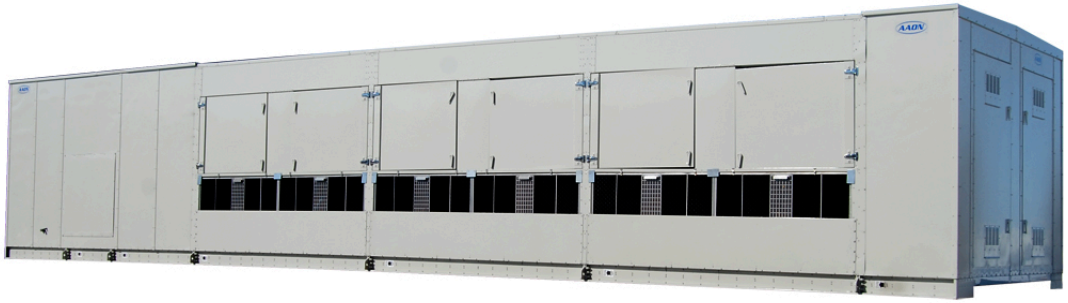
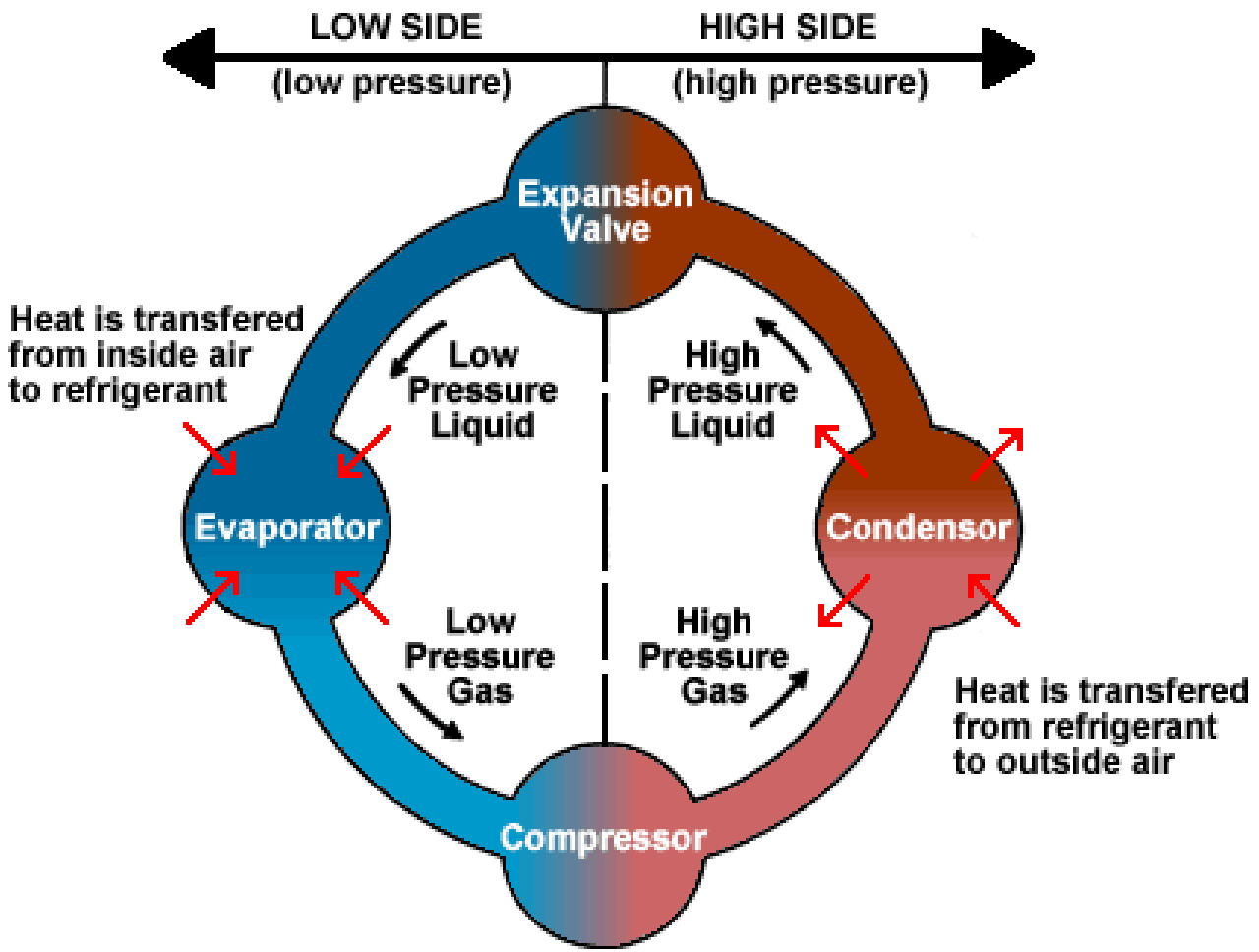
The Basics - Refrigeration Cycle

Jerry Cohen
President
Jacco & Assoc.

Agenda

- Basic Refrigerant Cycle
- P/h Chart
- Compressor Options
- Condenser Options
- Head Pressure Control
- Thermal Expansion
- Evaporator Options
- Lift
- Evaporative Condensing
- Water Treatment
- Refrigerant Piping




LOW SIDE
(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor

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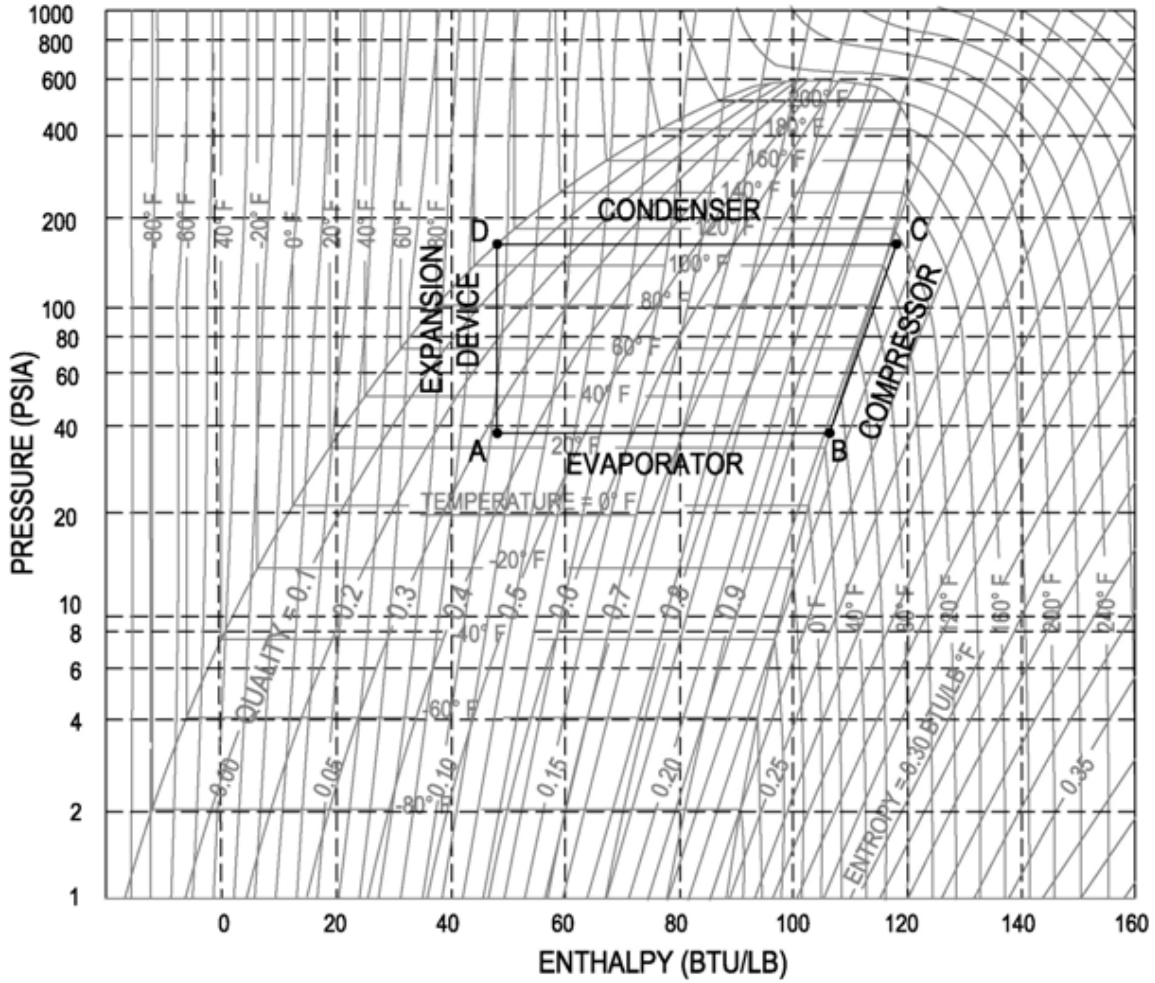
P/h Chart - Isotherm



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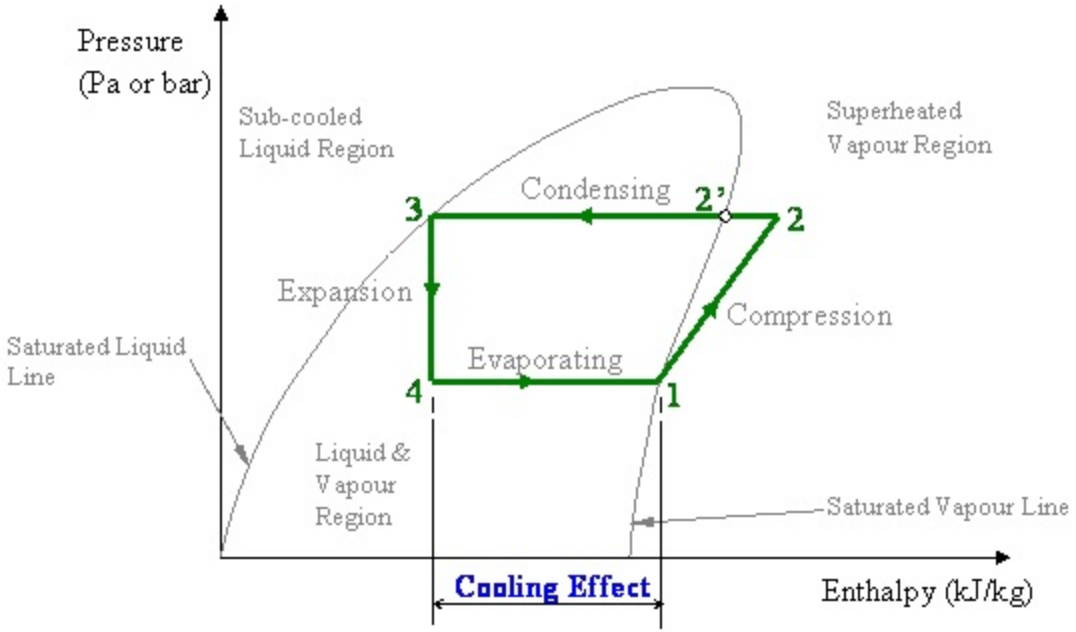
P/h Chart



p-H Diagram of Refrigeration Cycle

Superheat & Subcooling

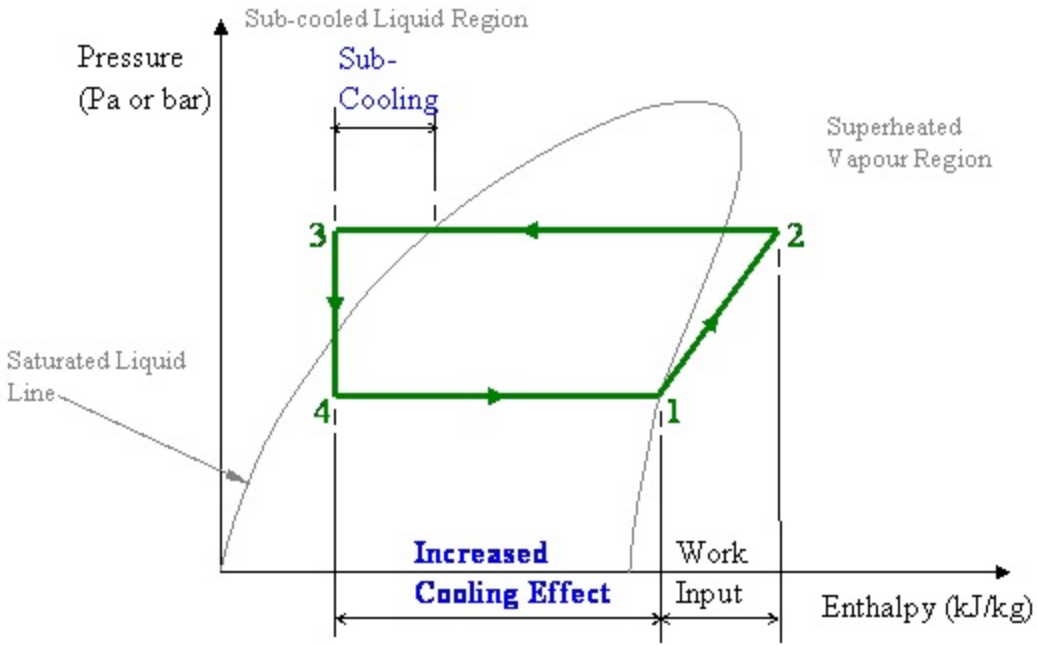
Defining Superheat
Superheat is defined as the difference between the temperature at which the refrigerant boils at the given pressure in the evaporator, and the temperature of the refrigerant gas as it leaves the evaporator. In essence, it's how much extra temperature the refrigerant picks up after it has boiled

Heating of a gas, at a constant pressure, above the point at which it has boiled.

Defining Sub-Cooling
Sub-Cooling is defined as the difference between the temperature at which the refrigerant condenses at the given pressure in the condenser, and the temperature of the liquid refrigerant gas as it leaves the condenser. In essence, it's how much extra temperature the refrigerant cools after it has condensed.

Cooling of a liquid, at a constant pressure, below the point at which it was condensed.

P/h Chart



p-H Diagram of Refrigeration Cycle with Sub-Cooling

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What is a Compressor?

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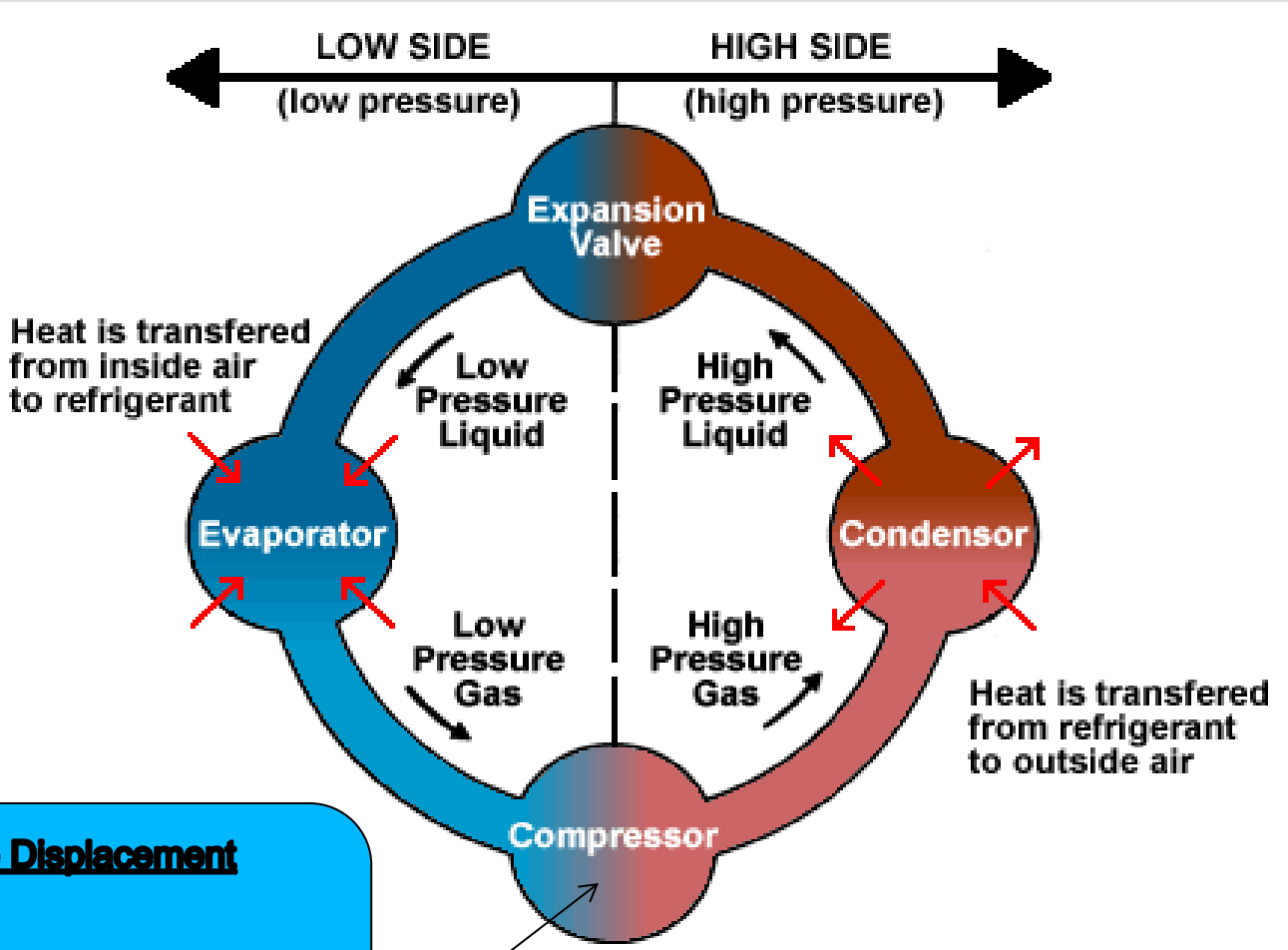

Positive Displacement
- Scroll
- Screw
- Reciprocating

Non Positive Displacement
-Centrifugal

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Scroll Compressor

- Limited to ~ 25 HP
- Tandem Compressor Options
- With or Without VFD

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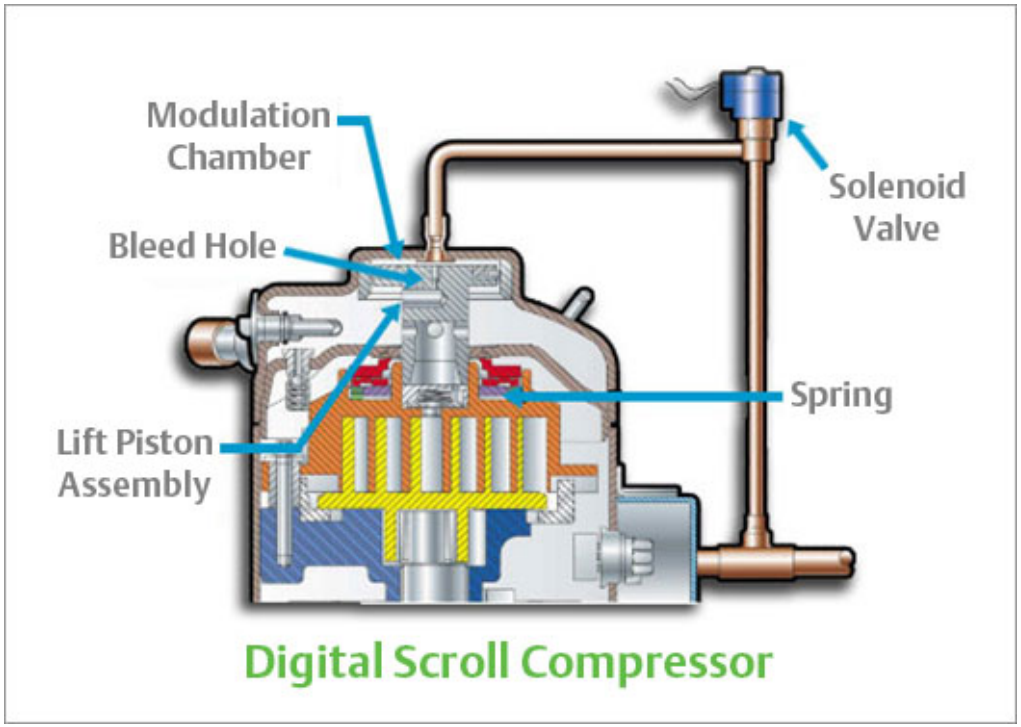
Digital Scroll Compressor

- Digital Scroll



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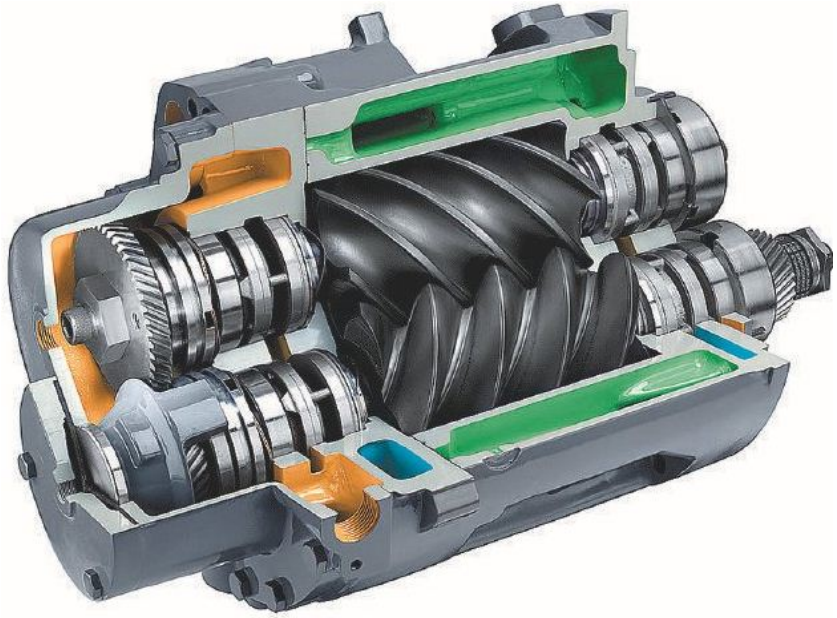
Screw Compressor

- Limited to ~ 500 HP
- With or Without VFD



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Reciprocating Compressor

- Limited to ~ 100 HP

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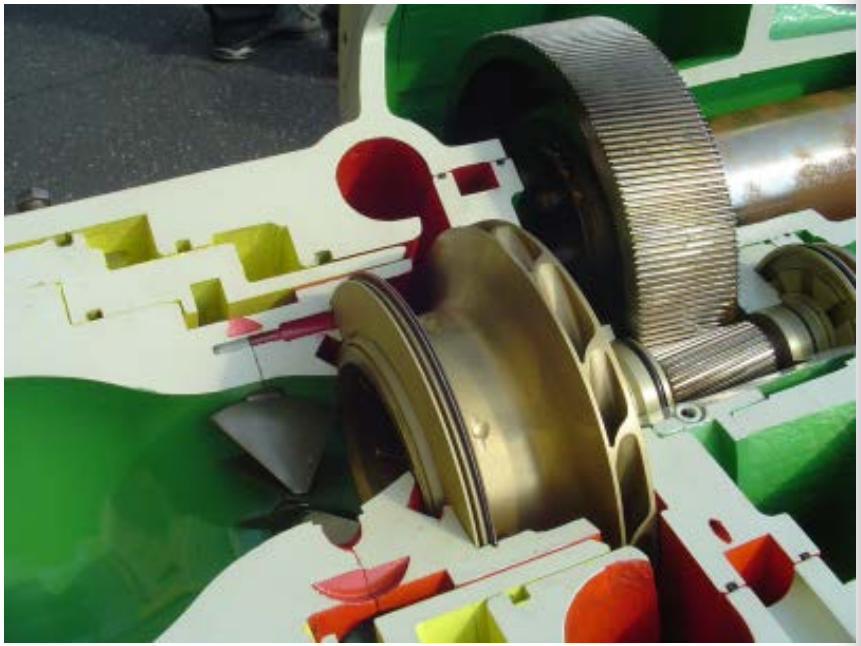
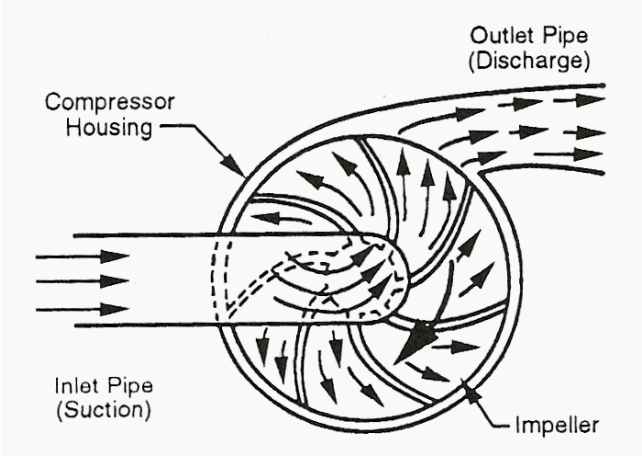
Centrifugal Compressor

- Virtually Unlimited
- With or Without VFD





Non Positive Displacement compressors raise the pressure and temperature of the refrigerant by converting kinetic energy into pressure.

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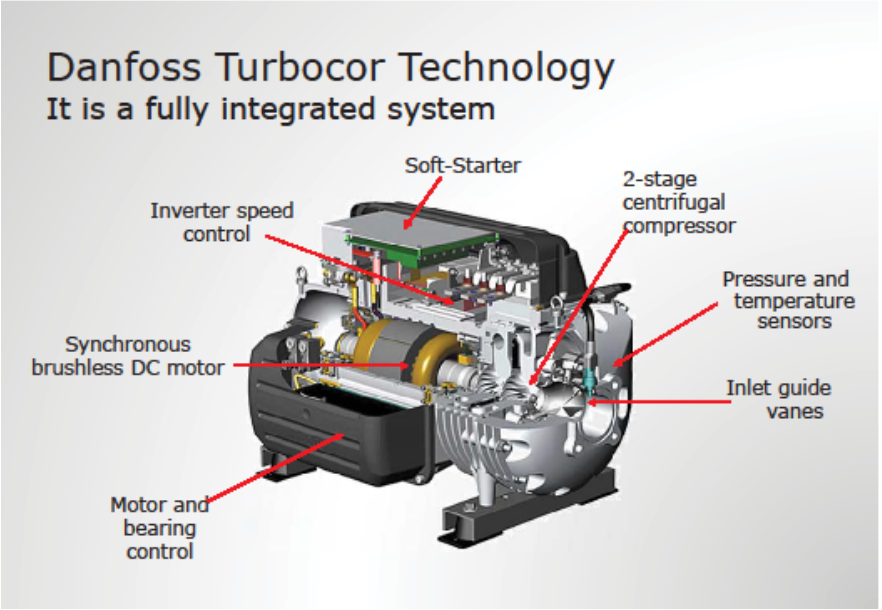
Centrifugal Compressor

- Oil Free Magnetic Bearing Centrifugal
- With VFD
- Limited to 75 & 150 HP



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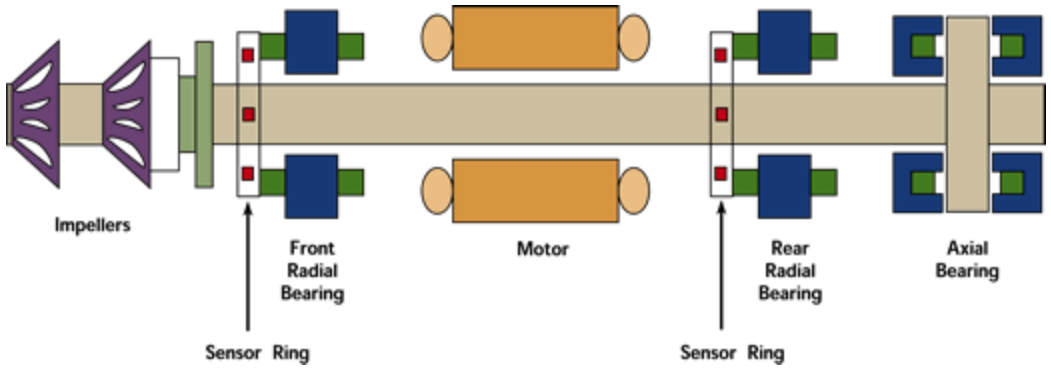
Magnetic Bearings

- Oil Free Magnetic Bearing Centrifugal
- Limited to 75 & 150 HP



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Hot Gas Bypass

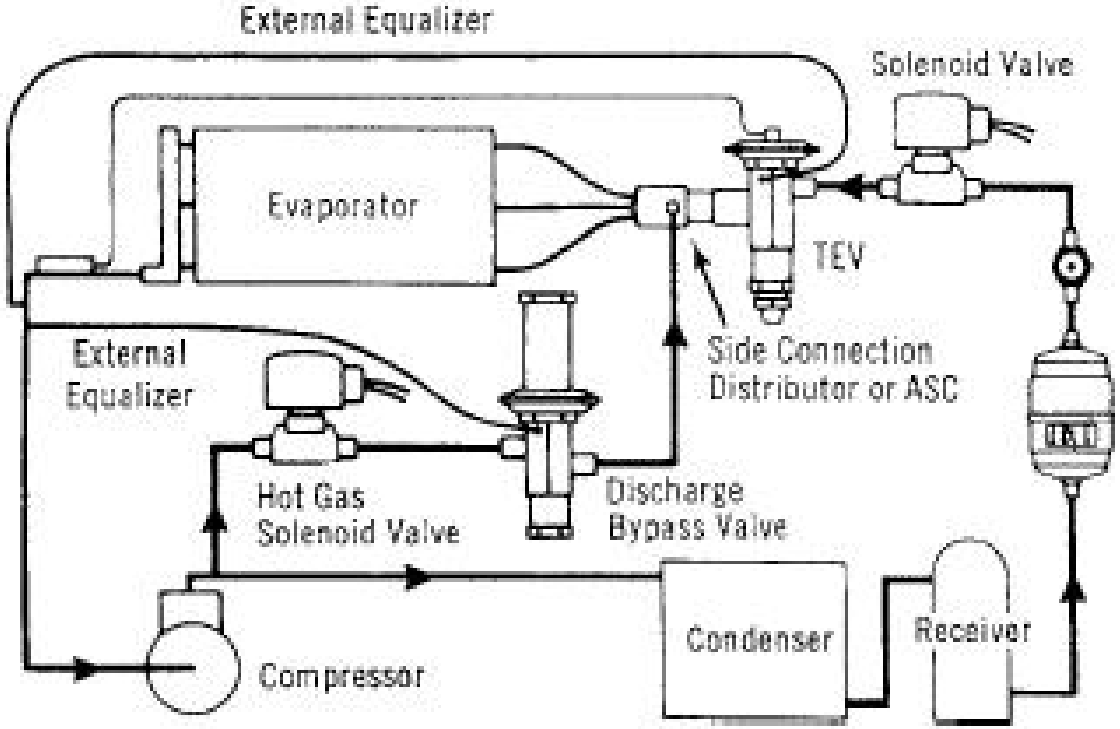
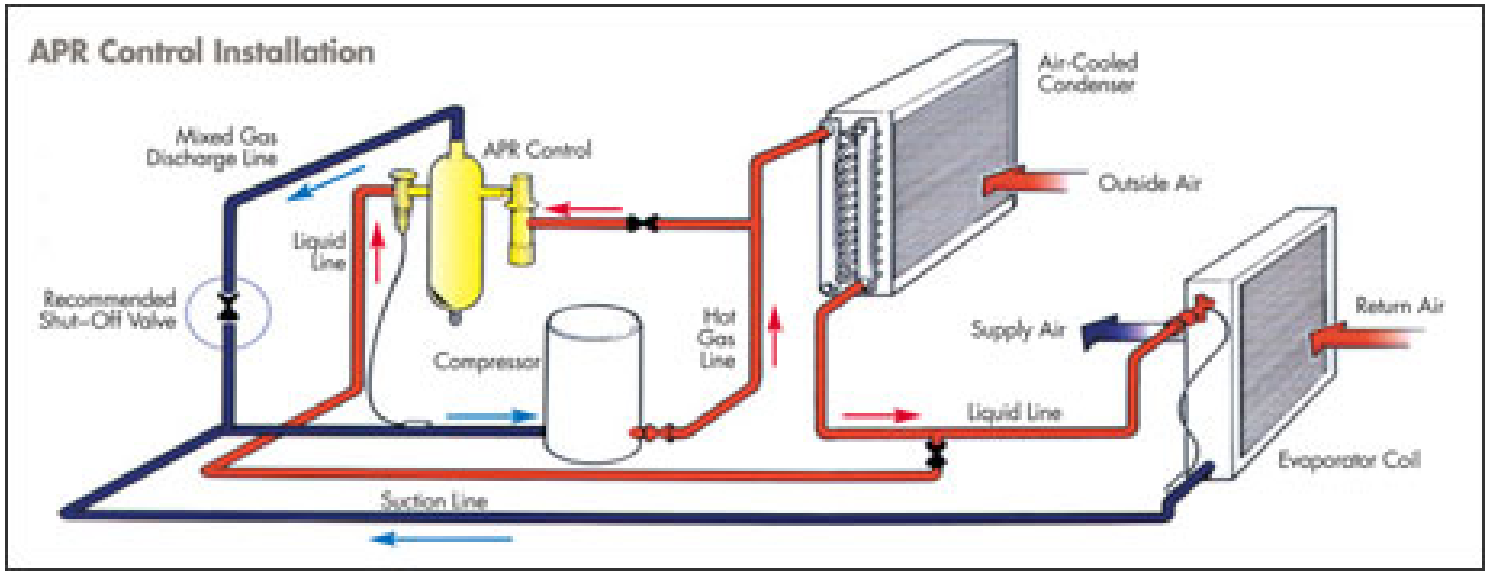
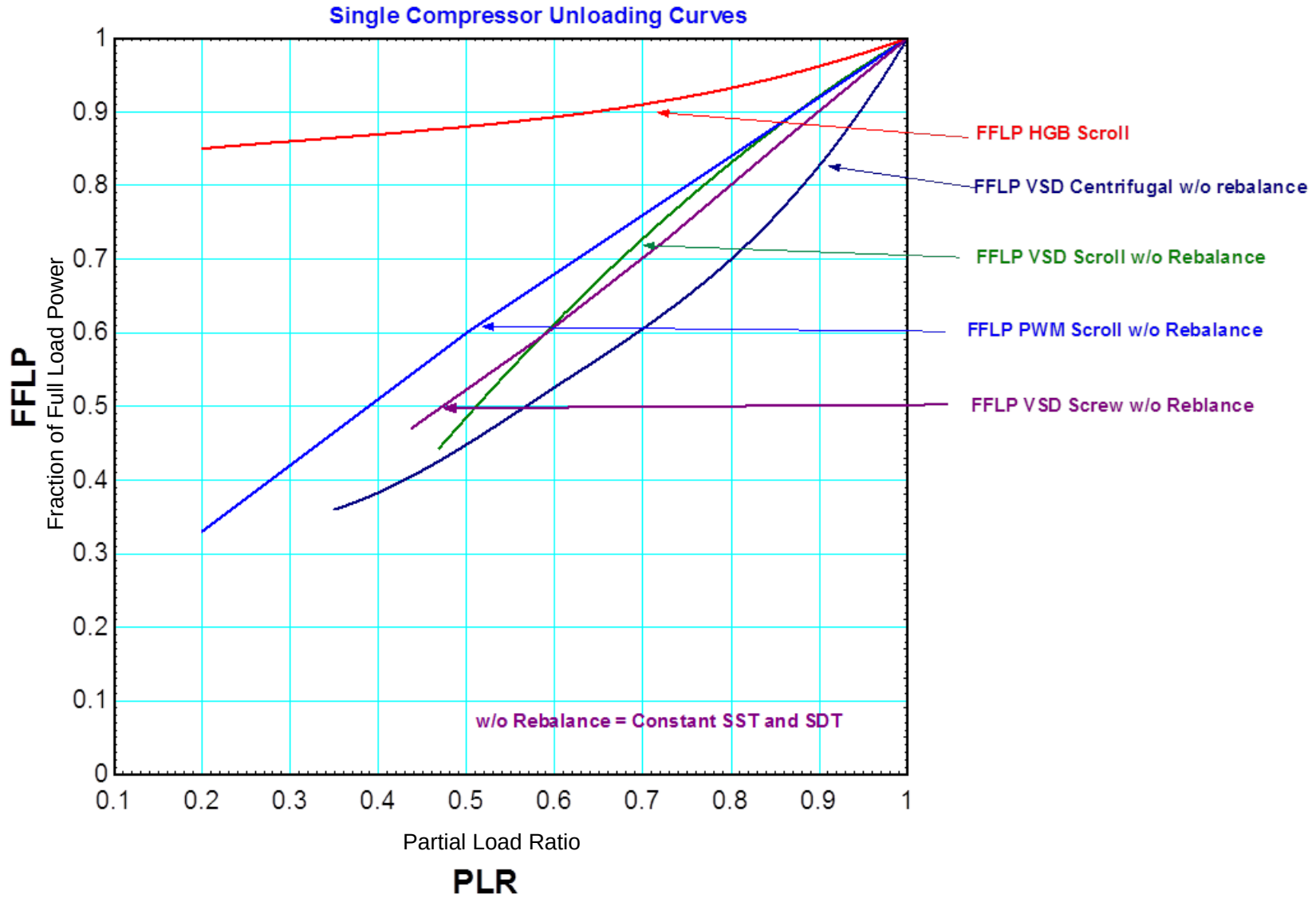


Figure 11-38 Connection arrangement for a discharge-bypass valve. (*Courtesy of Sporlan Valve.*)

Hot Gas Bypass




Single Compressor Unloading Curves
FFLP
Fraction of Full Load Power
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Partial Load Ratio
PLR
FFLP HGB Scroll
FFLP VSD Centrifugal w/o rebalance
FFLP VSD Scroll w/o Rebalance
FFLP PWM Scroll w/o Rebalance
FFLP VSD Screw w/o Reblance
w/o Rebalance = Constant SST and SDT

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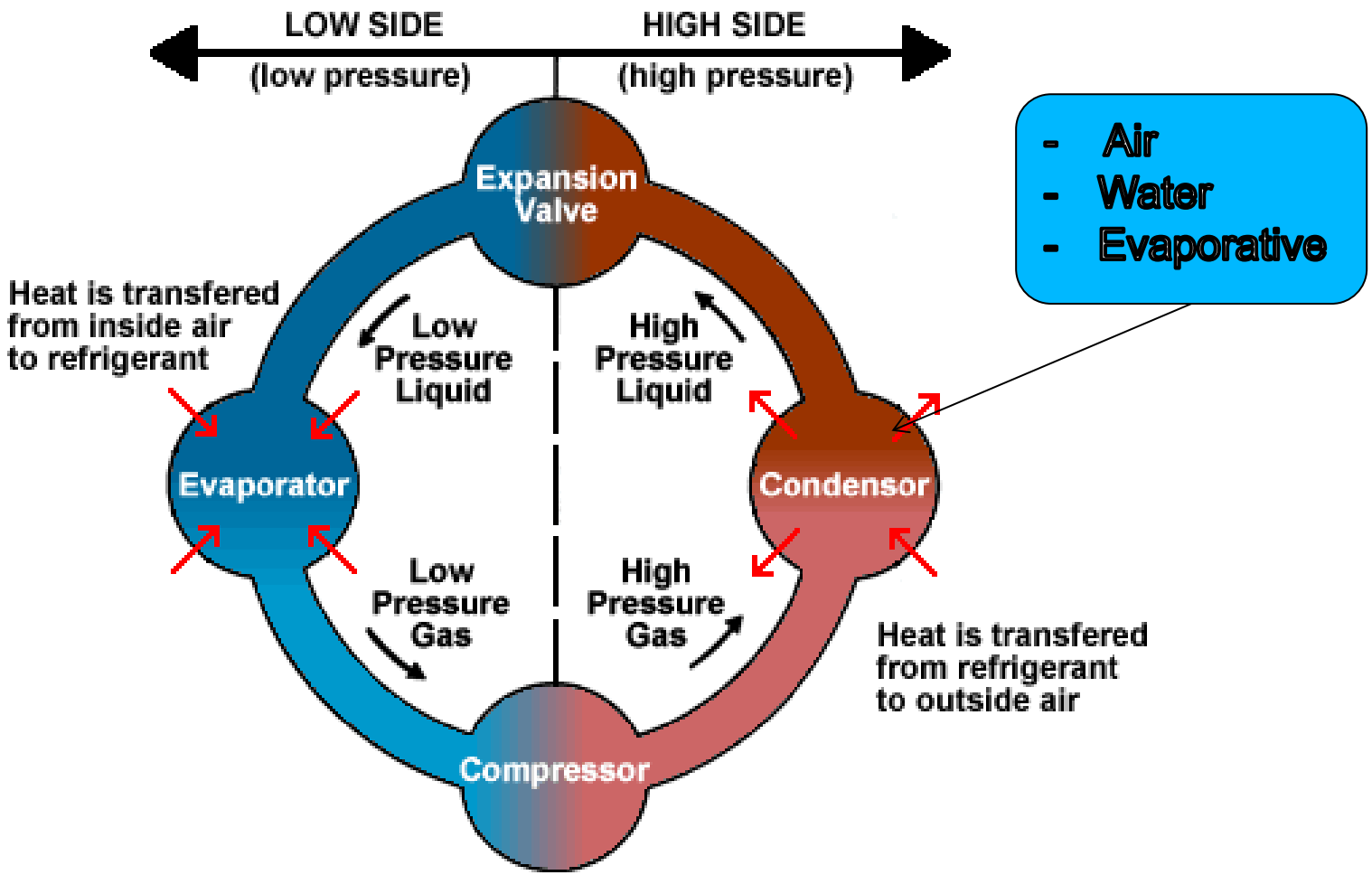
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(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Compressor
Heat is transfered from refrigerant to outside air
- Air
- Water
- Evaporative

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Condenser – Air Cooled

- Given 95 db/75 wb
- 125 Condensing Temperature

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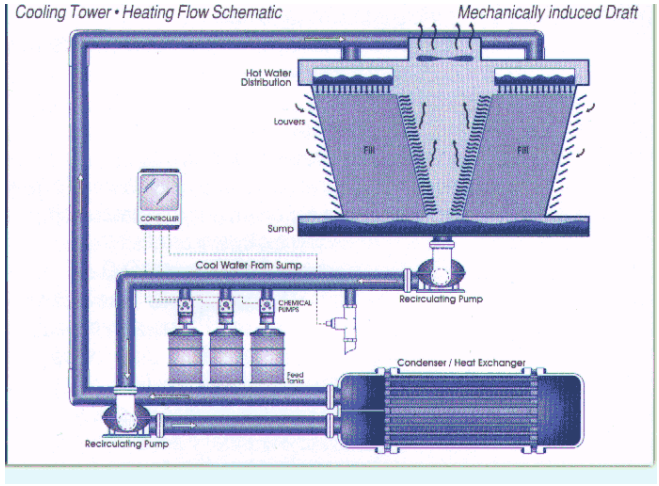
Condenser – Water Cooled

- Given 95 db/75 wb
- 105 Condensing Temperature



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Condenser – Evaporative Cooled

- Given 95 db/75 wb
- 105 Condensing Temperature
- Water Cooled WITHOUT the Condenser Pump

The Compressor is a Pump

- Air Cooled
- 35 Suction & 125 Condensing

- Water & Evaporative Cooled
- 35 Suction & 105 Condensing

Refrigerant Pressure/Temperature Chart

HFC-134a

105 Condensing Temperature = 134.9 PSIG

HFC-410a

105 Condensing Temperature = 339.9 PSIG

HFC-134a

125 Condensing Temperature = 184.5 PSIG

HFC-410a

125 Condensing Temperature = 444.5 PSIG

Refrigerant Pressure Temperature Chart

Temperature		Refrigerant				
°F	°C	R-22	R-410a	R-407c	R-134a	R-404a
-60	-51.1	*11.9*	*0.9*	*16.0*	*21.6*	-
-55	-48.3	*9.2*	1.8	*13.7*	*20.2*	-
-50	-45.6	*6.1*	4.3	*11.1*	*18.6*	-
-45	-42.8	*2.7*	7.0	*8.1*	*16.7*	-
-40	-40.0	0.6	10.1	*4.8*	*14.7*	4.9
-35	-37.2	2.6	13.5	*1.1*	*12.3*	7.5
-30	-34.4	4.9	17.2	1.5	*9.7*	10.3
-25	-31.7	7.5	21.4	3.7	*6.8*	13.5
-20	-28.9	10.2	25.9	6.2	*3.6*	16.8
-18	-27.8	11.4	27.8	7.2	*2.2*	18.3
-16	-26.7	12.6	29.7	8.4	*0.7*	19.8
-14	-25.6	13.9	31.8	9.5	0.4	21.3
-12	-24.4	15.2	33.9	10.7	1.2	22.9
-10	-23.3	16.5	36.1	11.9	2.0	24.6
-8	-22.2	17.9	38.4	13.2	2.8	26.3
-6	-21.1	19.4	40.7	14.6	3.7	28.0
-4	-20.0	20.9	43.1	15.9	4.6	29.8
-2	-18.9	22.4	45.6	17.4	5.5	31.7
0	-17.8	24.0	48.2	18.9	6.5	33.7
1	-17.2	24.8	49.5	19.6	7.0	34.7
2	-16.7	25.7	50.9	20.4	7.5	35.7
3	-16.1	26.5	52.2	21.2	8.0	36.7
4	-15.6	27.4	53.6	22.0	8.6	37.7
5	-15.0	28.3	55.0	22.8	9.1	38.8
6	-14.4	29.1	56.4	23.7	9.7	39.8
7	-13.9	30.0	57.9	24.5	10.2	40.9
8	-13.3	31.0	59.3	25.4	10.8	42.0
9	-12.8	31.9	60.8	26.2	11.4	43.1
10	-12.2	32.8	62.3	27.1	12.0	44.3
11	-11.7	33.8	63.9	28.0	12.6	45.4
12	-11.1	34.8	65.4	29.0	13.2	46.6
13	-10.6	35.8	67.0	29.9	13.8	47.8
14	-10.0	36.8	68.6	30.9	14.4	49.0
15	-9.4	37.8	70.2	31.8	15.1	50.2
16	-8.9	38.8	71.9	32.8	15.7	51.5
17	-8.3	39.9	73.5	33.8	16.4	52.7
18	-7.8	40.9	75.2	34.8	17.1	54.0
19	-7.2	42.0	77.0	35.9	17.7	55.3
20	-6.7	43.1	78.7	36.9	18.4	56.6
21	-6.1	44.2	80.5	38.0	19.2	57.9
22	-5.6	45.3	82.3	39.1	19.9	59.3
23	-5.0	46.5	84.1	40.2	20.6	60.6
24	-4.4	47.6	85.9	41.3	21.4	62.0
25	-3.9	48.8	87.8	42.4	22.1	63.4
26	-3.3	50.0	89.7	43.6	22.9	64.8
27	-2.8	51.2	91.6	44.7	23.7	66.2
28	-2.2	52.4	93.5	45.9	24.5	67.7
29	-1.7	53.7	95.5	47.1	25.3	69.2
30	-1.1	54.9	97.5	48.4	26.1	70.7
31	-0.6	56.2	99.5	49.6	26.9	72.1
32	0.0	57.5	101.6	50.9	27.8	73.8
33	0.6	58.8	103.6	52.1	28.6	75.3
34	1.1	60.2	105.7	53.4	29.5	76.9
35	1.7	61.5	107.9	54.8	30.4	78.5
36	2.2	62.9	110.0	56.1	31.3	80.2
37	2.8	64.3	112.2	57.5	32.2	81.7
38	3.3	65.7	114.4	58.9	33.1	83.5
39	3.9	67.1	116.7	60.3	34.1	85.2
40	4.4	68.6	118.9	61.7	35.0	86.9
41	5.0	70.0	121.2	63.1	36.0	88.6
42	5.6	71.5	123.6	64.6	37.0	90.4
43	6.1	73.0	125.9	66.1	38.0	92.2
44	6.7	74.5	128.3	67.6	39.0	94.0
45	7.2	76.1	130.7	69.1	40.0	95.8
46	7.8	77.6	133.2	70.6	41.1	97.6
47	8.3	79.2	135.6	72.2	42.2	99.5
48	8.9	80.8	138.2	73.8	43.2	101.4
49	9.4	82.4	140.7	75.4	44.3	103.3
50	10.0	84.1	143.3	77.1	45.4	105.3
55	12.8	92.6	156.6	106.0	51.2	115.3
60	15.6	101.6	170.7	116.2	57.4	126.0
65	18.3	111.3	185.7	127.0	64.0	137.4
70	21.1	121.5	201.5	138.5	71.1	149.3
75	23.9	132.2	218.2	150.6	78.6	161.9
80	26.7	143.7	235.9	163.5	86.7	175.4
85	29.4	155.7	254.6	177.0	95.2	189.6
90	32.2	168.4	274.3	191.3	104.3	204.5
95	35.0	181.9	295.0	206.4	113.9	220.2
100	37.8	196.0	316.9	222.3	124.1	236.8
105	40.6	210.8	339.9	239.0	134.9	254.2
110	43.3	226.4	364.1	256.5	146.3	272.5
115	46.1	242.8	289.6	274.9	158.4	291.9
120	48.9	260.0	416.4	294.2	171.1	312.1
125	51.7	278.1	444.5	314.5	184.5	333.4
130	54.4	297.0	474.0	335.7	198.7	355.6
135	57.2	316.7	505.0	357.8	213.5	379.1
140	60.0	337.4	537.6	380.9	229.2	403.7
145	62.8	359.1	571.7	405.1	245.6	429.6
150	65.6	381.7	607.6	430.3	262.8	456.8
155	68.3	405.4	645.2	456.6	281.0	484.8

Italics indicates vacuum (inches of mercury) Standard font indicates pressure (pounds per inch gauge)

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Why Head Pressure Control

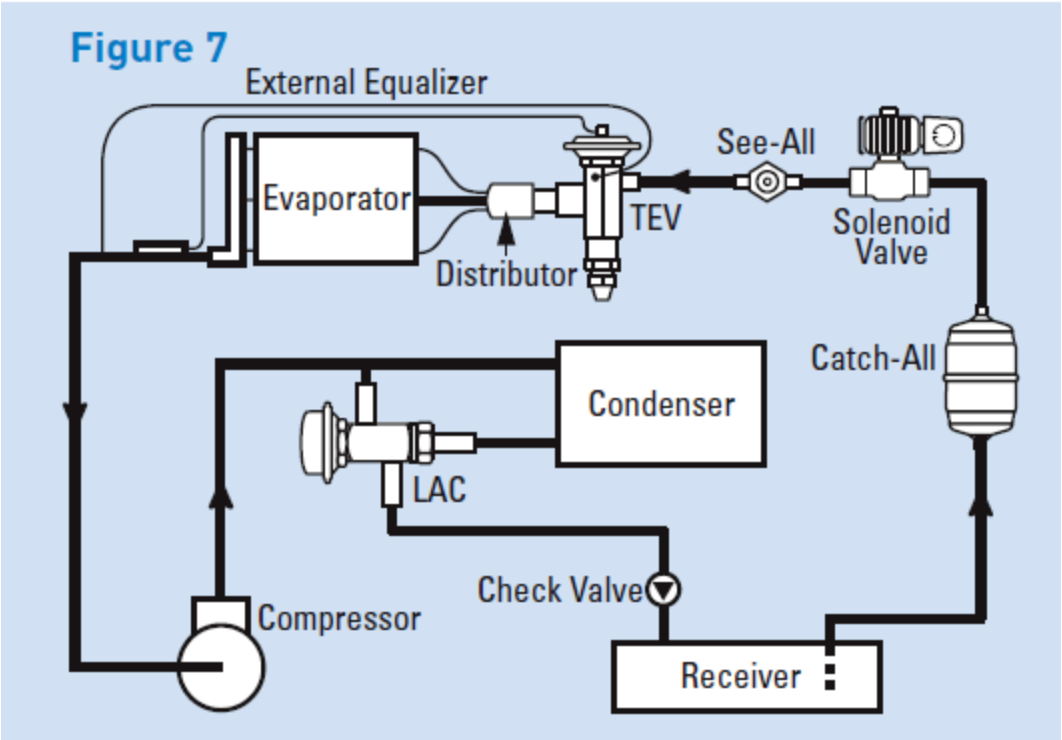
- Variable Speed Compressors
- Fluctuating Ambient Conditions
- Energy Savings
- Assure Proper TXV Operation

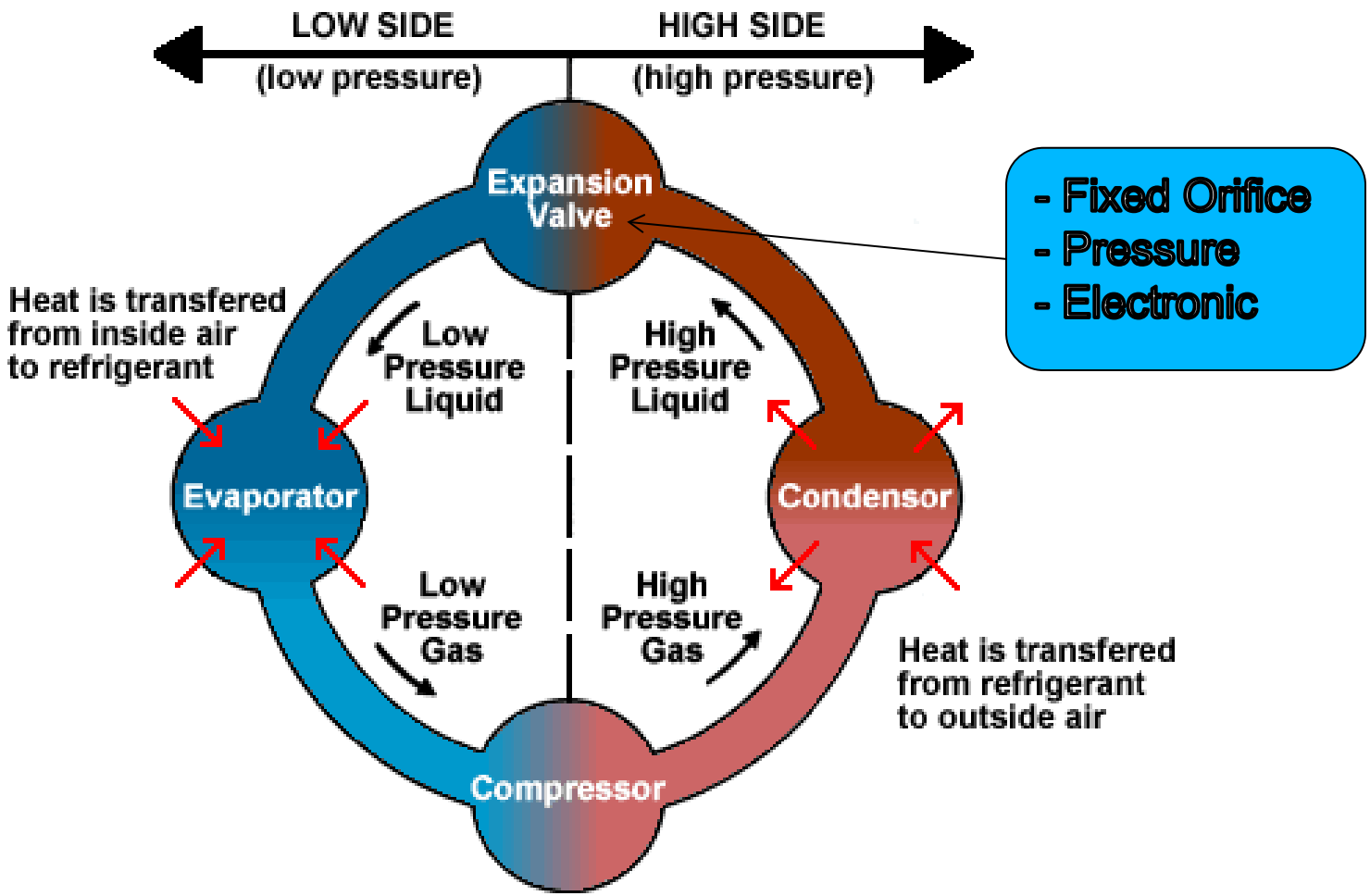
Common Head Pressure Control

- Condenser Fan Cycling
- Variable Speed Condenser Fan
  - Picture Cooling Tower w/ VFD

Low Ambient Head Pressure Control

- Flooded Condenser

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(low pressure)
HIGH SIDE
(high pressure)
Expansion Valve
- Fixed Orifice
- Pressure
- Electronic
Heat is transfered from inside air to refrigerant
Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor

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Capillary Tube, Fixed Orifice, Thermal Expansion

- Cheap but Effective

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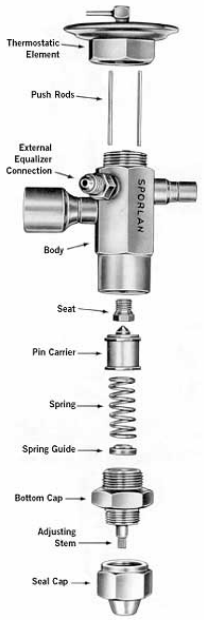
Pressure Thermal Expansion

- Old and Stable Technology



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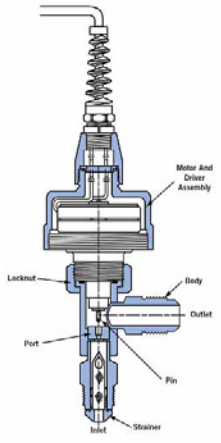
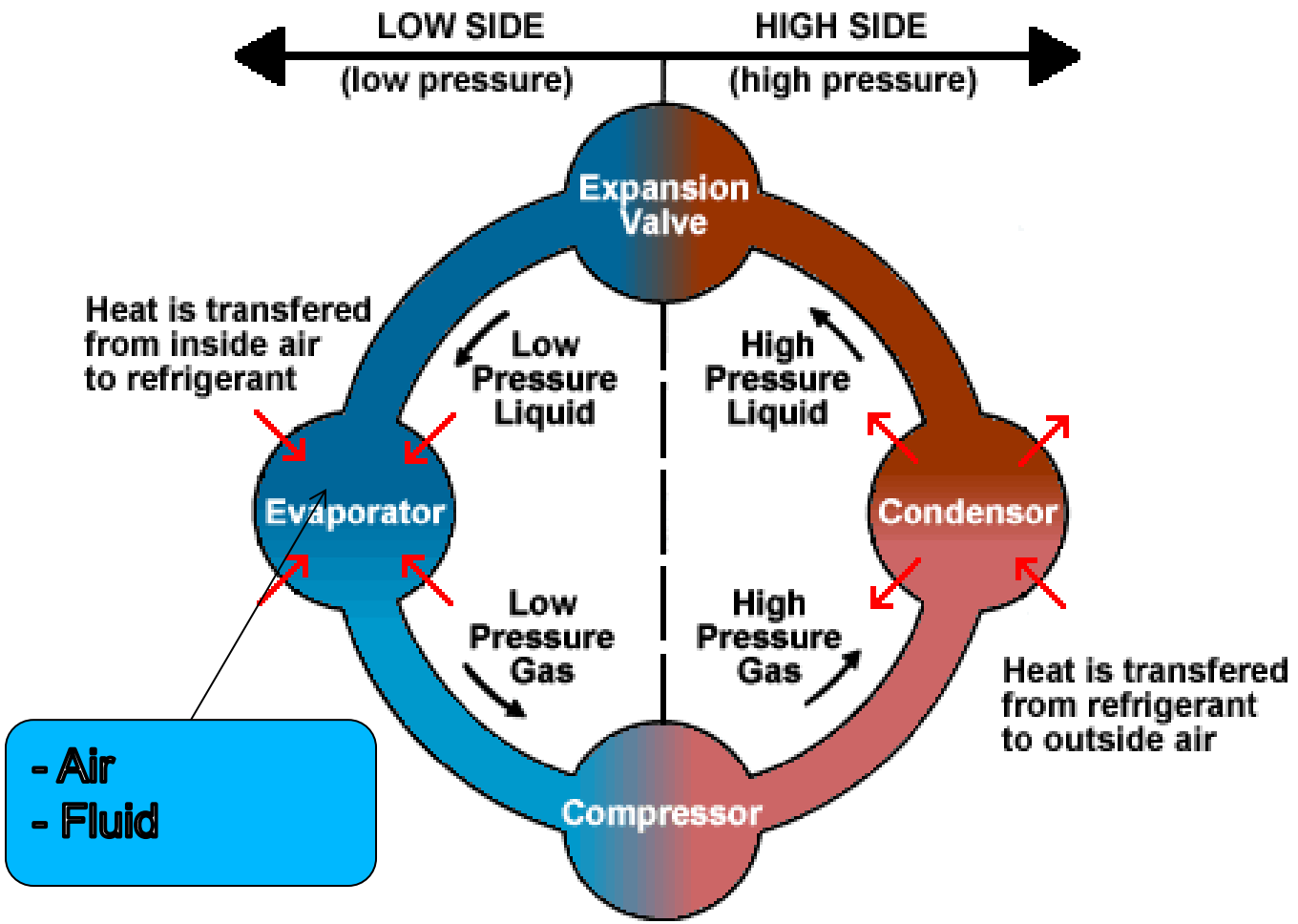
Electronic Thermal Expansion

- Very Controllable

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HIGH SIDE
(high pressure)
Expansion Valve
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Low Pressure Liquid
High Pressure Liquid
Evaporator
Condensor
Low Pressure Gas
High Pressure Gas
Heat is transfered from refrigerant to outside air
Compressor
- Air
- Fluid

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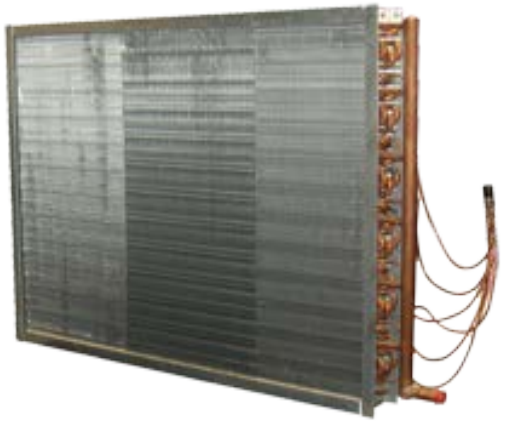
Evaporator – Air Cooled

- Given 55 Degree LAT
- 45 Degree Suction Temperature



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Evaporator – Chilled Water

- Given 55 Degree LAT
- 45 Degree Chilled Water/Glycol
- 35 Degree Suction Temperature

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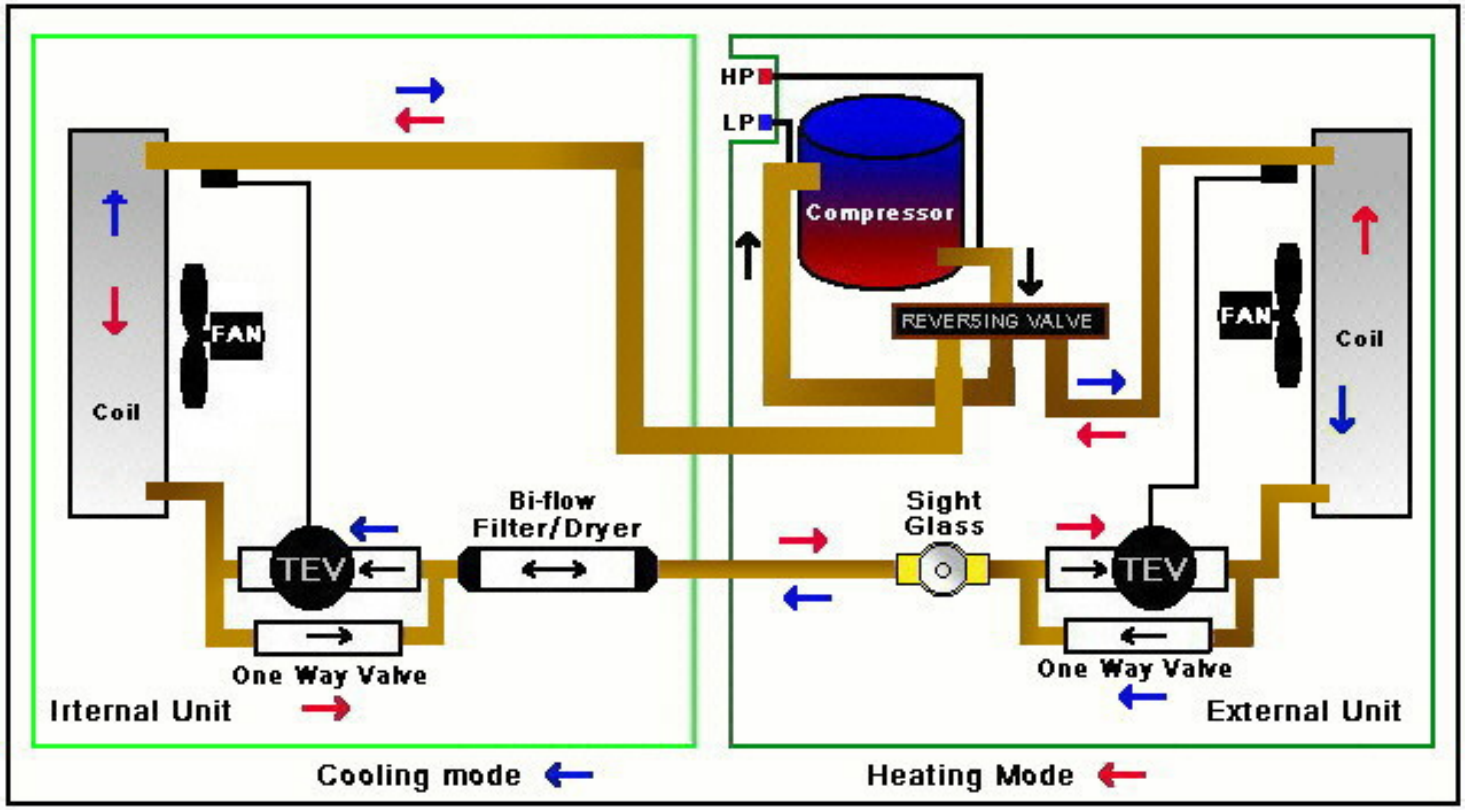
Heat Pump Refrigeration Cycle



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Pump Out vs. Pump Down

- The purpose of Pump Down and Pump Out is to minimize the effects of migration, which can result in a flooded start on the next startup.

Pump Out

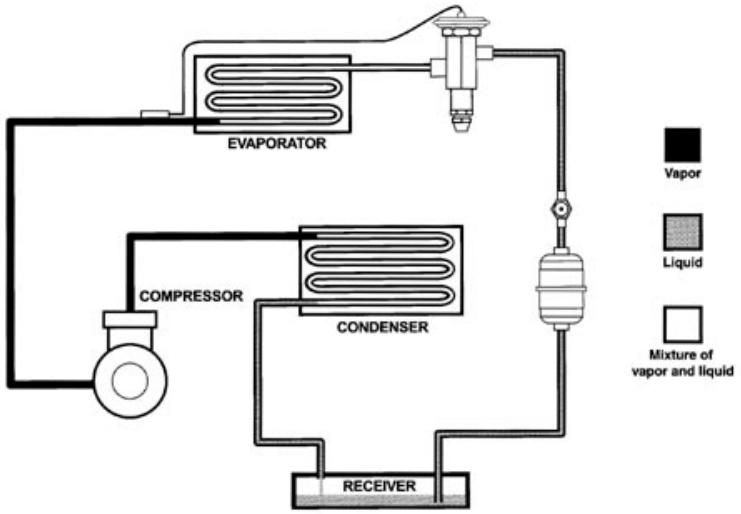
- Also known as a "one time pump out", is conducted by closing a solenoid in the liquid line while the compressor is still running, all of the refrigerant in the system downstream of the solenoid is removed. The compressor is shutdown by a low pressure control, and remains off until the next call for cooling which opens the solenoid valve and closes the contacts for the compressor. Thus the compressor pumps out the system after each running cycle, then remains off until the next call for cooling.

Pump Down

- Also known as "continuous pump down", is conducted exactly the same way as pump-out with the exception that the call for cooling ONLY controls the solenoid. Thus, during a normal running cycle, when demand is met, the solenoid is closed. The compressor pumps out all of the refrigerant downstream of the solenoid then shuts of on a low pressure control. The difference being that the compressor is allowed to restart any time the low pressure control makes, thus keeping the suction side of the system pumped down continuously. This usually comes into play if there is a leaking pump down solenoid.

Accumulators and Receivers

- A vessel for holding refrigerant liquefied by the condenser.
- A vessel for preventing liquid slugging of the compressor.



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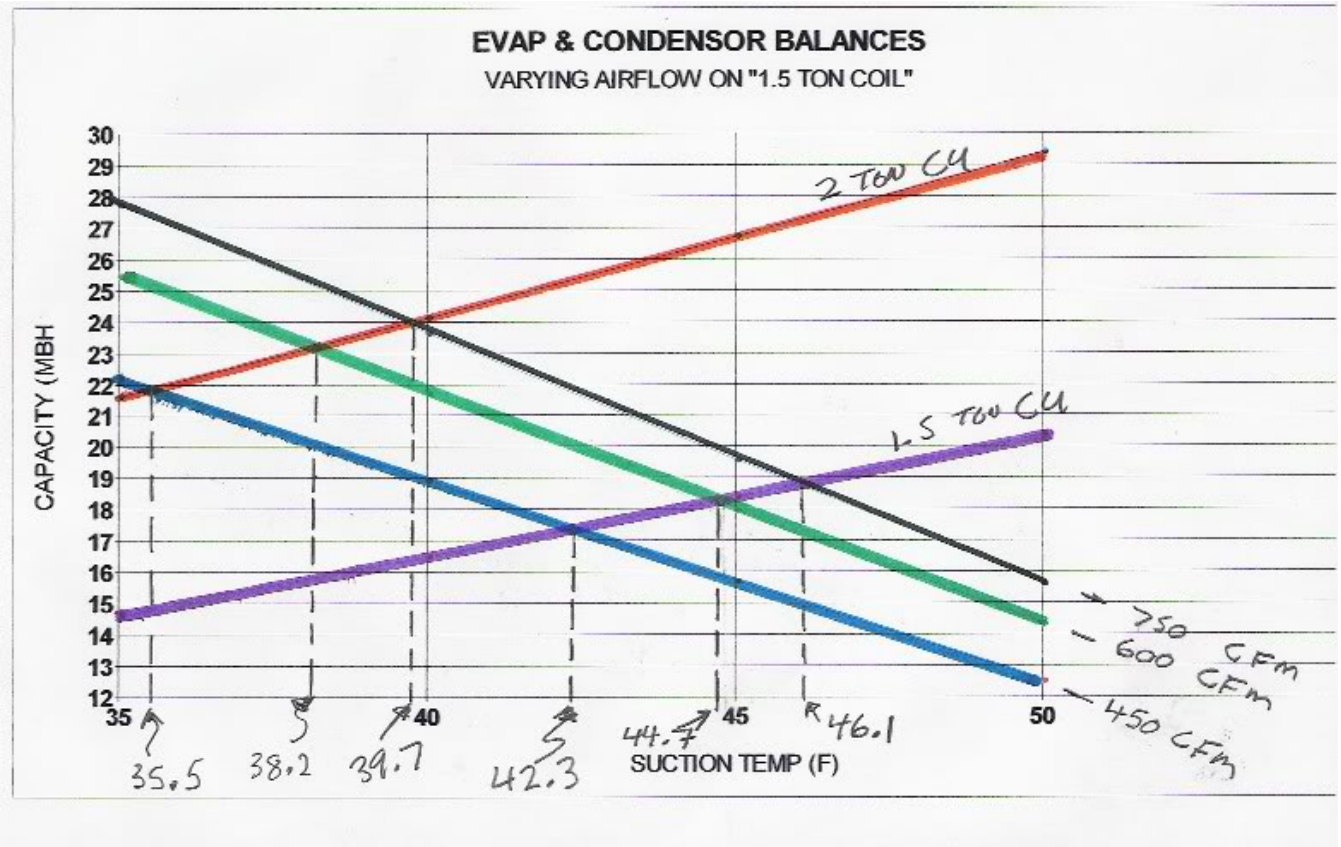
Condenser/Evaporator Balance



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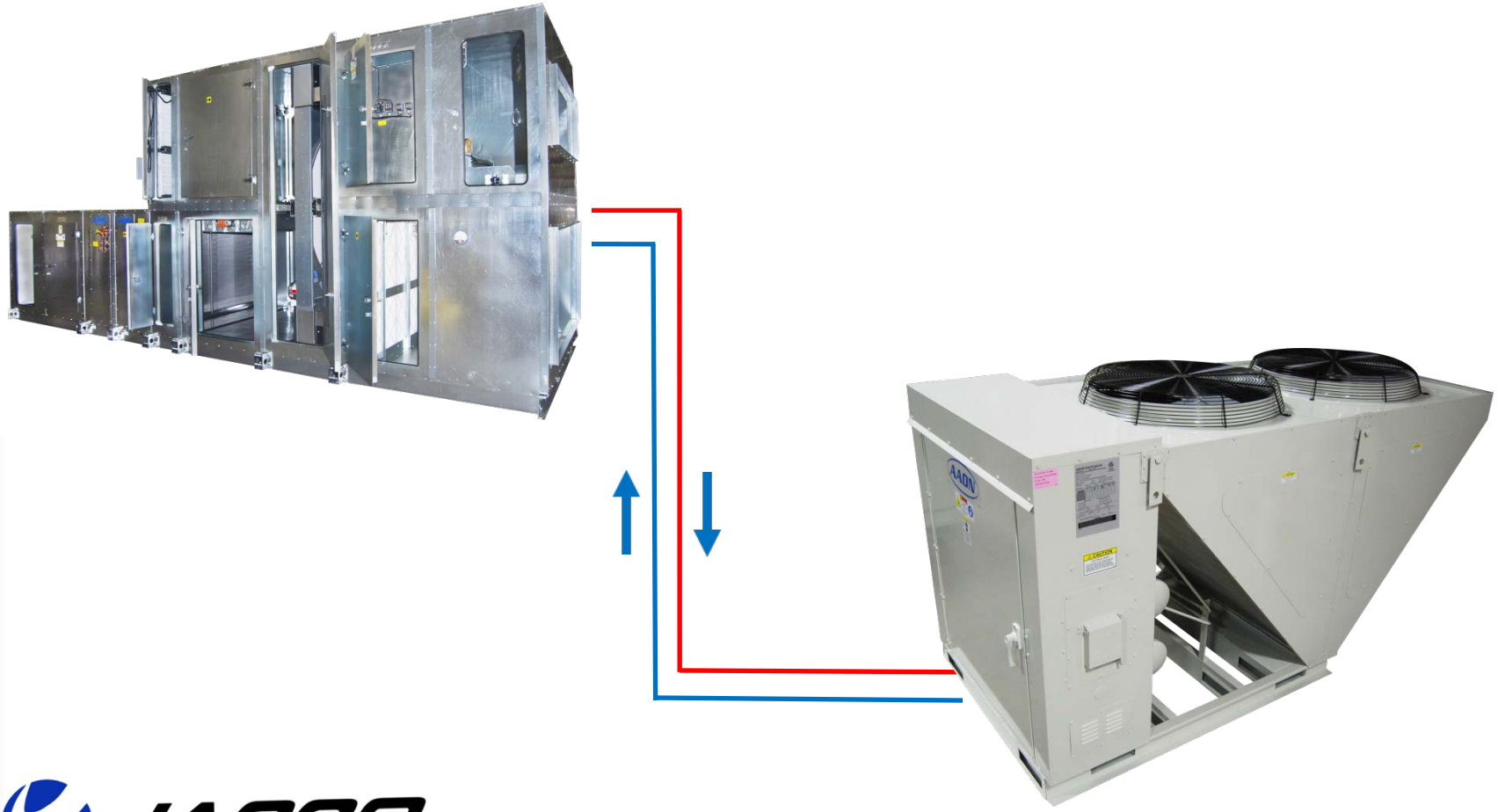
Refrigerant Piping

Cooling Only



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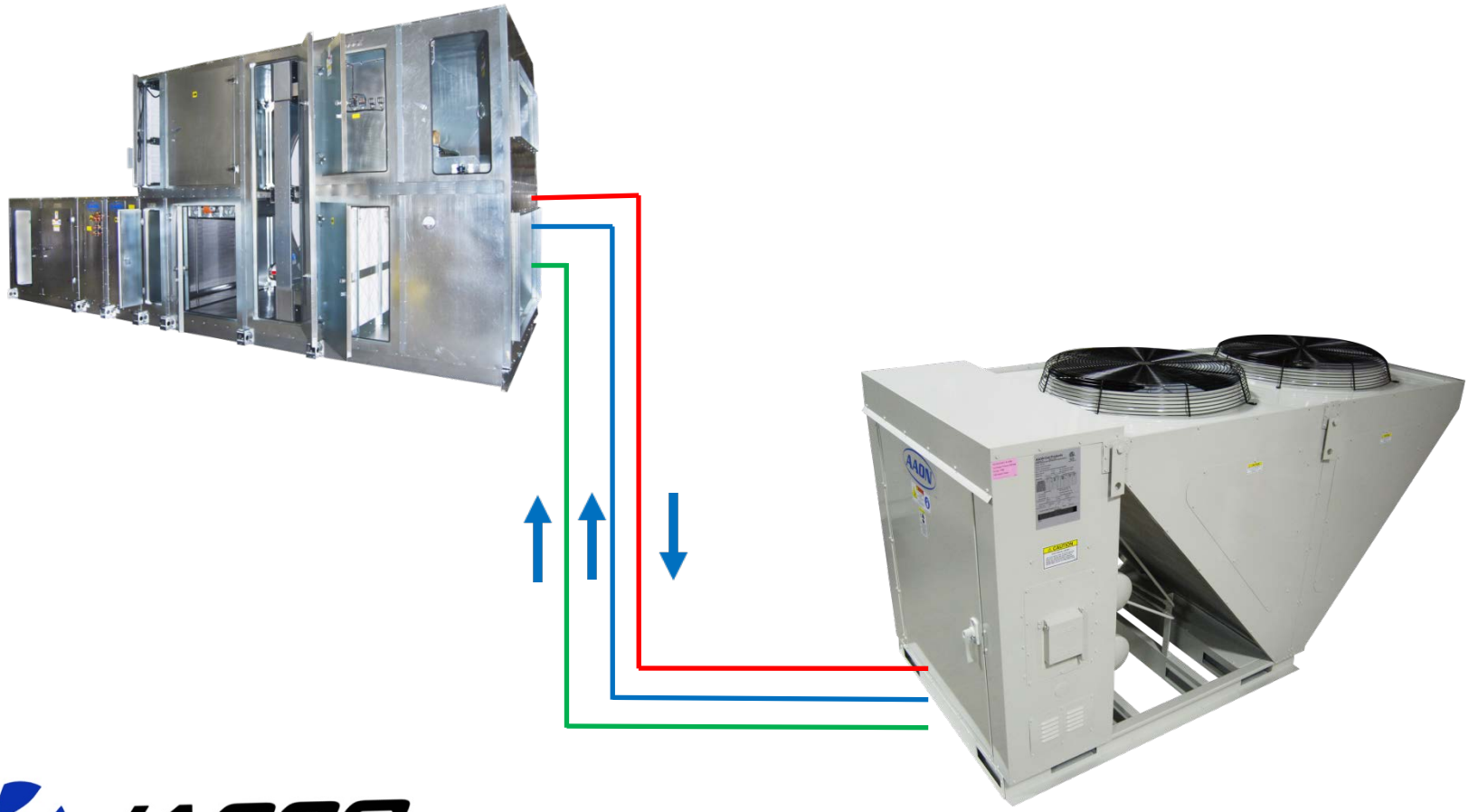
Cooling with MHGRH



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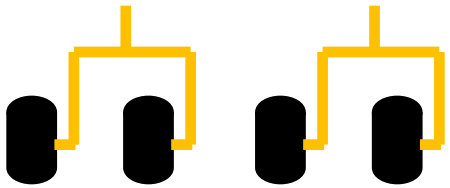
Determining Loads for Line Sizing

Dual Compressor Units (Two Independent Refrigerant Circuits)				
Condensing Unit Total Capacity (Tons)	Suction Line (Tons)	Liquid Line (Tons)	Reheat Line (Tons)	Hot Gas Bypass Line (Tons)
100%	50%	50%	50%	50%



Dual Tandem Compressor Units (Two Independent Refrigerant Circuits)				
Condensing Unit Total Capacity (Tons)	Suction Line (Tons)	Liquid Line (Tons)	Reheat Line (Tons)	Hot Gas Bypass Line (Tons)
100%	50%	50%	50%	25%

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Suction Line

1. Suction Line – Vertical UP, Vertical Down, or Horizontal
   Minimum Velocity = 1000 fpm
   Maximum Velocity = 4000 fpm
   Maximum Line Loss = 6F

2. Suction Line Flow – Vertical UP
   Tonnage > Minimum Tonnage Required for Oil Return*
   Velocity > Minimum Velocity Required for Oil Return*
   Trap Every 10 Feet along Vertical-Up Riser

*For oil to flow up along a pipe wall, a minimum drag of gas flow (friction gradient) is required. ECat uses the following data to ensure oil is returned up vertical suction lines.

Line Size	
2 in. or less	**Above 2 in.**
0.35 psi/100 ft	0.20 psi/100 ft

For tandem compressors and variable capacity compressors the oil return must work with one compressor operating with reduced capacity. So, the vertical line must be selected to return oil at minimum flow. This can result in too high a pressure drop at full capacity.

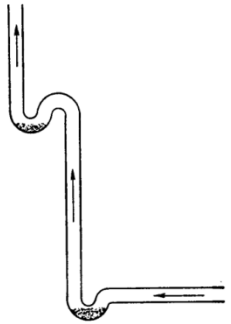
Suction Line – Variable Capacity Compressors

Rule 1 – The oil MUST BE returned to the compressor, there is no rule 2.

1. Size the vertical portion of the suction line to maintain the minimum velocity for oil return at minimum load and suffer the pressure drop penalty at full capacity. Refrigerant and oil must not log in the line when it is active.

2. For long vertical lines provide traps, size the vertical suction line for minimum load and provide traps to accumulate oil when the refrigerant line is idle, not when it is active. Make sure the compressor can handle the slug oil when restarted, an accumulator may be required.

3. To maintain oil return at the minimum load without a pressure drop penalty use a double suction riser.



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Double Suction Riser

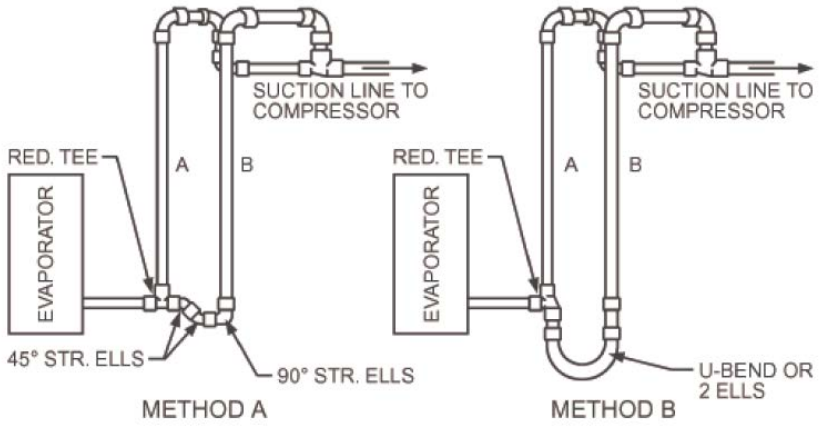

Fig. 3 Double-Suction Riser Construction

1. Two vertical lines operate in parallel at the full load to return suction gas and oil to compressor. The pressure drop in riser A and B are equal when both have gas flow. The diameter of riser A is always less than riser B.

2. At reduced load the velocity in riser B drops to the point where it can not return oil. The trap on riser B fills with oil and seals off the gas flow in riser B and all gas flows thru riser A. Riser A must be sized to return oil at minimum flow.

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Liquid Line Sizing Rules

Liquid Line – Vertical Down, or Horizontal - Maximum Line Loss 6F

Liquid Line – Vertical Up

Maximum Line Loss 8F Including Loss, accessories (LLSV, Filter/Dryer) and Liquid Lift

The TXV is rated for 100% liquid at the inlet (no flash gas)

Every foot of vertical lift = -.43 psi or -.095 F sub-cooling for R410A. For proper operation of the system the sub-cooling at the TXV inlet should be at least 2F.

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Hot Gas Line Sizing Rules

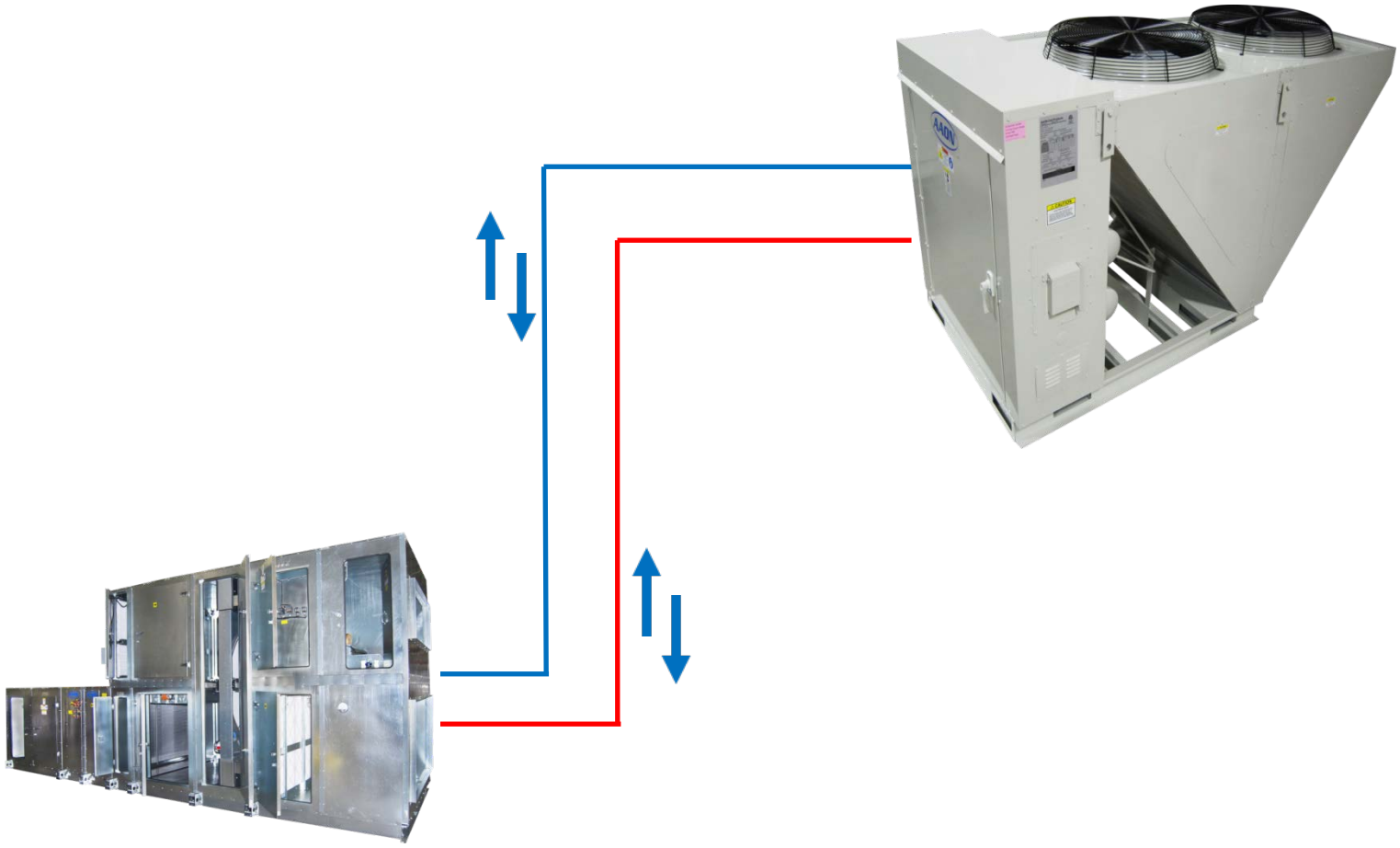
HGB Line - Vertical UP, Vertical Down, or Horizontal
Size as discharge line for Single Compressor with SST = 32, SDT = 90

HGB Line – Vertical UP
Trap Every 10 Feet along Vertical-Up Riser
Drain line in accordance AAON piping guidelines.

Reheat Line = Vertical UP, Vertical Down, or Horizontal
Minimum Velocity = 900 fpm
Maximum Velocity = 3000 fpm
Maximum Line Loss = 10F

Reheat Line –Vertical UP
Tonnage > Minimum Tonnage Required for Oil Return
Velocity > Minimum Velocity Required for Oil Return
Trap Every 10 Feet along Vertical-Up Riser
Drain line in accordance AAON piping guidelines.

Heat Pump



Heat Pump Suction/Discharge Line

Rule 1 – The oil MUST BE returned to the compressor, there is no rule 2.

Economics, pressure drop, noise, and oil entrainment establish feasible design velocities in refrigerant lines (ASHRAE Table 1 is a guide).

Table 1 Recommended Gas Line Velocities

Suction line	900 to 4000 fpm
Discharge line	2000 to 3500 fpm

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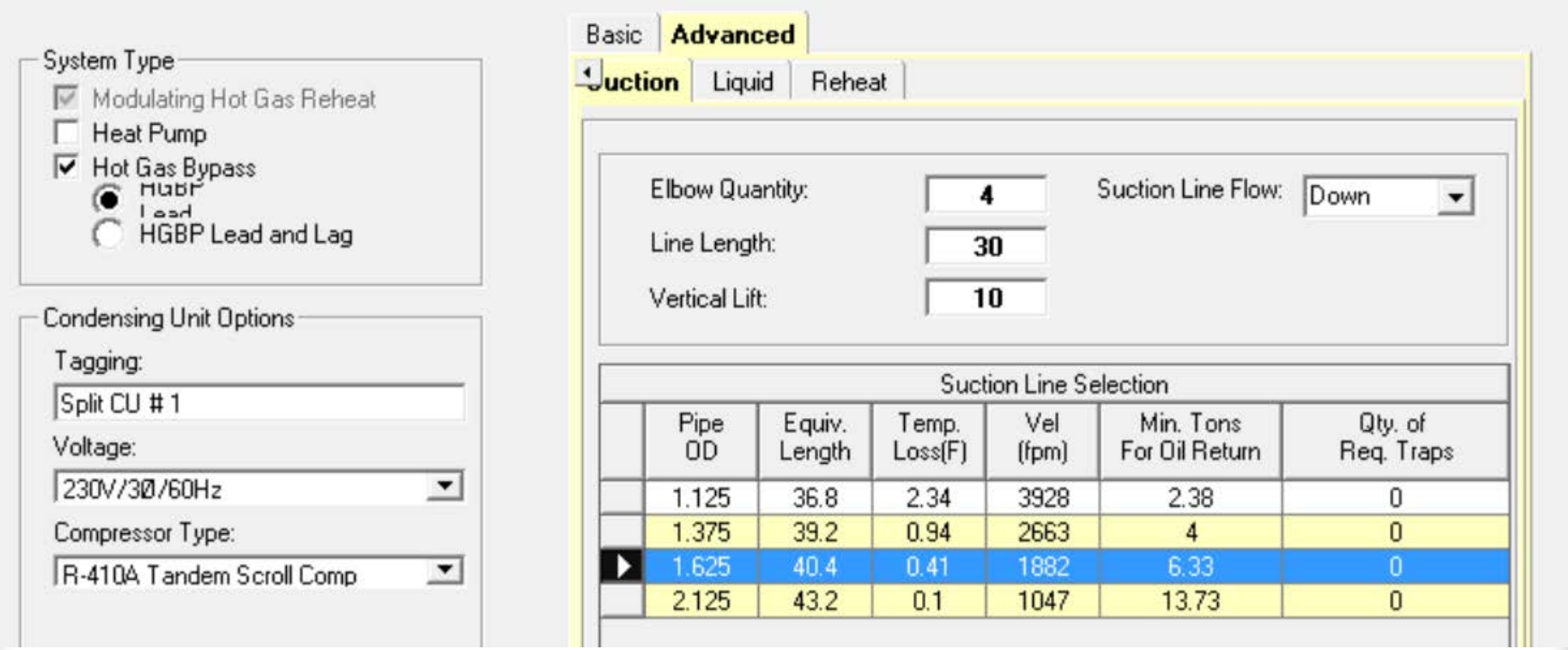
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Modulating Hot Gas Reheat
Heat Pump
Hot Gas Bypass
HGBP Lead and Lag
Condensing Unit Options
Tagging:
Split CU # 1
Voltage:
230V/3Ø/60Hz
Compressor Type:
R-410A Tandem Scroll Comp
Basic
Advanced
Liquid
Reheat
Elbow Quantity:
4
Suction Line Flow:
Down
Line Length:
30
Vertical Lift:
10
Suction Line Selection
Pipe OD
Equiv. Length
Temp. Loss(F)
Vel (fpm)
Min. Tons For Oil Return
Qty. of Req. Traps
1.125 36.8 2.34 3928 2.38 0
1.375 39.2 0.94 2663 4 0
1.625 40.4 0.41 1882 6.33 0
2.125 43.2 0.1 1047 13.73 0

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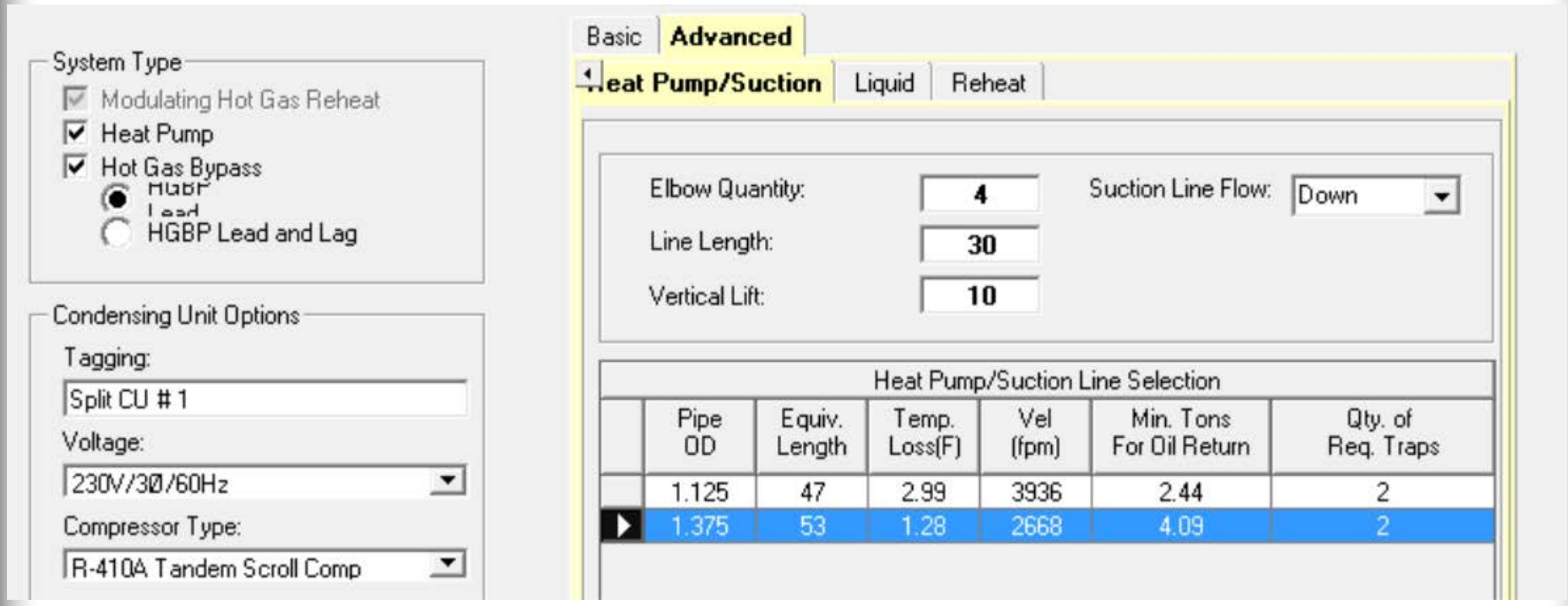
System Type
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Tagging:
Split CU # 1
Voltage:
230V/3Ø/60Hz
Compressor Type:
R-410A Tandem Scroll Comp
Basic
Advanced
Heat Pump/Suction
Liquid
Reheat
Elbow Quantity:
4
Suction Line Flow:
Down
Line Length:
30
Vertical Lift:
10
Heat Pump/Suction Line Selection
Pipe OD
Equiv. Length
Temp. Loss(F)
Vel (fpm)
Min. Tons For Oil Return
Qty. of Req. Traps
1.125
47
2.99
3936
2.44
2
1.375
53
1.28
2668
4.09
2

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Important Functions

- **Perform System Rating** at the balance point of the Evaporator, Compressor and Condenser for a given Ambient and Evaporator Entering Conditions.
- **Rate and allow selection of interconnecting piping including:**
  - **Suction Line**
  - **Discharge Line (heat pump heating mode)**
  - **Liquid Line**
  - **HGB Line**
  - **Reheat Line**
- **Rate the system with the selected line sizes.**

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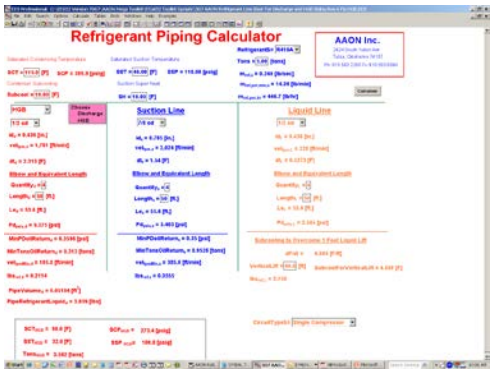
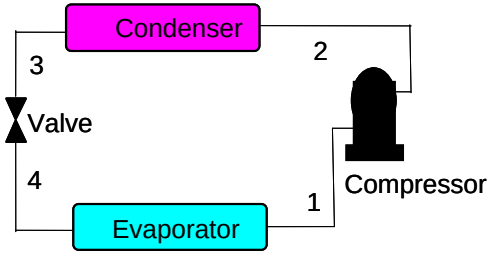
In other words, combine 4 programs

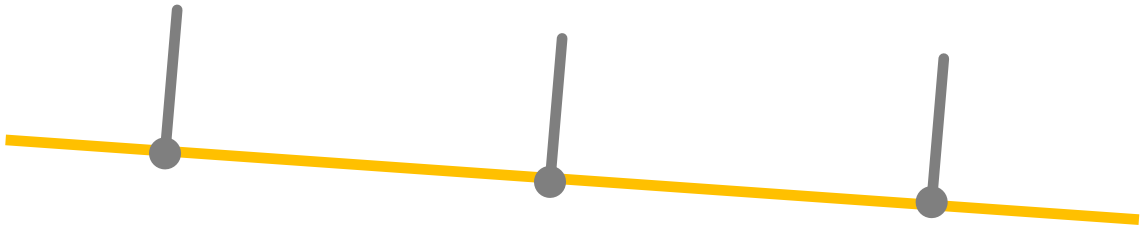
1. **AHU Rating Program**
2. **CU Rating Program**
3. **EES Refrigerant Line Sizer**
4. **System Balance Program**





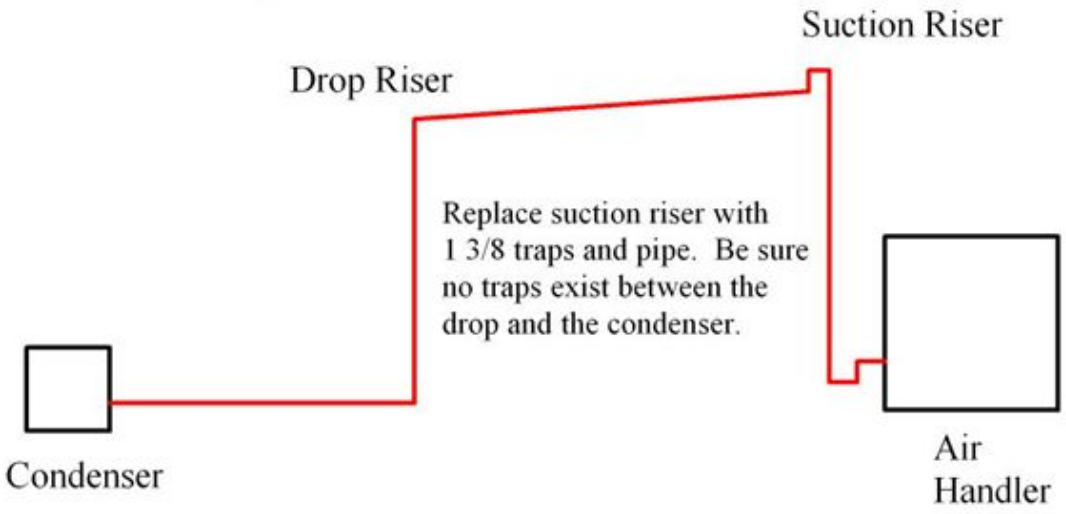
Refrigerant Line Sizing Rules

Another Rule 1 Refrigerant lines are never horizontal and should always slope (1/8” per foot) in direction of flow.



Refrigerant Piping

All piping must pitch from the top of the suction riser down to the condenser without any additional lifts or traps. The fall needs to be 1/8th per foot. The suction riser must be straight up with no 45's or elbows. Suction line should be 1 5/8OD. Elbows to be long radius. All existing system traps other than suction riser should be eliminated from the suction line. Liquid line can be left alone.



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Break