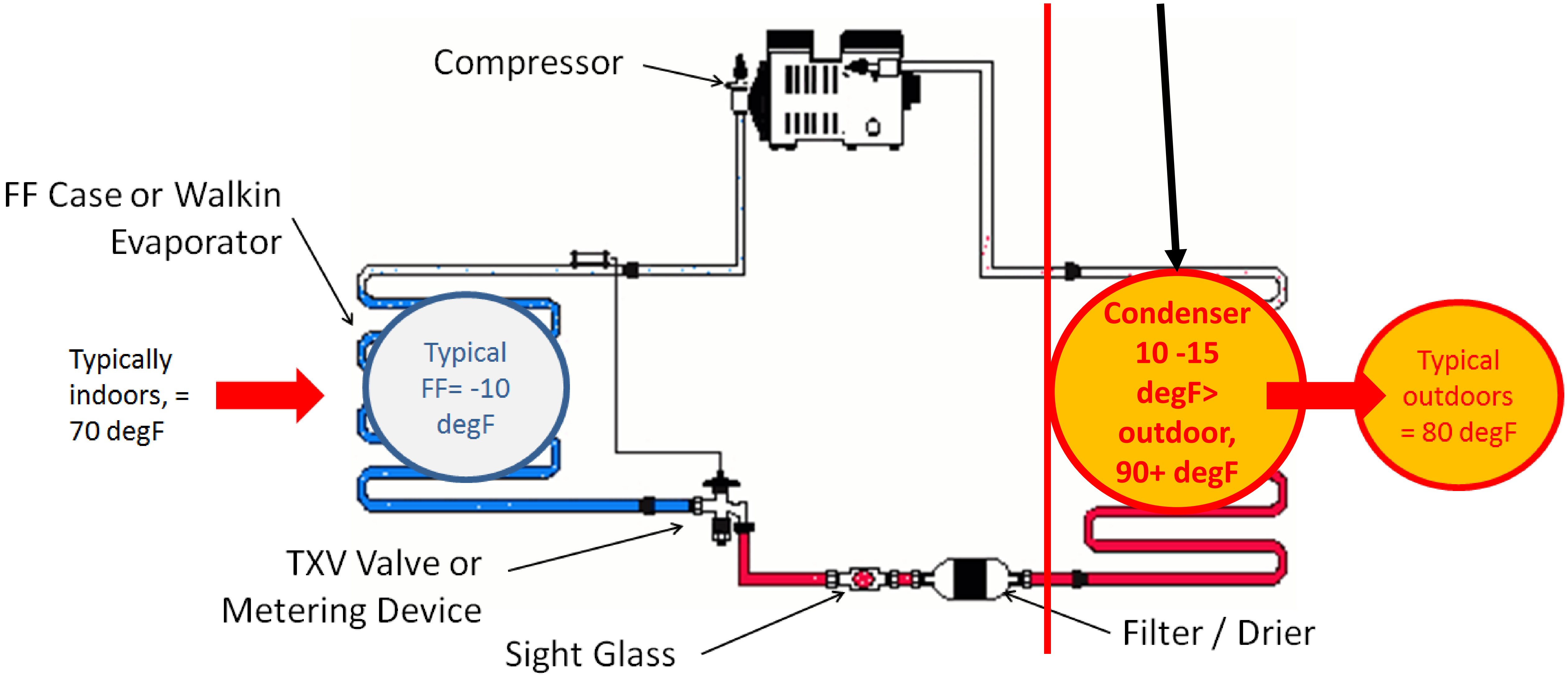
Refrigeration

- Doing the impossible – moving heat from a cold place to a warm place!



Refrigeration

- How do we do the impossible?
- **By using a thermodynamic sleight of hand!**



Pressure Temperature Relationship:

TEMPERATURE - PRESSURE CHART

PRESSURE-POUNDS PER SQUARE INCH FOR HCFC-22 REFRIGERANT

TEMPERATURE °F	PRESSURE PSI	TEMPERATURE °F	PRESSURE PSI	TEMPERATURE °F	PRESSURE PSI
-40	0.5	15	37.7	44	74.5
-35	2.6	16	38.7	45	76.0
-30	4.9	17	39.8	46	77.6
-25	7.4	18	40.9	47	79.2
-20	10.1	19	41.9	48	80.8
-18	11.3	20	43.0	49	82.4
-16	12.5	21	44.1	50	84.0
-14	13.8	22	45.3	55	92.6
-12	15.1	23	46.4	60	101.6
-10	16.5	24	47.6	65	111.2
-8	17.9	25	48.8	70	121.4
-6	19.3	26	49.9	75	132.2
-4	20.8	27	51.2	80	142.6
-2	22.4	28	52.4	85	155.7
0	24.0	29	53.6	90	168.4
1	24.8	30	54.9	95	181.8
2	25.6	31	56.2	100	195.9
3	26.5	32	57.5	105	210.8
4	27.3	33	58.8	110	226.4
5	28.2	34	60.1	115	242.7
6	29.1	35	61.5	120	259.9
7	30.0	36	62.8	125	277.9
8	30.9	37	64.2	130	296.8
9	31.8	38	65.6	135	316.6
10	32.8	39	67.1	140	337.3
11	33.7	40	68.5	145	358.9
12	34.7	41	70.0	150	381.5
13	35.7	42	71.5	155	405.1
14	36.7	43	73.0		

"Saturation Pressure" = the equilibrium pressure for refrigerant at a given temperature. By "equilibrium" we mean the refrigerant can be liquid, vapor, or a mix. Most of the 'action' in refrigeration systems, evaporation and condensation, occurs with the system refrigerant in a saturation condition, the first at the lower temperature condition, the second at the higher temperature condition.

Saturation Again…

ATMOSPHERIC PRESSURES, ABSOLUTE VALUES				COMPOUND GAGE READING in. Hg VACUUM	SATURATION POINTS of H_2O (BOILING—CONDENSING) °F
psia	in. Hg	mm Hg	microns		
14.696	29.921	759.999	759,999	00.000	212.00
14.000	28.504	724.007	724,007	1.418	209.56
13.000	26.468	672.292	672,292	3.454	205.88
12.000	24.432	620.577	620,577	5.490	201.96
11.000	22.396	568.862	568,862	7.526	197.75
10.000	20.360	517.147	517,147	9.617	193.21
9.000	18.324	465.432	465,432	11.598	188.28
8.000	16.288	413.718	413,718	13.634	182.86
7.000	14.252	362.003	362,003	15.670	176.85
6.000	12.216	310.289	310,289	17.706	170.06
5.000	10.180	258.573	258,573	19.742	162.24
4.000	8.144	206.859	206,859	21.778	152.97
3.000	6.108	155.144	155,144	23.813	141.48
2.000	4.072	103.430	103,430	25.849	126.08
1.000	2.036	51.715	51,715	27.885	101.74
0.900	1.832	46.543	46,543	28.089	98.24
0.800	1.629	41.371	41,371	28.292	94.38
0.700	1.425	36.200	36,200	28.496	90.08
0.600	1.222	31.029	31,029	28.699	85.21
0.500	1.180	25.857	25,857	28.903	79.58
0.400	0.814	20.686	20,686	29.107	72.86
0.300	0.611	15.514	15,514	29.310	64.47
0.200	0.407	10.343	10,343	29.514	53.14
0.100	0.204	5.171	5,171	29.717	35.00
0.000	0.000	0.000	0.000	29.921	—

NOTE: psia × 2.035 966 = in. Hg   psia × 51.715 = mm Hg   psia × 51,715 = microns

Refrigeration Efficiency

- How efficiently can we move heat from a cold place to a warm place? Carnot (the man, not the company) had something to say about this.

$$COP_R = \frac{1}{\frac{T_H}{T_C} - 1} = \frac{T_C}{T_H - T_C}$$

Temperature Difference Affect on Coefficient of Performance			
Refr Fixture Temp	Outside Temp	Difference	COP
-10 °F	40 °F	50 °R	8.99
-10 °F	50 °F	60 °R	7.49
-10 °F	60 °F	70 °R	6.42
-10 °F	70 °F	80 °R	5.62
-10 °F	80 °F	90 °R	5.00
-10 °F	90 °F	100 °R	4.50
20 °F	40 °F	20 °R	23.98
20 °F	50 °F	30 °R	15.99
20 °F	60 °F	40 °R	11.99
20 °F	70 °F	50 °R	9.59
20 °F	80 °F	60 °R	7.99
20 °F	90 °F	70 °R	6.85

Refrigeration Efficiency Continued

The effects of Carnot's Laws manifest themselves as compressor compression ratios, and hence heat of rejection and efficiency at various operating conditions.

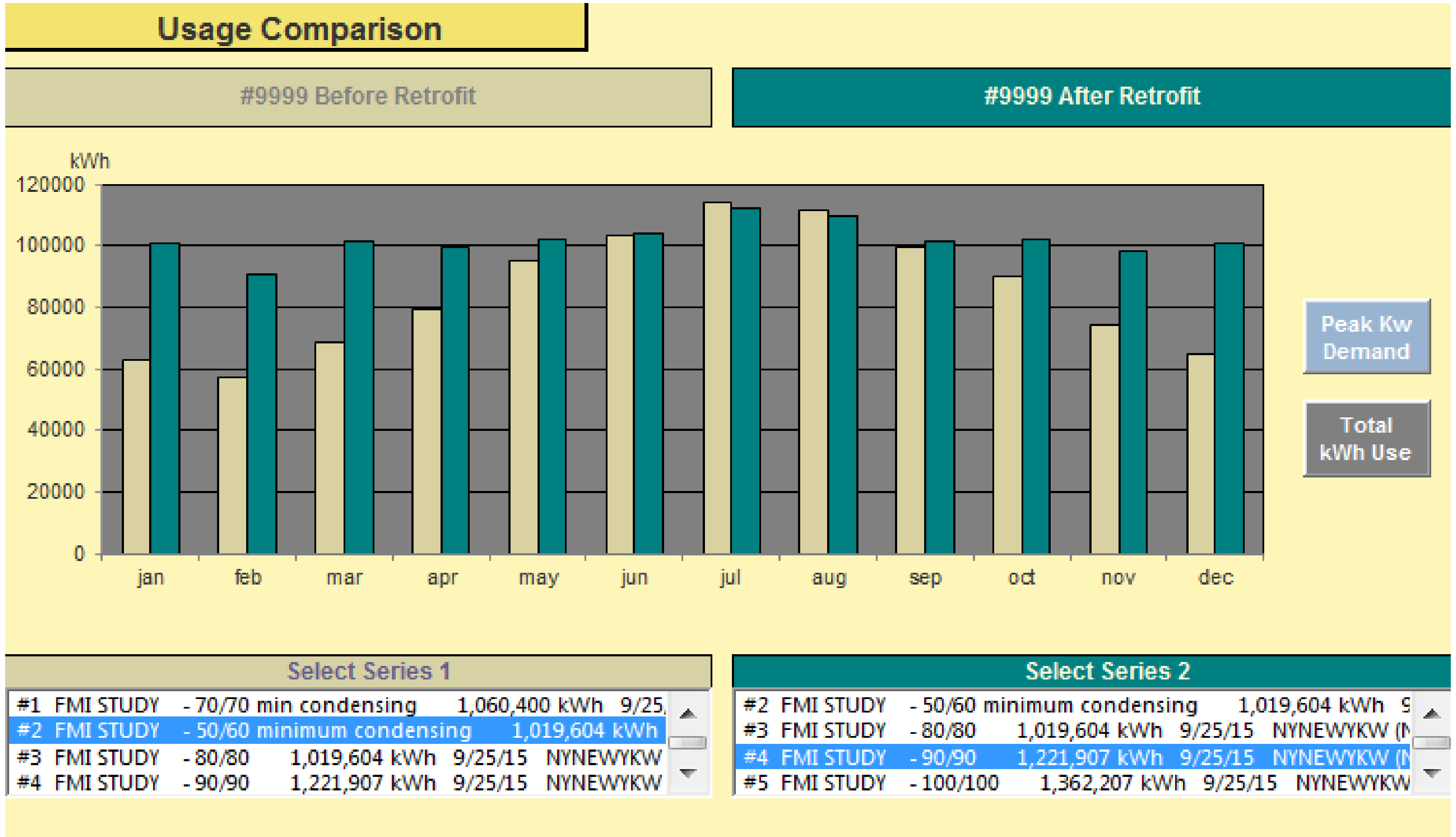
Table 1. Heat of Compression Factor for Suction Cooled Compressors.

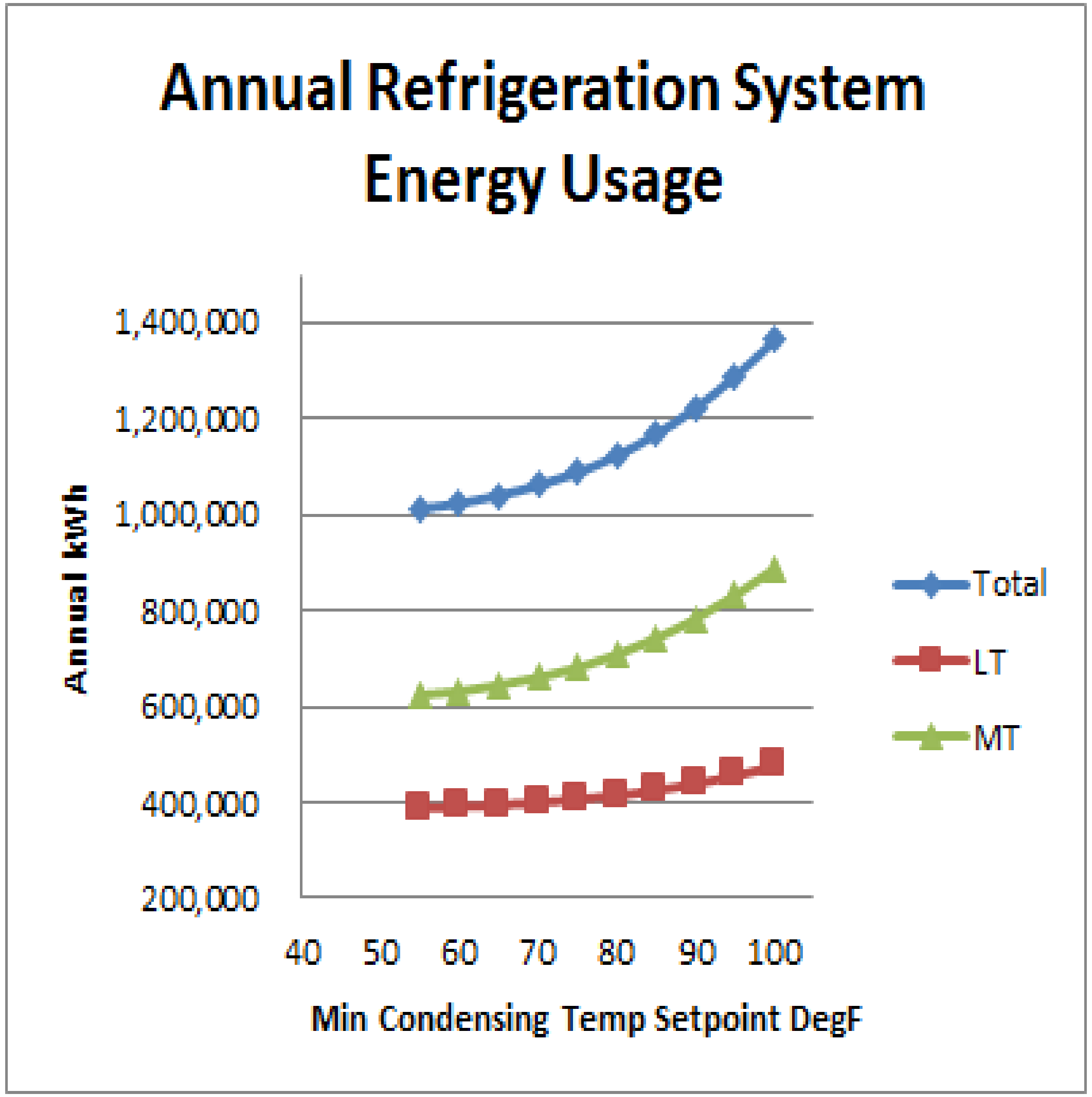
Suction Temp. °F	Condensing Temperature °F				
	90°	100°	110°	120°	130°
-40°	1.56	1.63	1.72	1.81	1.94
-30°	1.49	1.55	1.62	1.7	1.8
-20°	1.43	1.49	1.55	1.62	1.7
-10°	1.38	1.43	1.49	1.55	1.63
0°	1.34	1.38	1.43	1.49	1.56
5°	1.31	1.36	1.41	1.48	1.55
10°	1.29	1.34	1.39	1.44	1.52
15°	1.26	1.31	1.36	1.41	1.48
20°	1.24	1.28	1.33	1.38	1.44
25°	1.22	1.26	1.31	1.36	1.42
30°	1.2	1.24	1.28	1.33	1.39
40°	1.17	1.2	1.24	1.28	1.33

Bad

Good

How Much Gain For The Possible Pain?





1,222,000 kWh @90/90 min vs 1,060,000 kWh at 70/70 min = **162,000 kWh SAVED**
or @50/60 min, 192,000 kWh saved

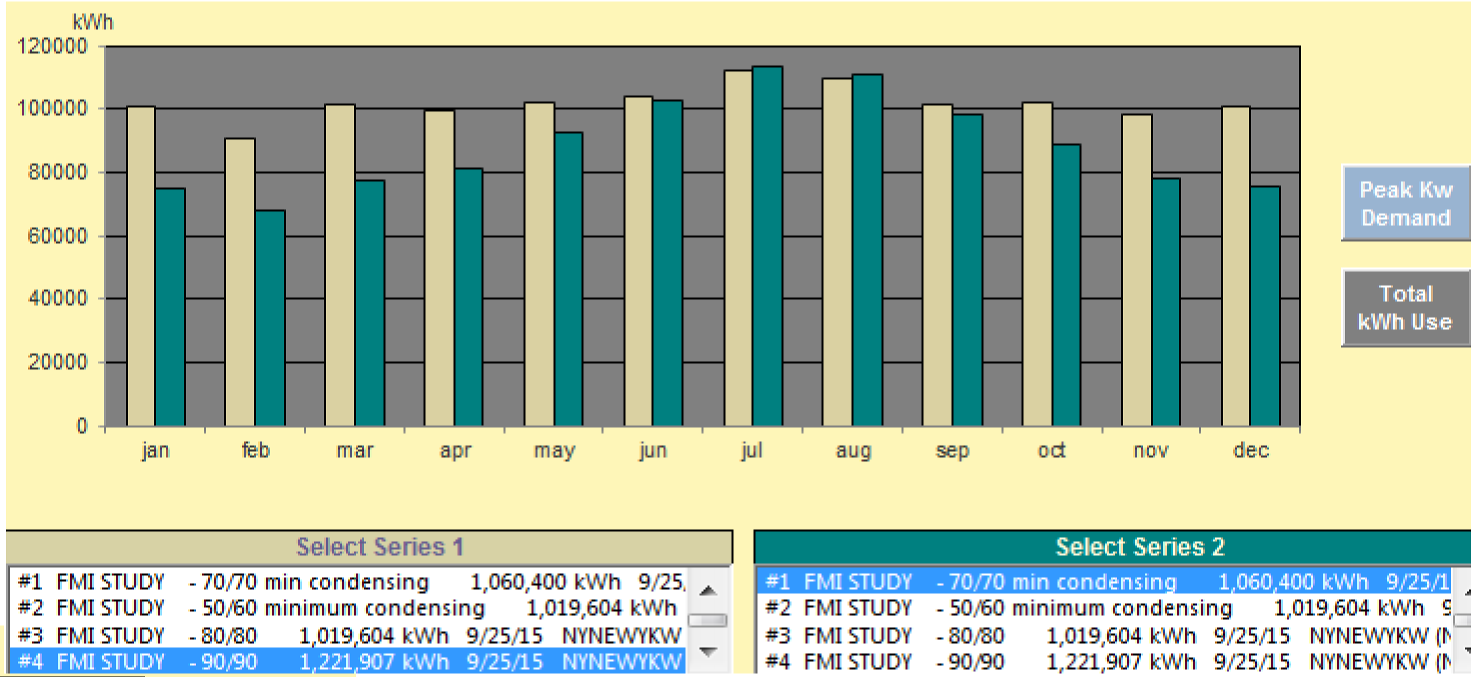
How Often and In What Climates Can You Gain from Lower Condensing Pressures?

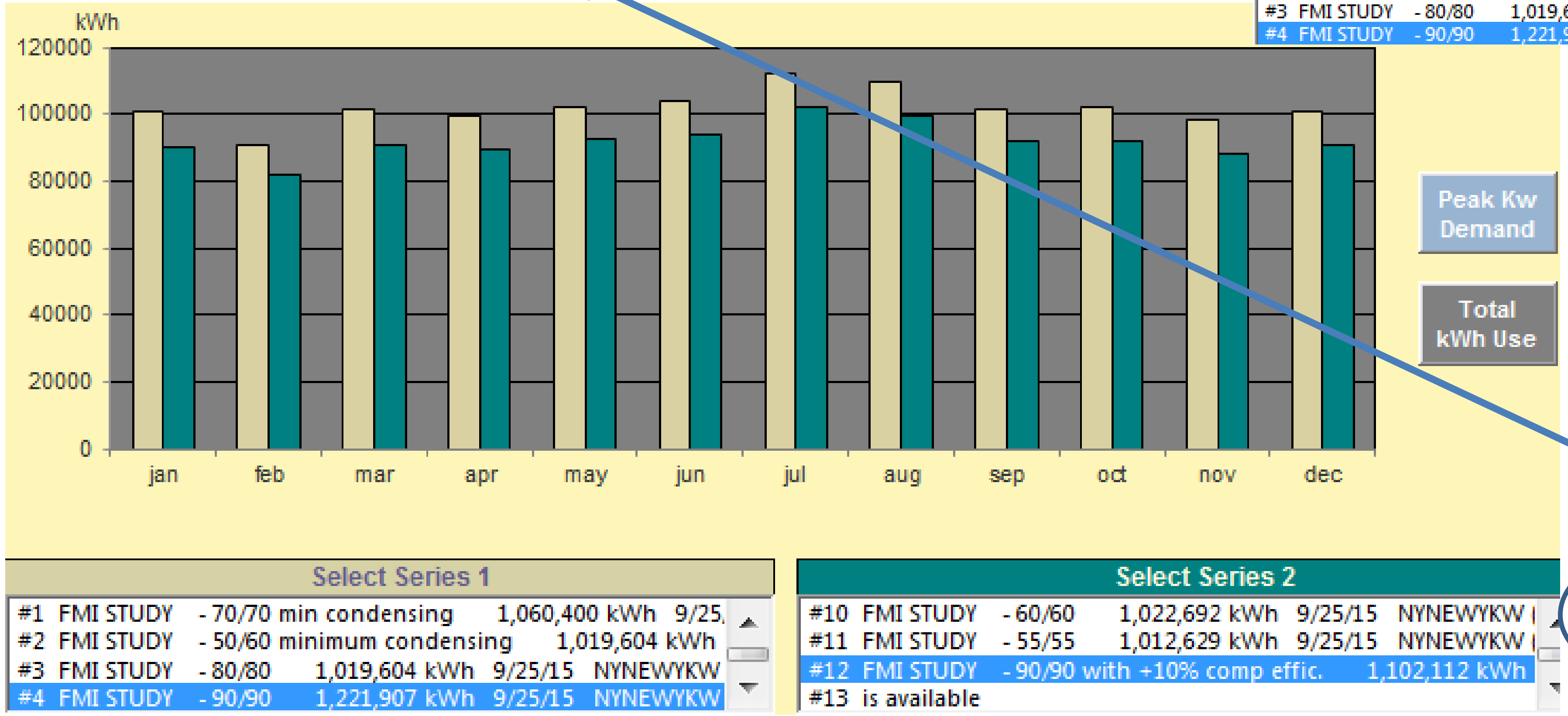
Quite Often, Almost All Climates

ASHRAE Data - Typical Year				
		ARLROCKW.WY2	AZPHNIXT.WY2	NYNEWYKW.WY2
		Little Rock AR	Phoenix AZ	New York, NY
Month	Bin Temp	DryBulb Hours	DryBulb Hours	DryBulb Hours
All	113 °F	0 hrs	1 hrs	0 hrs
All	107 °F	0 hrs	68 hrs	0 hrs
All	100 °F	9 hrs	281 hrs	0 hrs
All	94 °F	57 hrs	685 hrs	5 hrs
All	87 °F	500 hrs	919 hrs	64 hrs
All	81 °F	654 hrs	974 hrs	335 hrs
All	74 °F	1236 hrs	1010 hrs	826 hrs
All	68 °F	1116 hrs	872 hrs	968 hrs
All	61 °F	1246 hrs	1127 hrs	1303 hrs
All	55 °F	871 hrs	1084 hrs	972 hrs
All	48 °F	691 hrs	735 hrs	710 hrs
All	42 °F	870 hrs	604 hrs	1028 hrs
All	35 °F	641 hrs	305 hrs	1043 hrs
All	29 °F	478 hrs	87 hrs	793 hrs
All	22 °F	257 hrs	8 hrs	468 hrs
All	16 °F	104 hrs	0 hrs	212 hrs
All	9 °F	30 hrs	0 hrs	28 hrs
All	3 °F	0 hrs	0 hrs	5 hrs
Average Annual Temp		58 °F	68 °F	51 °F

Why This Measure Rather Than Others?

Savings From Reducing Head Pressures: 1,222,000 kWh @90/90 vs 1,060,000 kWh @ 70/70 = 162,000 kWh Saved or; @50/60 or 192,000 saved





Savings From Improving Compressor Efficiencies By a Nearly Impossible 10%: 1,222,000 kWh base vs 1,102,000 kWh +10% = 120,000 kWh saved

So What Are These Tables Telling Us?

- To make your refrigeration system more energy efficient, a lot more efficient:
  - **lower the temperature of your high temperature reservoir (the temperature you reject heat to), that is, allow system operation at lower head/ condensing temperatures and pressures, whenever outside temperatures present this opportunity.**
  - This means lowering pressure control setpoints for your condenser fans, or if water-cooled then water regulating valves, plus holdback valve and other system control settings that artificially maintain high condensing press./temps during periods of low outside temperatures
  - **Also** raise the temperature of the low temperature reservoir (the temperature at which you accept heat – evaporator temperature or suction temperature) but that is a subject for next year's presentation

- Sounds simple, yes? Sadly, it is not.

Real World Refrigeration

Should Be

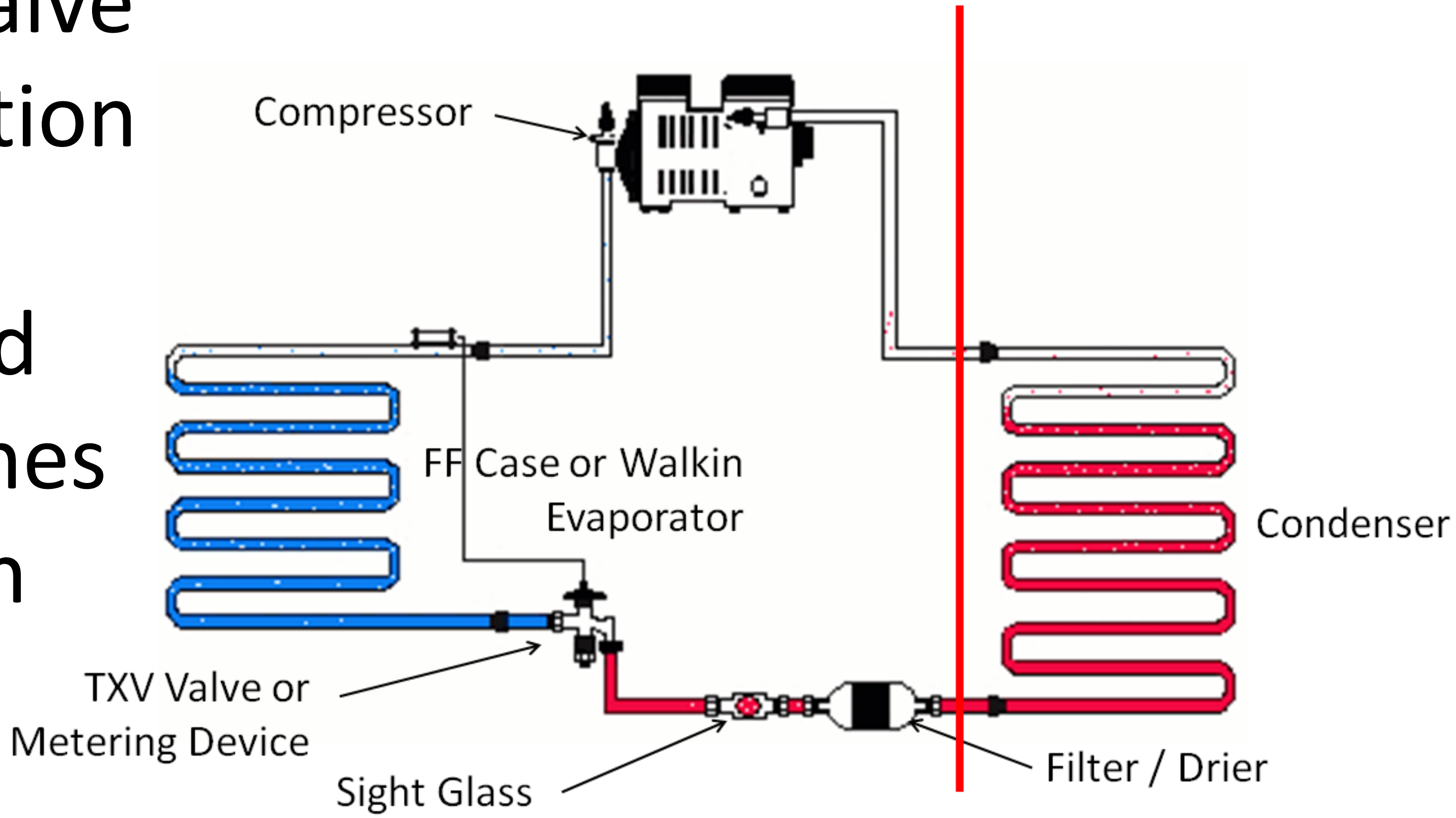
Generally Is

Generally Is

Required Product temperature	Typical Actual Refrigeration Temperature	Outside Temp	Possible Heat Rejection Temperature (10°F TD Condenser)	Typical Heat Rejection Temperature	Best Possible COP	Typical Base COP	**Minimum** Efficiency Loss
-10 °F	-20 °F	40 °F	50 °F	90 °F	6.28	4.00	-36%
-10 °F	-20 °F	50 °F	60 °F	90 °F	5.50	4.00	-27%
-10 °F	-20 °F	60 °F	70 °F	90 °F	4.89	4.00	-18%
-10 °F	-20 °F	70 °F	80 °F	90 °F	4.40	4.00	-9%
-10 °F	-20 °F	80 °F	90 °F	90 °F	4.00	4.00	0%
-10 °F	-20 °F	90 °F	100 °F	100 °F	3.66	3.66	0%

Why Are Condensing (Heat Rejection) Temp/Press Setpoints Commonly Set So High?

- To maintain a high differential pressure across TXV valves to promote good valve operation or make up for poor operation
- To avoid the formation of flash gas (refrigerant in vapor rather than liquid form) in refrigeration system liquid lines
- To keep compressor load high enough during periods of low temperature operation to maintain steady system operation
- **<u>More often than not, though, just habit</u>**



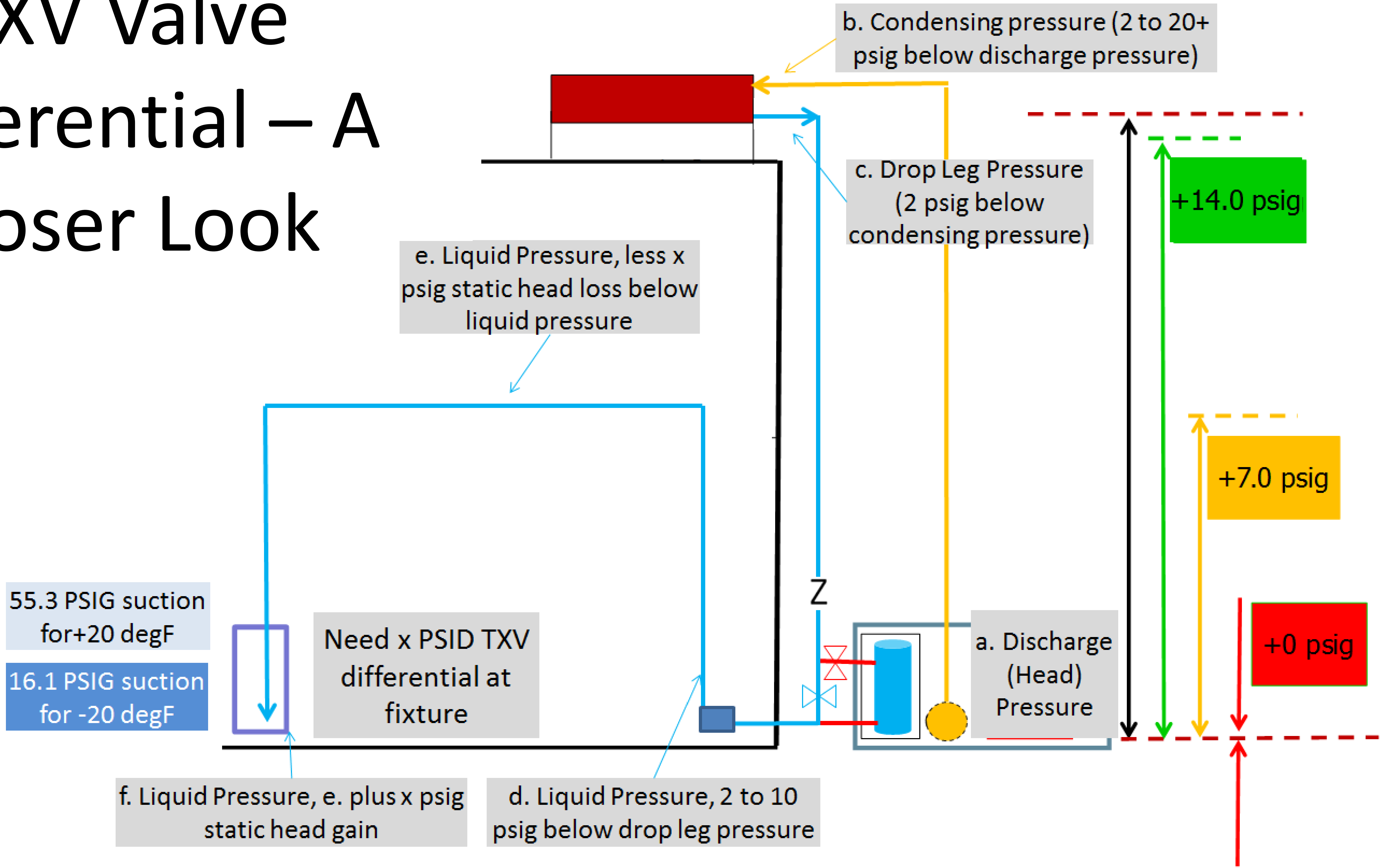
High TXV Valve Pressure Differential Obstacle to Lowering Condensing Pressures

- Conventional TXVs thought to require 100 PSID for good operation, ‘balanced port’ TXVs something less, 40 to 60 PSID
- Even with conventional TXVs, 70 deg F should not be an issue!!

Average annual temp. in PA

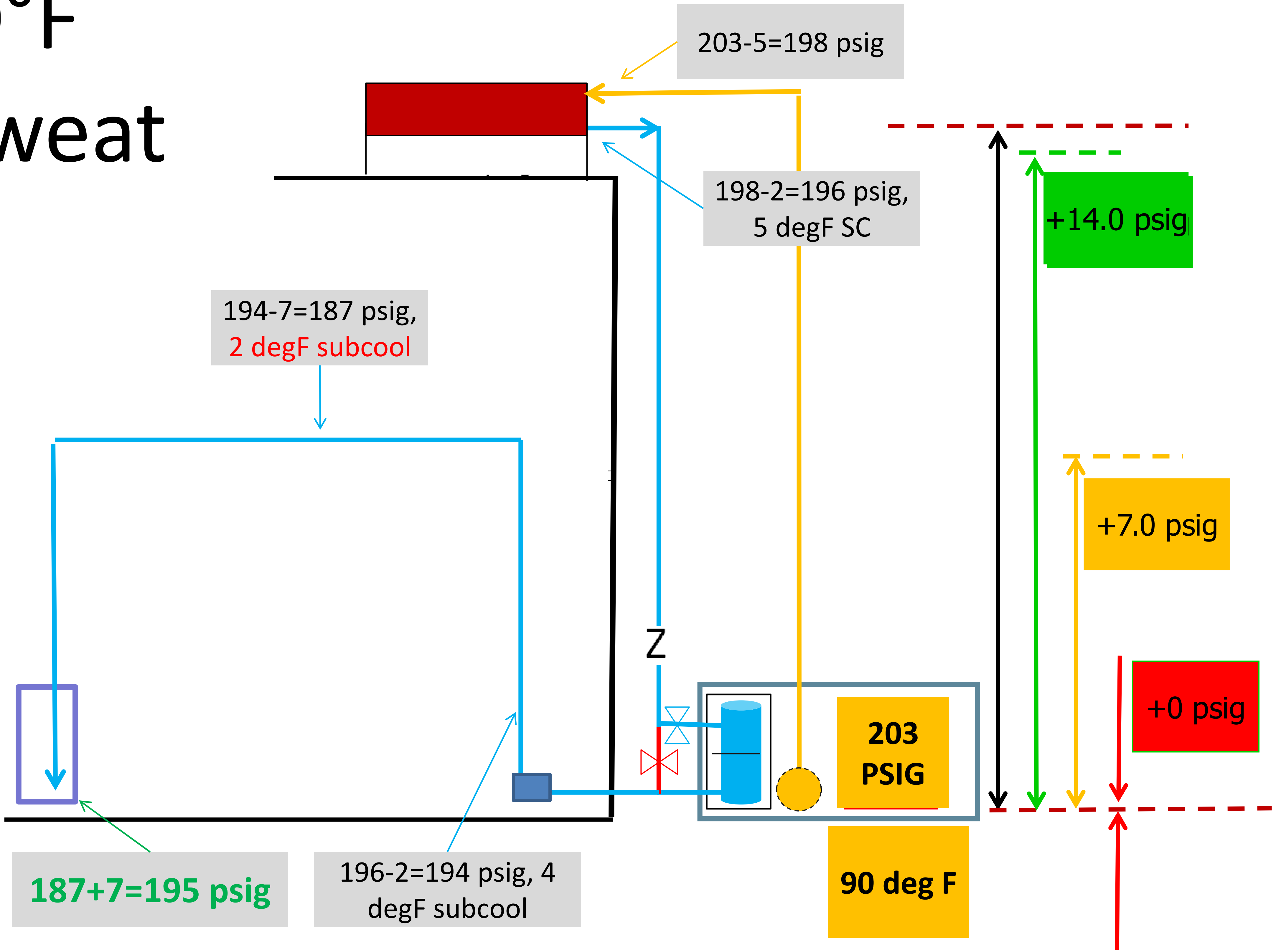
Required Product Temperature	Typical Actual Refrigeration Temperature	Associated (Saturation) Pressure	Possible Heat Rejection Temperature (10°F TD Condenser)	Associated (Saturation) Pressure	Valve Pressure Diff.	Typical Heat Rejection Temperature	Associated (Saturation) Pressure	Valve Pressure Diff.	Efficiency Loss @ 90°F Minimum Heat Rejection Temperature
+30	+20 °F	55.3 PSIG	50 °F	103.9 PSIG	48.6 PSIG	90 °F	186.8 PSIG	131.5 PSID	-57%
+30	+20 °F	55.3 PSIG	60 °F	124.6 PSIG	69.3 PSIG	90 °F	186.8 PSIG	131.5 PSID	-43%
+30	+20 °F	55.3 PSIG	70 °F	147.9 PSIG	92.6 PSIG	90 °F	186.8 PSIG	131.5 PSID	-29%
+30	+20 °F	55.3 PSIG	80 °F	173.9 PSIG	118.6 PSIG	90 °F	186.8 PSIG	131.5 PSID	-14%
+30	+20 °F	55.3 PSIG	90 °F	202.9 PSIG	147.6 PSIG	90 °F	186.8 PSIG	131.5 PSID	0%
+30	+20 °F	55.3 PSIG	100 °F	236.0 PSIG	180.7 PSIG	100 °F	236.0 PSIG	180.7 PSID	0%

TXV Valve Differential – A Closer Look



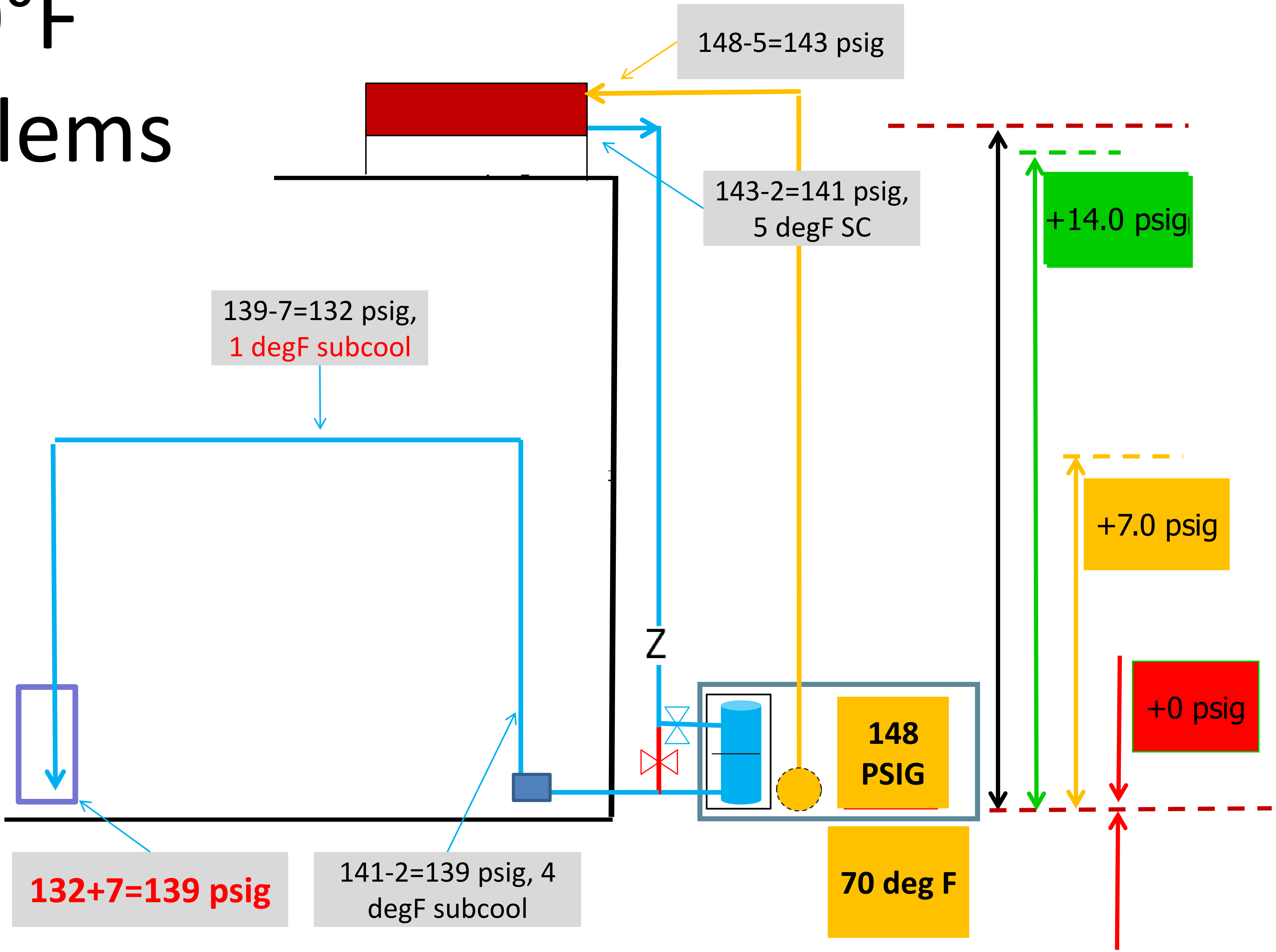
90°F
no sweat

+20 °F =55.3 PSIG suction, so **need 155** PSIG at MT fixture for 100 PSID for TXV



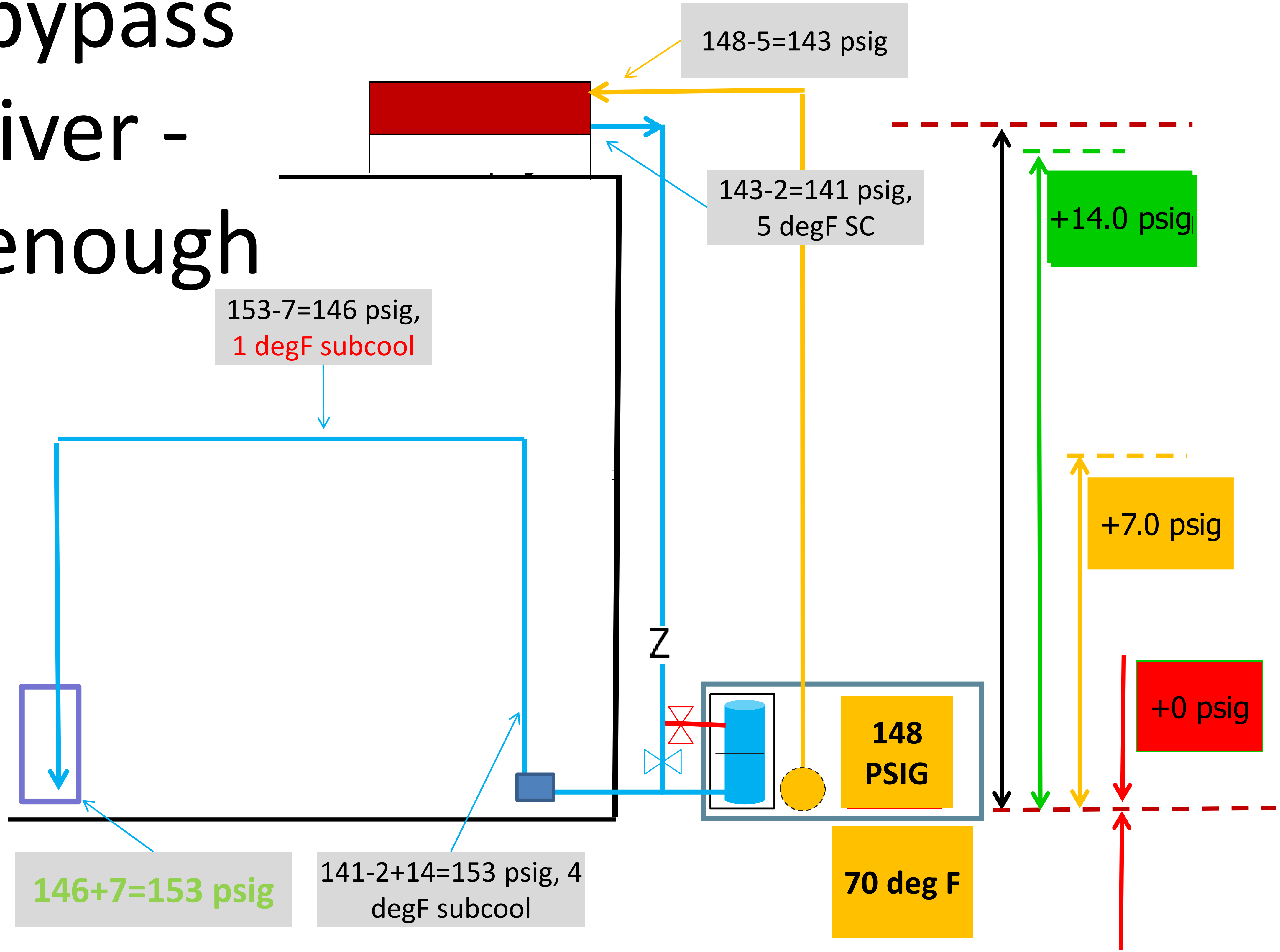
70°F problems

+20 °F =55.3 PSIG suction, so **need 155** PSIG at MT fixture for 100 PSID for TXV

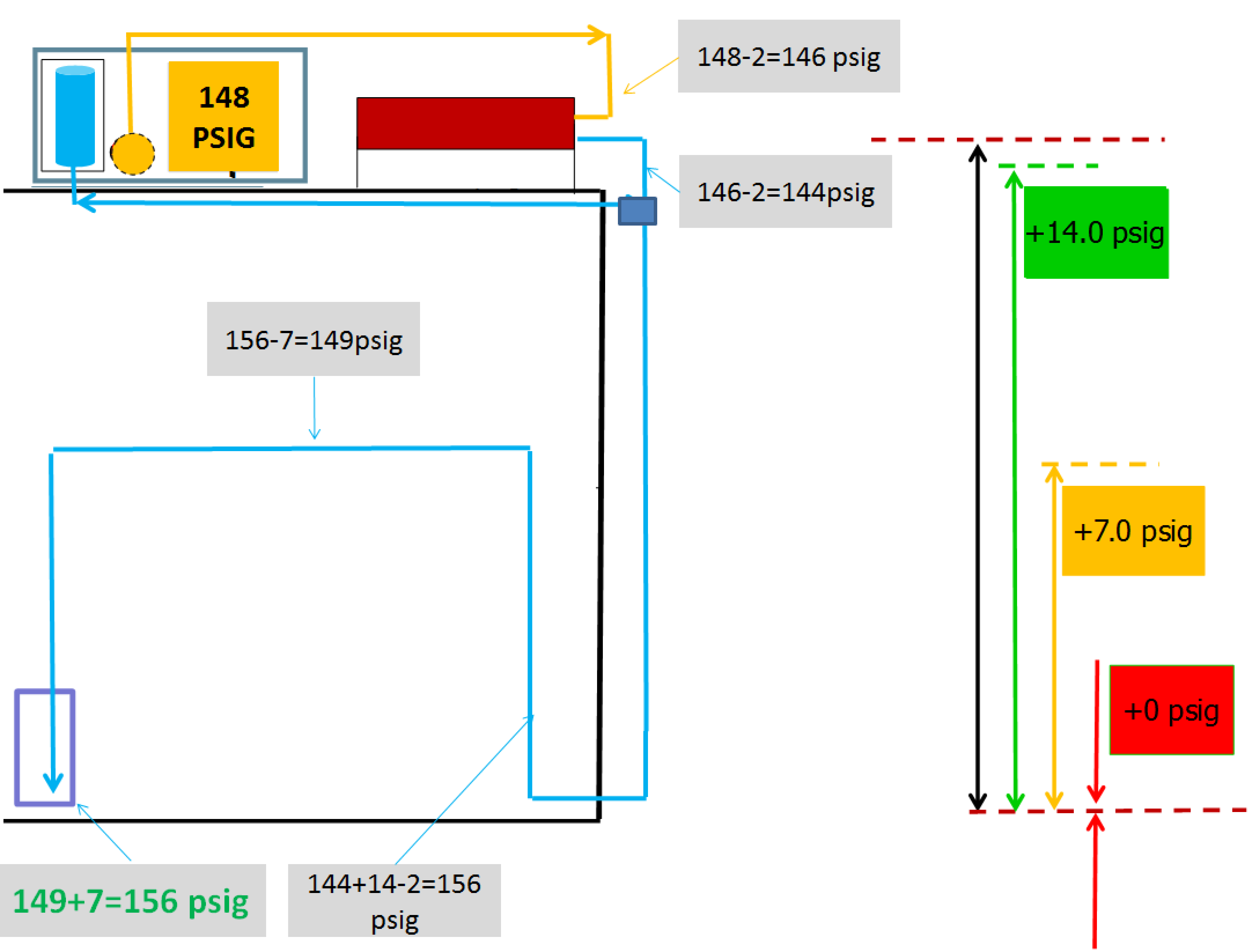


70°F bypass receiver - close enough

+20 °F =55.3 PSIG suction, so **need 155** PSIG at MT fixture for 100 PSID for TXV



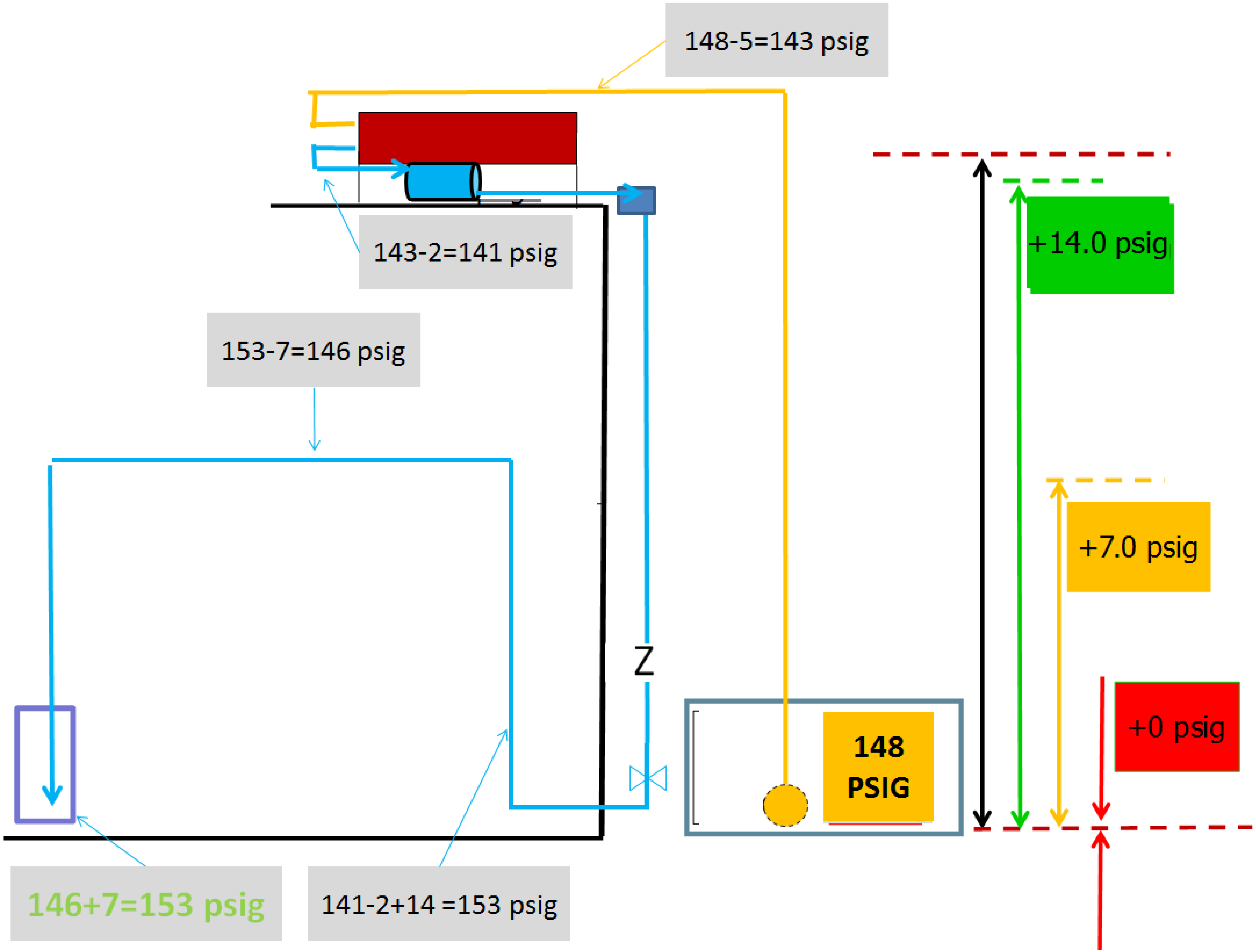
70°F another way



+20 °F =55.3 PSIG suction, so **need 155** PSIG at MT fixture for 100 PSID for TXV

70°F a retrofit way

+20 °F =55.3 PSIG suction, so **need 155** PSIG at MT fixture for 100 PSID for TXV



Removing High TXV Valve Press. Differential Obstacle to Lowering Condensing Pressures

- Why not remove all TXV obstacles to efficient system operation (being able to take advantage of low outside temperatures to reduce energy usage) – use EEVs instead
- Pulse or stepper, both work well, also resist clogging and other common TXV problems
- 2 PSID sufficient for EEVs!

Removing Flash Valve Obstacles To Lowering Condensing Temperatures (this is the hard stuff)

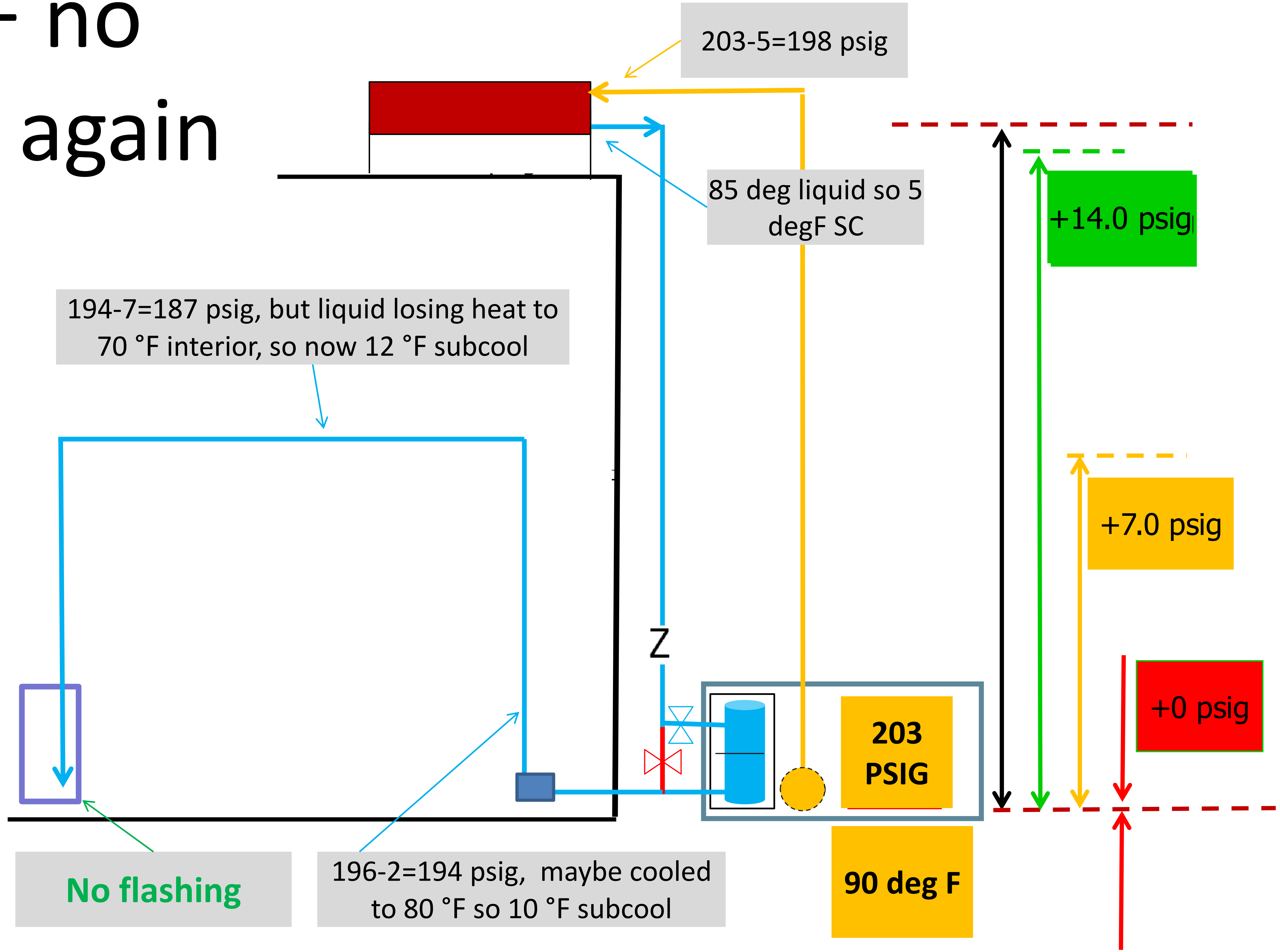
- When flash gas occurs, liquid refrigerant flow through the TXVs ceases and the refrigeration system may inadvertently pump itself down
- Commonly reported as “refrigerant logging in receiver”
- Caused by a drop in liquid pressure, or an increase in liquid temperature, or a combination of the two, that results in the liquid dropping below saturation conditions and flashing as a result

Avoiding Flash Gas

- What’s working against us with regard to flash gas as we try to lower condensing pressures?
  - Pressure drop in liquid lines and valves that lowers liquid pressure
  - Temperature gain in liquid lines that increases liquid temperature (what does that tell you about dropping minimum condensing temperatures in stores with no liquid line insulation – nothing below 70 degF)
  - Lines run in unconditioned ceiling plenum areas
  - Low refrigeration loads – long ‘residence times’ in liquid lines
- What’s working for us
  - Careful system design and resulting low liquid line pressure drops
  - Mechanical subcoolers
  - Condenser flooding and increased subcooling at condenser outlet

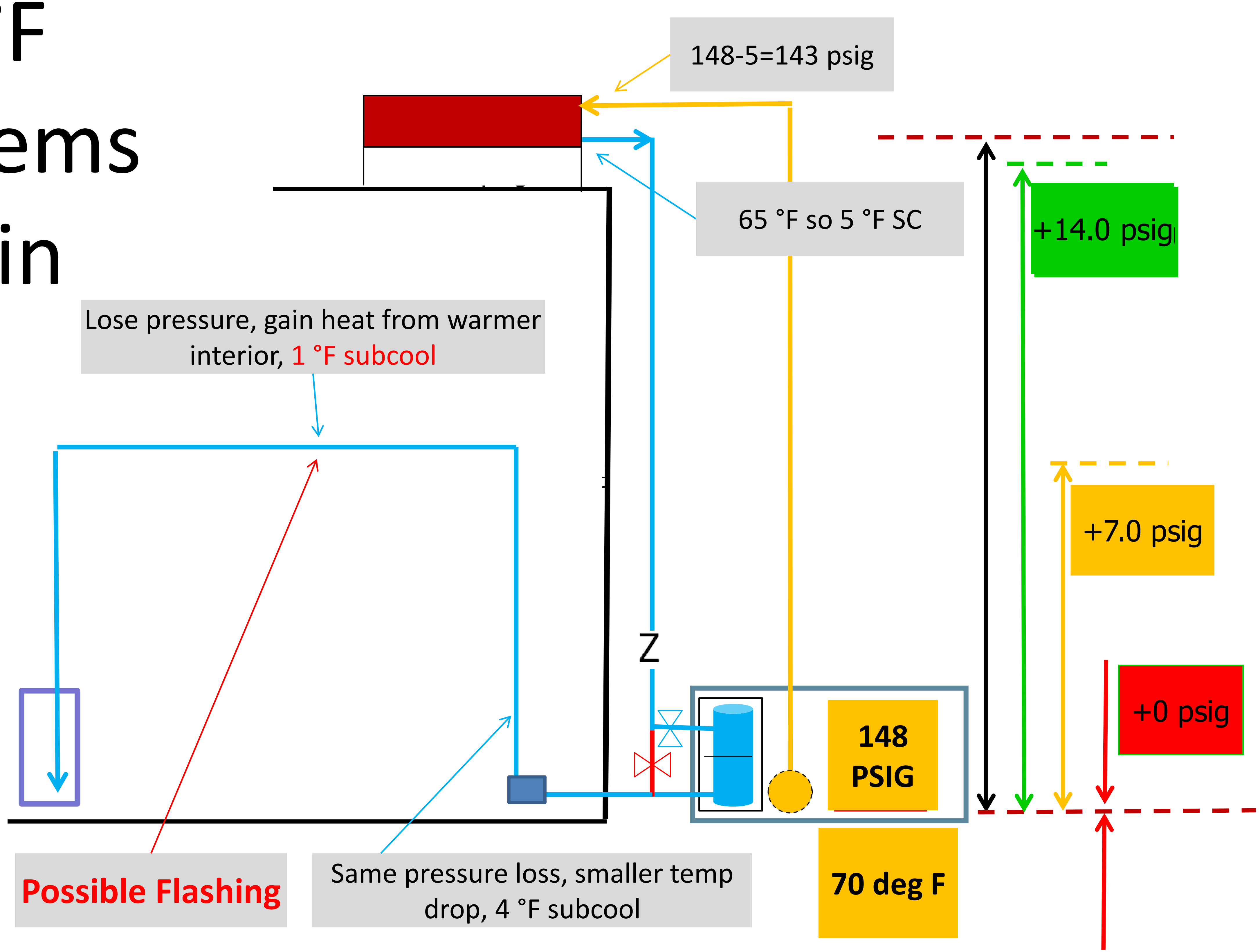
90°F no sweat again

@ 50°F outdoor temp



70°F problems again

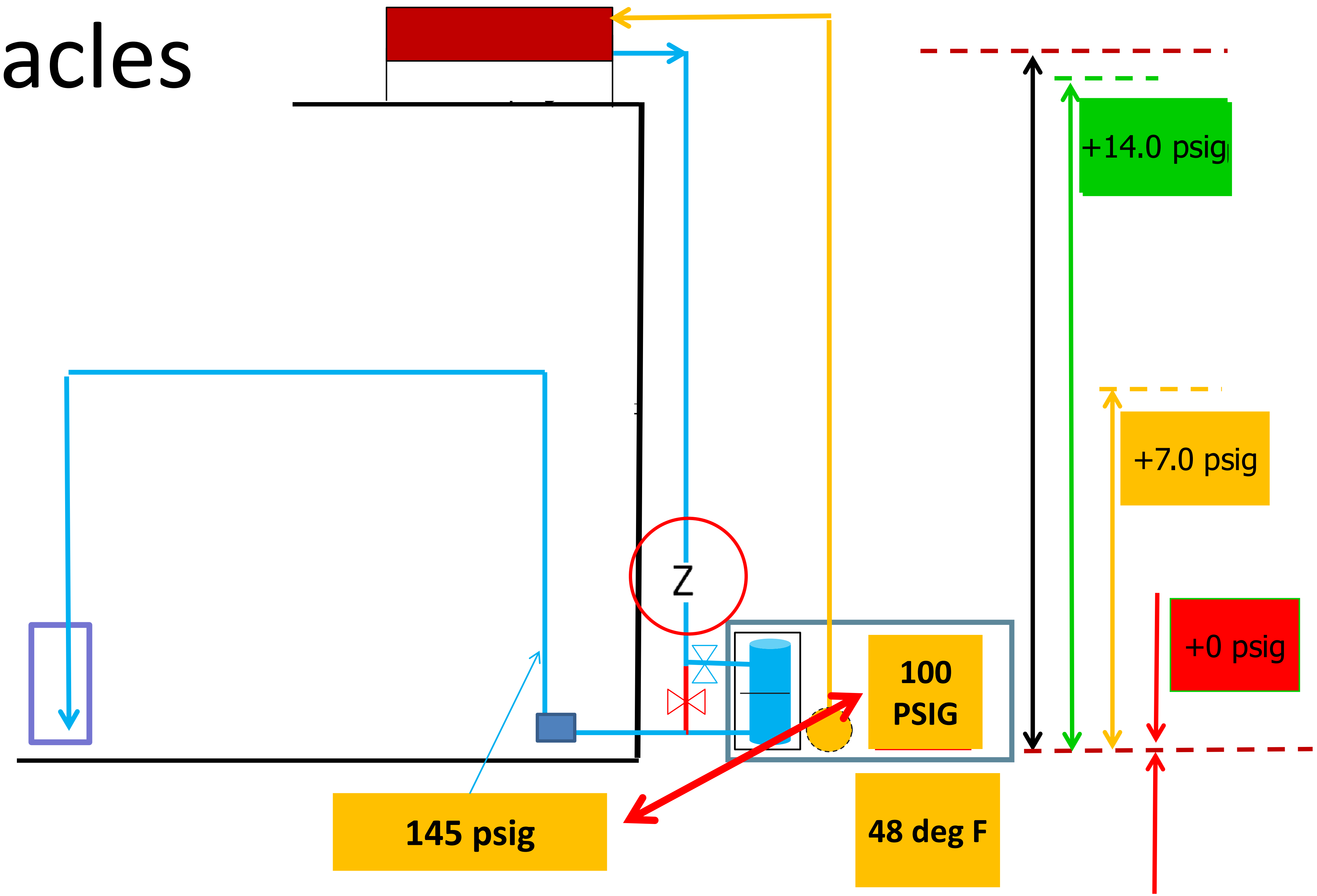
@ 50°F outdoor temp



Other Potential High Side Issue At Low Condensing Pressure Operating Regimes

- Death spiral scenario
  - Low load, low outside temperatures, compressor cycles off, sudden drop in discharge pressure
  - System goes upside down, liquid pressure now higher than discharge pressure
  - Discharge pressures collapse
- Contributing factors
  - Unvented receivers, drop leg check valves, split condenser, undersized (even correctly sized) drop leg piping

Other Obstacles



Other Potential High Side Issue At Low Condensing Pressure Operating Regimes

- Receivers in warm compressor rooms
- If the receiver is at 80 degF, so is your refrigeration system condensing pressure no matter what your fan setpoints, and you are probably backing a lot of refrigerant up into the condenser

Wrap Up

- Do lower system operating condensing pressures as much as possible given system geometry and characteristics
- Carefully coordinate condenser fan setpoints, holdback valve (where used) setpoints, receiver temperature environments, and other compressor rack operating parameters to avoid flash gas and other problems that can occur under lower high side operating pressure regimes
- For new stores, consider EEVs and placing receivers at the condensers