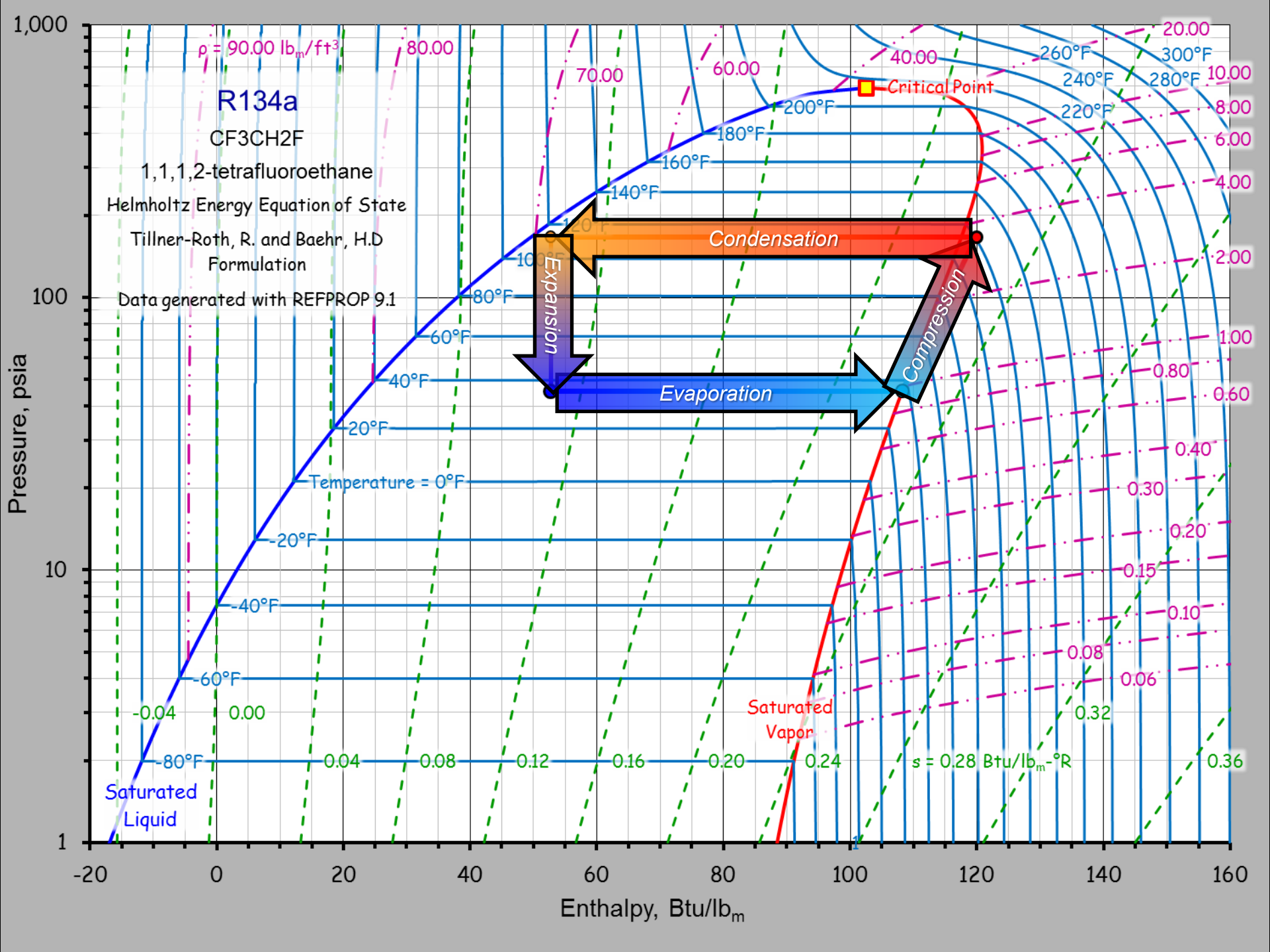
Chilled Water Plants; Basic Principles, Ongoing Commissioning/Operation, and Optimization

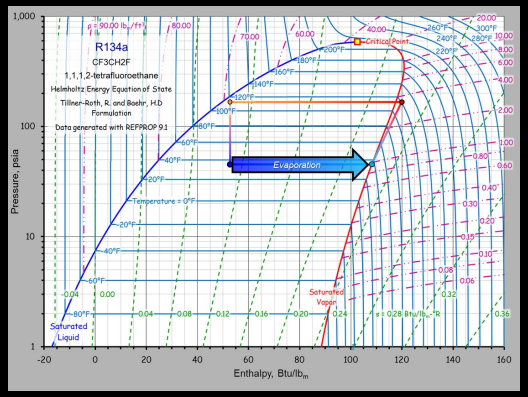
Cooling Equipment

Presented By:
David Sellers
Senior Engineer, Facility Dynamics Engineering

Vapor Compression Refrigeration Machines

An application of saturated system and phase change principles and concepts


R134a
CF3CH2F
1,1,1,2-tetrafluoroethane
Helmholtz Energy Equation of State
Tillner-Roth, R. and Baehr, H.D
Formulation
Data generated with REFPROP 9.1
ρ = 90.00 lbm/ft3
80.00
70.00
60.00
40.00
20.00
Critical Point
260°F
300°F
240°F
280°F
220°F
200°F
180°F
160°F
140°F
120°F
100°F
80°F
60°F
40°F
20°F
Temperature = 0°F
-20°F
-40°F
-60°F
-80°F
Condensation
Expansion
Compression
Evaporation
Saturated
Liquid
Saturated
Vapor
-0.04
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.32
0.36
s = 0.28 Btu/lbm-°R
10.00
8.00
6.00
4.00
2.00
1.00
0.80
0.60
0.40
0.30
0.20
0.15
0.10
0.08
0.06
1,000
100
10
1
Pressure, psia
-20
0
20
40
60
80
100
120
140
160
Enthalpy, Btu/lbm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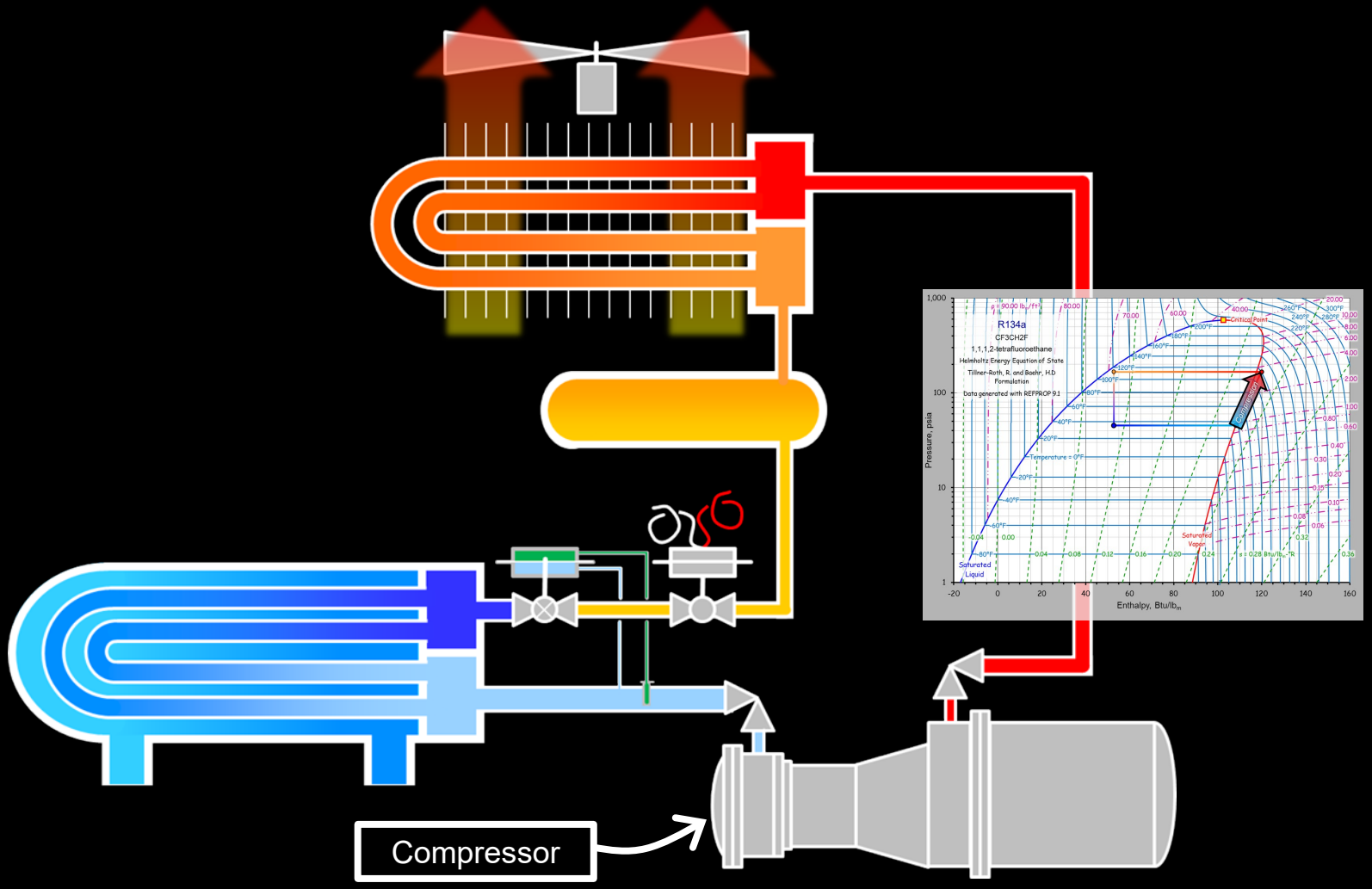
Formulation
Data generated with REFPROP 9.1
Critical Point
Evaporation
Saturated Liquid
Saturated Vapor
Pressure, psia
Enthalpy, Btu/lbm

Evaporator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Helmholtz Energy Equation of State
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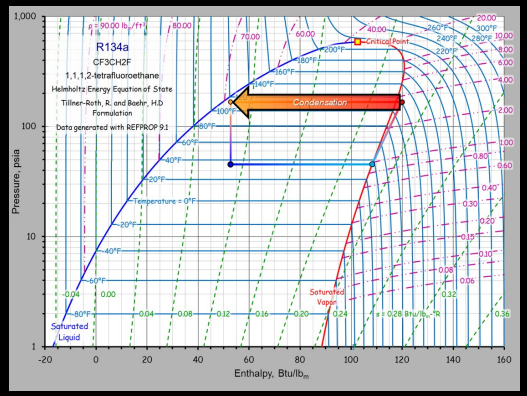
Formulation
Data generated with REFPROP 9.1
Critical Point
Compressor
Saturated Liquid
Saturated Vapor
Temperature = 0°F
Pressure, psia
Enthalpy, Btu/lbm
Compressor

Condenser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Pressure, psia
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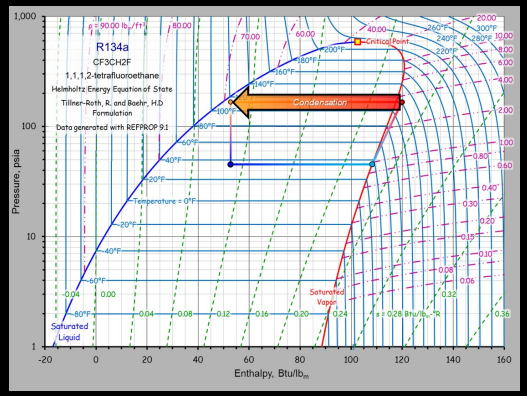
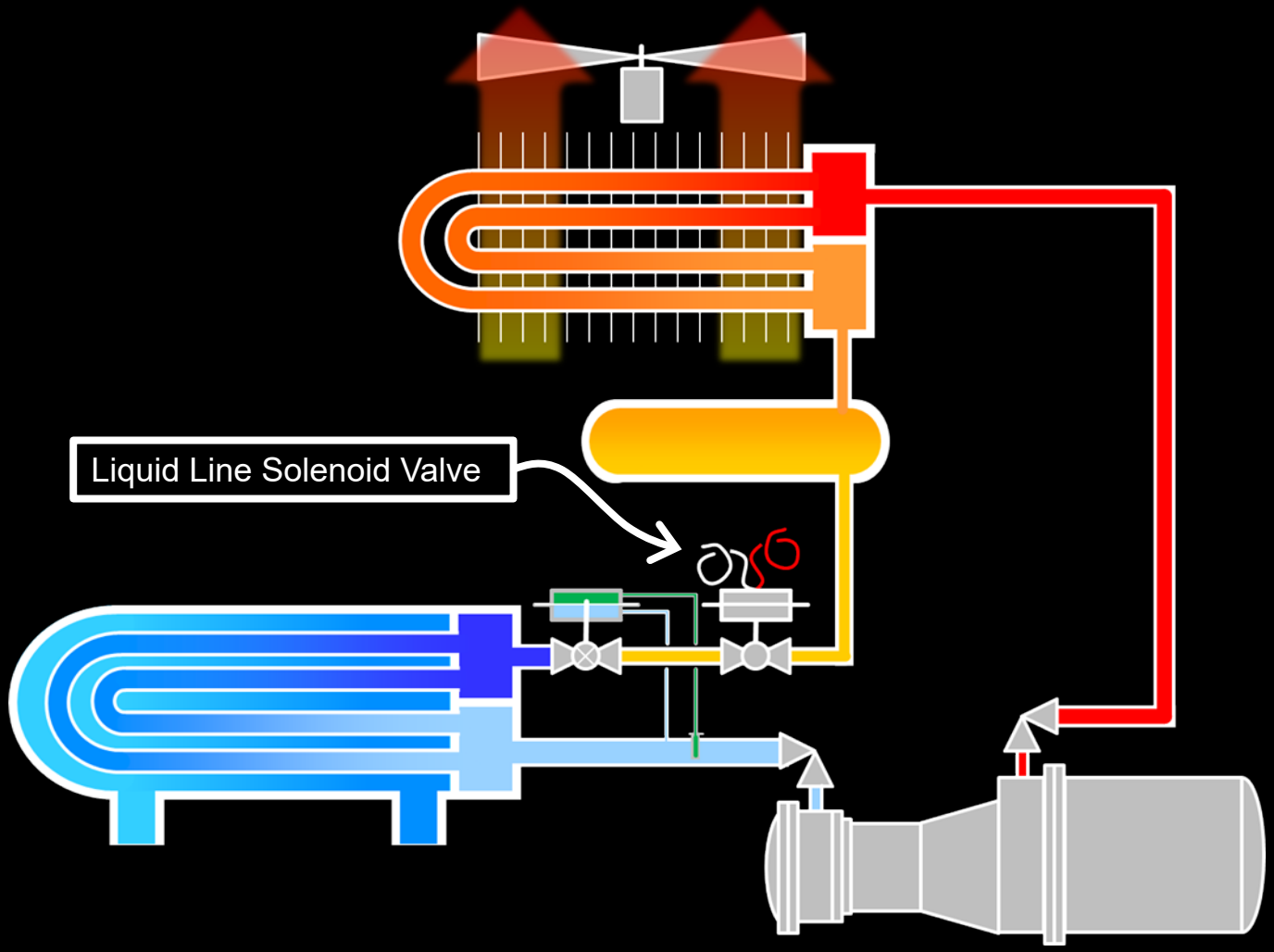
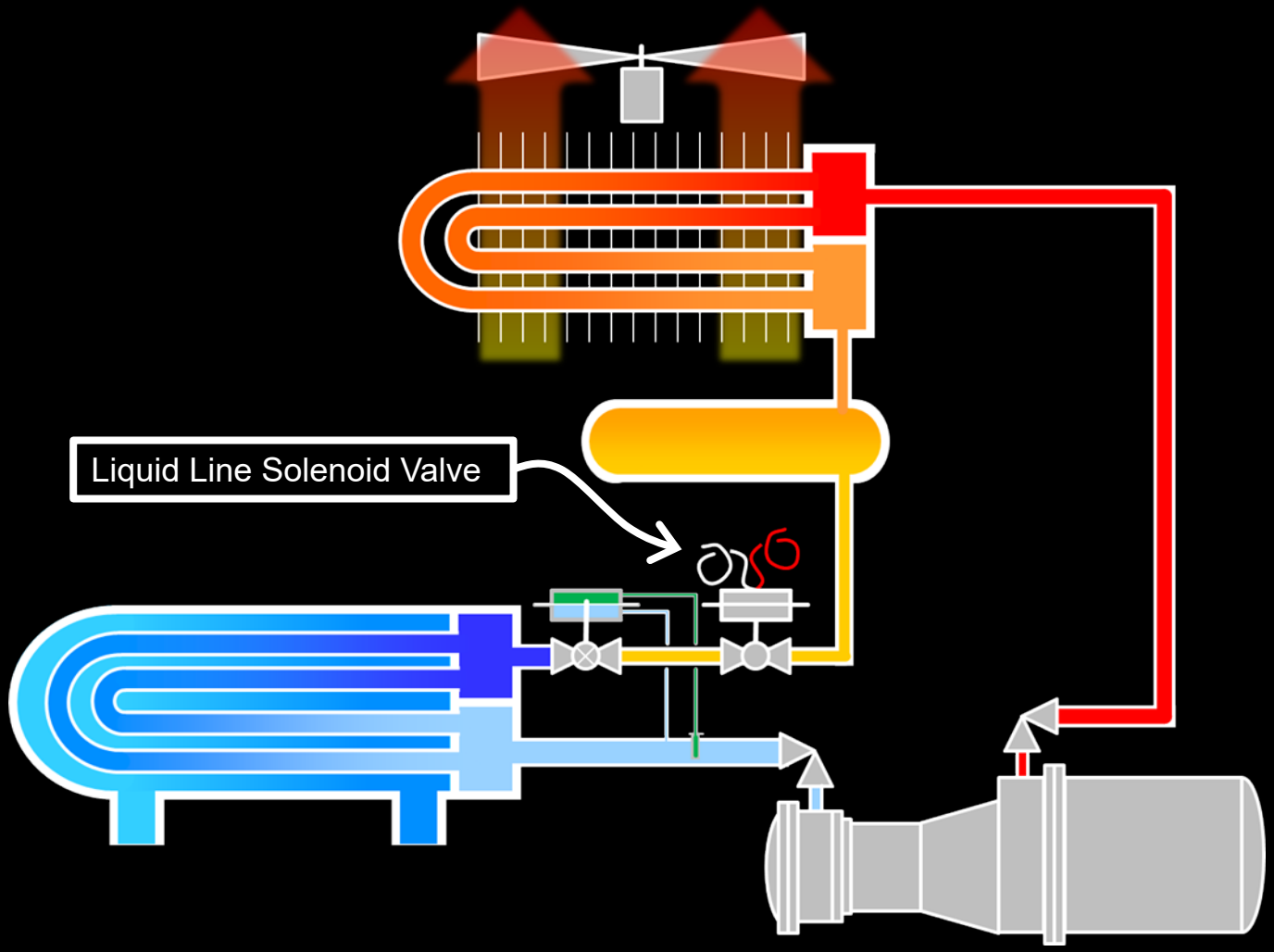


Condenser

Receiver


Liquid Line Solenoid Valve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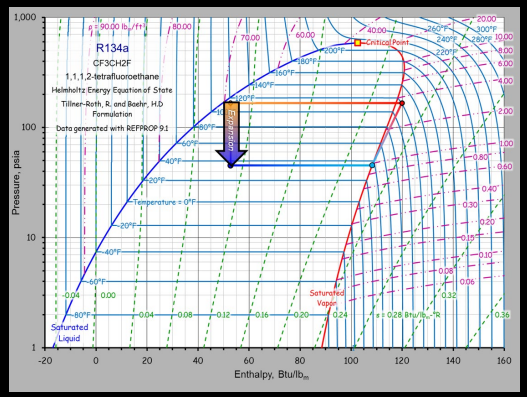
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Helmholtz Energy Equation of State
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Formulation
Data generated with REFPROP 9.1
Critical Point
Saturated Liquid
Saturated Vapor
Pressure, psia
Enthalpy, Btu/lbm

Liquid Line Solenoid Valve
Expansion Valve

Ideal Refrigerant Properties

Now

Nontoxic

- Nonflammable
- Zero ozone depletion potential (ODP)
- Zero global warming potential (GWP)
- Short atmospheric lifetime
- High latent heat of vaporization
- Low power consumption
- Low vapor specific volume
- Compressor discharge temperature below 260°F
- Evaporating pressure above atmospheric pressure
- Condensing pressure below the critical pressure

1928

- Low condensing pressure
- Evaporating pressure near atmospheric pressure
- Condensing pressure not much higher than evaporating pressure
- Low latent heat of vaporization for small machines to ensure controllability
- Low vapor specific volume
- Compatible with lubricating oil
- Non-corrosive
- Stable/does not decompose with age
- Does not form non-condensable gasses upon contact with moisture
- Does not form explosive compounds upon contact with lubricant
- Non-explosive and non-inflammable
- Low cost and easy to obtain
- Non-poisonous and no discomfort if it leaks into air

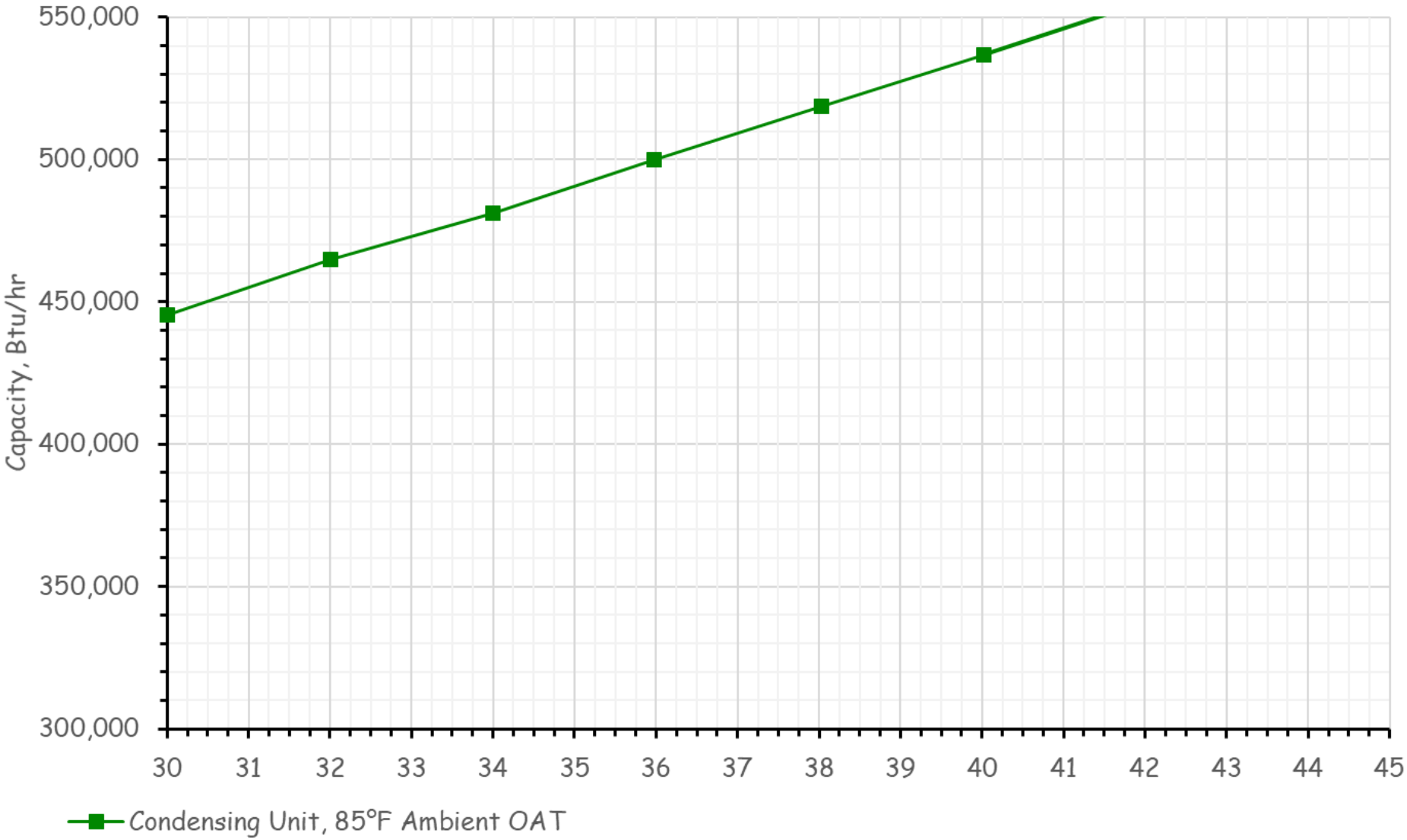
See the Refrigerants Supplement for More Information

Refrigeration Compressor Performance

Basis for Example

- Trane RAU air cooled condensing unit
  - Contains compressors, and condenser coil
  - Connects to a remote coil or evaporator
  - 40 tons, 2 circuits,
  - Four 10 ton compressors
  - R410a

https://www.trane.com/commercial/north-america/us/en.html


550,000
500,000
450,000
400,000
350,000
300,000
Capacity, Btu/hr
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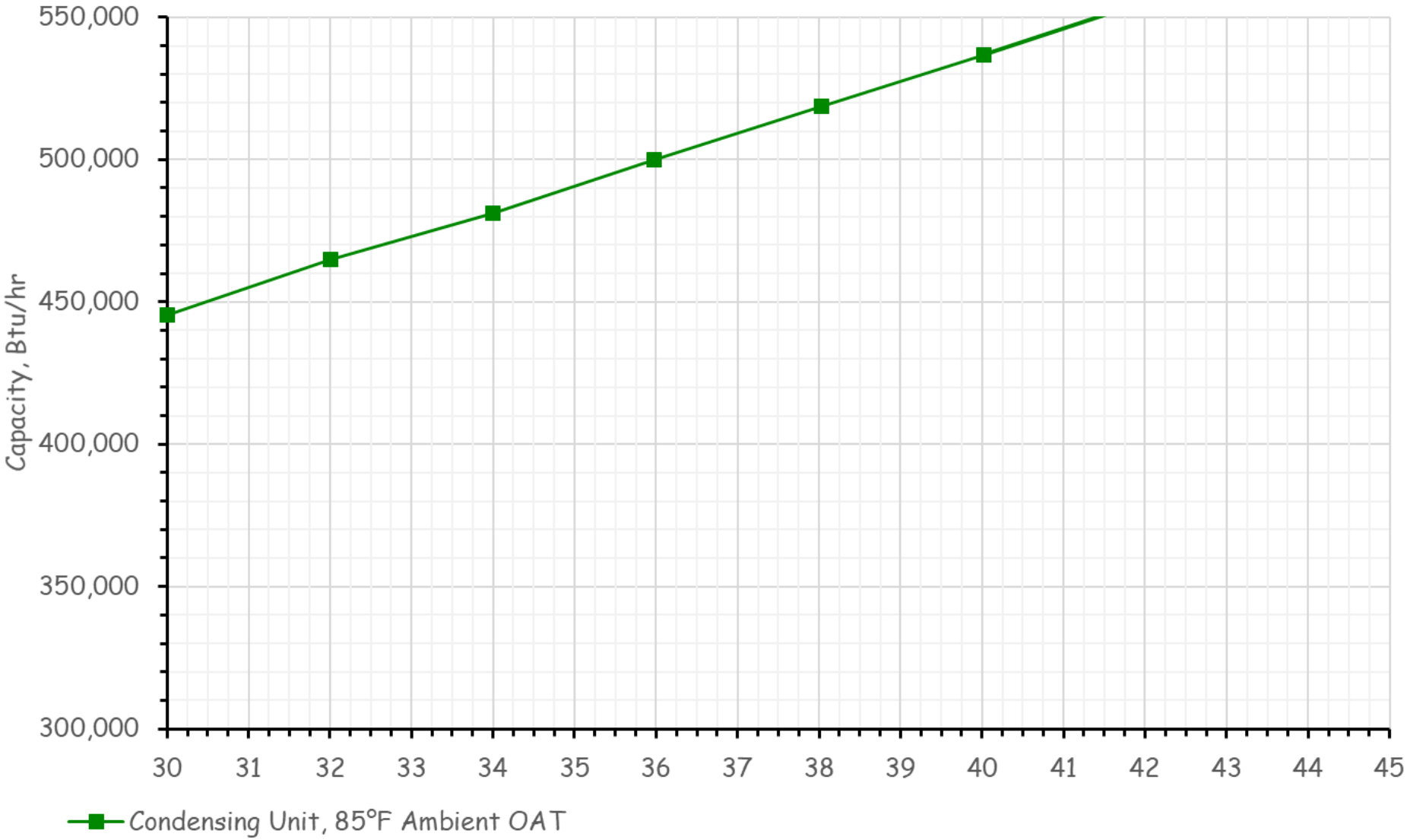
45
Condensing Unit, 85°F Ambient OAT
Operating Saturated Suction Temperature
Operating Point


550,000
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Capacity, Btu/hr
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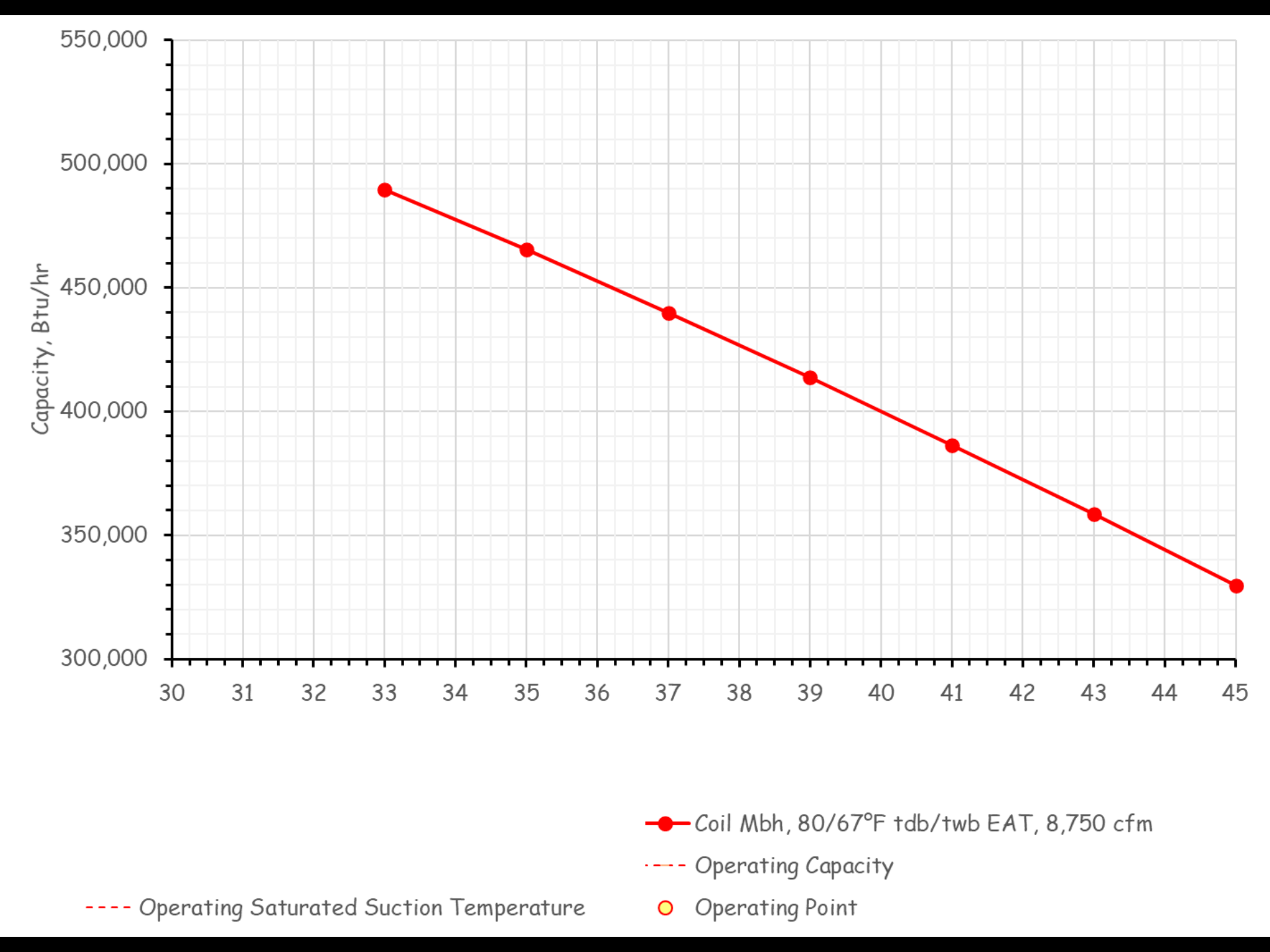
45
Condensing Unit, 85°F Ambient OAT
Operating Saturated Suction Temperature
Operating Point

Evaporator Performance

Basis for Example

- Greenheck Direct Expansion (Dx) Coil
  - 8,750 cfm
  - 500 fpm face velocity
  - 4 row
  - 10 fins per Inch
  - Intertwined

Courtesy https://www.capitalcoil.com/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300,000
Capacity, Btu/hr
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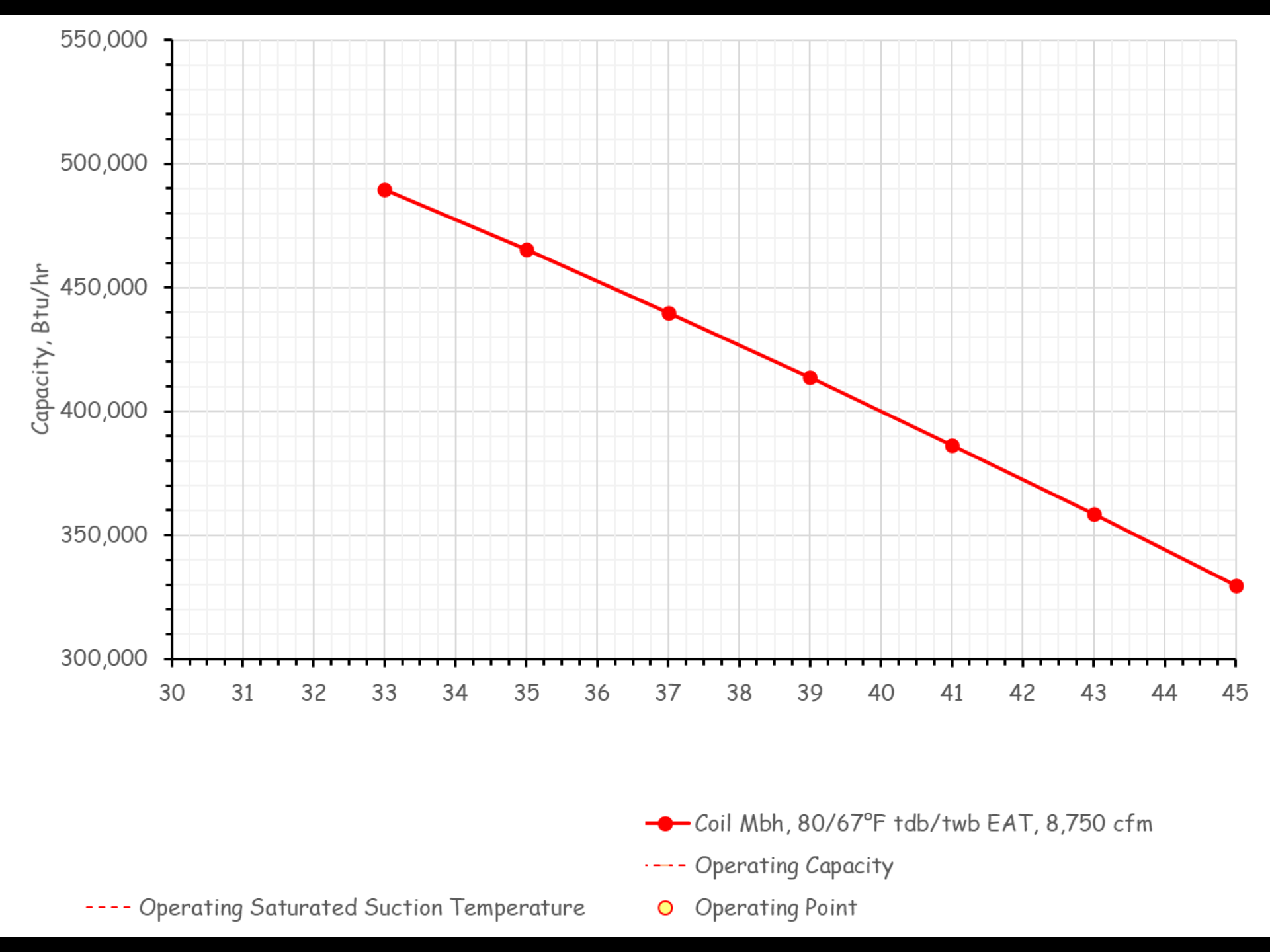
Coil Mbh, 80/67°F tdb/twb EAT, 8,750 cfm
Operating Capacity
Operating Saturated Suction Temperature
Operating Point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Capacity, Btu/hr
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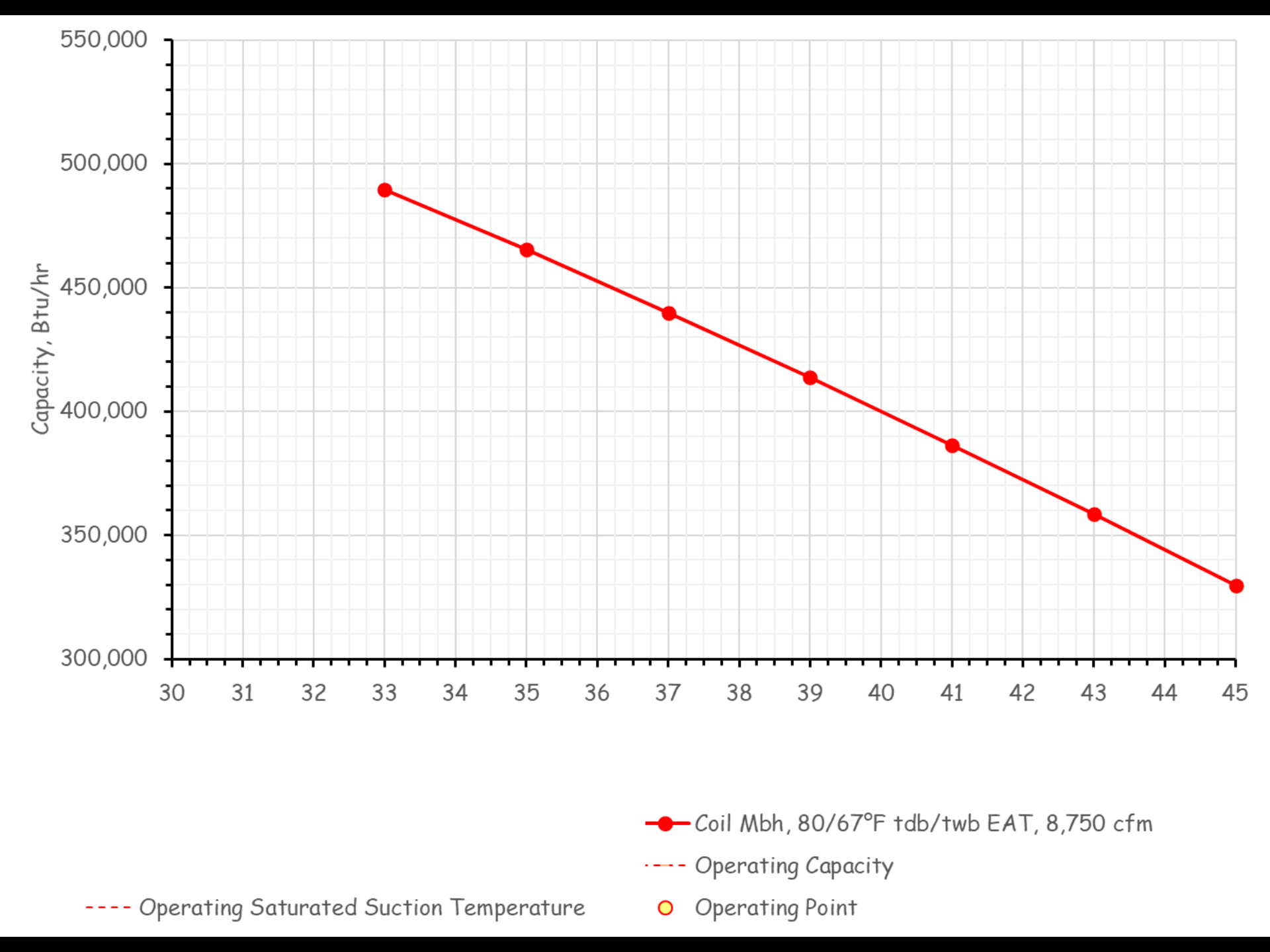
45
Coil Mbh, 80/67°F tdb/twb EAT, 8,750 cfm
Operating Capacity
Operating Saturated Suction Temperature
Operating Point

Compressor and Evaporator Interactions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Coil Mbh, 80/67°F tdb/twb EAT, 8,750 cfm
Operating Capacity
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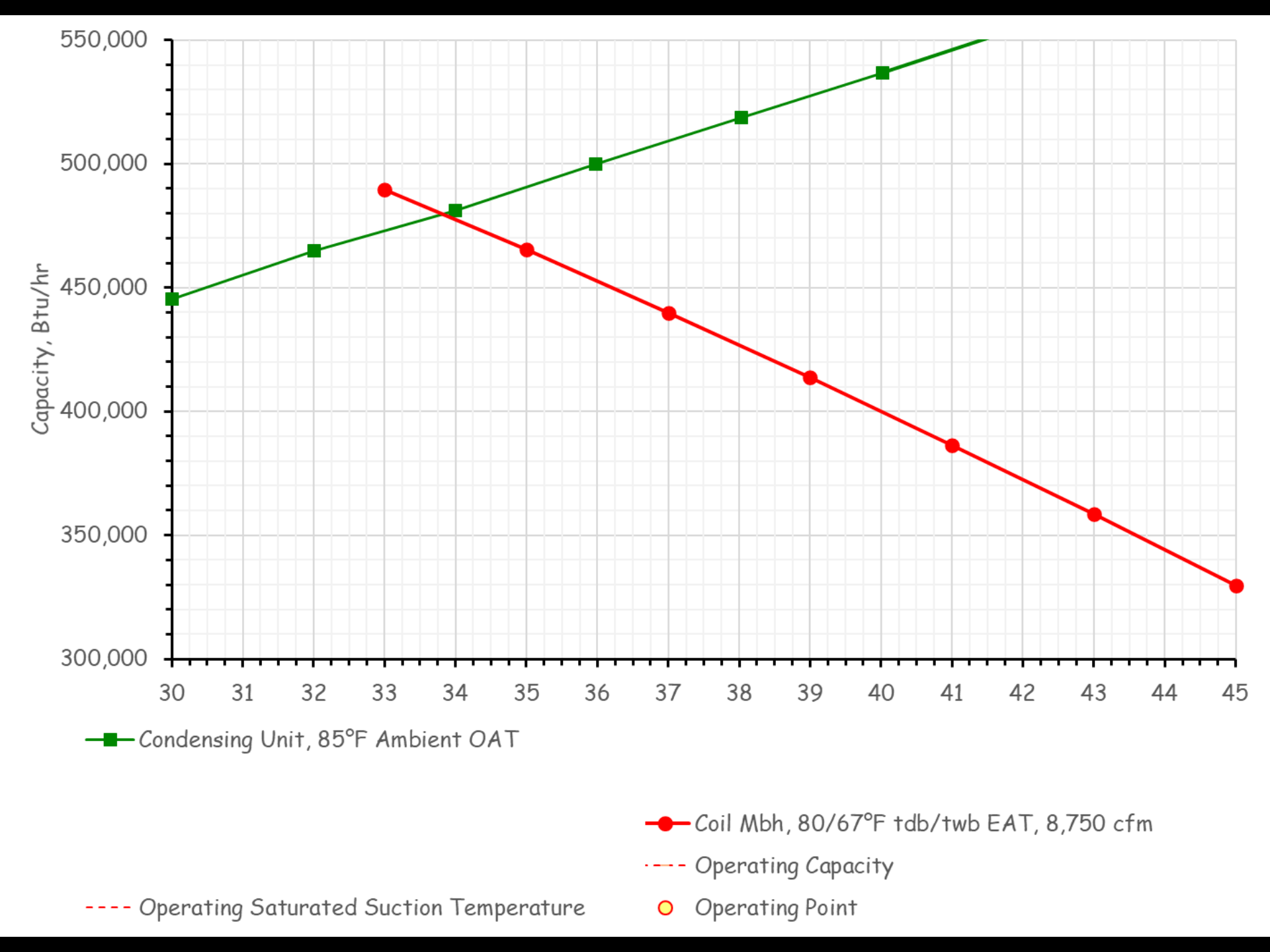
Operating Point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Capacity, Btu/hr
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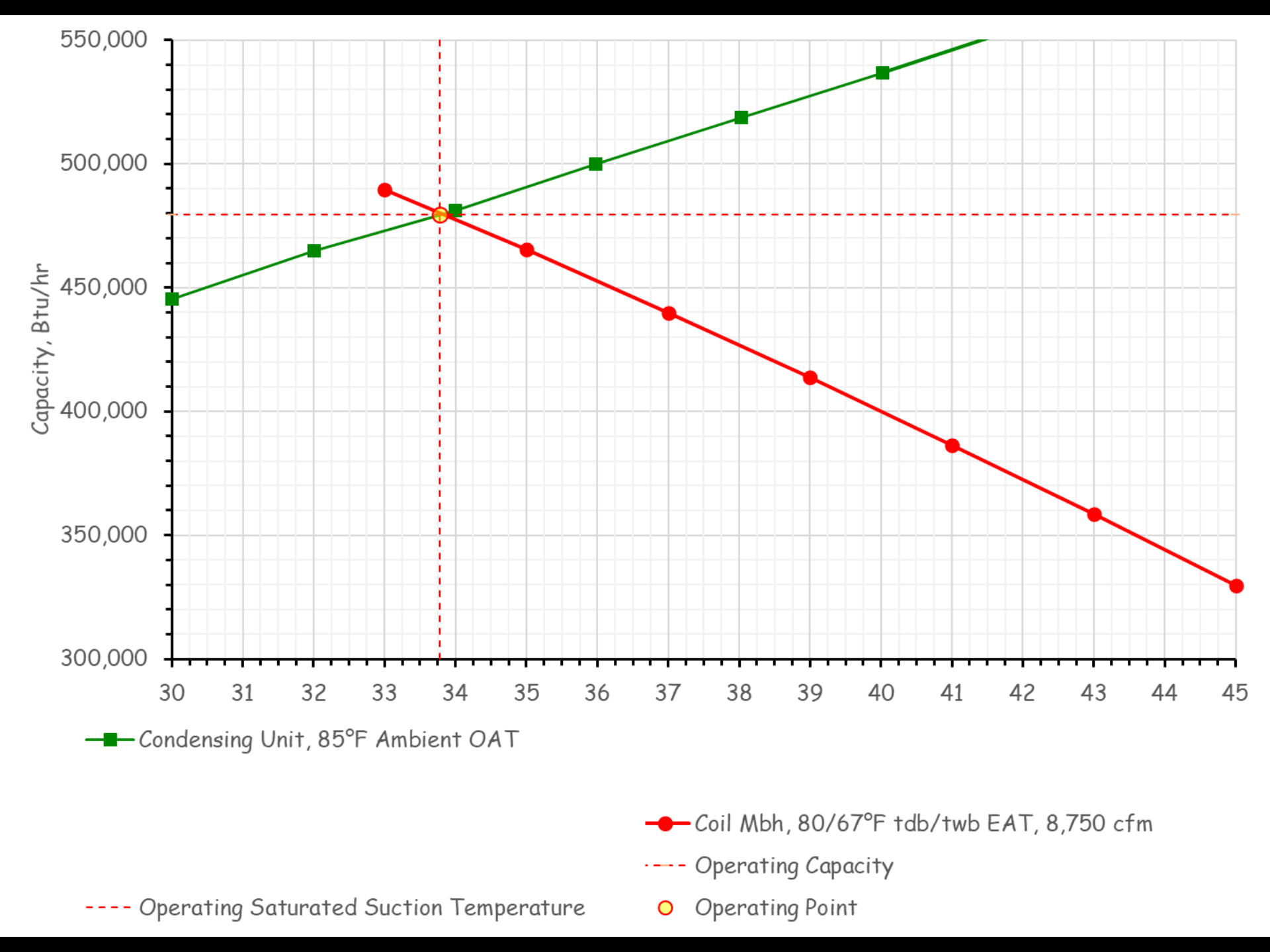
Condensing Unit, 85°F Ambient OAT
Coil Mbh, 80/67°F tdb/twb EAT, 8,750 cfm
Operating Capacity
Operating Saturated Suction Temperature
Operating Point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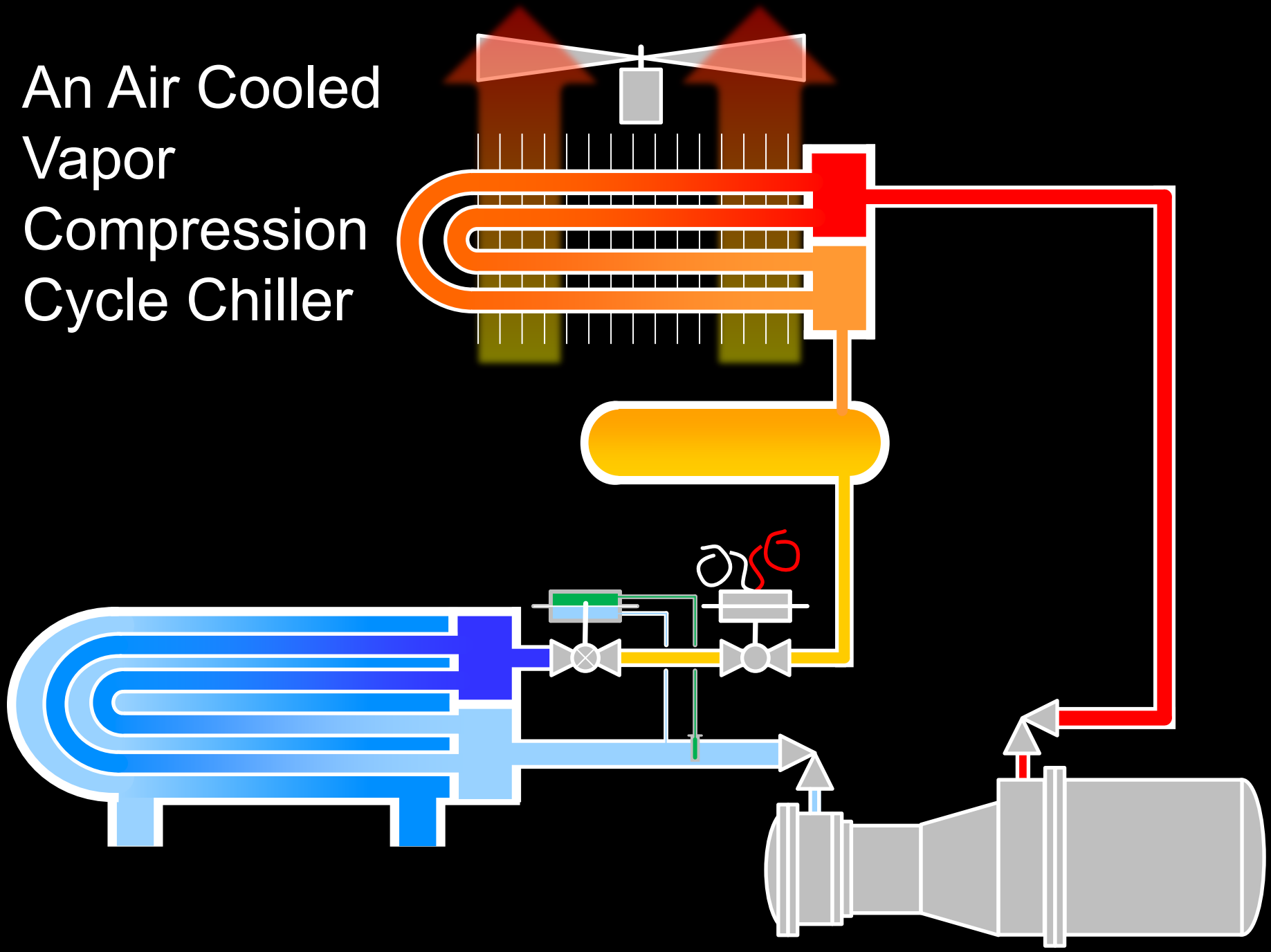
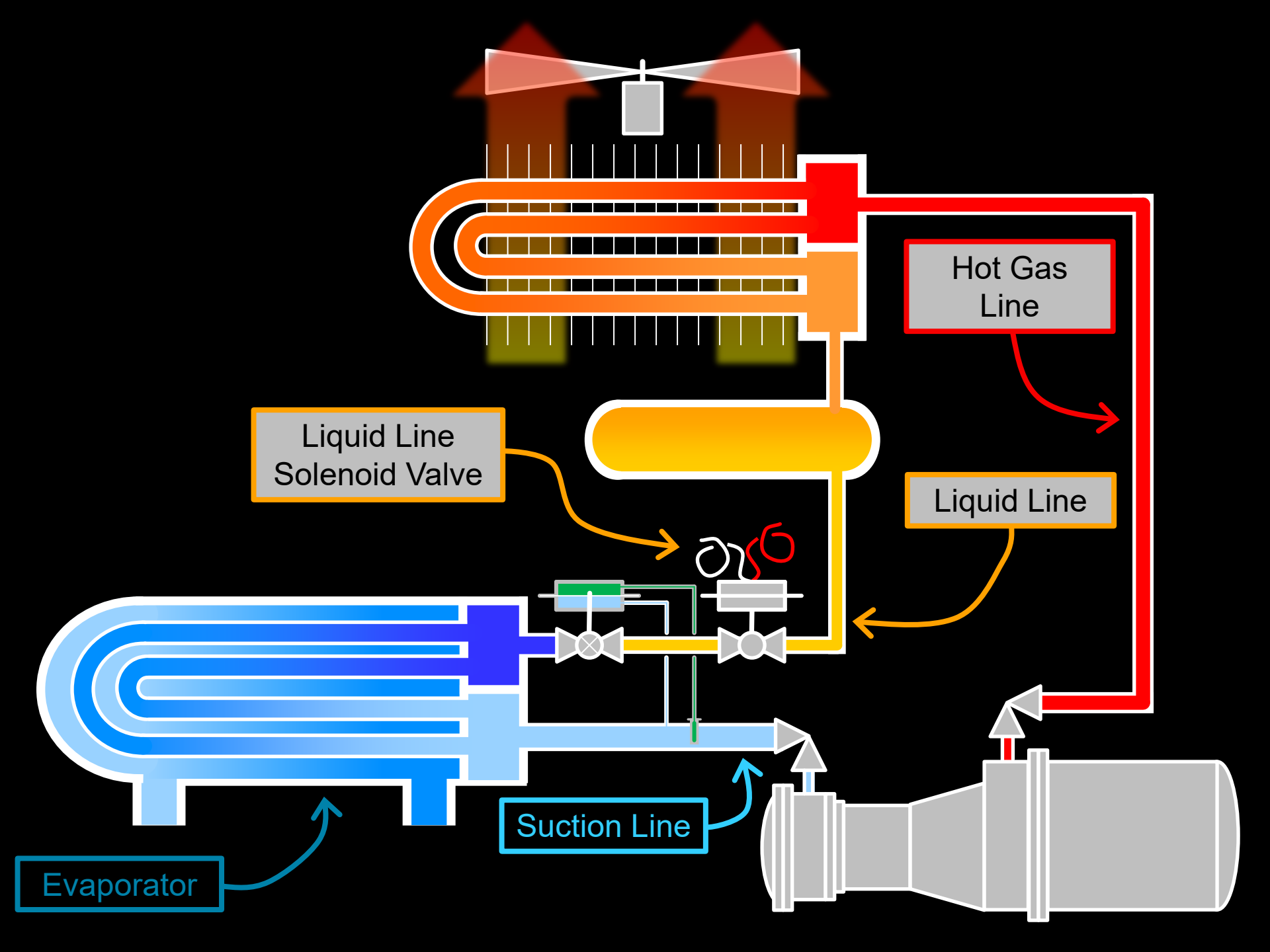
Condensing Unit, 85°F Ambient OAT
Coil Mbh, 80/67°F tdb/twb EAT, 8,750 cfm
Operating Capacity
Operating Saturated Suction Temperature
Operating Point


An Air Cooled
Vapor
Compression
Cycle Chiller


CH-1
TECHNICAL
Black Jet

An Air Cooled Vapor Compression Cycle Chiller

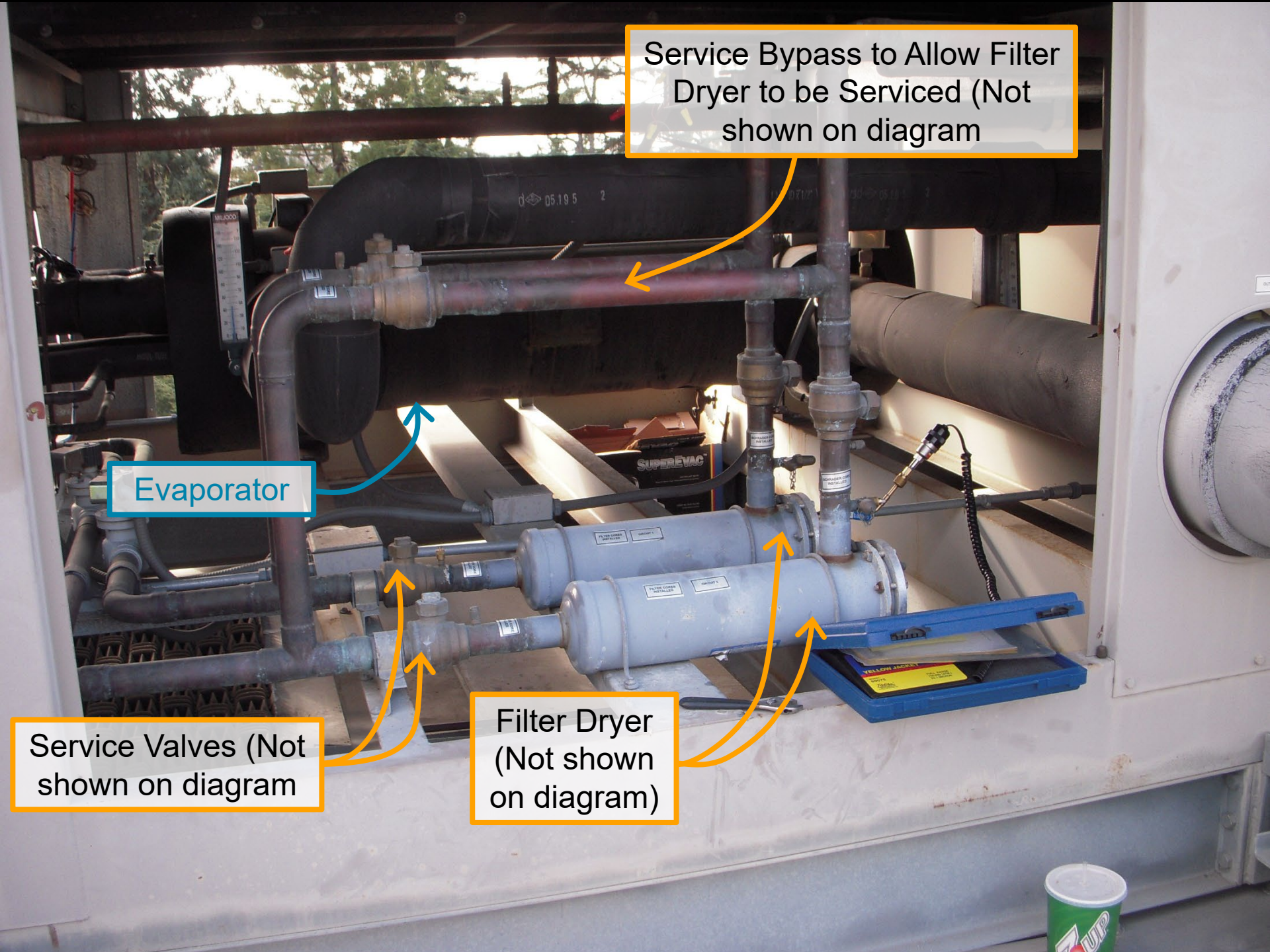


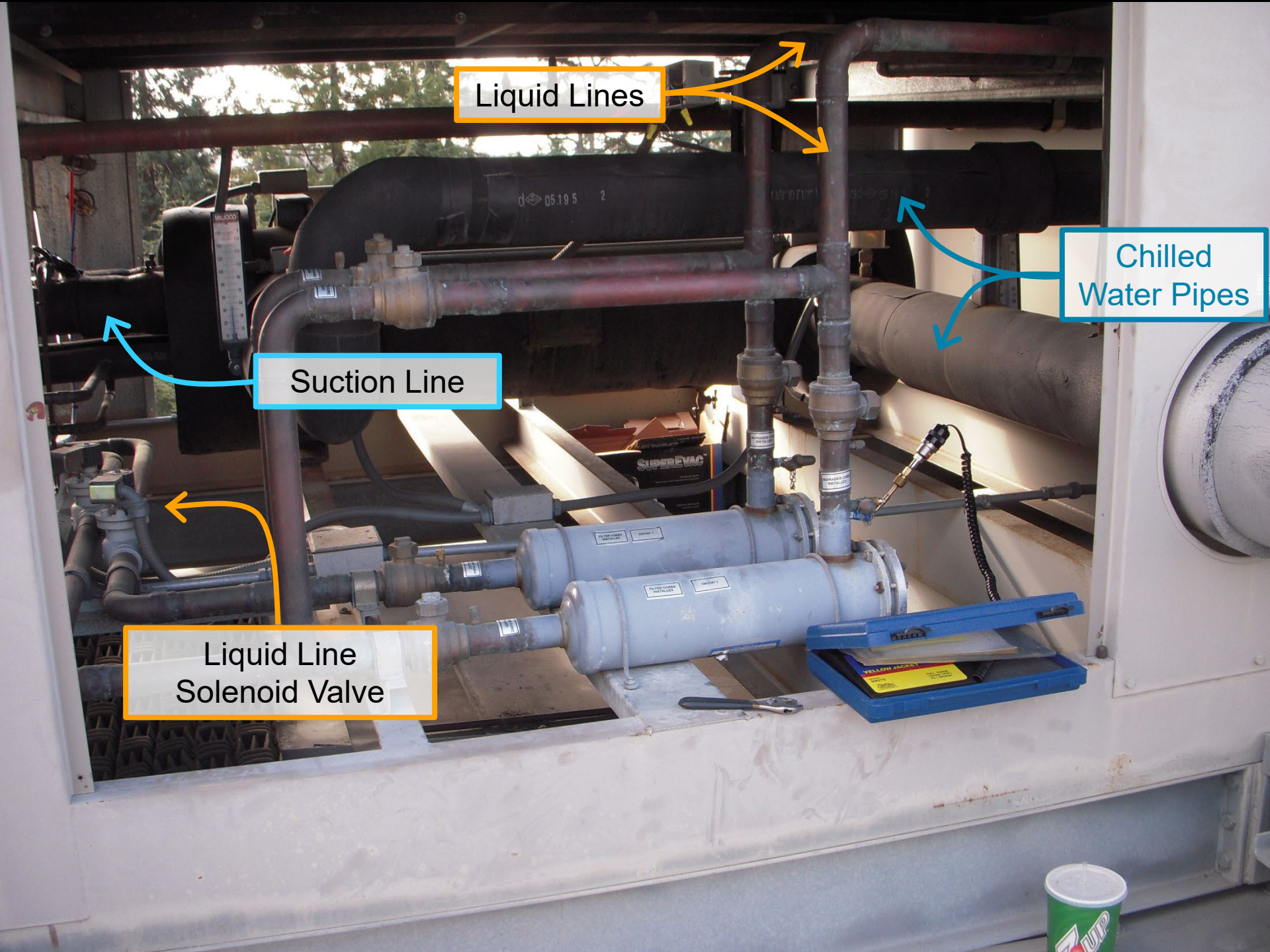

Hot Gas Line
Liquid Line Solenoid Valve
Liquid Line
Suction Line
Evaporator

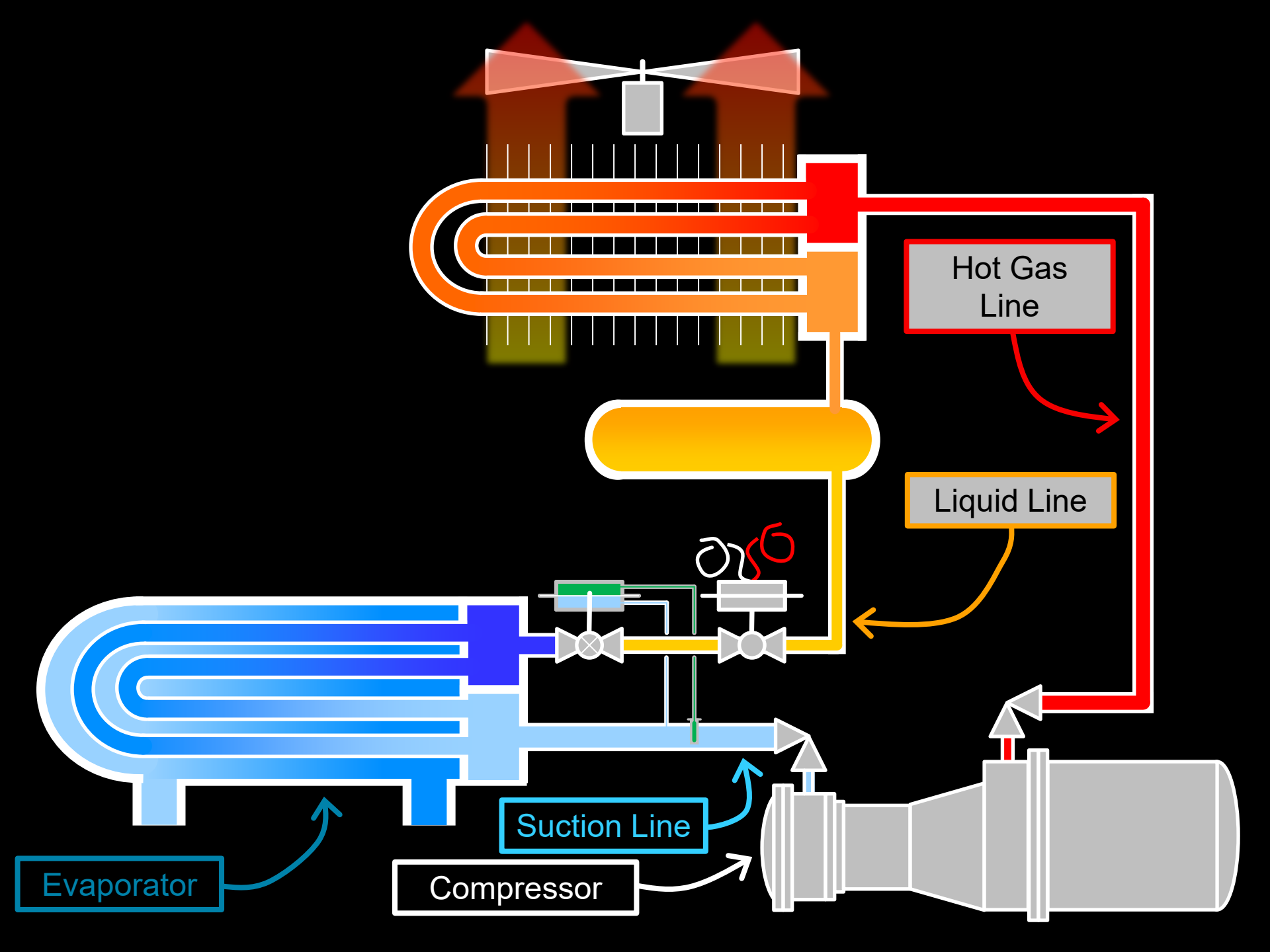
Which Pipe is Which

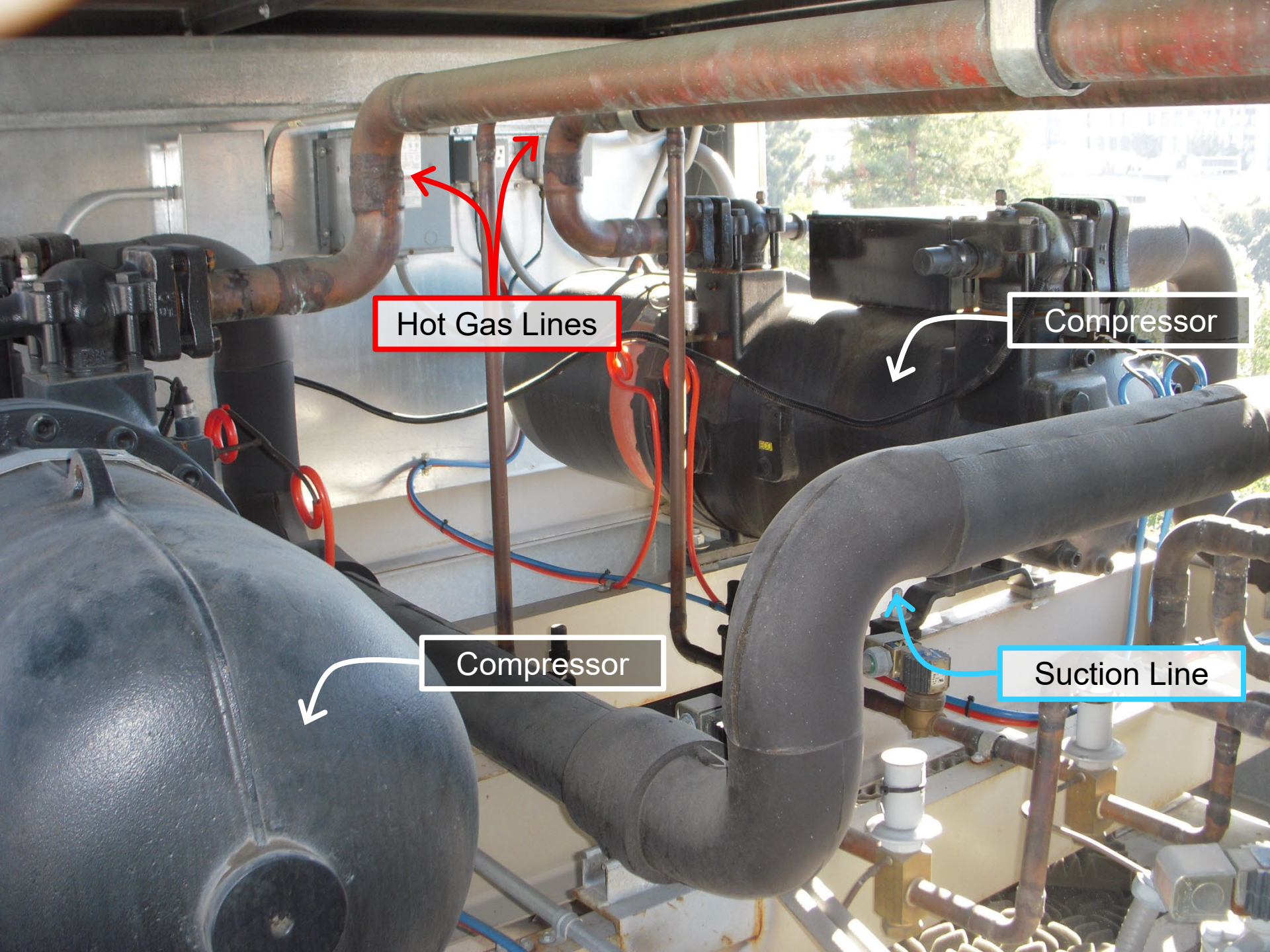
- Suction Line
- Liquid Line
- Hot gas line

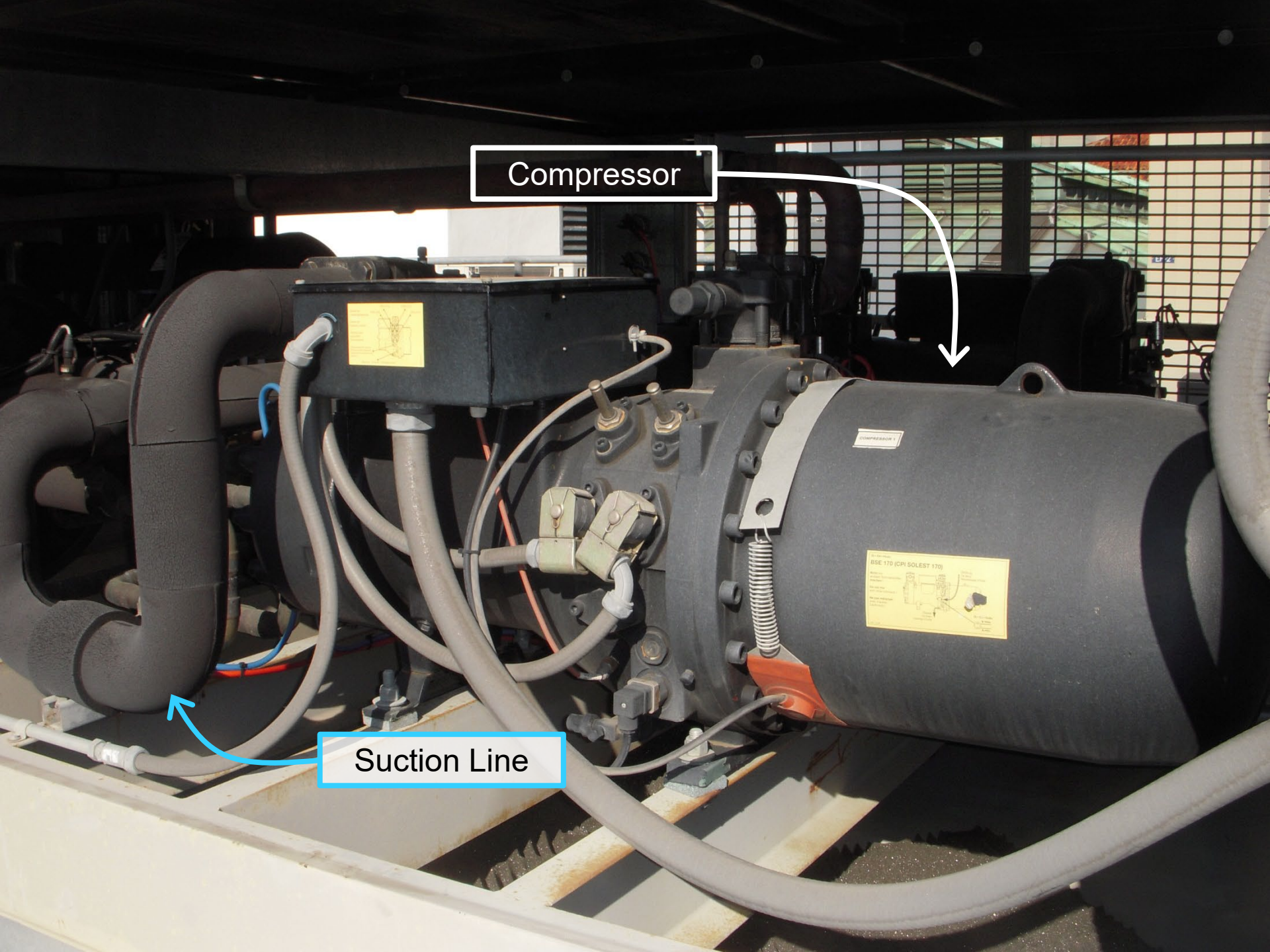
- Largest, coldest and insulated
- Smallest, warm, usually not insulated
- Size between suction and liquid line size, hot, typically not insulated


Service Bypass to Allow Filter Dryer to be Serviced (Not shown on diagram
Evaporator
Service Valves (Not shown on diagram
Filter Dryer (Not shown on diagram)

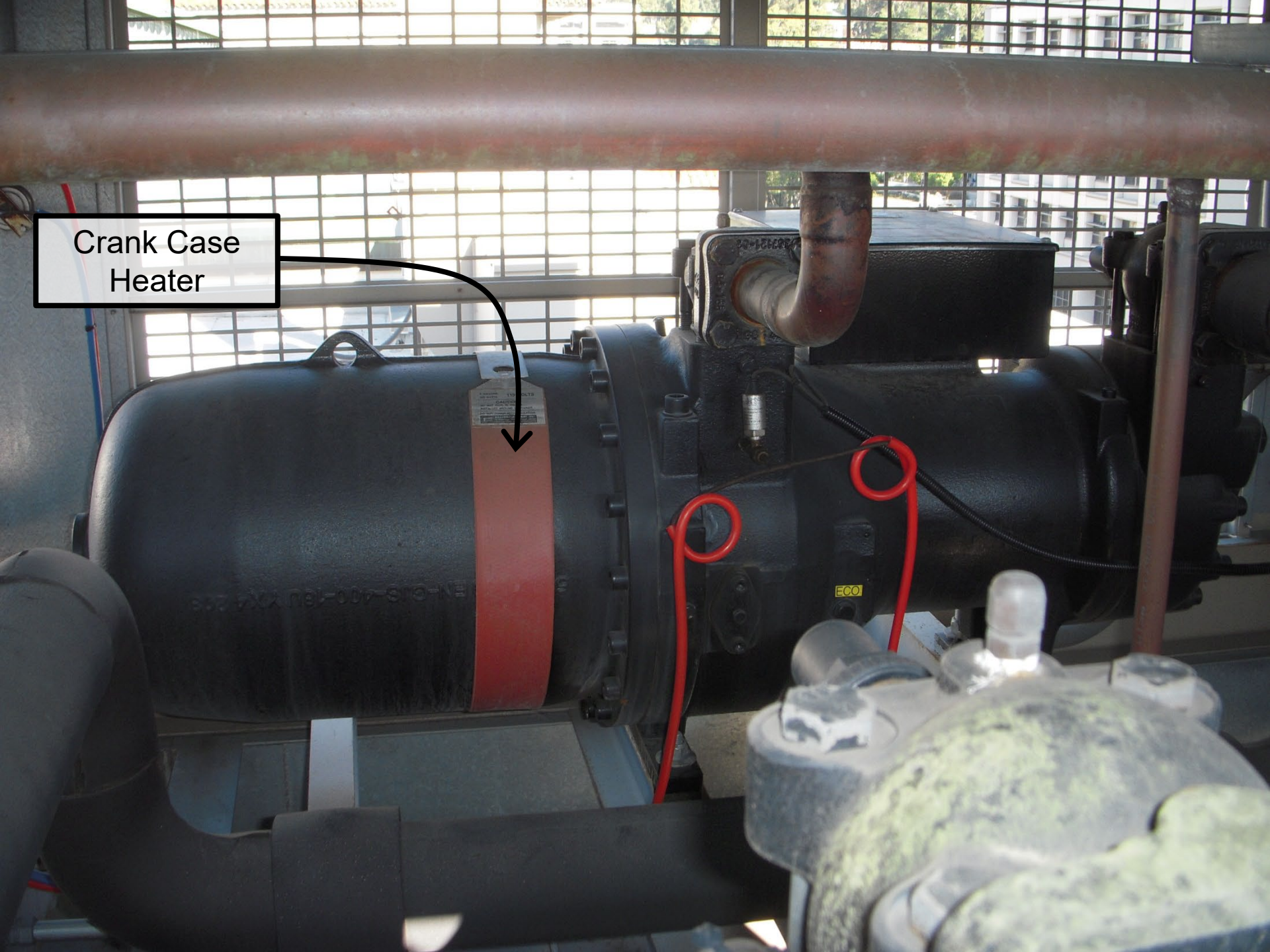

Liquid Lines
Chilled Water Pipes
Suction Line
Liquid Line Solenoid Valve

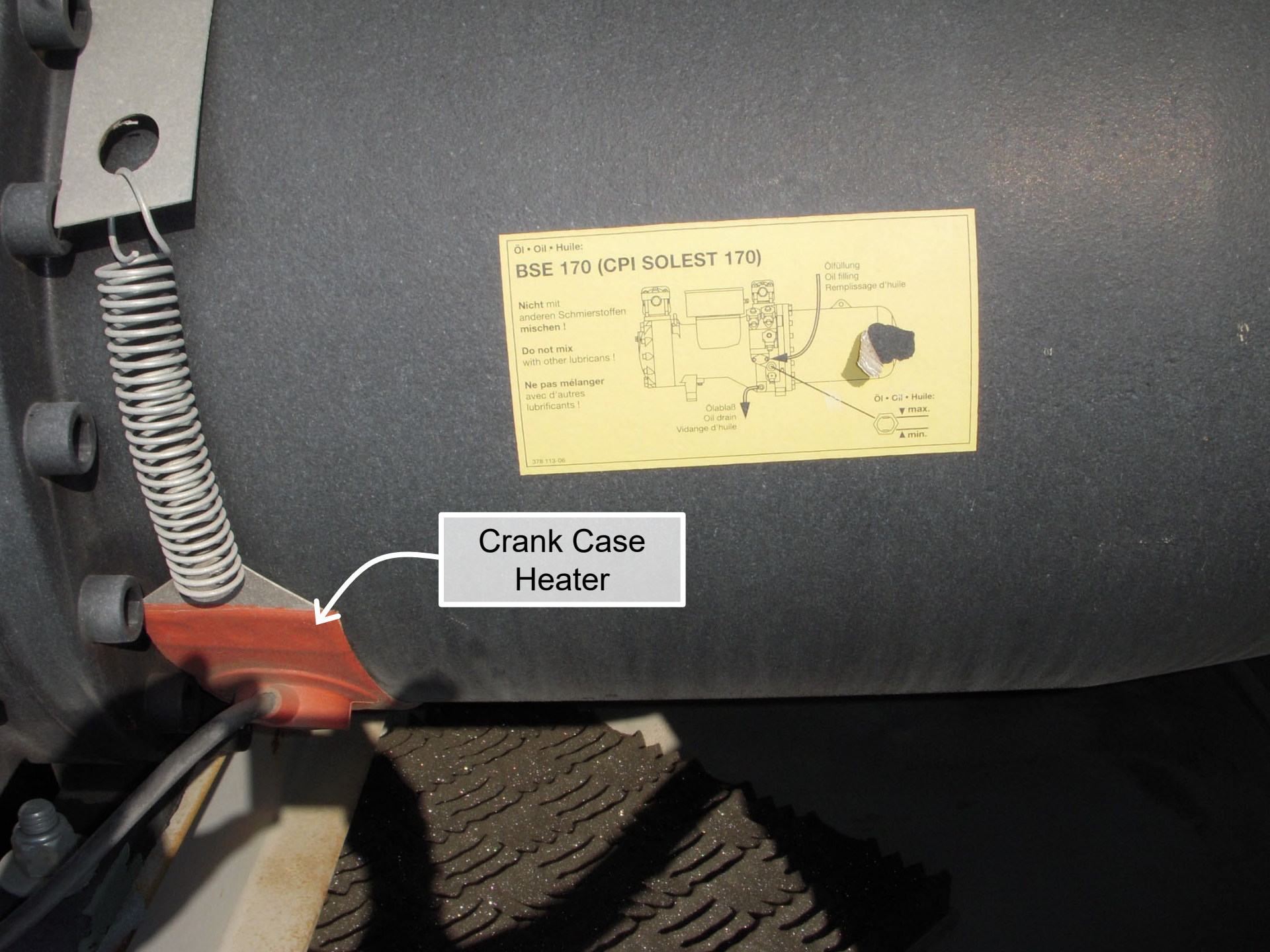

Hot Gas Line
Liquid Line
Suction Line
Compressor
Evaporator

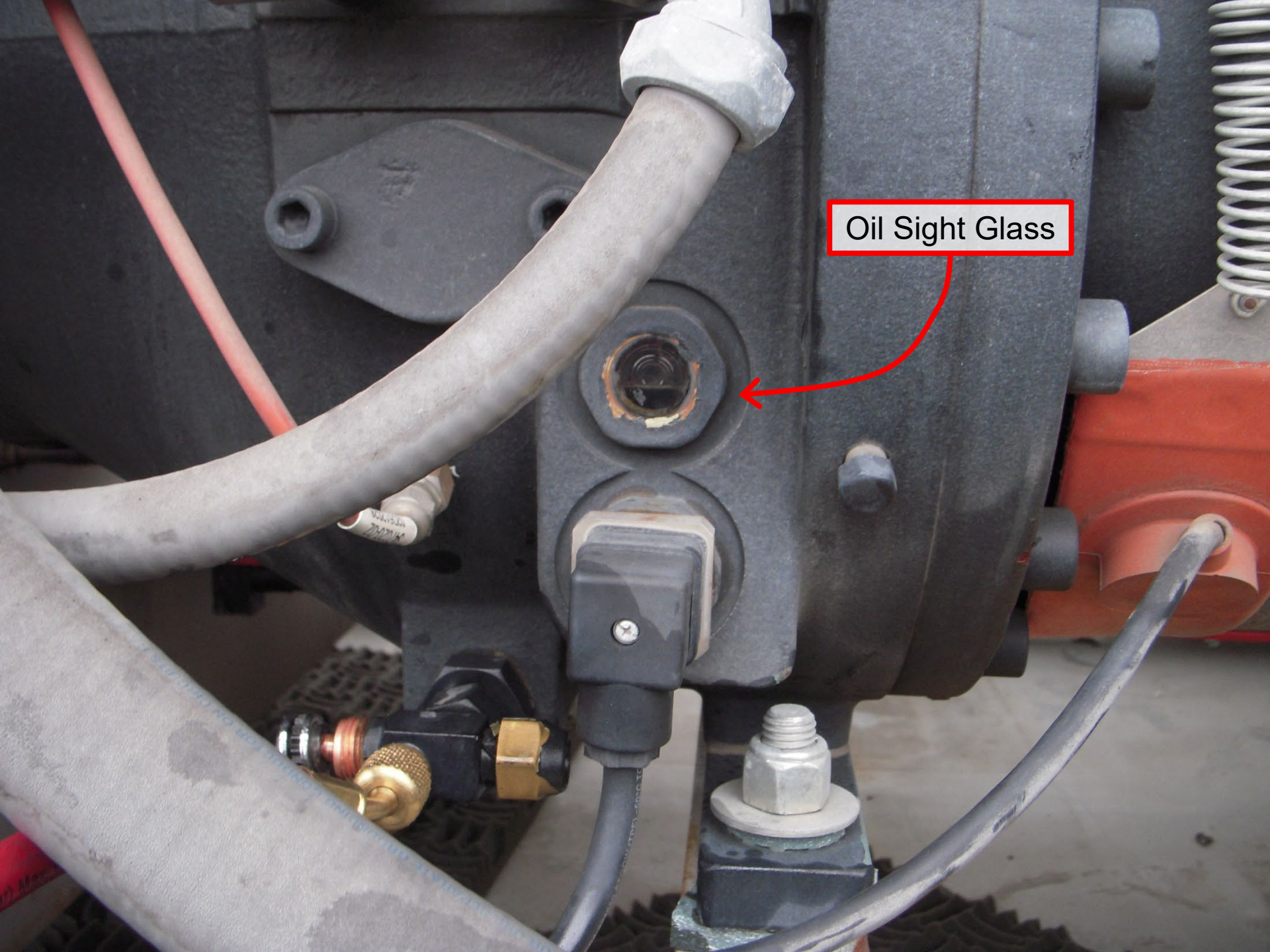

Hot Gas Lines
Compressor
Compressor
Suction Line


Compressor
Suction Line


Unloaders


Crank Case
Heater


Öl • Oil • Huile:
BSE 170 (CPI SOLEST 170)
Nicht mit anderen Schmierstoffen mischen !
Do not mix with other lubricans !
Ne pas mélanger avec d'autres lubrificants !
Ölfüllung
Oil filling
Remplissage d'huile
Ölablaß
Oil drain
Vidange d'huile
Öl • Oil • Huile:
▼ max.
▲ min.
378 113-06
Crank Case Heater

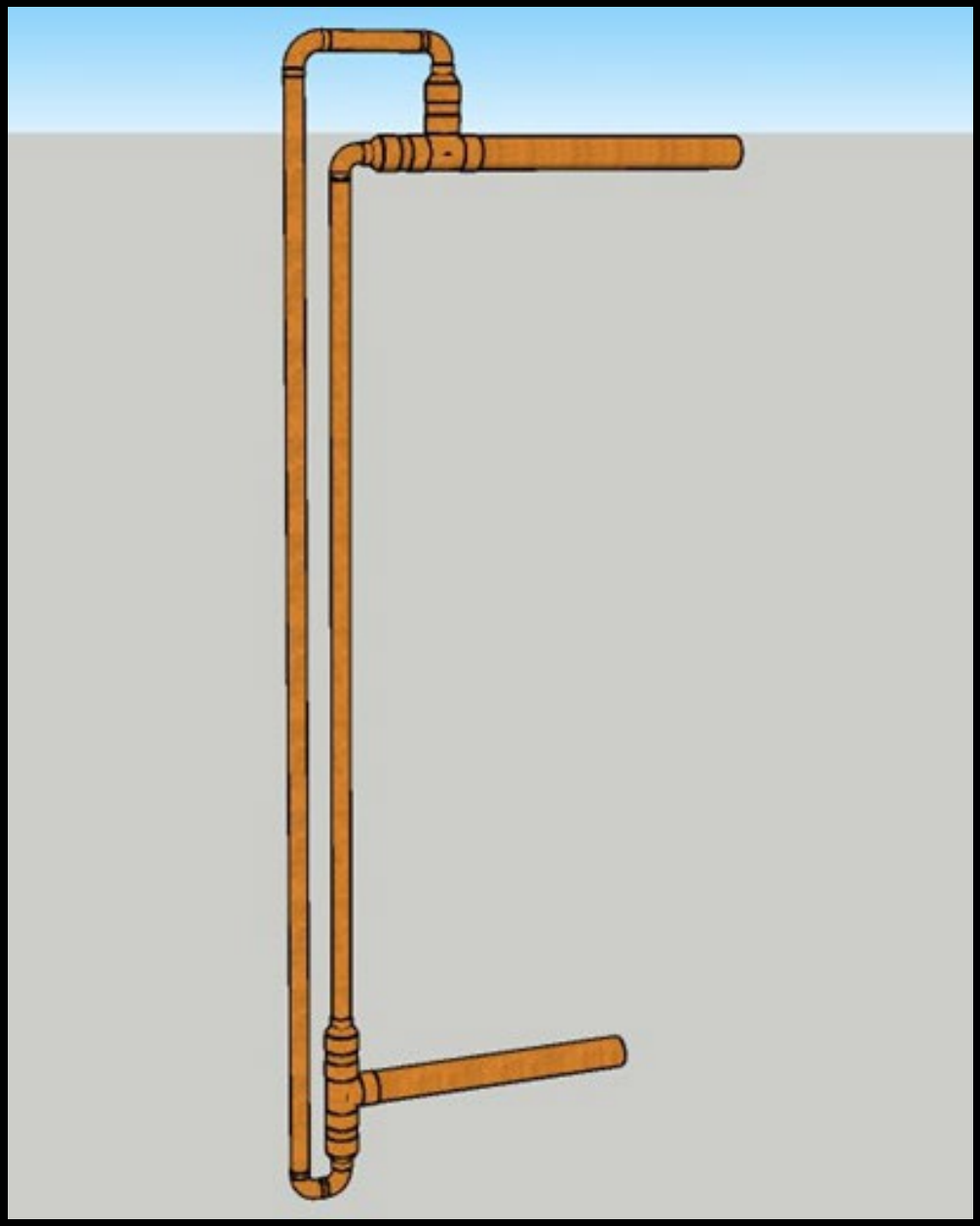

Oil Sight Glass

Hand Pump for Adding Oil

Oil Management is Crucial

Design the Piping to Bring it Back

- Pitch towards the compressor
- Maintain velocities that will carry the oil back
- Use double suction risers to change elevation



Installation Practices

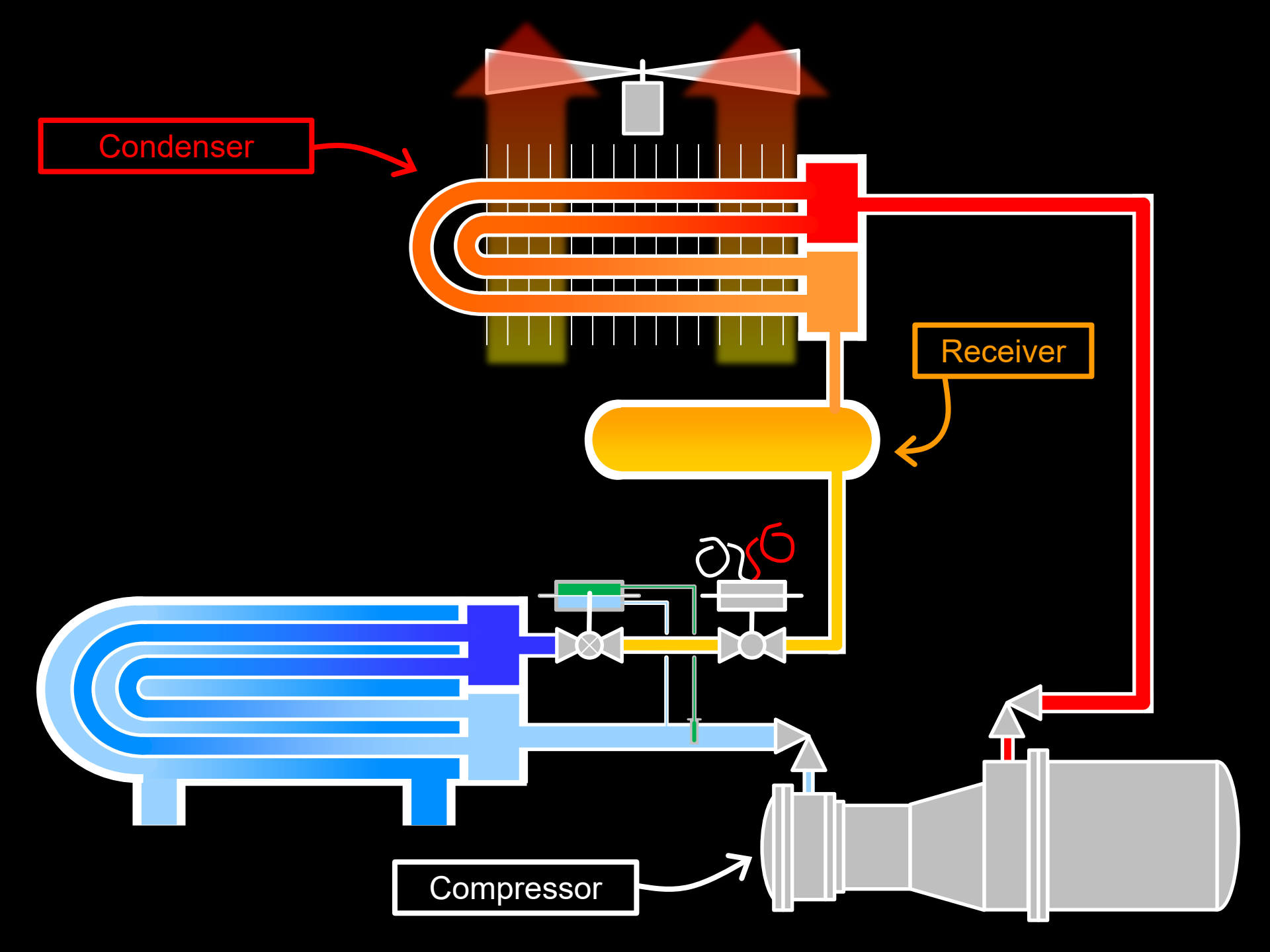
Refrigerant piping installation practice critical to short and long term system integrity

- General requirements no different from those employed with any built up refrigeration system
- Details associated with R410 systems may vary from standard practice in the field at this point in time

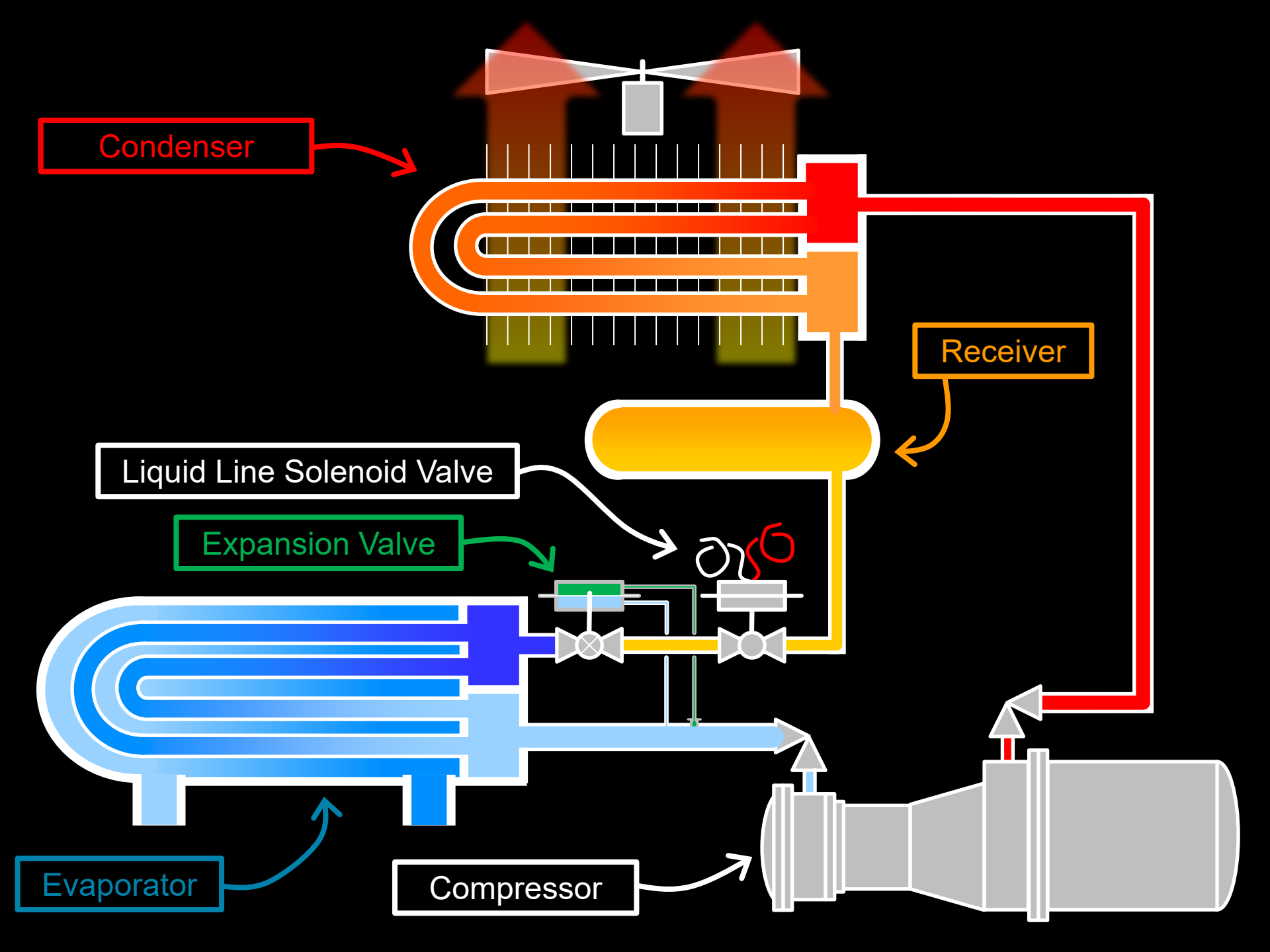
Nitrogen Purge is Essential While Brazing

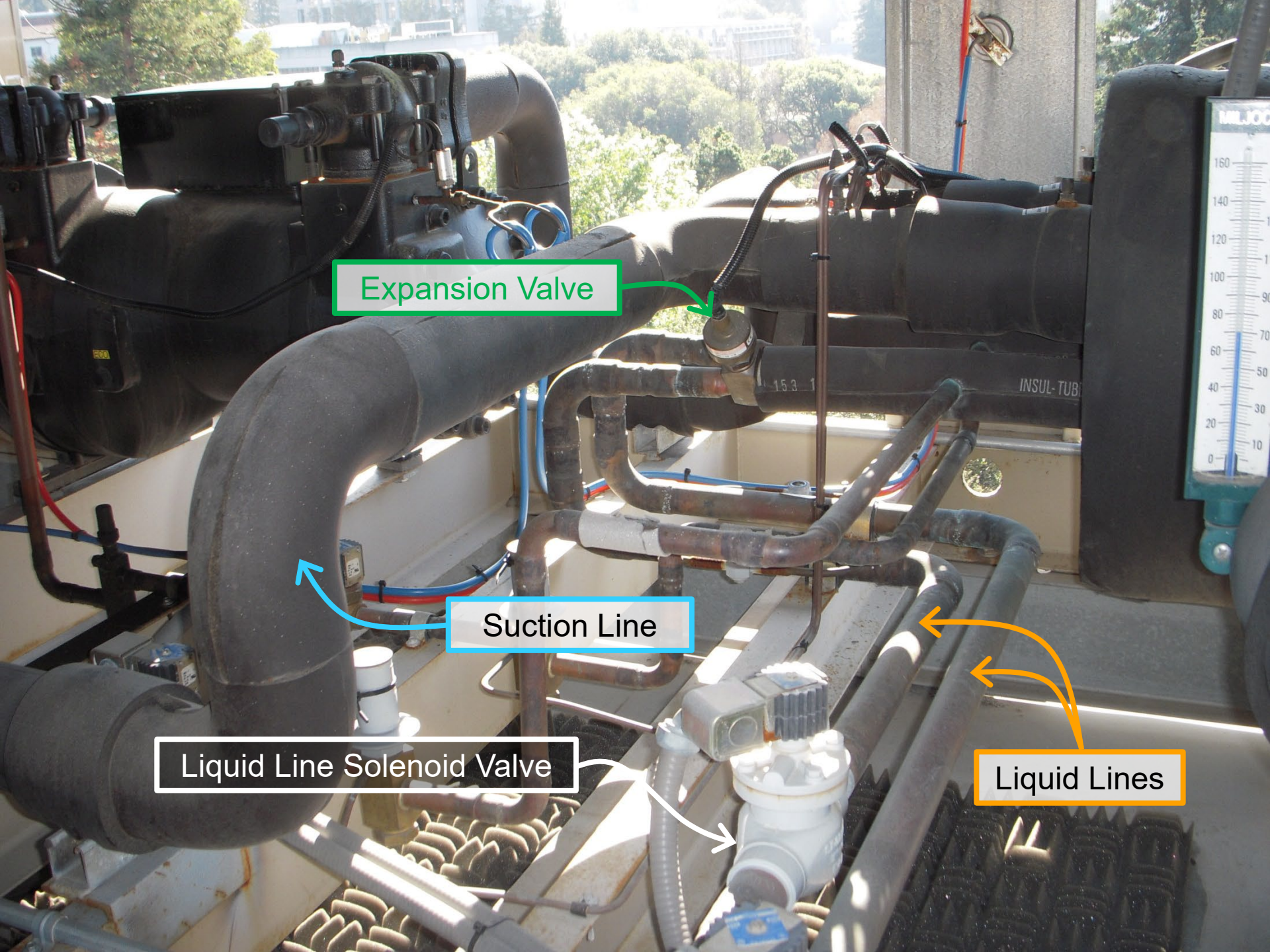
Courtesy http://www.reflok.pl

Courtesy http://www.hvactrainingsolutions.net

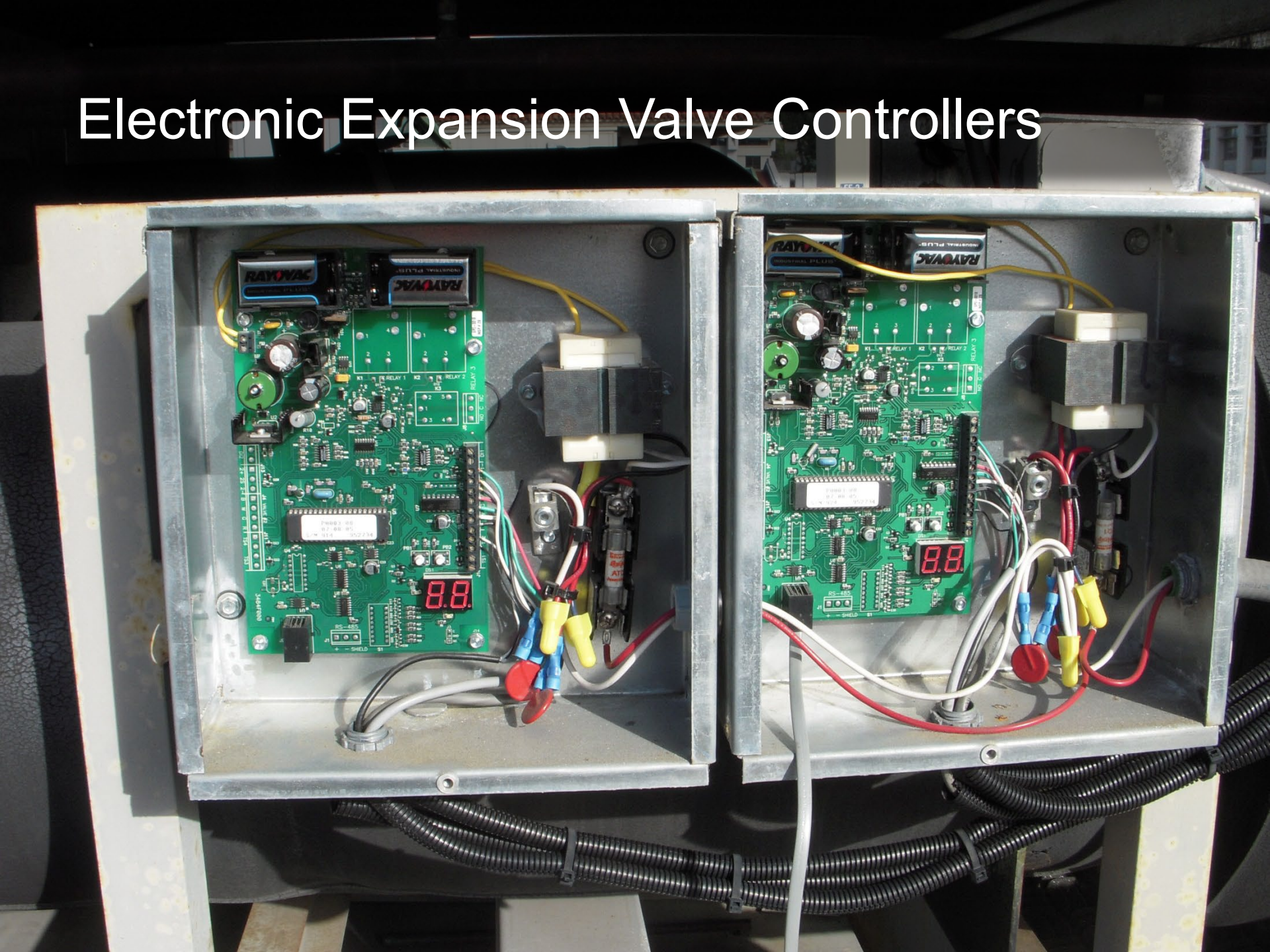

Condenser
Receiver
Compressor


Condenser
CH-1
TECHNICAL


Condenser
Receiver
Liquid Line Solenoid Valve
Expansion Valve
Evaporator
Compressor

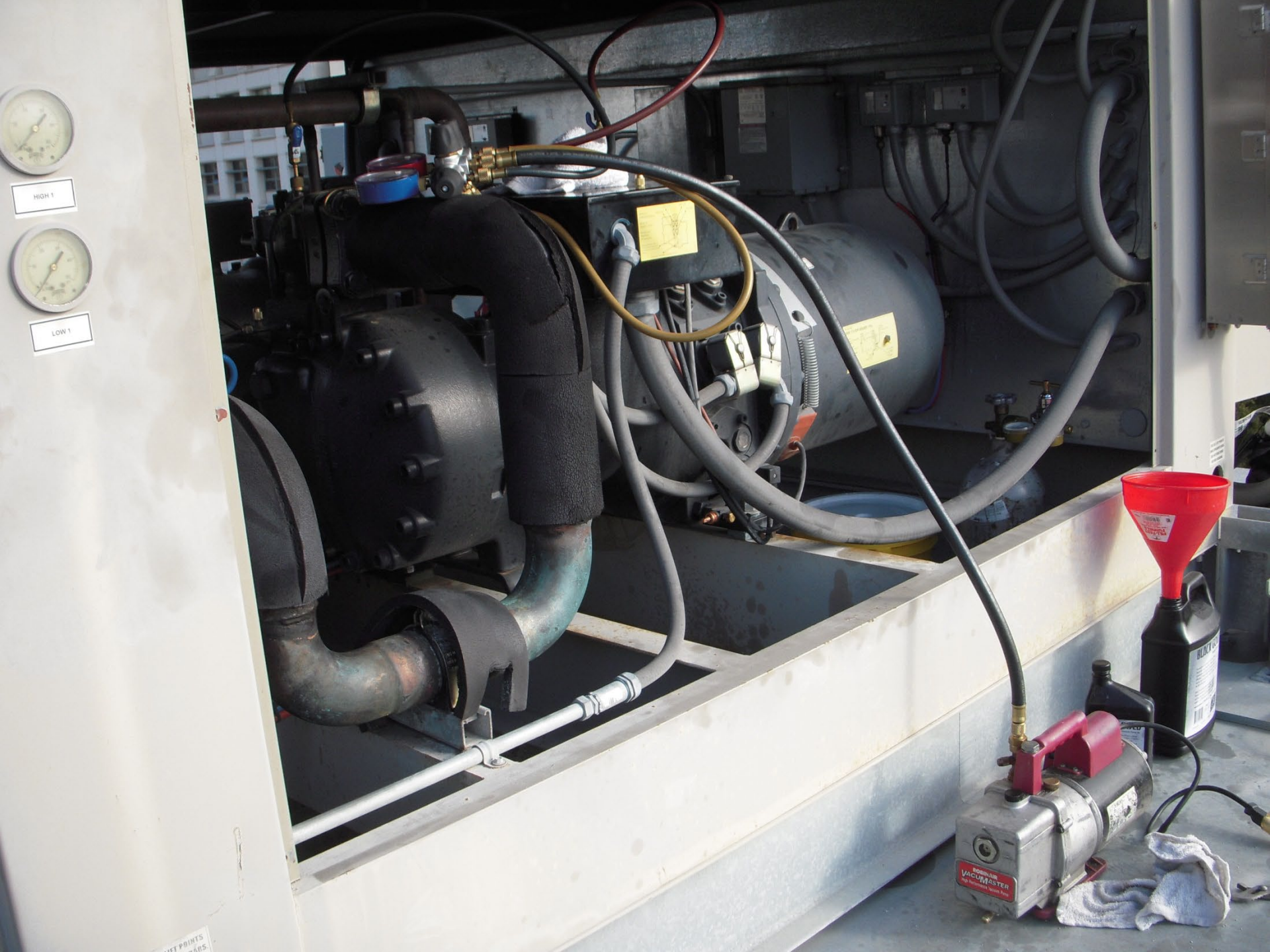

Expansion Valve
Suction Line
Liquid Line Solenoid Valve
Liquid Lines

Electronic Expansion Valve Controllers



A Refrigerant Sight Glass

Vacuum Pump Evacuating the System in Preparation for Charging


HIGH 1
LOW 1
VACUMASTER

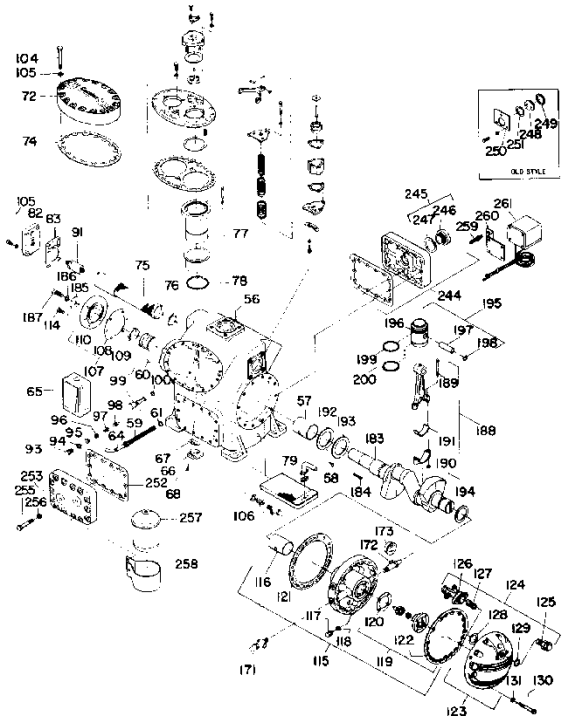
Screw Compressors


CHILLED WATER SUPPLY
HGM-MZ

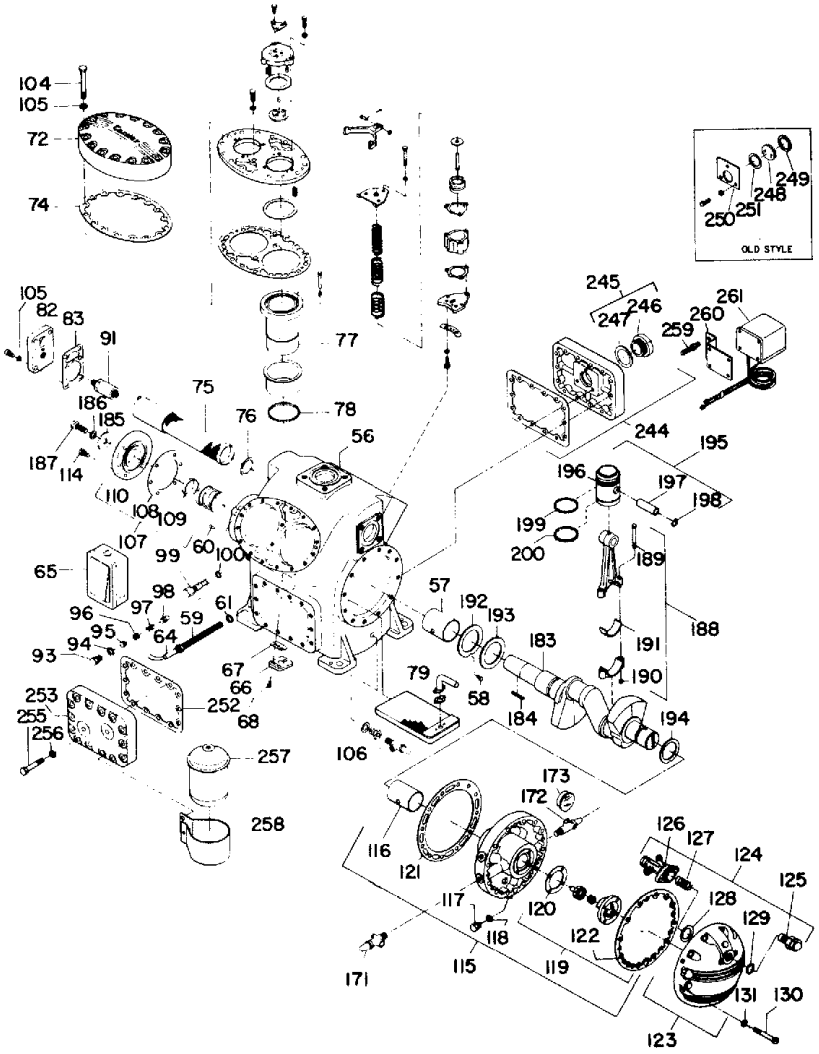

CONDENSER WATER SUPPLY

Scroll Compressors

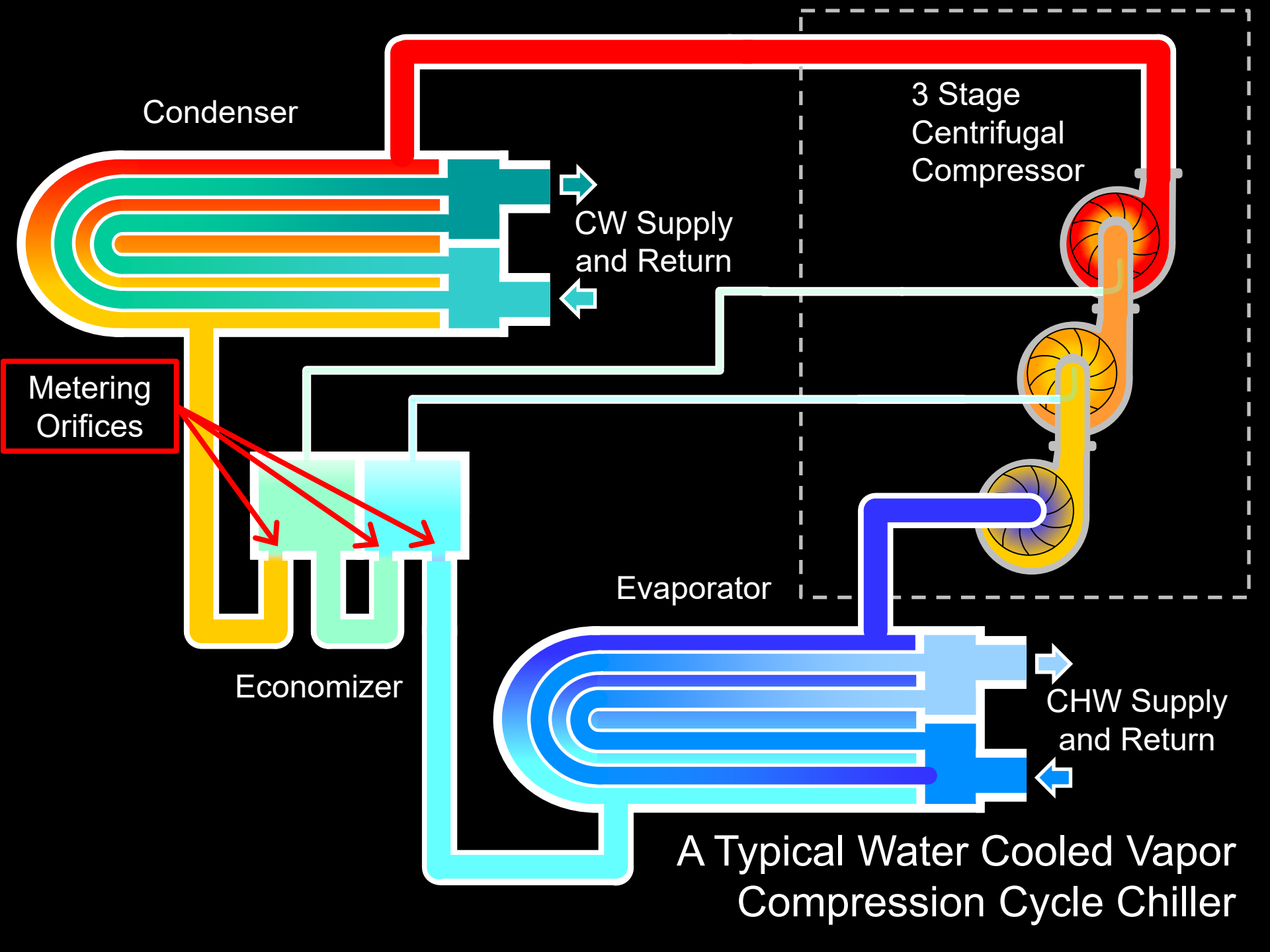
Reciprocating Compressors



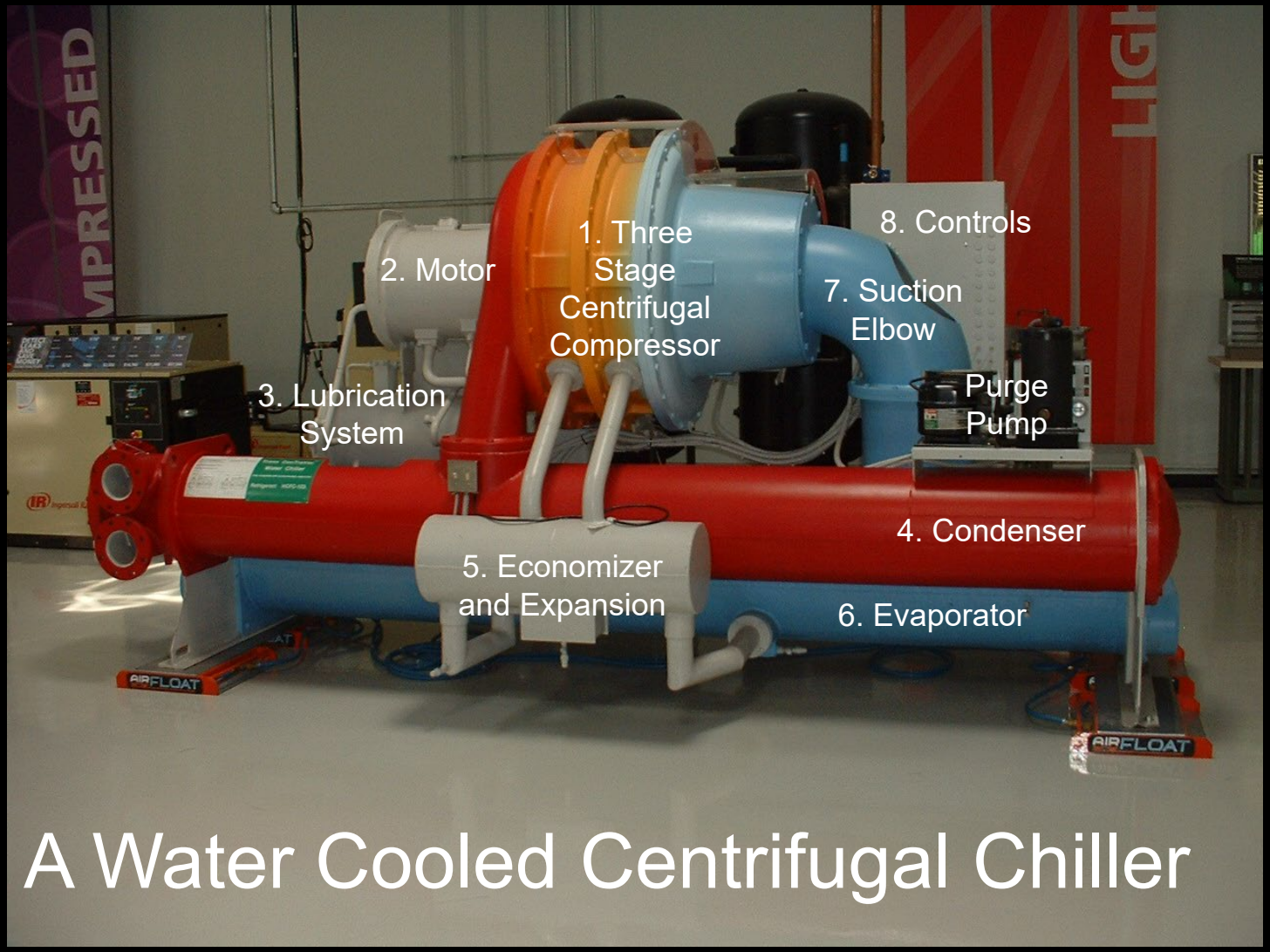
COMPRESSOR
(5H40 shown)



COMPRESSOR
(5H40 shown)

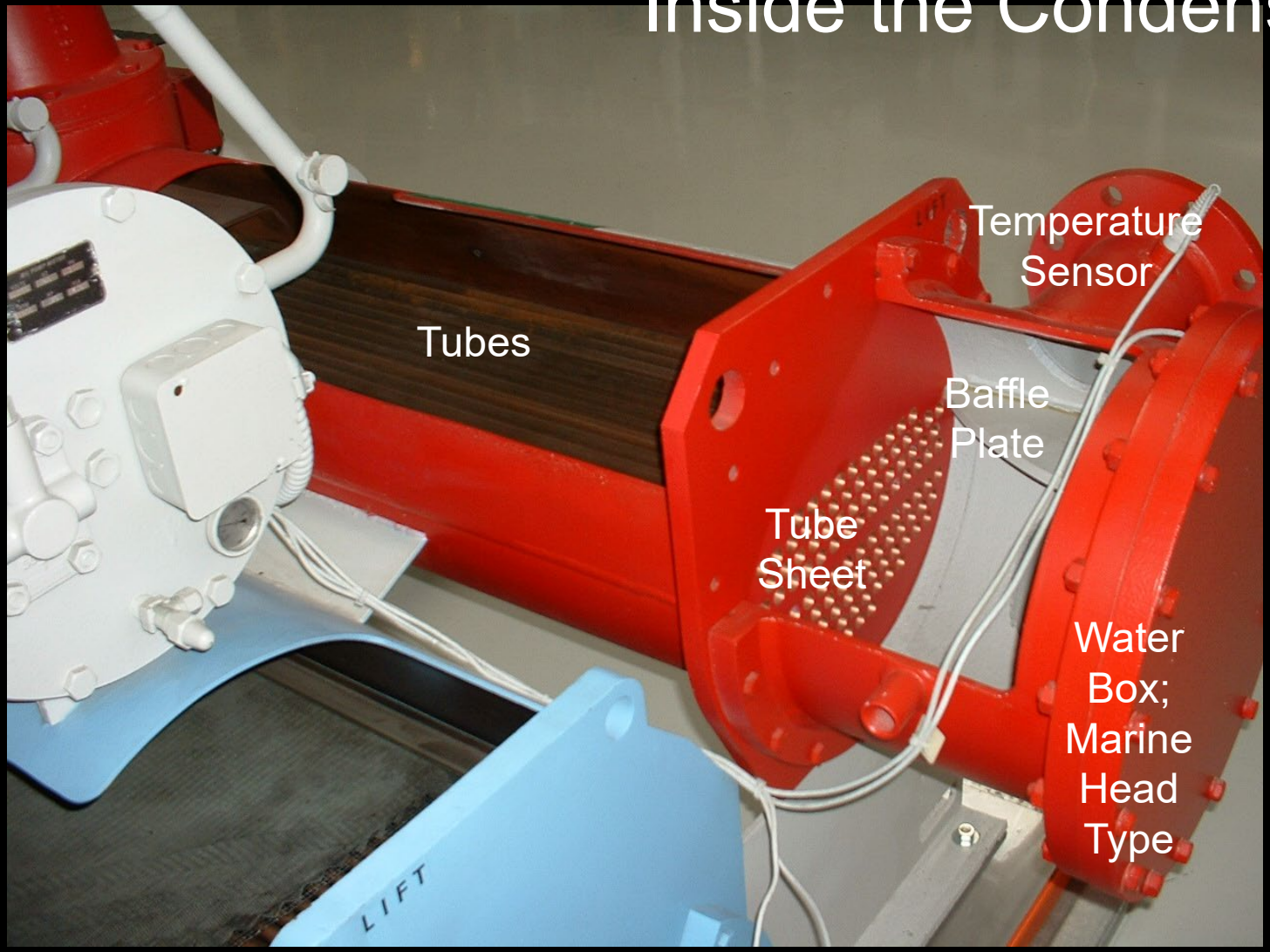

Condenser
3 Stage
Centrifugal
Compressor
CW Supply
and Return
Metering
Orifices
Evaporator
Economizer
CHW Supply
and Return
A Typical Water Cooled Vapor
Compression Cycle Chiller

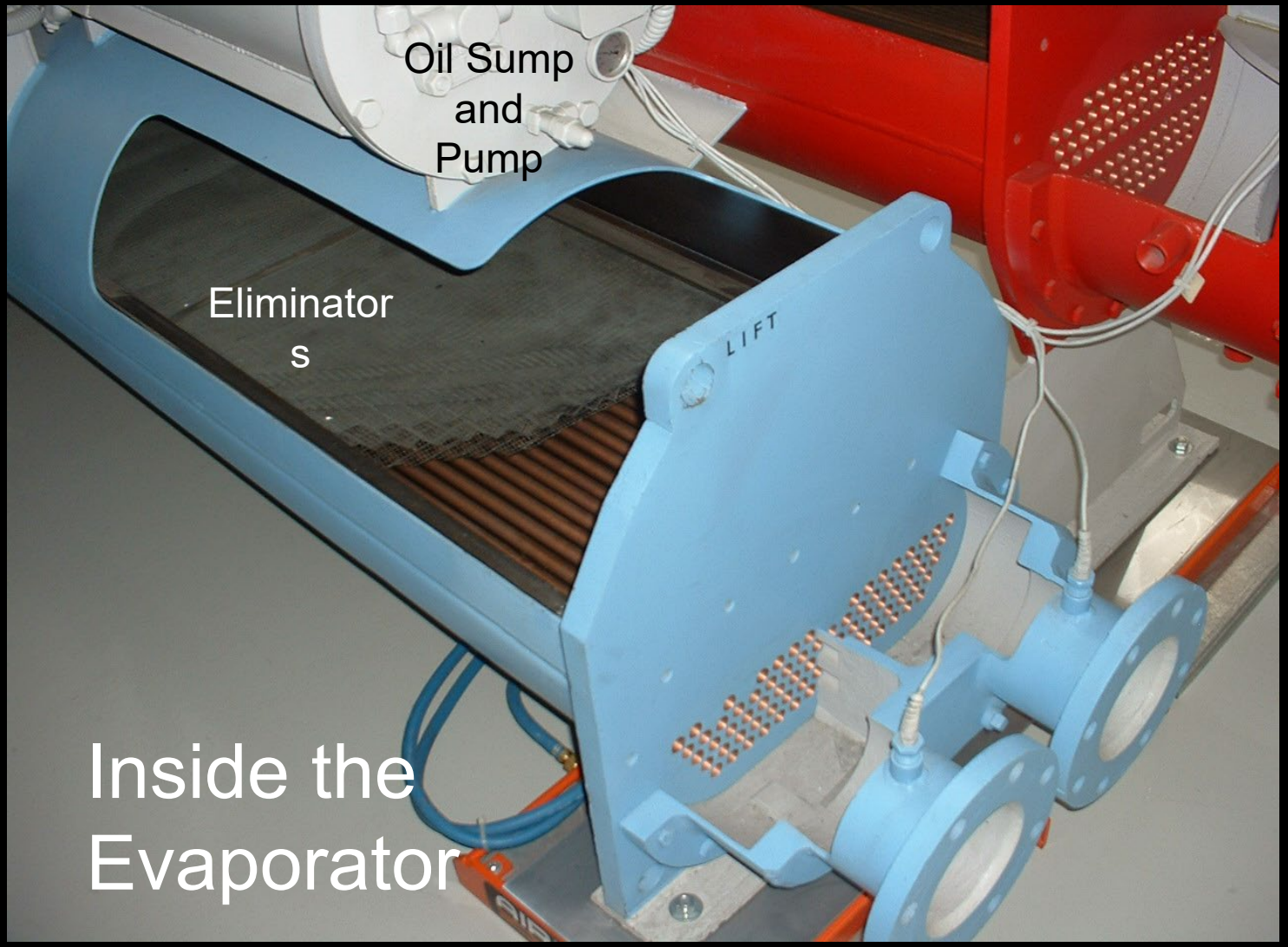
A Water Cooled Centrifugal Chiller



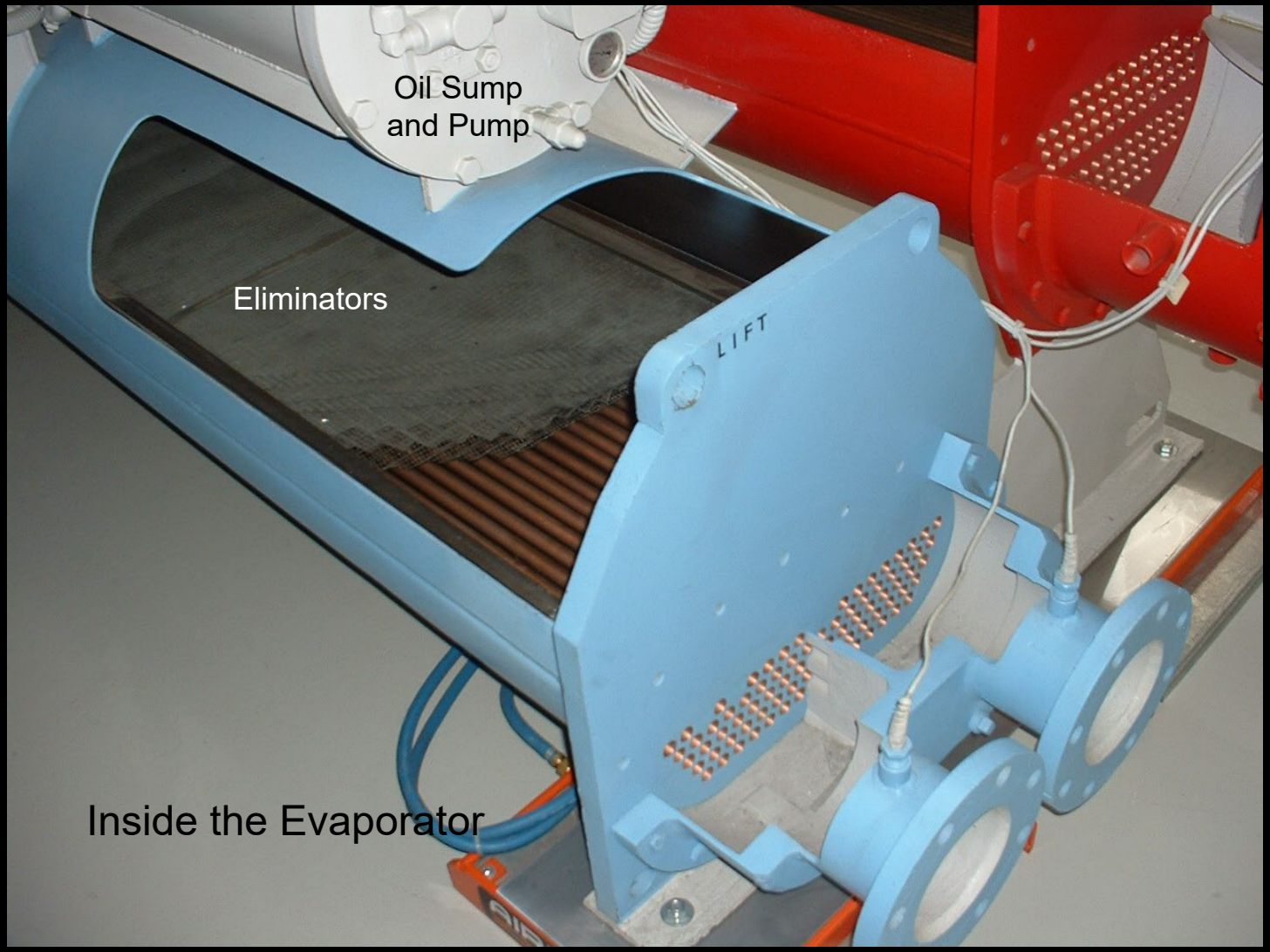
A Water Cooled Centrifugal Chiller

Inside the Condenser



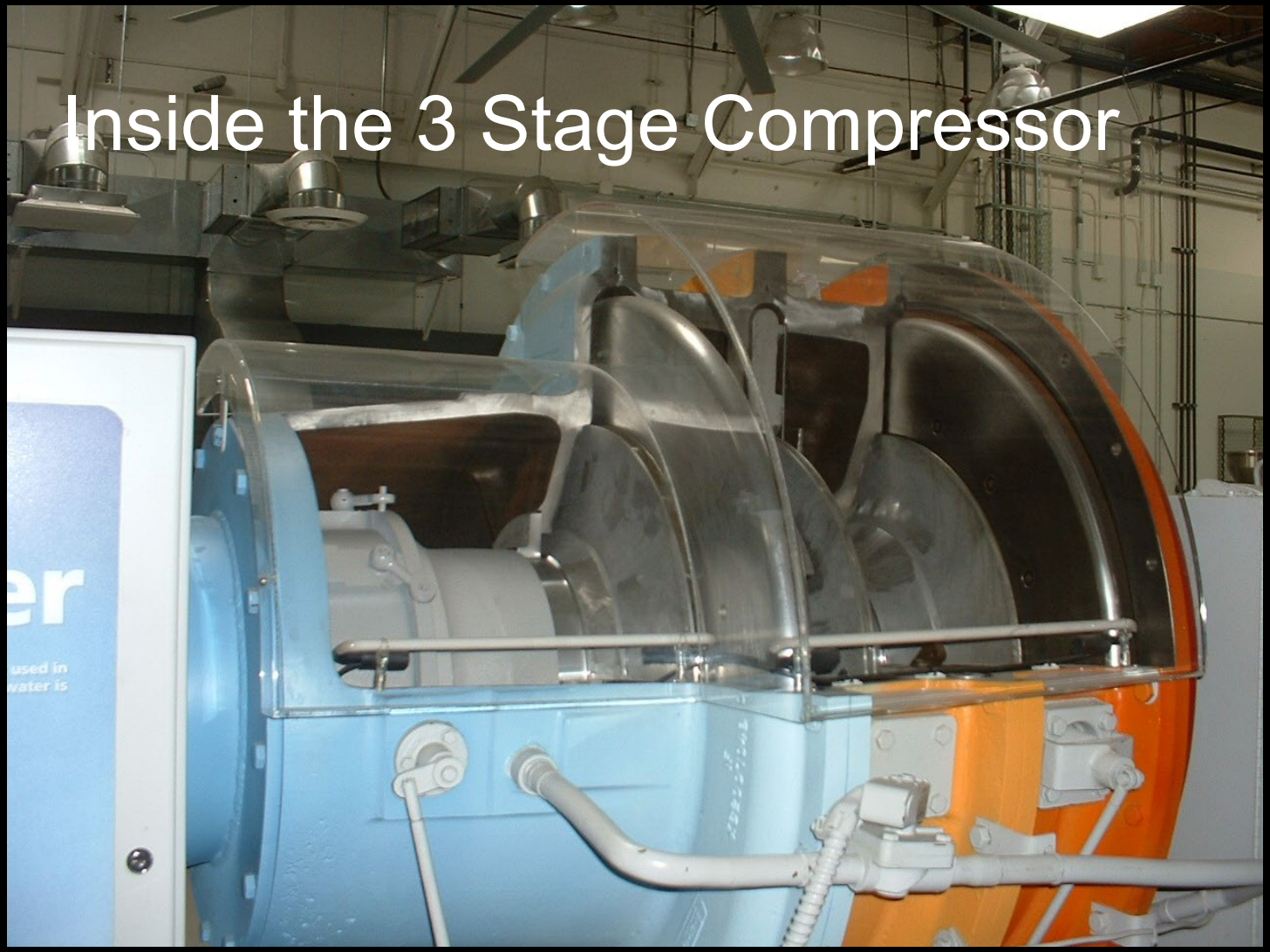


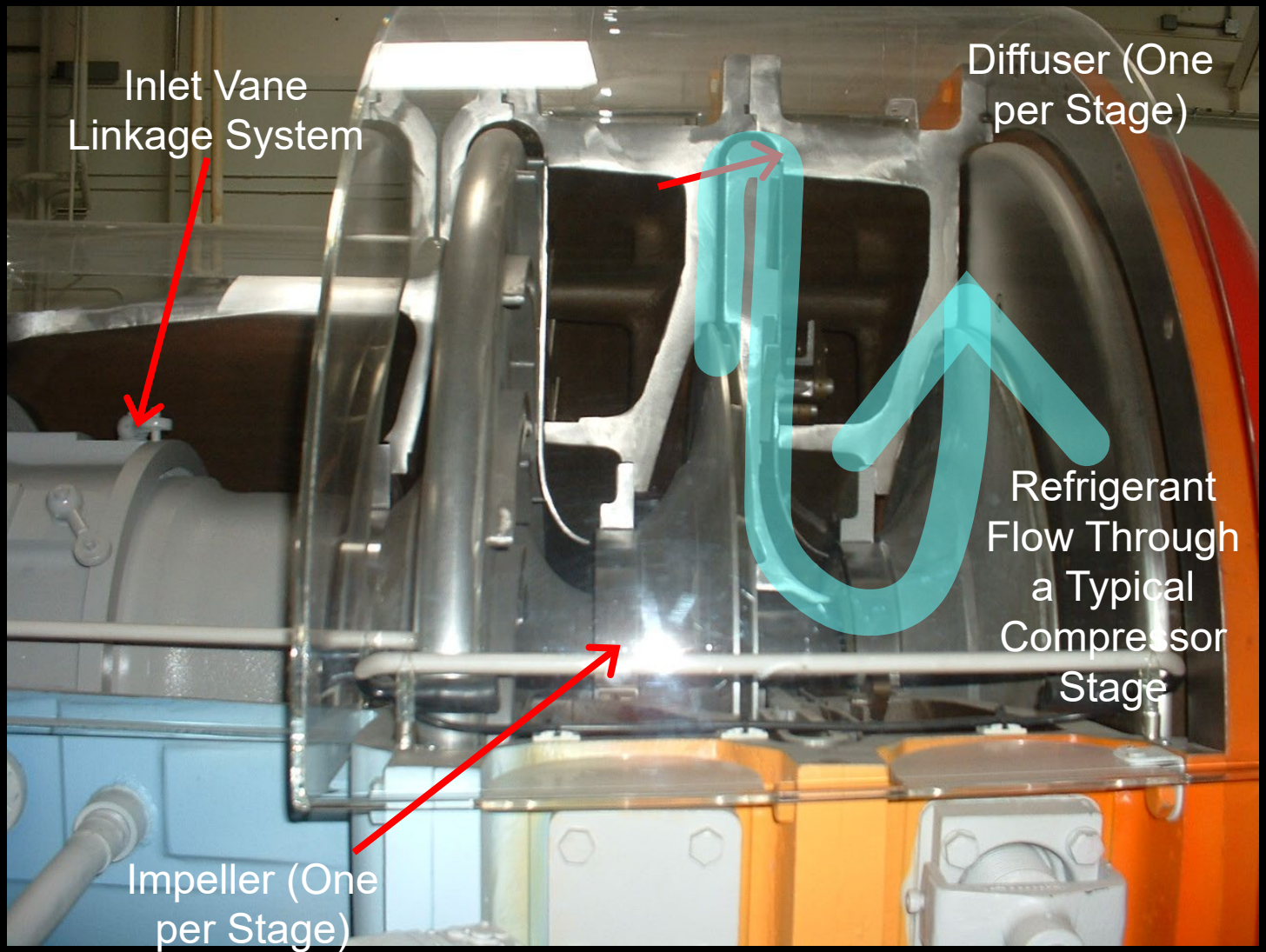
Inside the Evaporator



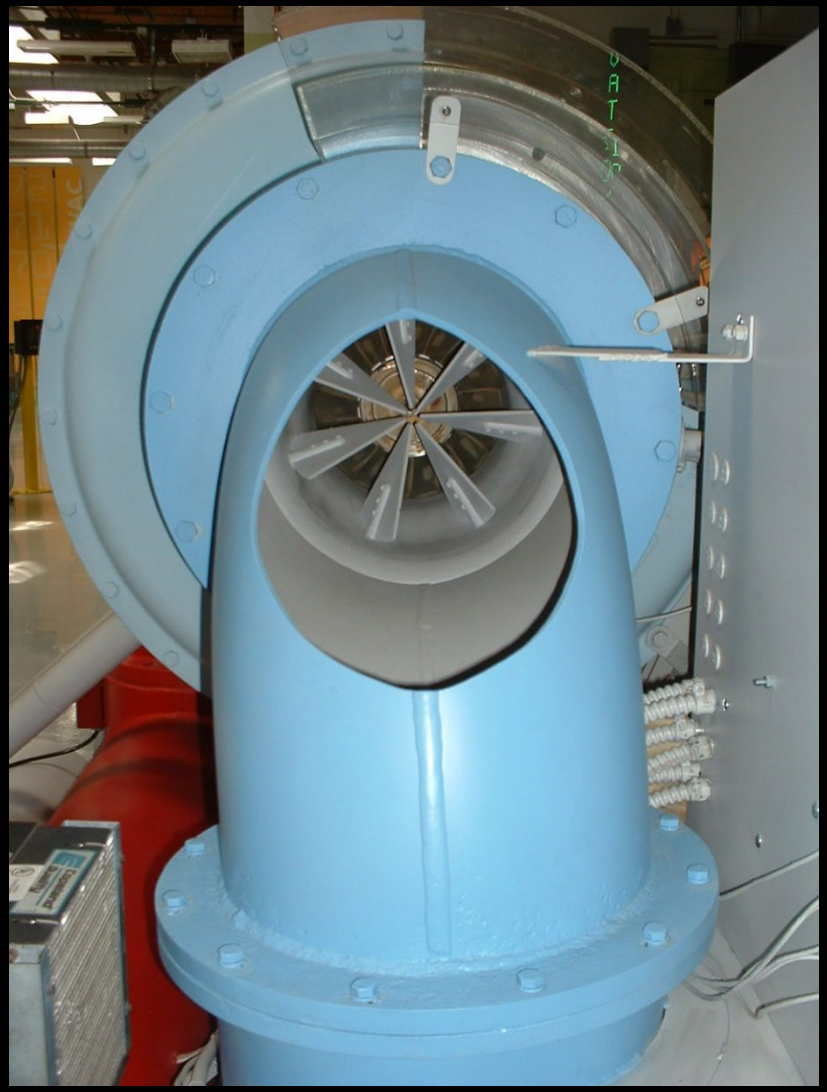
Inside the Evaporator

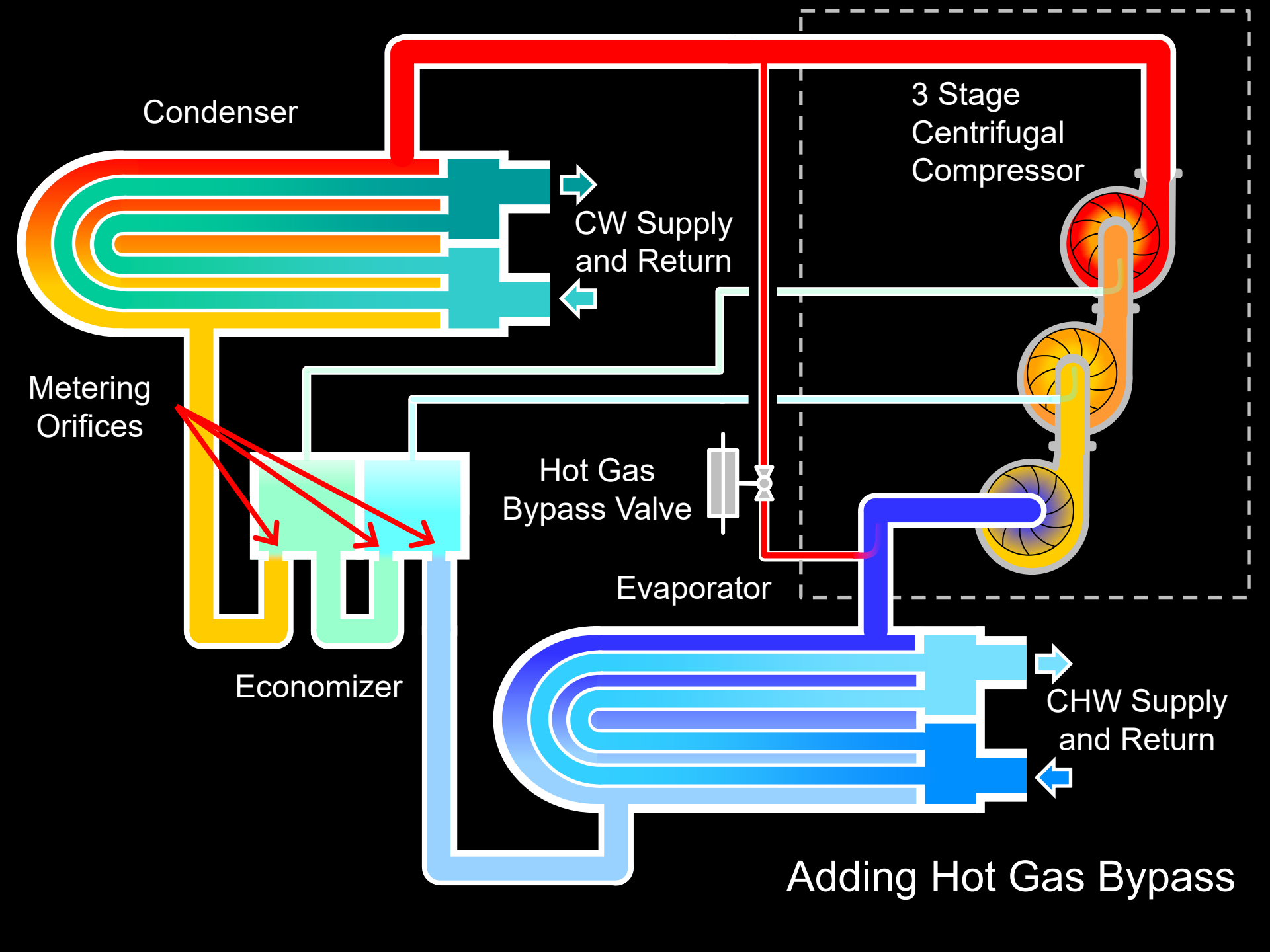
Inside the 3 Stage Compressor

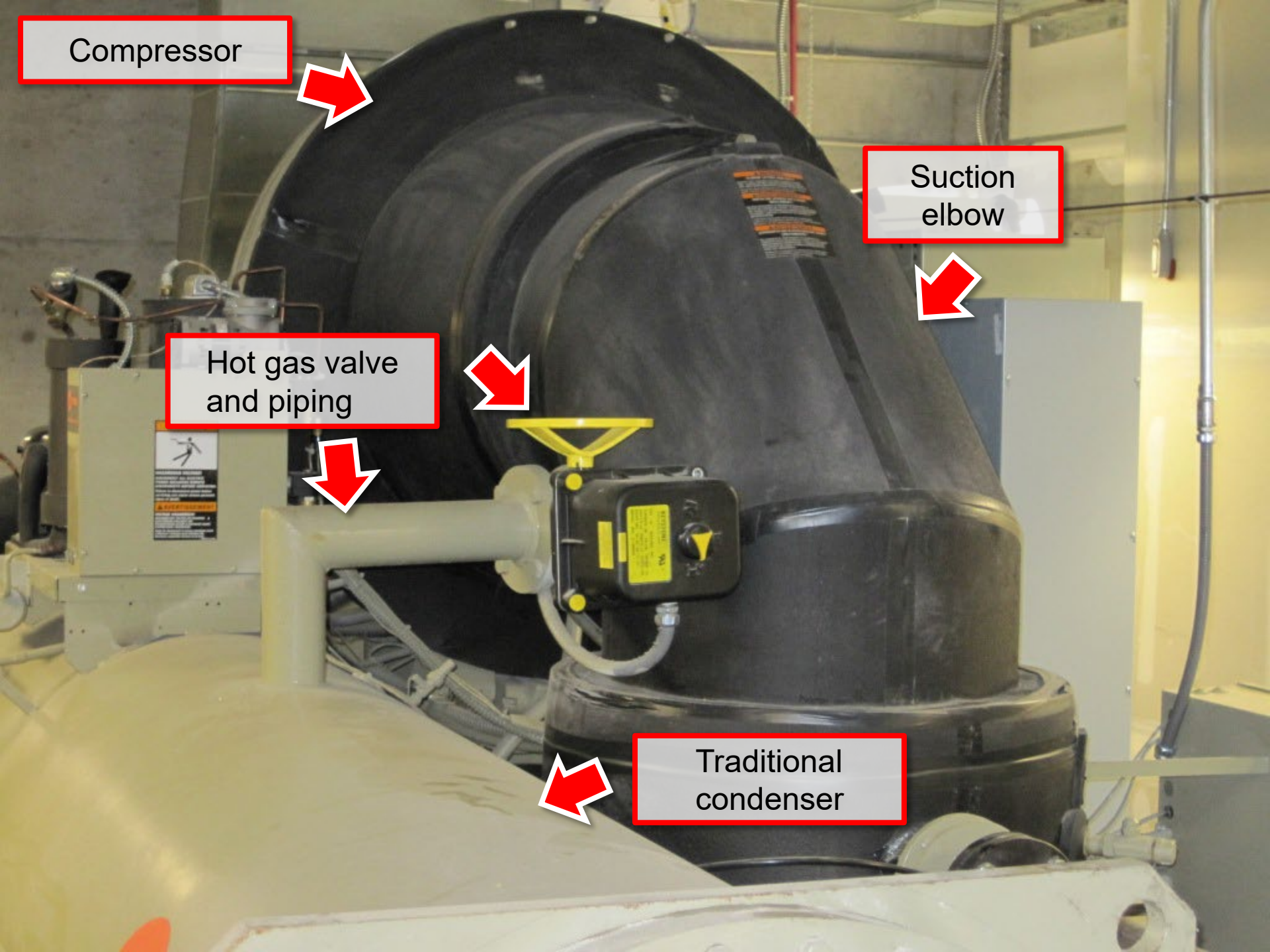


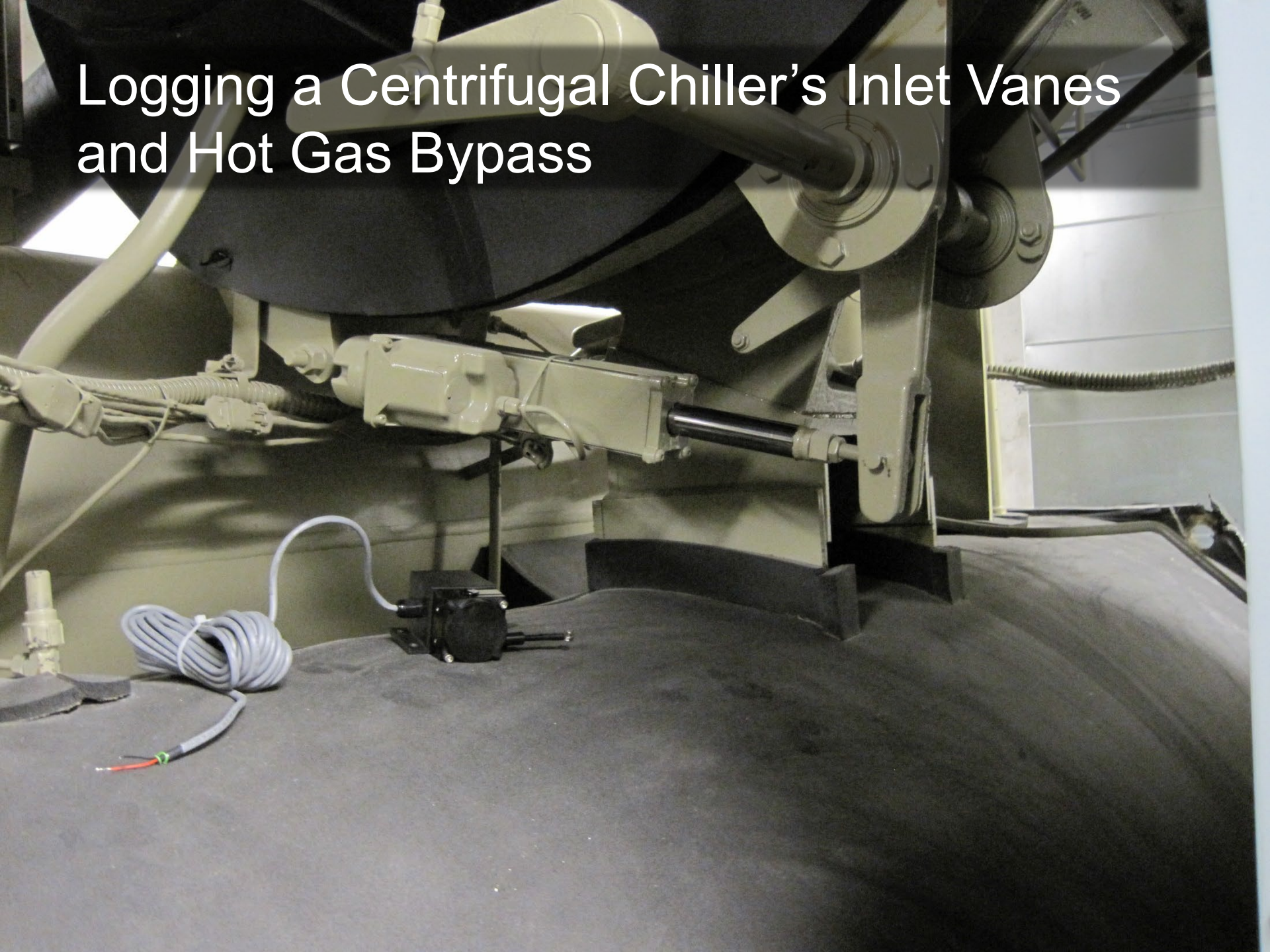

Inlet Vane
Linkage System
Diffuser (One
per Stage)
Refrigerant
Flow Through
a Typical
Compressor
Stage
Impeller (One
per Stage)

Inlet Vanes and Suction Elbow



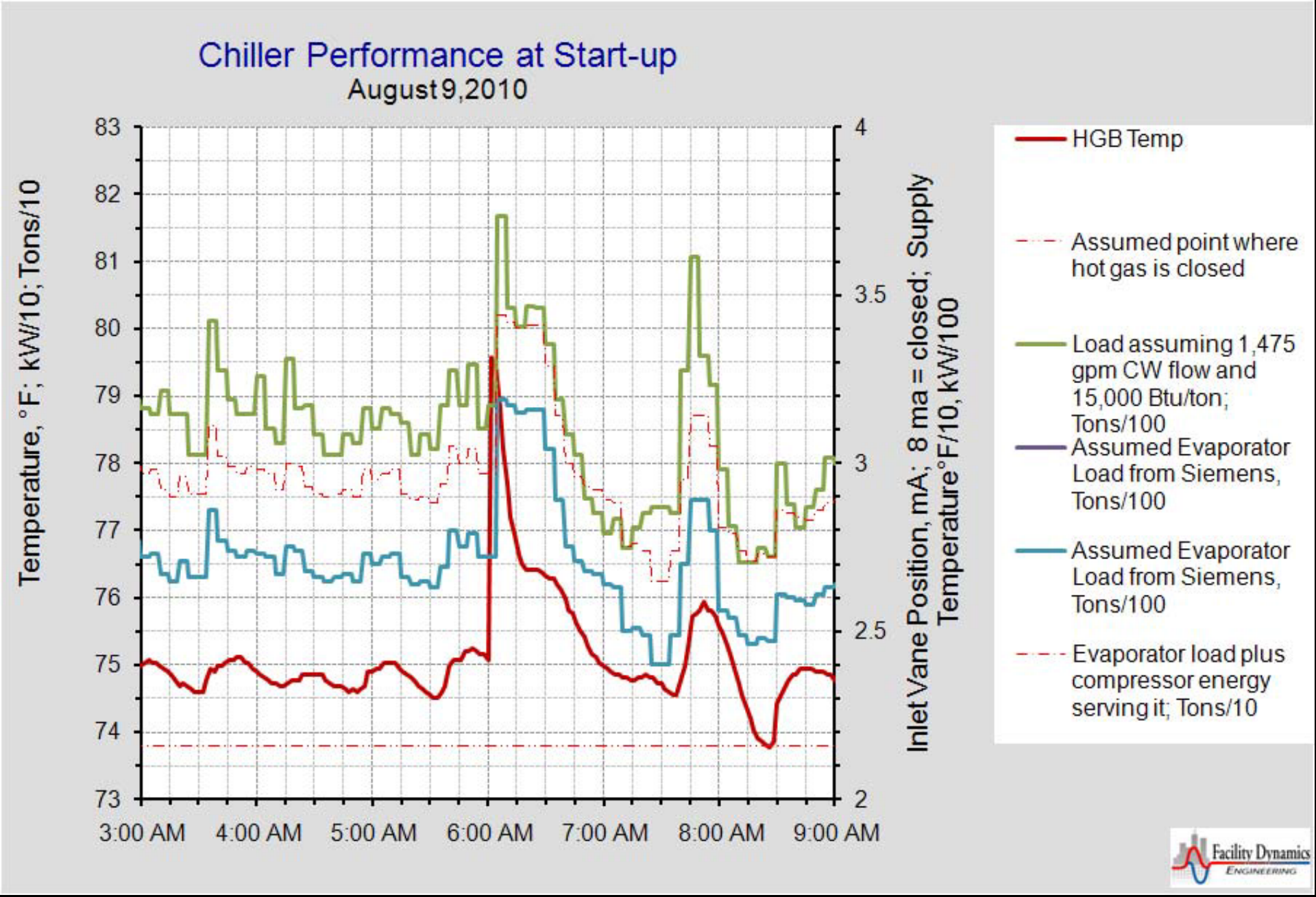

Condenser
3 Stage
Centrifugal
Compressor
CW Supply
and Return
Metering
Orifices
Hot Gas
Bypass Valve
Evaporator
Economizer
CHW Supply
and Return
Adding Hot Gas Bypass


Compressor
Suction elbow
Hot gas valve and piping
Traditional condenser

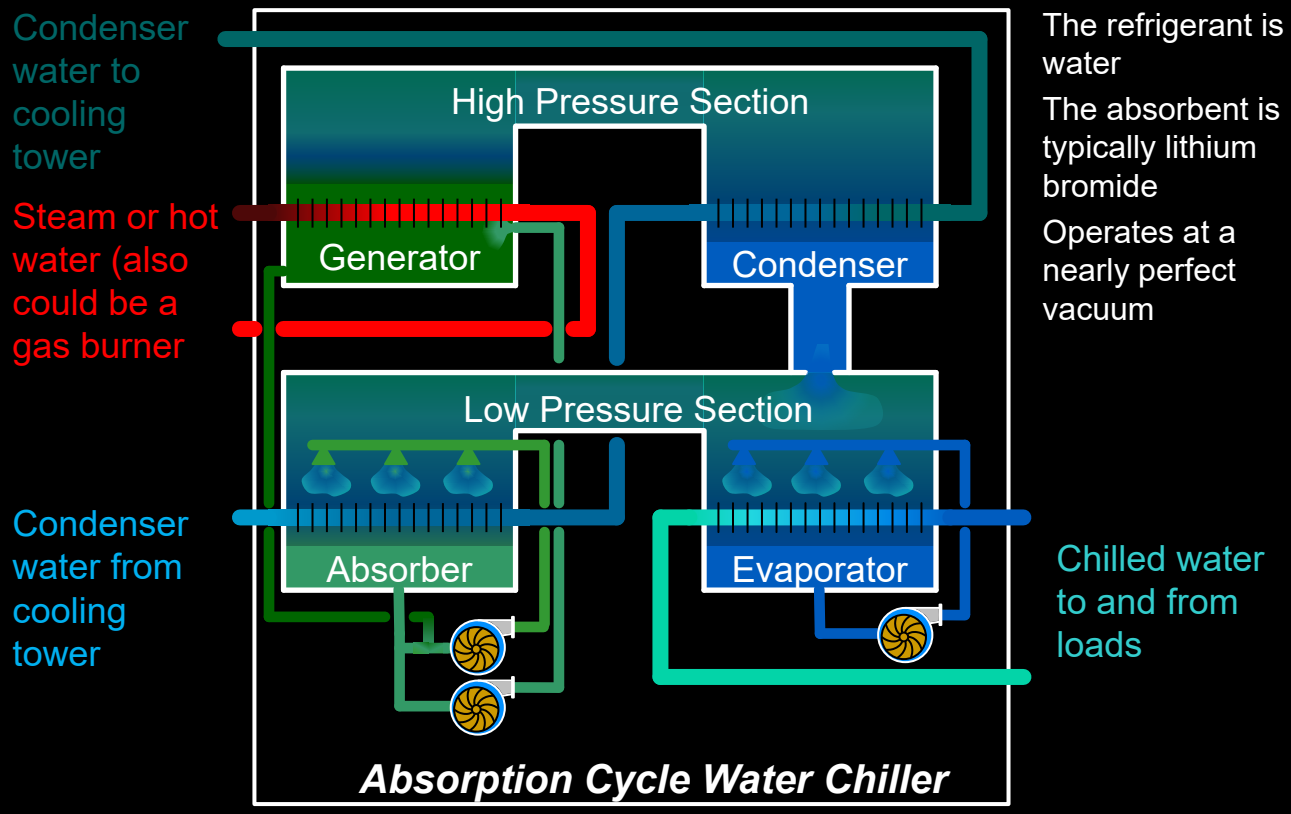

Logging a Centrifugal Chiller’s Inlet Vanes and Hot Gas Bypass


PT1MA-15-FR-420E-C25-G
celesco

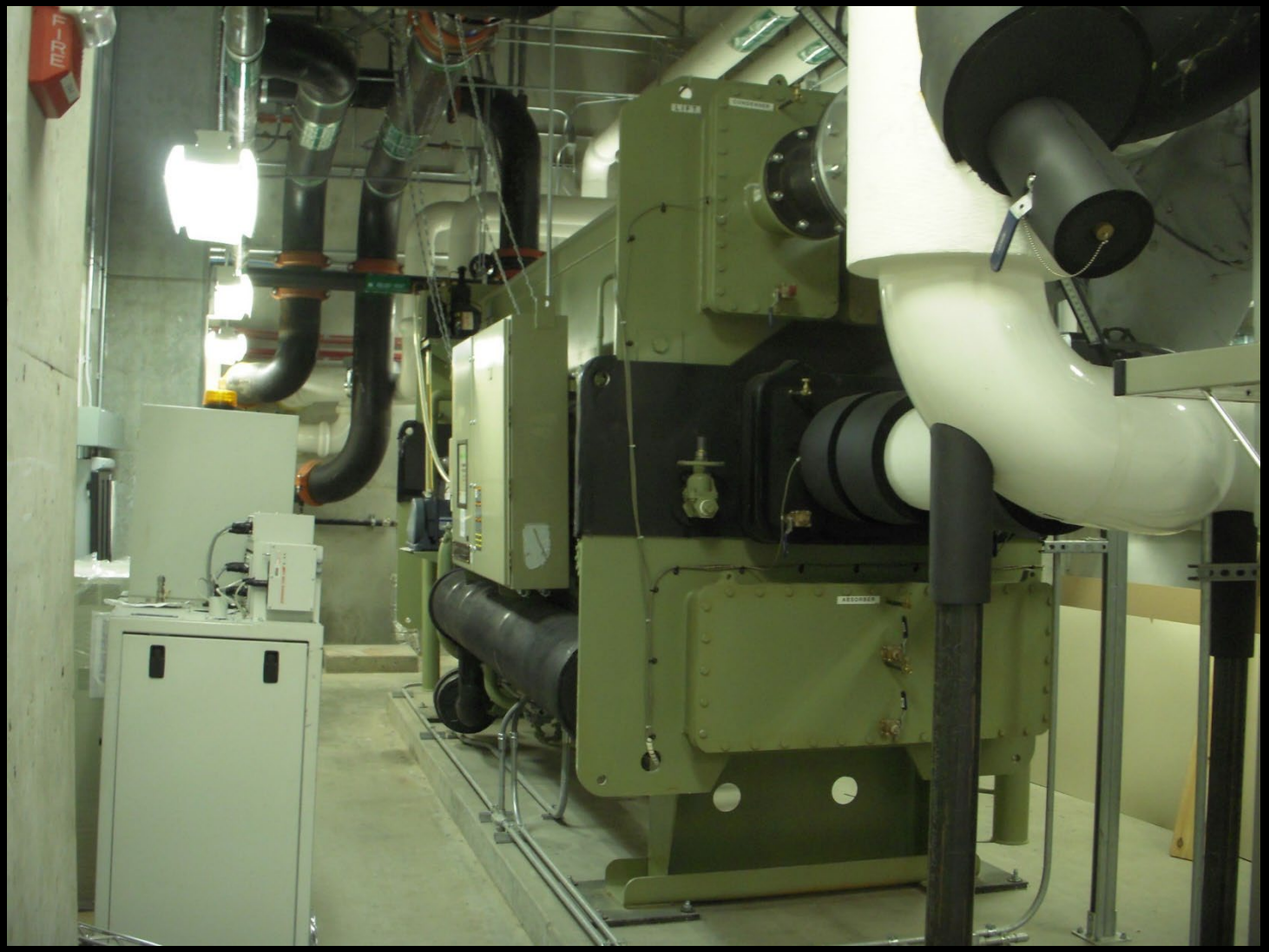

WARRANTY WILL BE REQUIRED
VOID IF ACTUATOR IS
OPERATED WHEN THE COVER
IS NOT IN PLACE


Chiller Performance at Start-up
August 9, 2010
Temperature, °F; kW/10; Tons/10
Inlet Vane Position, mA; 8 ma = closed; Supply Temperature °F/10, kW/100
83
82
81
80
79
78
77
76
75
74
73
4
3.5
3
2.5
2
3:00 AM
4:00 AM
5:00 AM
6:00 AM
7:00 AM
8:00 AM
9:00 AM
HGB Temp
Assumed point where hot gas is closed
Load assuming 1,475 gpm CW flow and 15,000 Btu/ton; Tons/100
Assumed Evaporator Load from Siemens, Tons/100
Assumed Evaporator Load from Siemens, Tons/100
Evaporator load plus compressor energy serving it; Tons/10
Facility Dynamics
Engineering

Absorption Chiller



Taking a Closer Look at an Absorption Chiller




CHILLED WATER RETURN


TRANE
R1
IN
OUT


2
11/19/2019 09:30

Different Cooling Sources = Different Operating Requirements

Vapor Compression Chiller

Cold condenser water = *Good*

Many moving parts; frequent or rapid cycling = *Compressor failure*

Improper start/stop /sequencing = *Energy and demand penalty*

Set point fine tuning = *Performance and efficiency optimization*

Absorption Cycle Chiller

Cold condenser water = *Bad*

Fewer moving parts; frequent or rapid cycling = *Not gonna happen*

Improper start/stop /sequencing = *Angry boiler plant operators*

Set point fine tuning = *Just fooling your self (you're lucky its running)*

Free Cooling Cycle

Cold condenser water = *Relative thing*

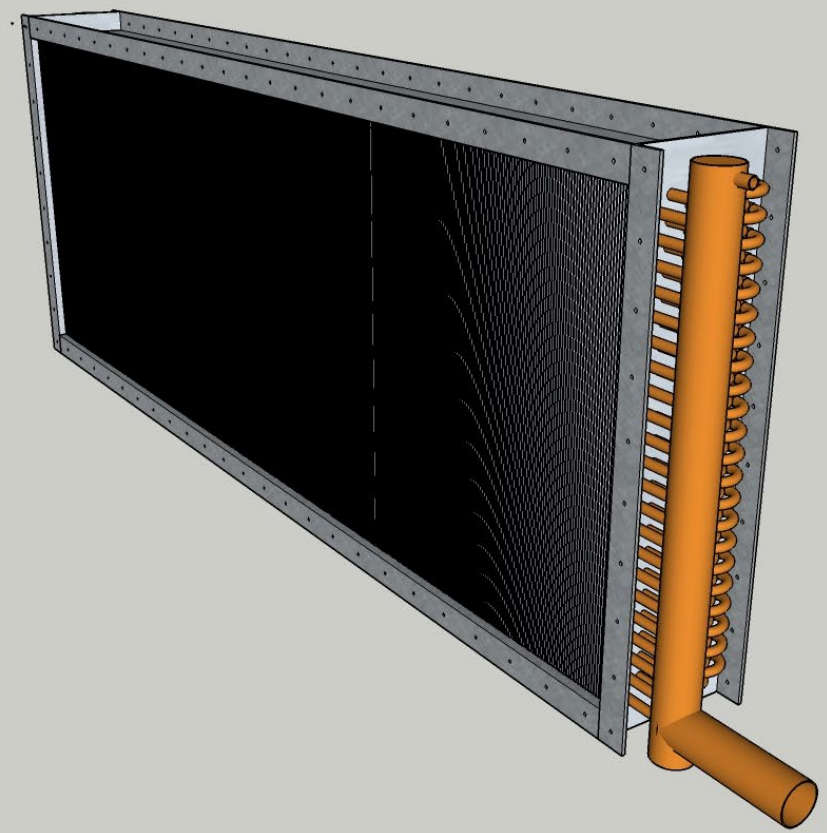
Some moving parts; frequent or rapid cycling = *Motor overheating*

Improper start/stop /sequencing = *Cooling tower failure*

Set point fine tuning = *Performance and efficiency optimization*

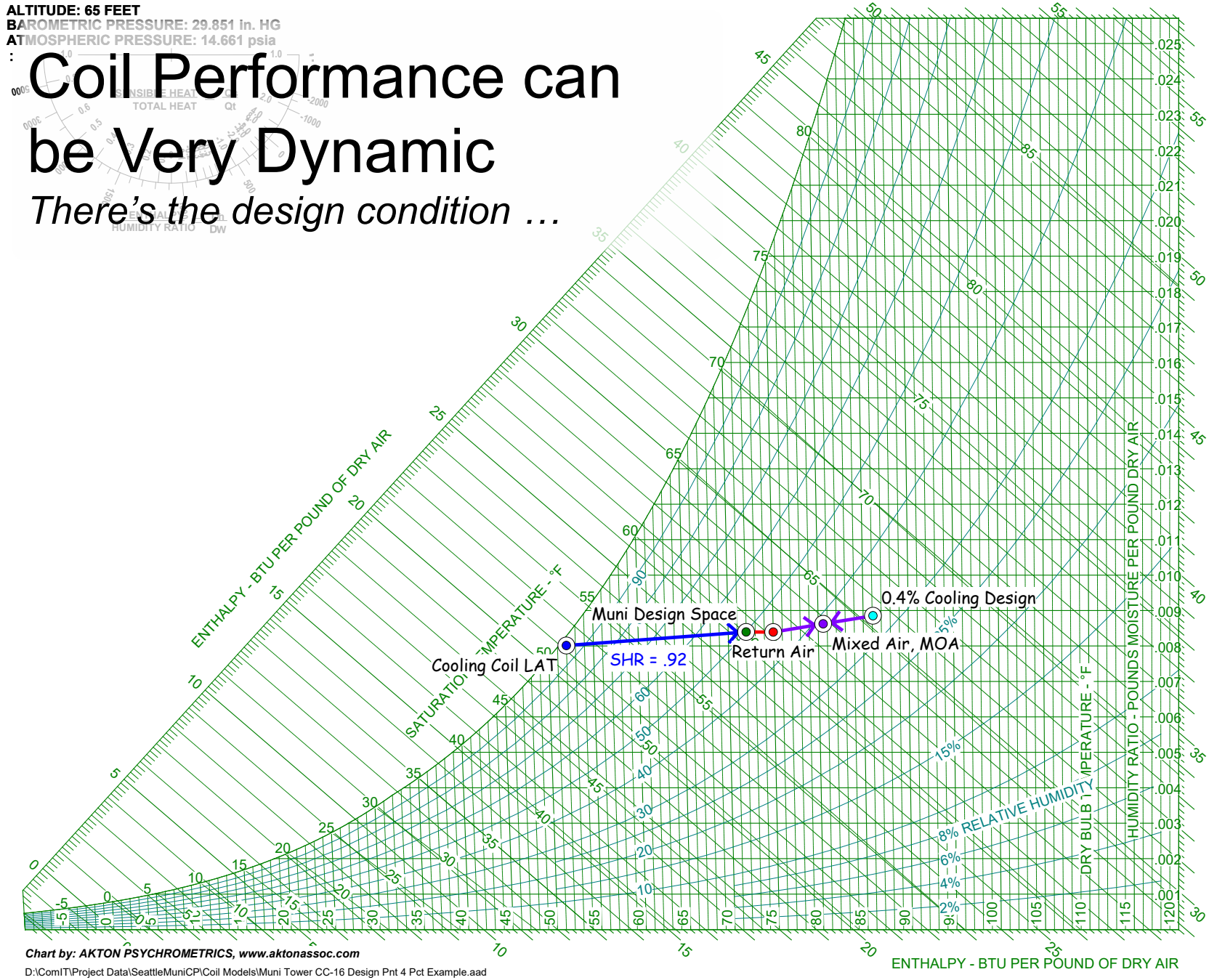
Monitoring operating data = *Ongoing performance optimization*

Heat Transfer:
A Common HVAC System Goal



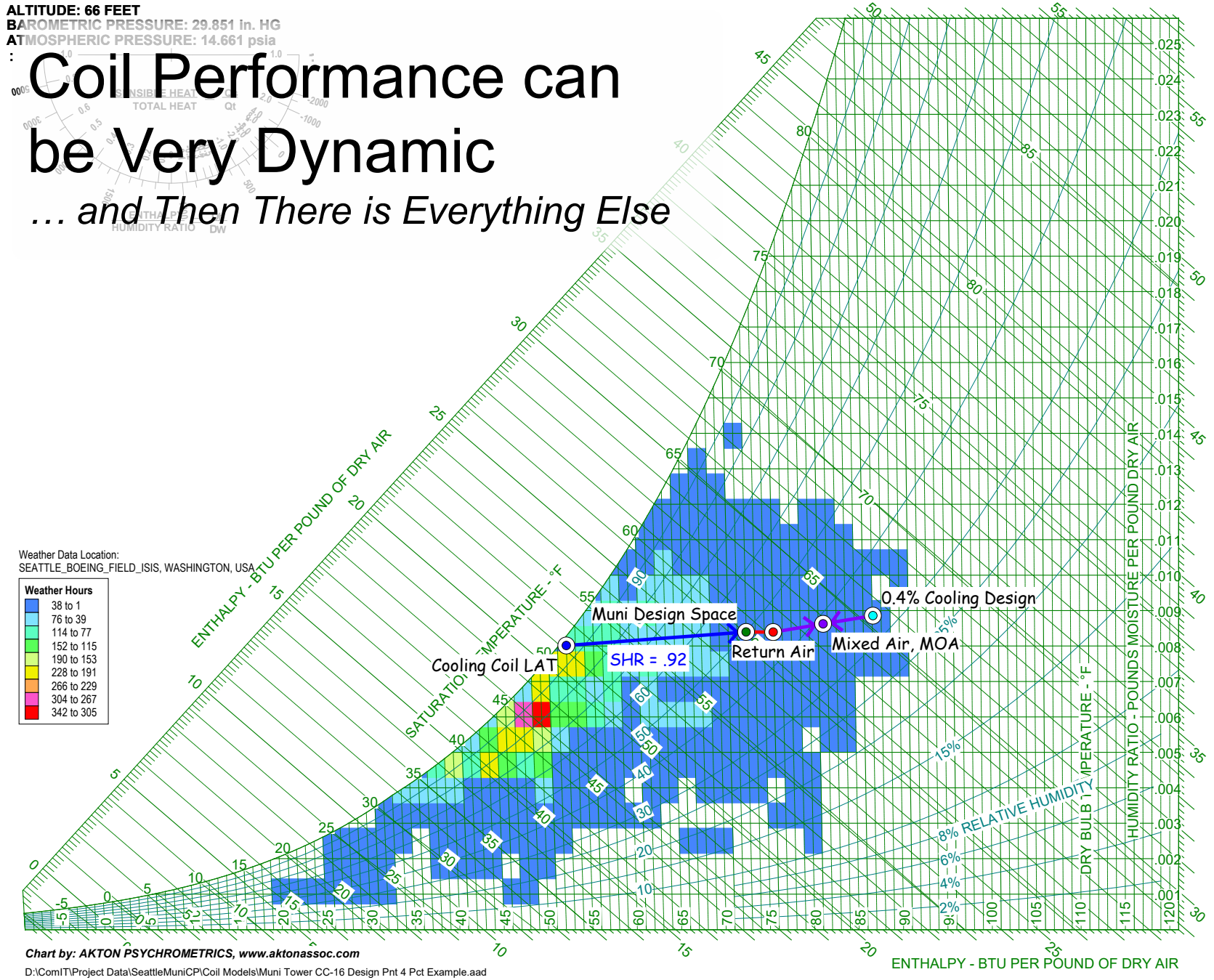
Coil Performance can be Very Dynamic

There's the design condition …

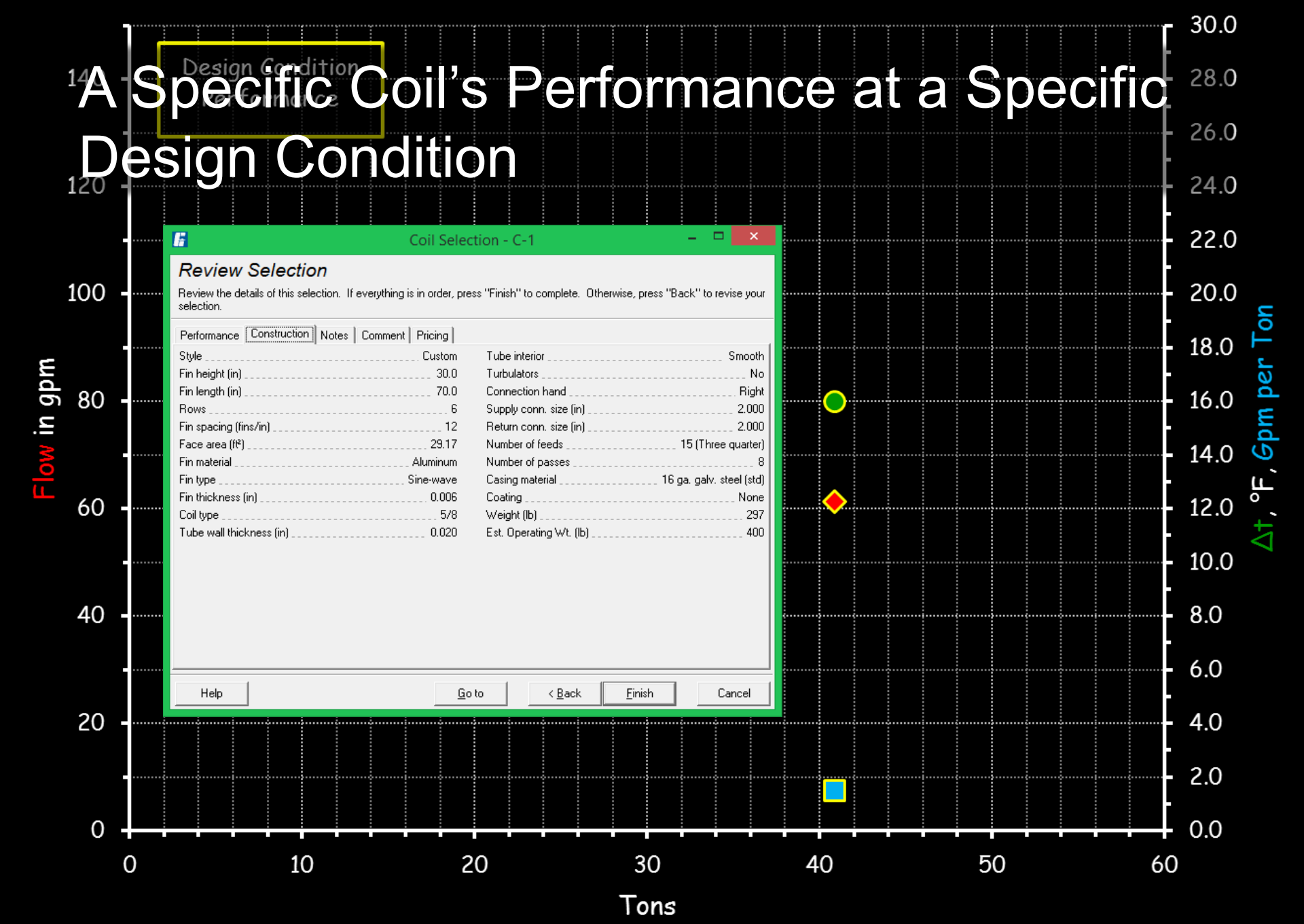


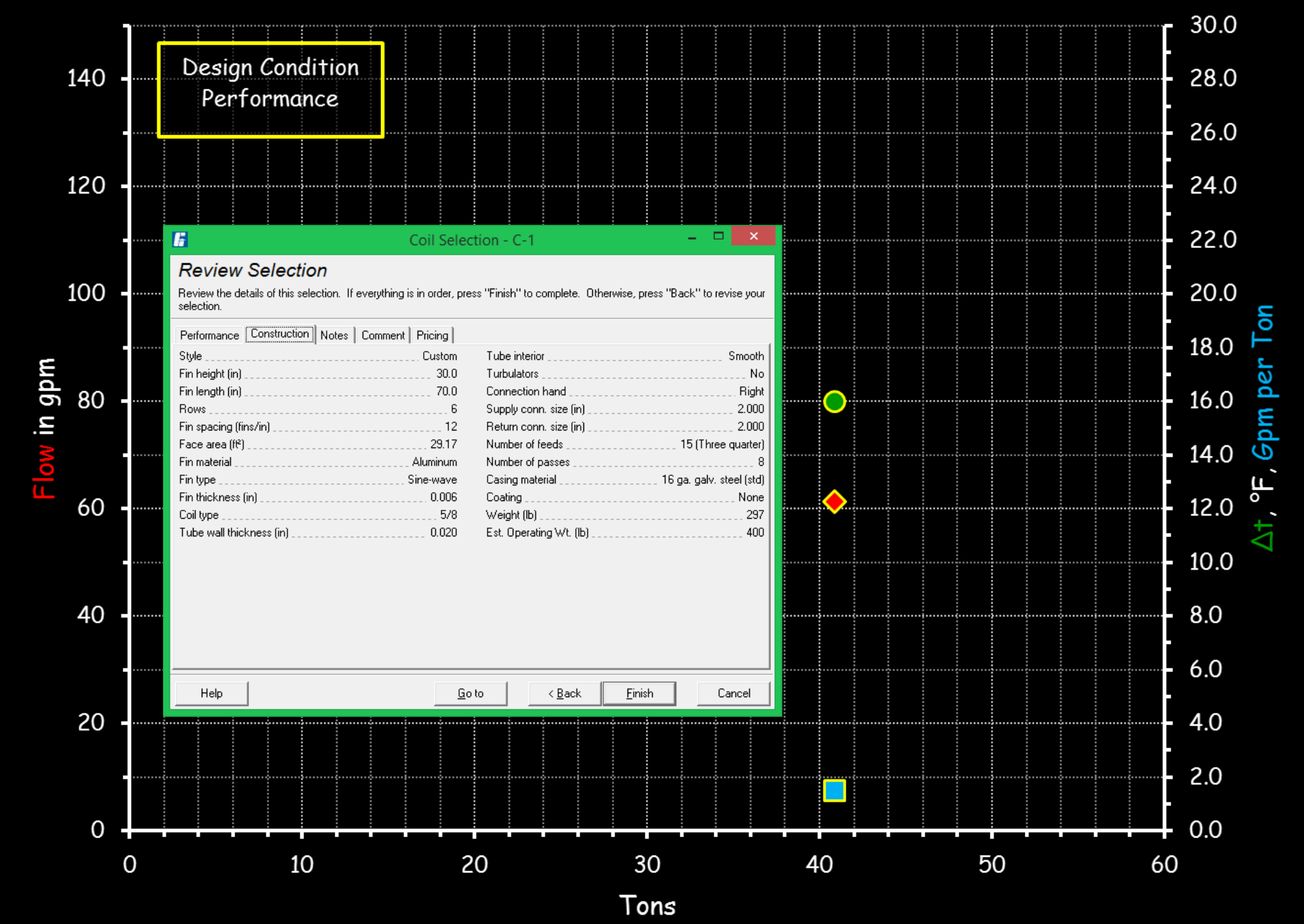
Coil Performance can be Very Dynamic

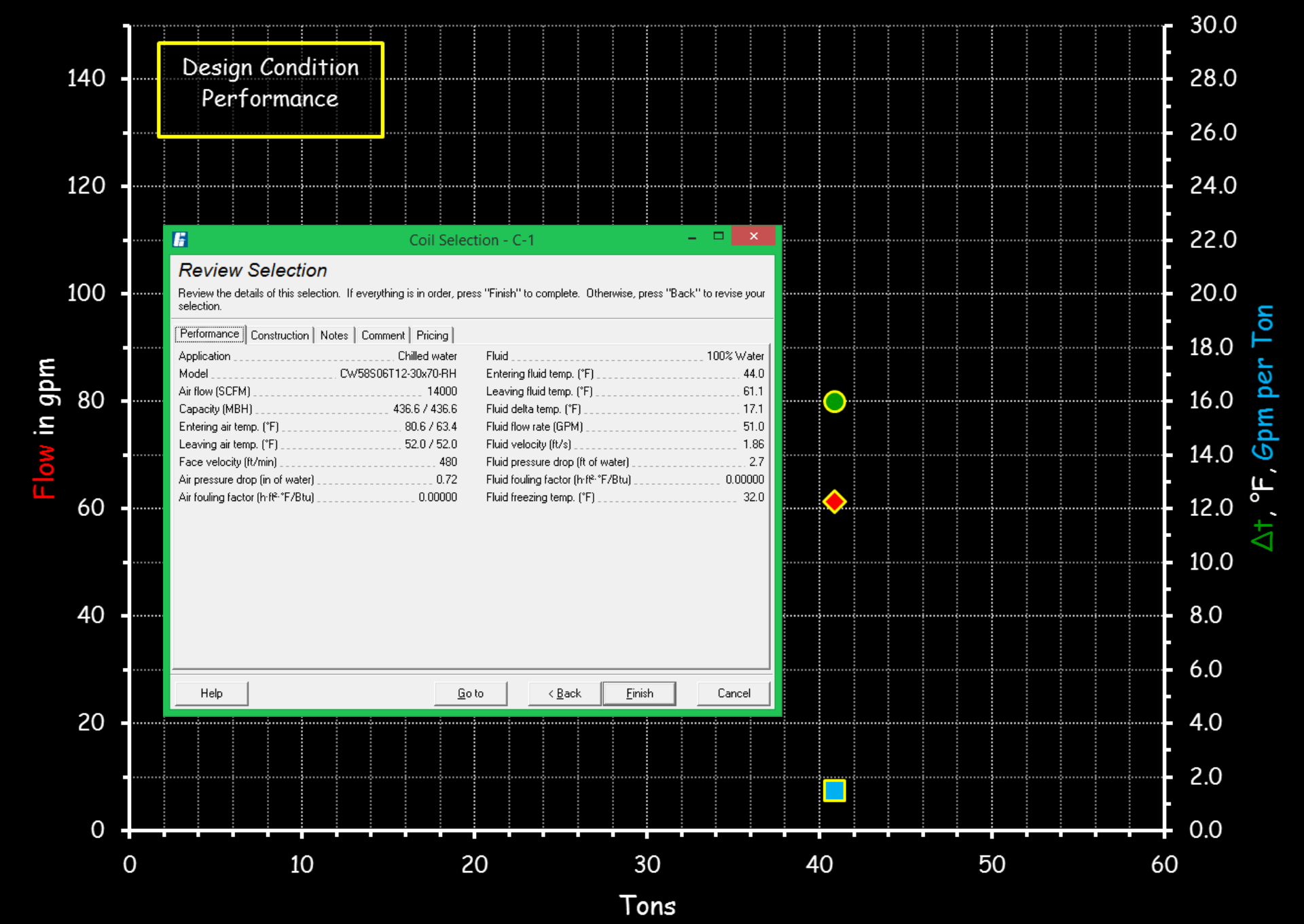
… and Then There is Everything Else

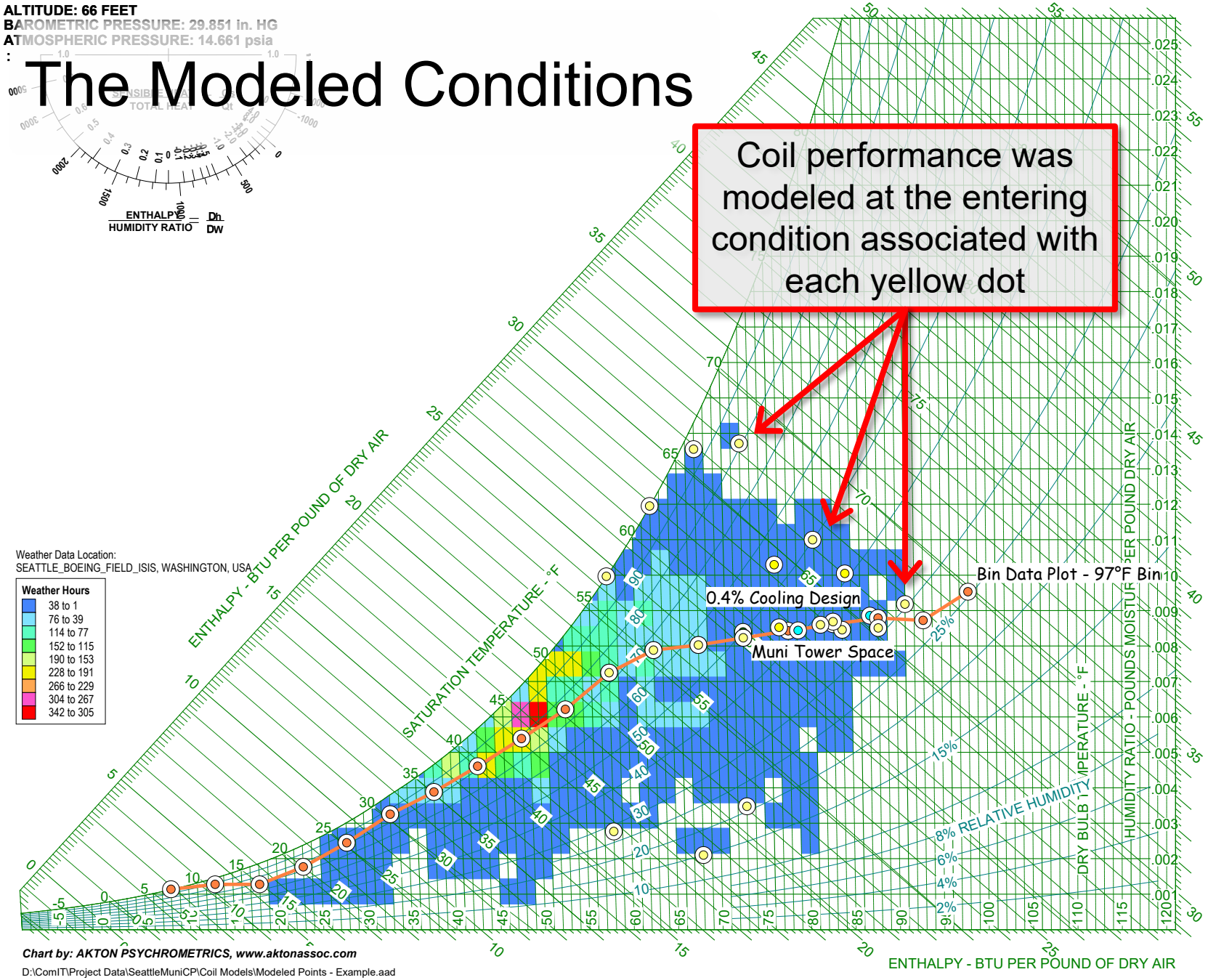


A Specific Coil's Performance at a Specific Design Condition



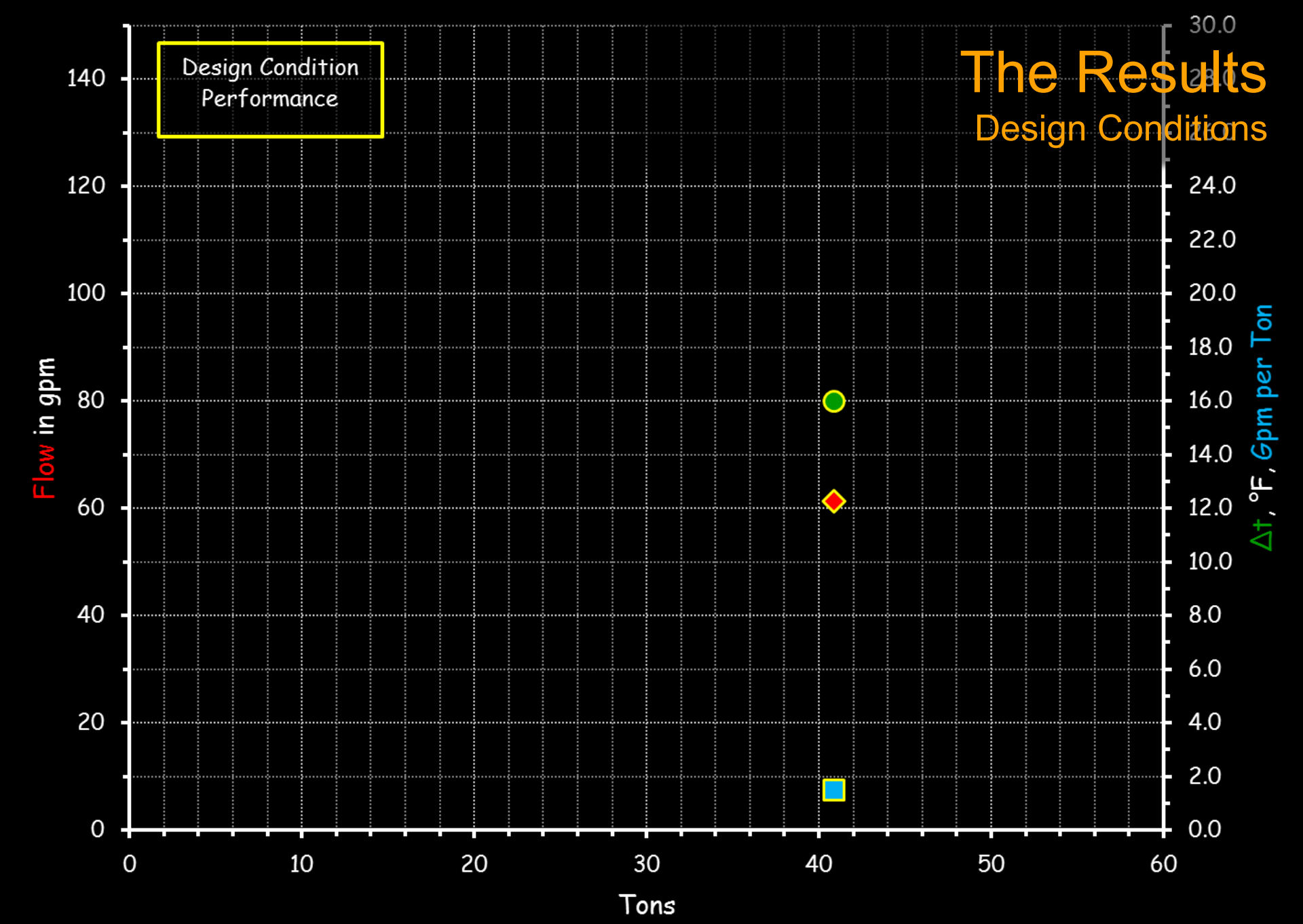

Design Condition
Performance
Coil Selection - C-1
Review Selection
Review the details of this selection. If everything is in order, press "Finish" to complete. Otherwise, press "Back" to revise your selection.
Performance
Construction
Notes
Comment
Pricing
Style Custom
Fin height (in) 30.0
Fin length (in) 70.0
Rows 6
Fin spacing (fins/in) 12
Face area (ft²) 29.17
Fin material Aluminum
Fin type Sine-wave
Fin thickness (in) 0.006
Coil type 5/8
Tube wall thickness (in) 0.020
Tube interior Smooth
Turbulators No
Connection hand Right
Supply conn. size (in) 2.000
Return conn. size (in) 2.000
Number of feeds 15 (Three quarter)
Number of passes 8
Casing material 16 ga. galv. steel (std)
Coating None
Weight (lb) 297
Est. Operating Wt. (lb) 400
Help
Go to
< Back
Finish
Cancel
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0
10
20
30
40
50
60

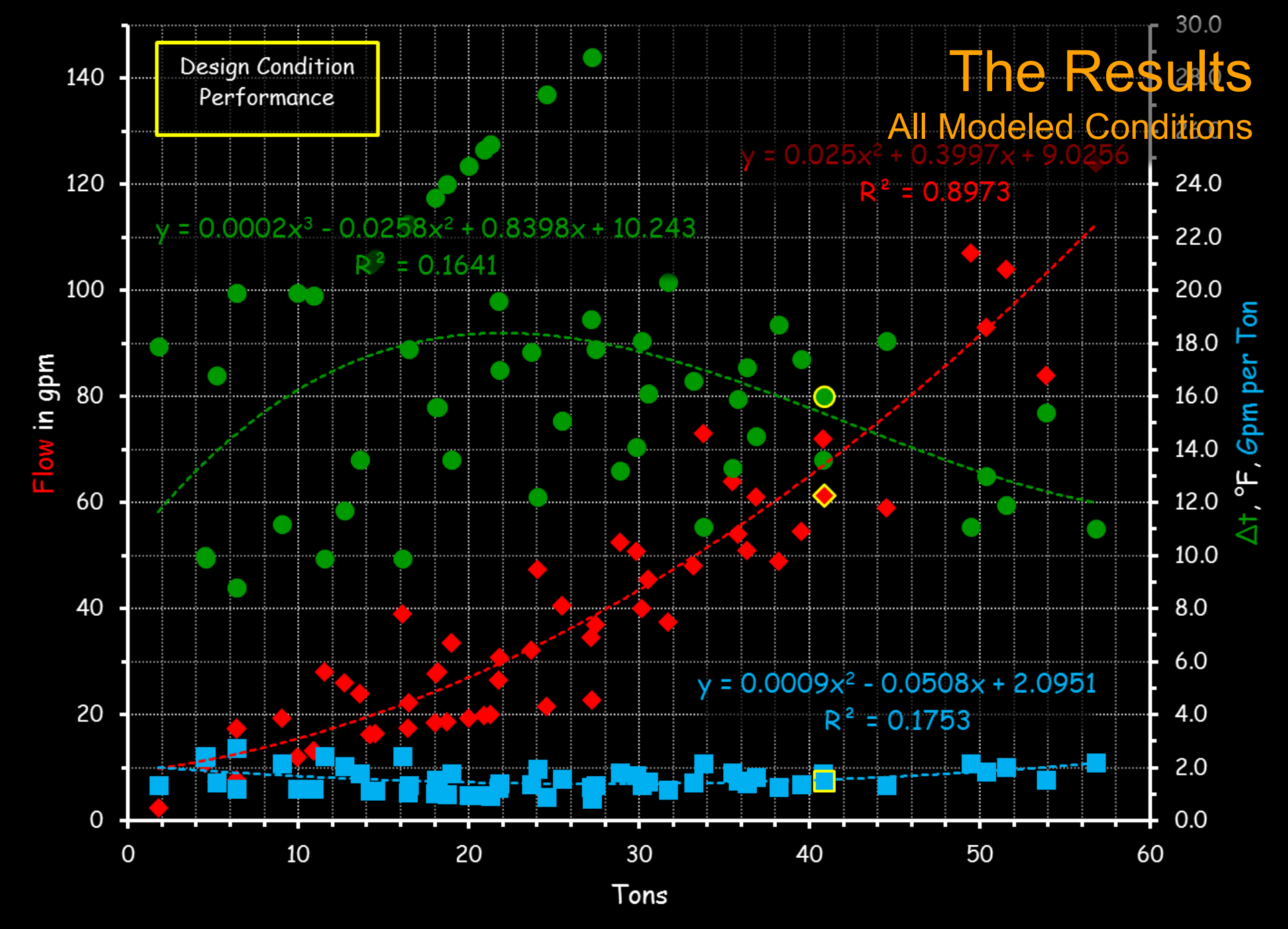

Design Condition
Performance
Coil Selection - C-1
Review Selection
Review the details of this selection. If everything is in order, press "Finish" to complete. Otherwise, press "Back" to revise your selection.
Performance
Construction
Notes
Comment
Pricing
Application Chilled water
Model CW58S06T12-30x70-RH
Air flow (SCFM) 14000
Capacity (MBH) 436.6 / 436.6
Entering air temp. (°F) 80.6 / 63.4
Leaving air temp. (°F) 52.0 / 52.0
Face velocity (ft/min) 480
Air pressure drop (in of water) 0.72
Air fouling factor (h·ft²·°F/Btu) 0.00000
Fluid 100% Water
Entering fluid temp. (°F) 44.0
Leaving fluid temp. (°F) 61.1
Fluid delta temp. (°F) 17.1
Fluid flow rate (GPM) 51.0
Fluid velocity (ft/s) 1.86
Fluid pressure drop (ft of water) 2.7
Fluid fouling factor (h·ft²·°F/Btu) 0.00000
Fluid freezing temp. (°F) 32.0
Help
Go to
< Back
Finish
Cancel
Flow in gpm
0
20
40
60
80
100
120
140
Tons
0
10
20
30
40
50
60
Δt, °F, Gpm per Ton
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0

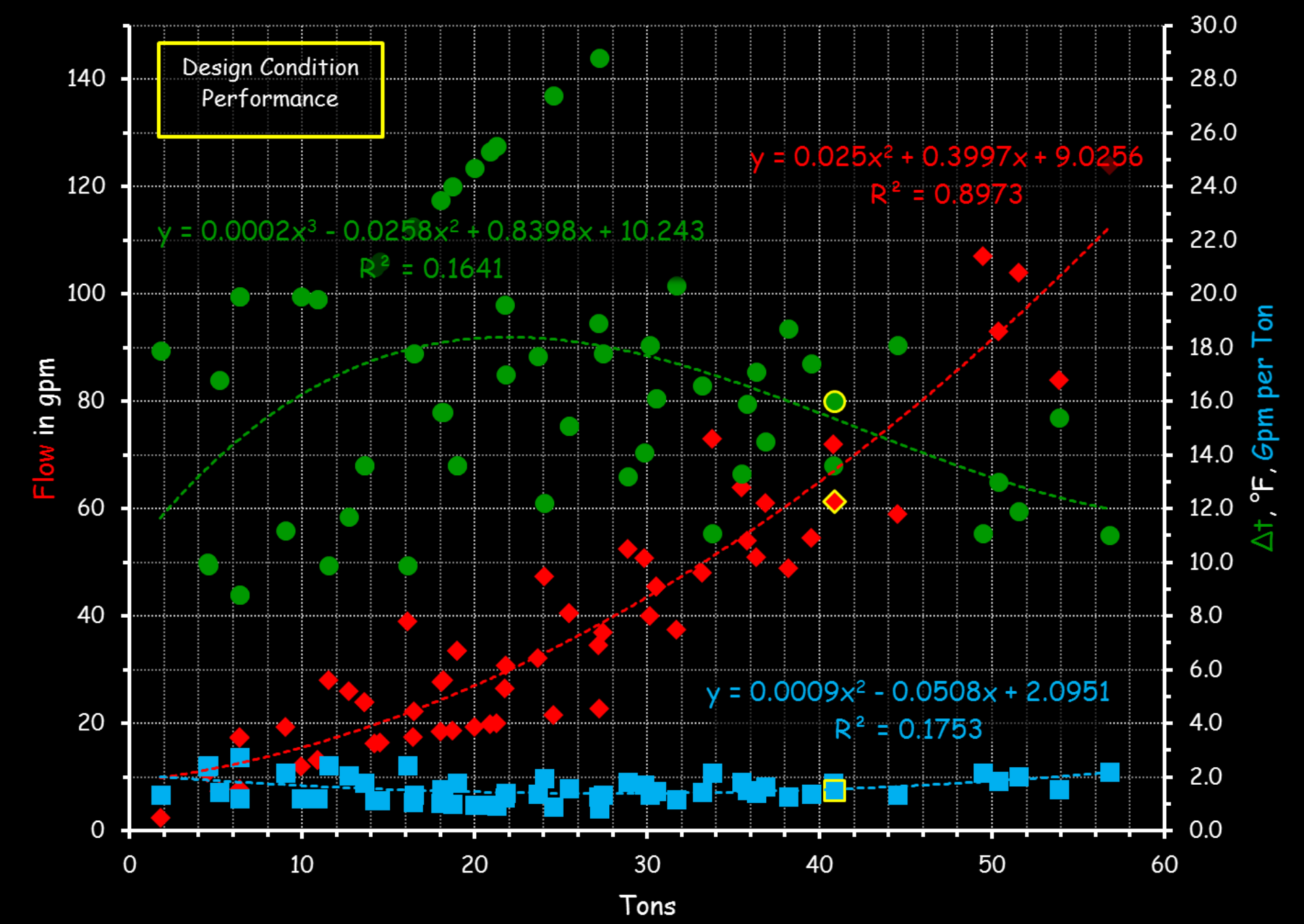

ALTITUDE: 66 FEET
BAROMETRIC PRESSURE: 29.851 in. HG
ATMOSPHERIC PRESSURE: 14.661 psia
:
The Modeled Conditions
Coil performance was modeled at the entering condition associated with each yellow dot
ENTHALPY / HUMIDITY RATIO = Dh / DW
Weather Data Location:
SEATTLE_BOEING_FIELD_ISIS, WASHINGTON, USA
Weather Hours
38 to 1
76 to 39
114 to 77
152 to 115
190 to 153
228 to 191
266 to 229
304 to 267
342 to 305
0.4% Cooling Design
Bin Data Plot - 97°F Bin
Muni Tower Space
ENTHALPY - BTU PER POUND OF DRY AIR
SATURATION TEMPERATURE - °F
HUMIDITY RATIO - POUNDS MOISTURE PER POUND DRY AIR
DRY BULB TEMPERATURE - °F
15% RELATIVE HUMIDITY
8%
6%
4%
2%
25%
Chart by: AKTON PSYCHROMETRICS, www.aktonassoc.com
D:\ComIT\Project Data\SeattleMuniCP\Coil Models\Modeled Points - Example.aad

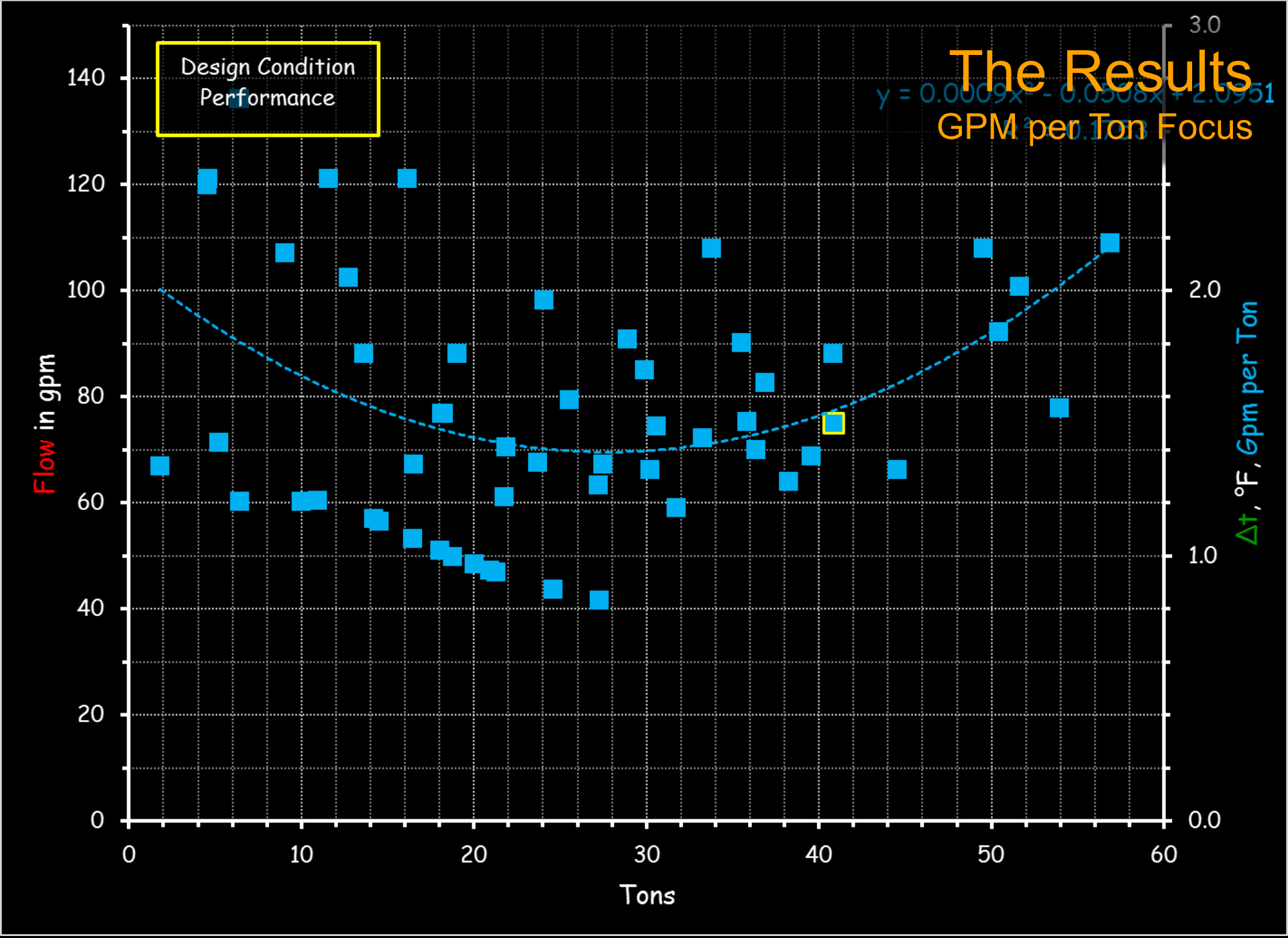
The Results

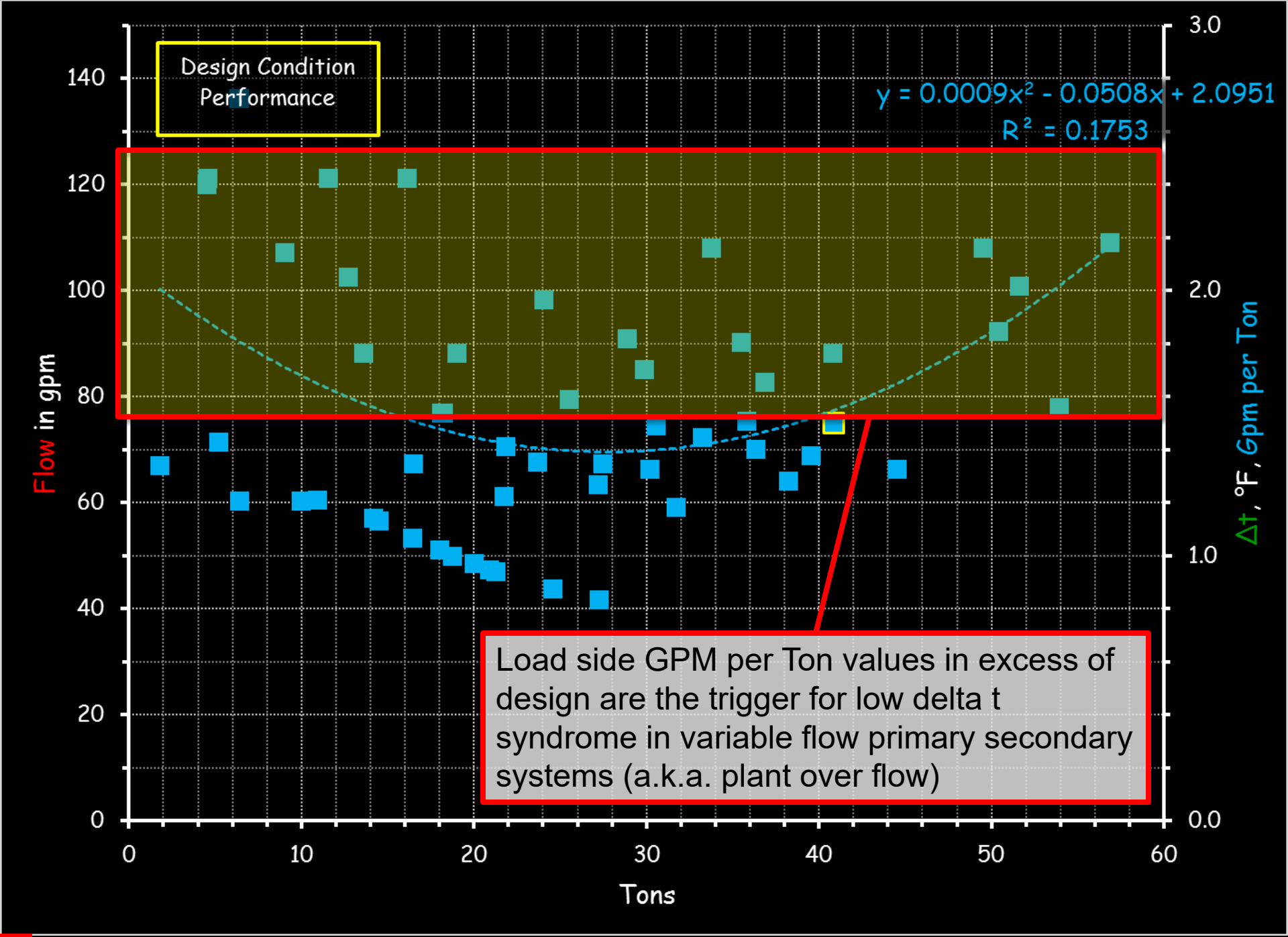
Design Conditions




Design Condition
Performance
The Results
All Modeled Conditions
y = 0.025x² + 0.3997x + 9.0256
R² = 0.8973
y = 0.0002x³ - 0.0258x² + 0.8398x + 10.243
R² = 0.1641
y = 0.0009x² - 0.0508x + 2.0951
R² = 0.1753
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
30.0
0
10
20
30
40
50
60

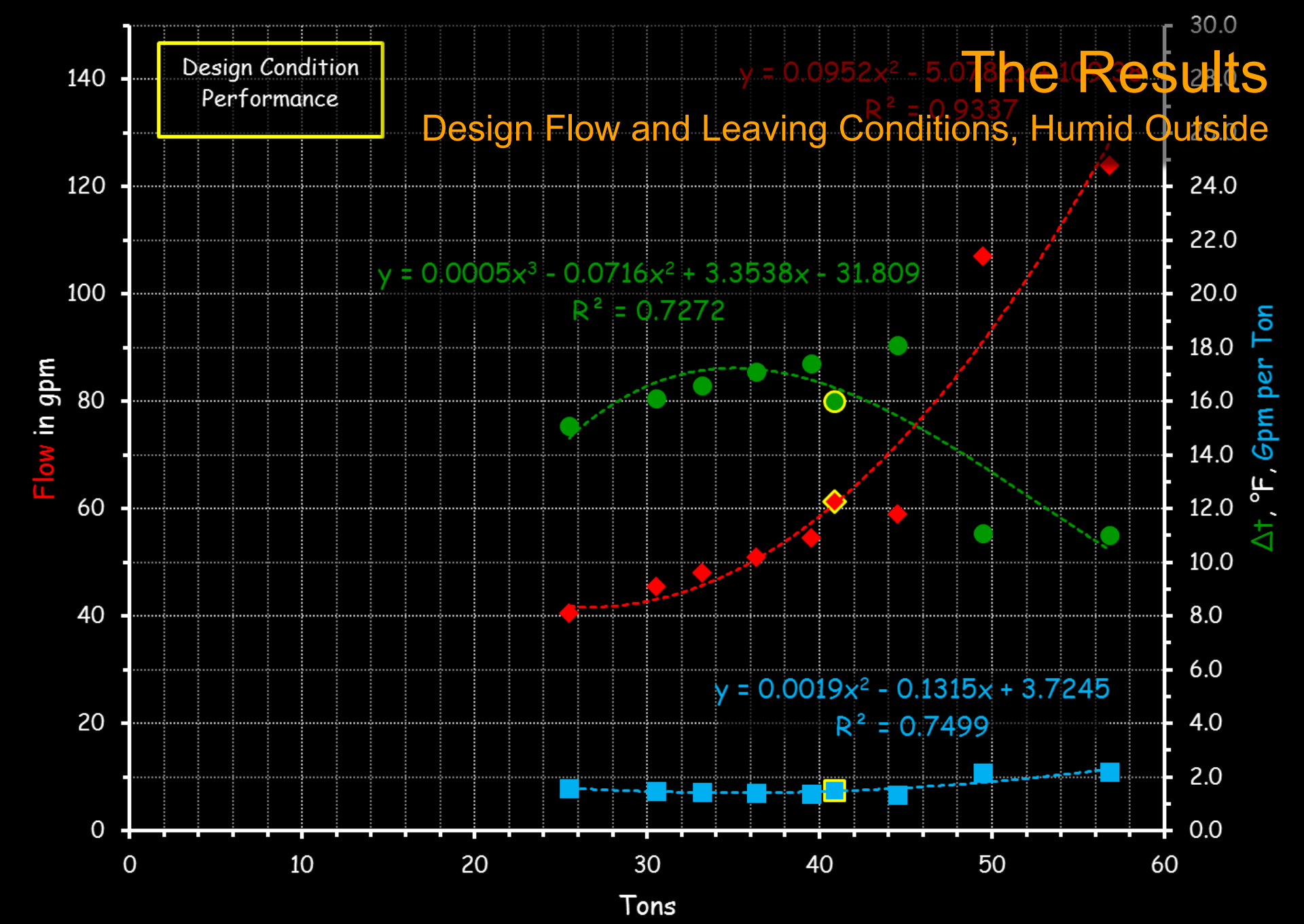

Design Condition
Performance
y = 0.025x² + 0.3997x + 9.0256
R² = 0.8973
y = 0.0002x³ - 0.0258x² + 0.8398x + 10.243
R² = 0.1641
y = 0.0009x² - 0.0508x + 2.0951
R² = 0.1753
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
0
10
20
30
40
50
60


Design Condition
Performance
The Results
GPM per Ton Focus
y = 0.0009x² - 0.0508x + 2.0951
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
1.0
2.0
3.0
0
10
20
30
40
50
60


Design Condition
Performance
y = 0.0009x² - 0.0508x + 2.0951
R² = 0.1753
Flow in gpm
Δt, °F, Gpm per Ton
Tons
0
20
40
60
80
100
120
140
0.0
1.0
2.0
3.0
0
10
20
30
40
50
60
Load side GPM per Ton values in excess of design are the trigger for low delta t syndrome in variable flow primary secondary systems (a.k.a. plant over flow)

The Results

Design Flow and Leaving Conditions, Humid Outside

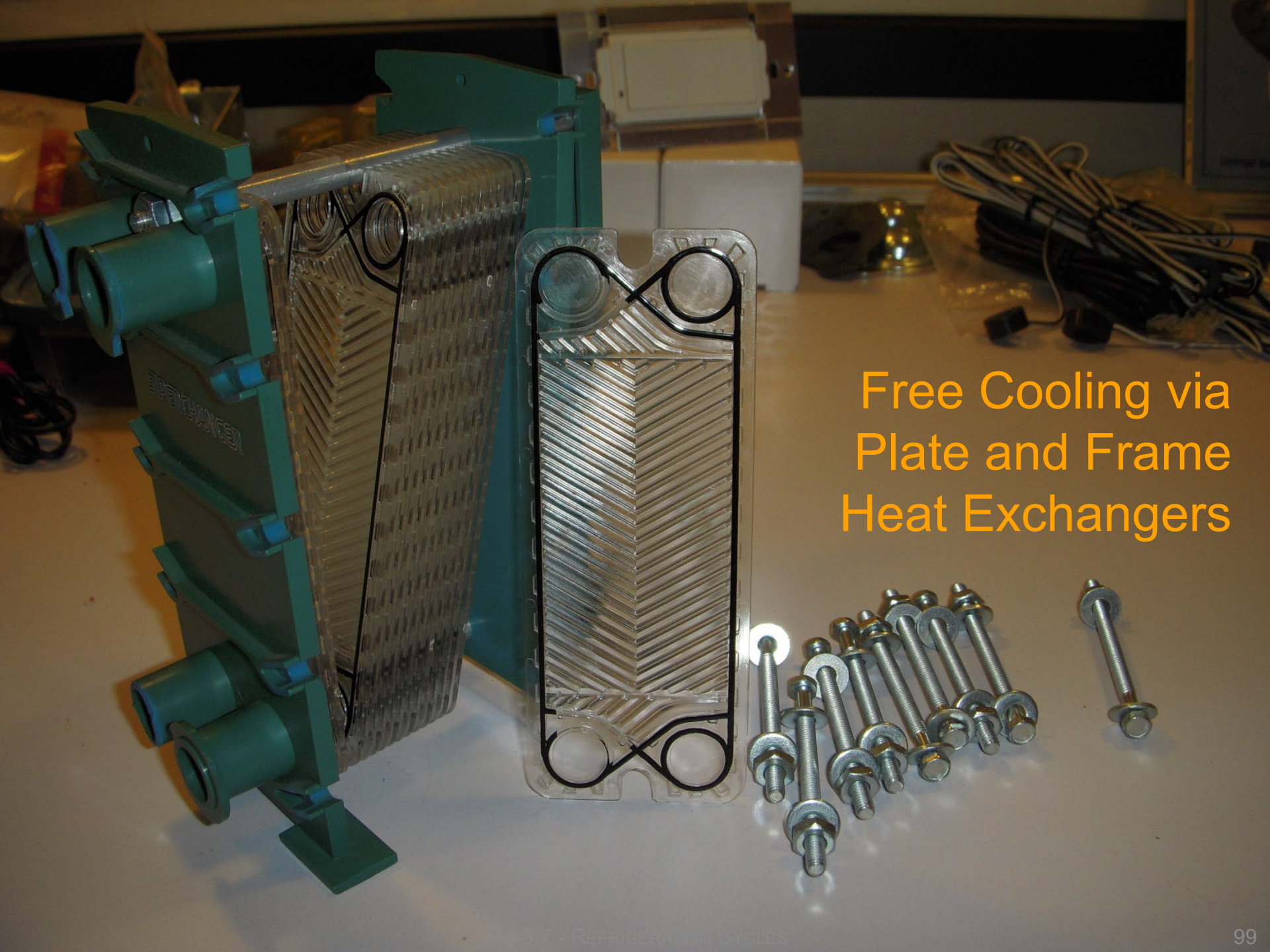


Other Types of Heat Transfer Elements will Exhibit Similar Variability

Characteristics will vary with

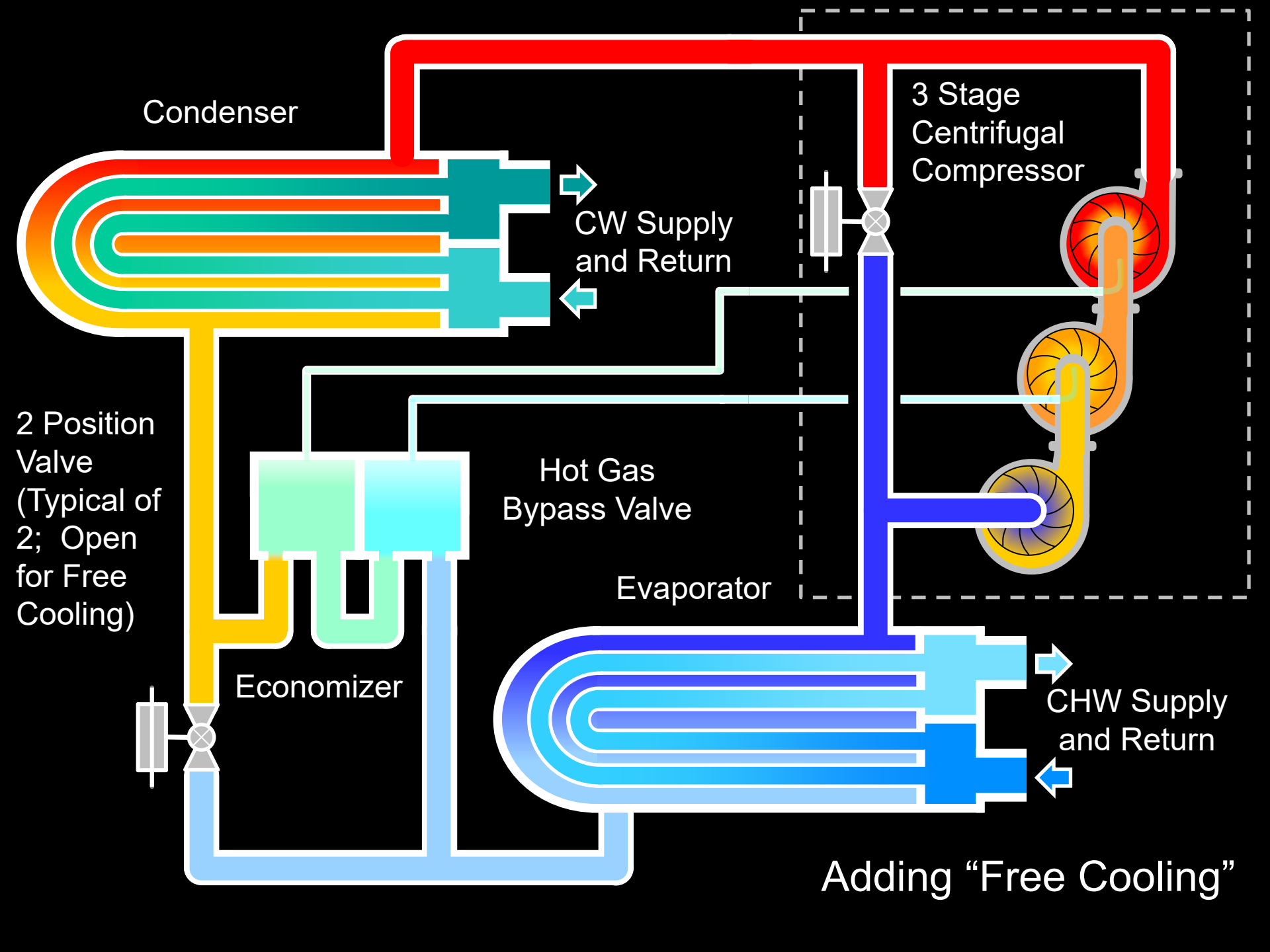
- Changes in flow
- Changes in entering conditions
- Transitions from turbulent to laminar flow
- Phase changes on either side of the heat exchanger
  - Condensing water from air
  - Steam condensing to water
- Age
  - Corrosion
  - Fouling

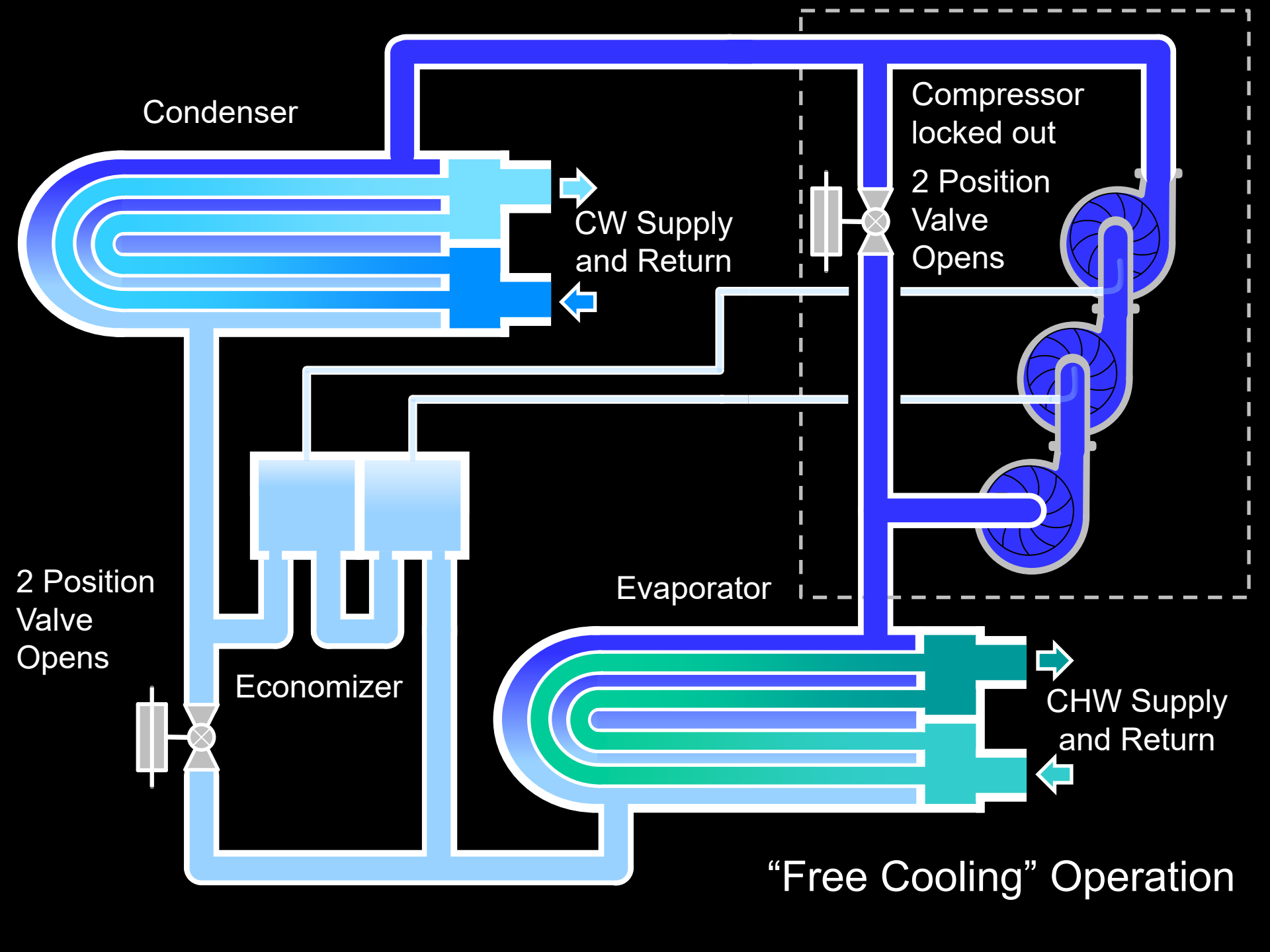
1. The control system will have to deal with all this
   - A loop that was tuned today may not be stable tomorrow
   - Logic that makes good sense under some conditions may not work under others
2. The control system can introduce additional variables
   - Reset strategies
   - Elements with non-linear output or response characteristics


Free Cooling via
Plate and Frame
Heat Exchangers

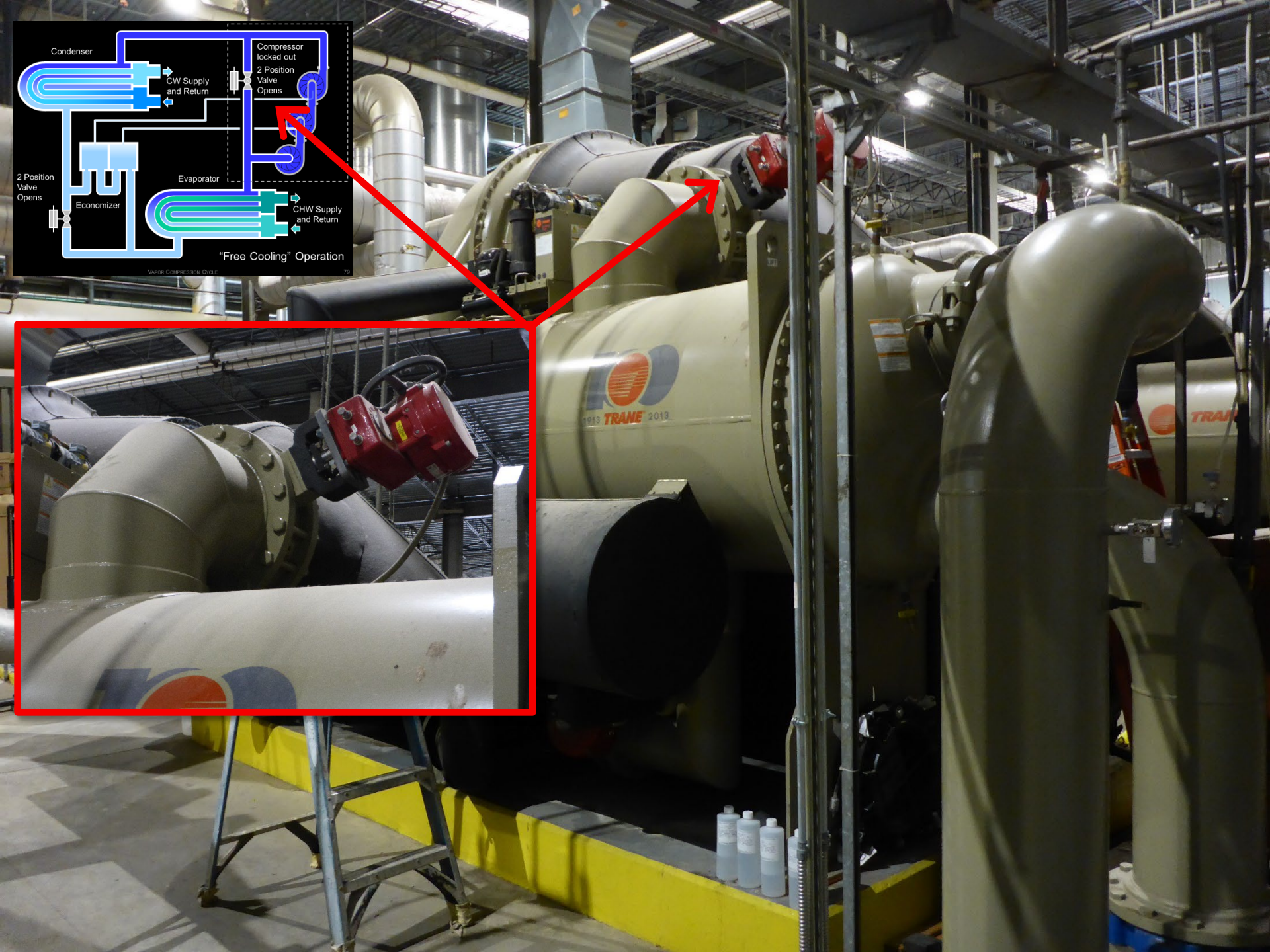
Free Cooling via Plate and Frame Heat Exchangers

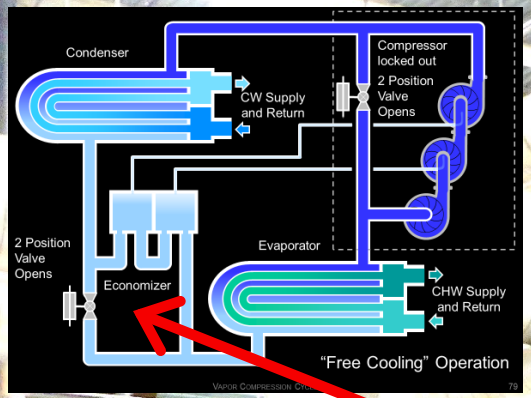
Free Cooling via Plate and Frame Heat Exchangers

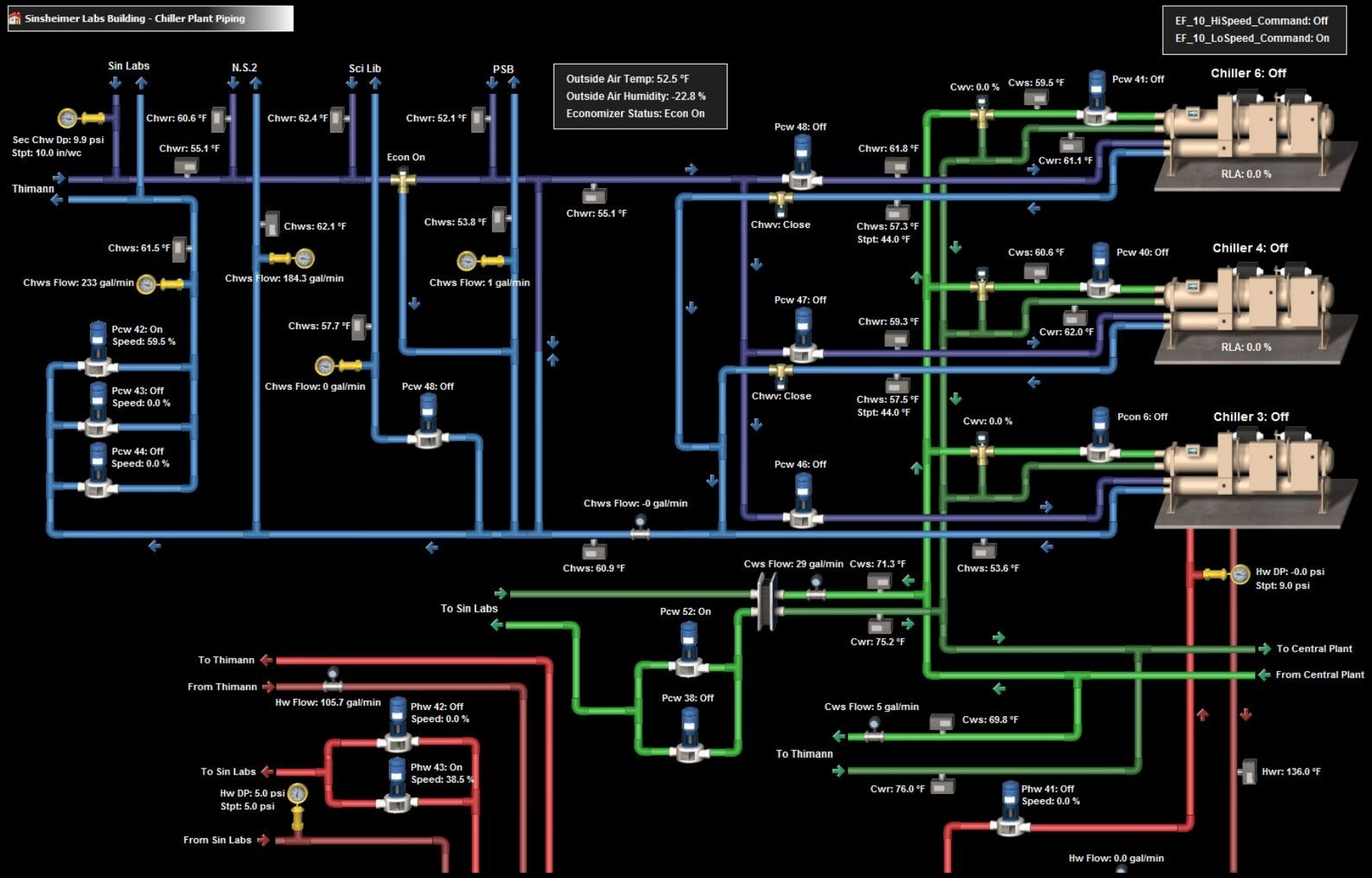

Condenser
3 Stage
Centrifugal
Compressor
CW Supply
and Return
2 Position
Valve
(Typical of
2; Open
for Free
Cooling)
Hot Gas
Bypass Valve
Evaporator
Economizer
CHW Supply
and Return
Adding “Free Cooling”


Condenser
CW Supply
and Return
Compressor
locked out
2 Position
Valve
Opens
2 Position
Valve
Opens
Economizer
Evaporator
CHW Supply
and Return
“Free Cooling” Operation


Condenser
CW Supply and Return
Compressor locked out
2 Position Valve Opens
2 Position Valve Opens
Evaporator
Economizer
CHW Supply and Return
"Free Cooling" Operation
Vapor Compression Cycle
79

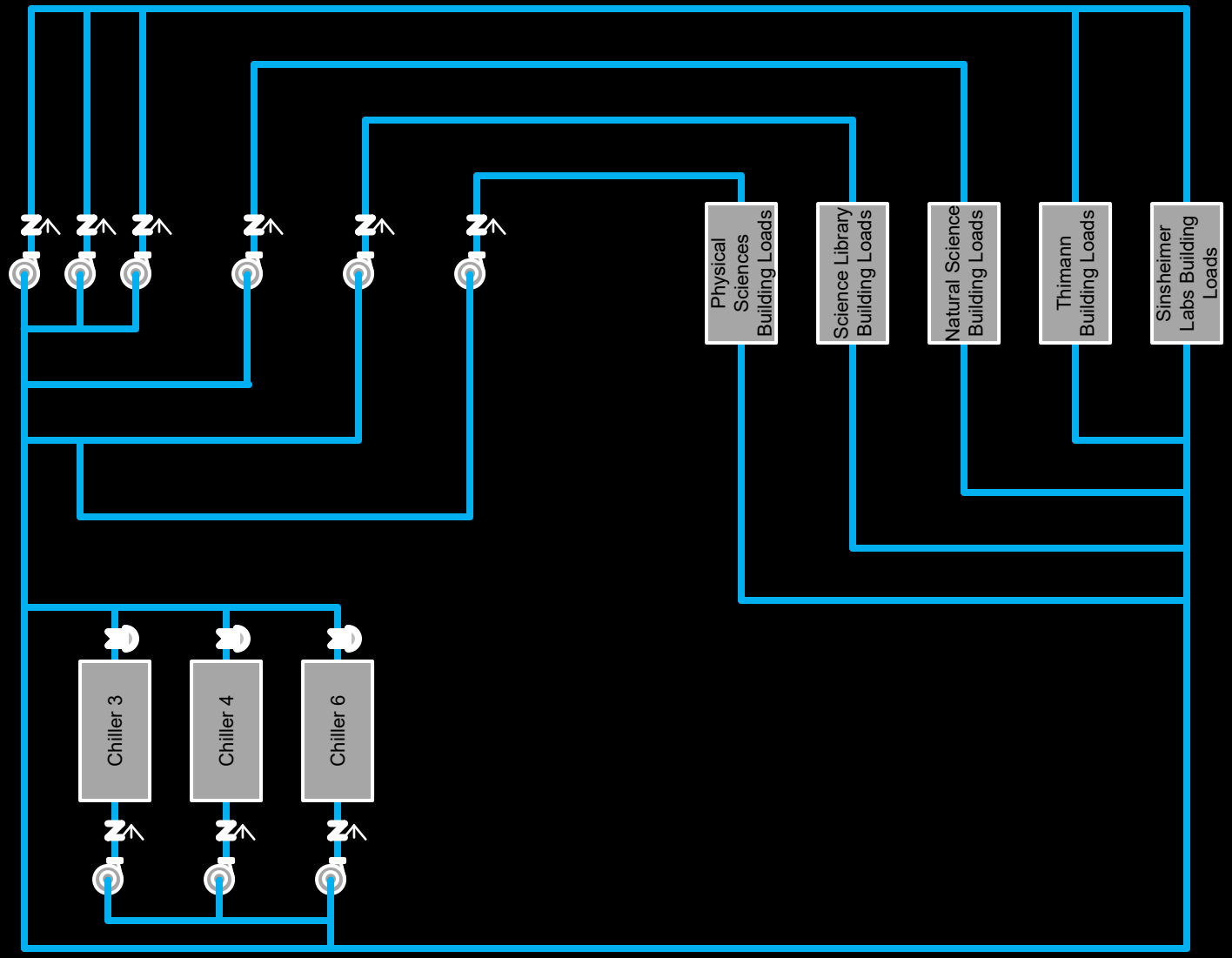

Condenser
CW Supply and Return
Compressor locked out
2 Position Valve Opens
2 Position Valve Opens
Evaporator
Economizer
CHW Supply and Return
"Free Cooling" Operation
Vapor Compression Cycle
79
1913 TRANE 2013


Condenser
CW Supply and Return
Compressor locked out
2 Position Valve Opens
2 Position Valve Opens
Evaporator
Economizer
CHW Supply and Return
"Free Cooling" Operation



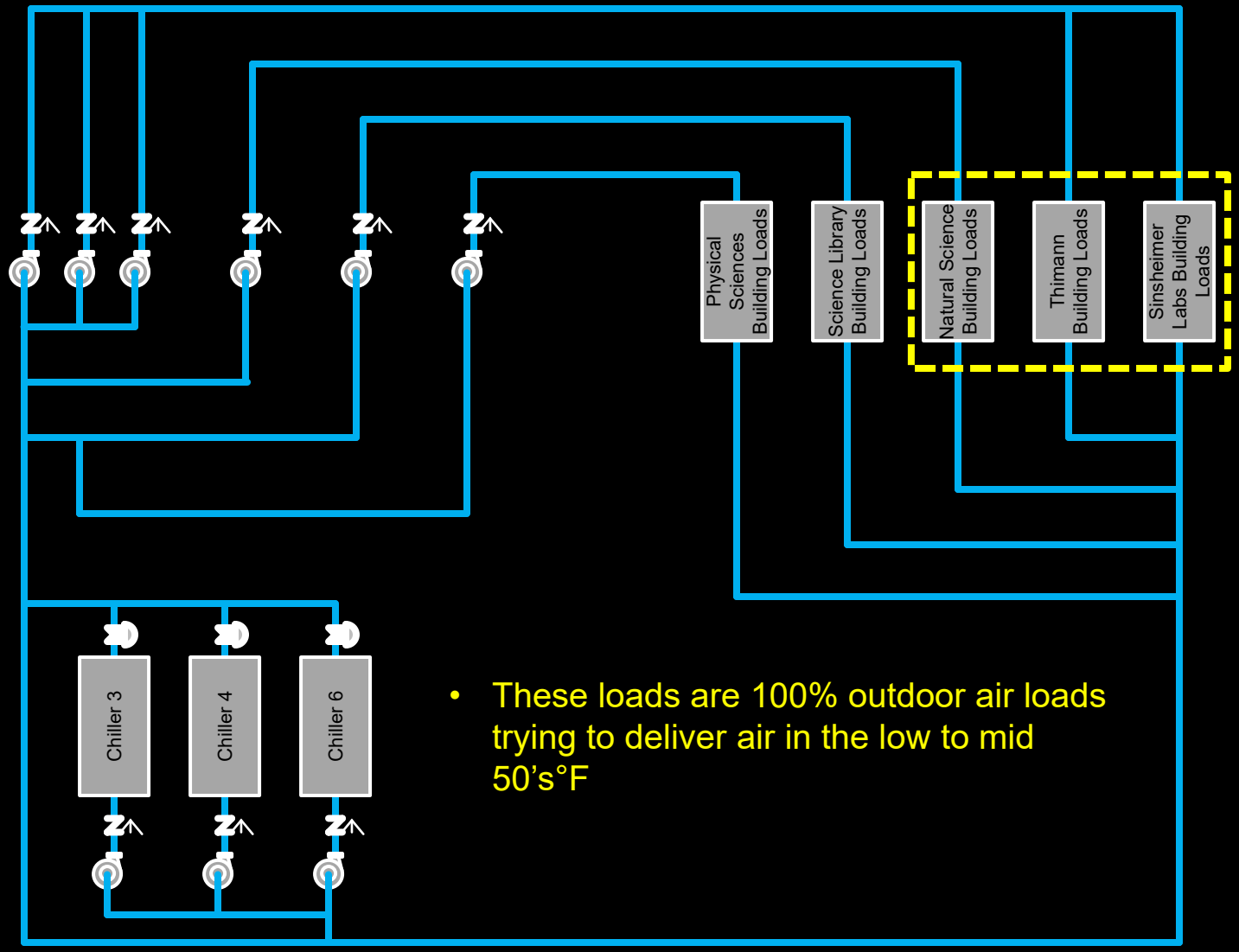
The Control System Graphic

UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS



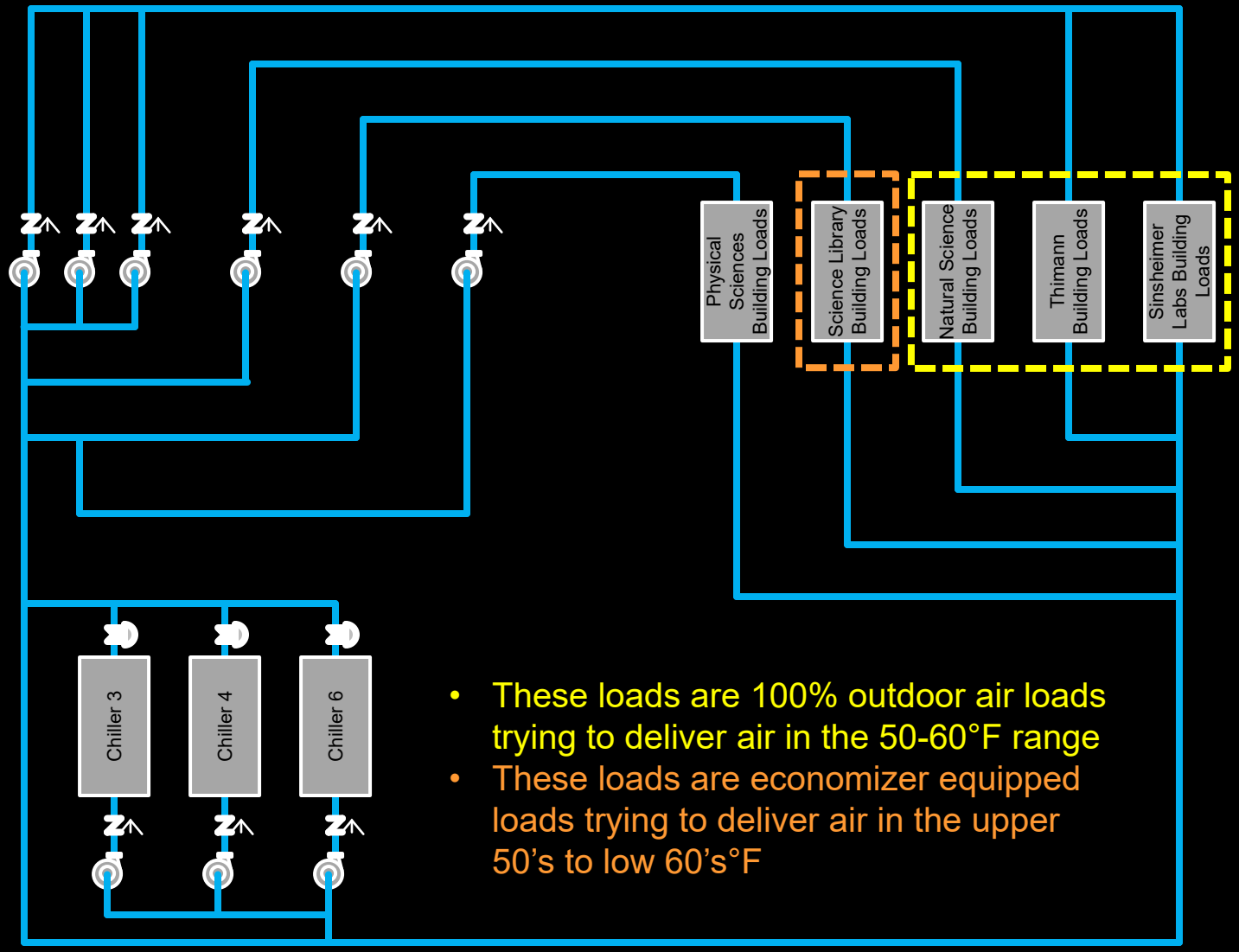
The Untangled System Diagram

UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS



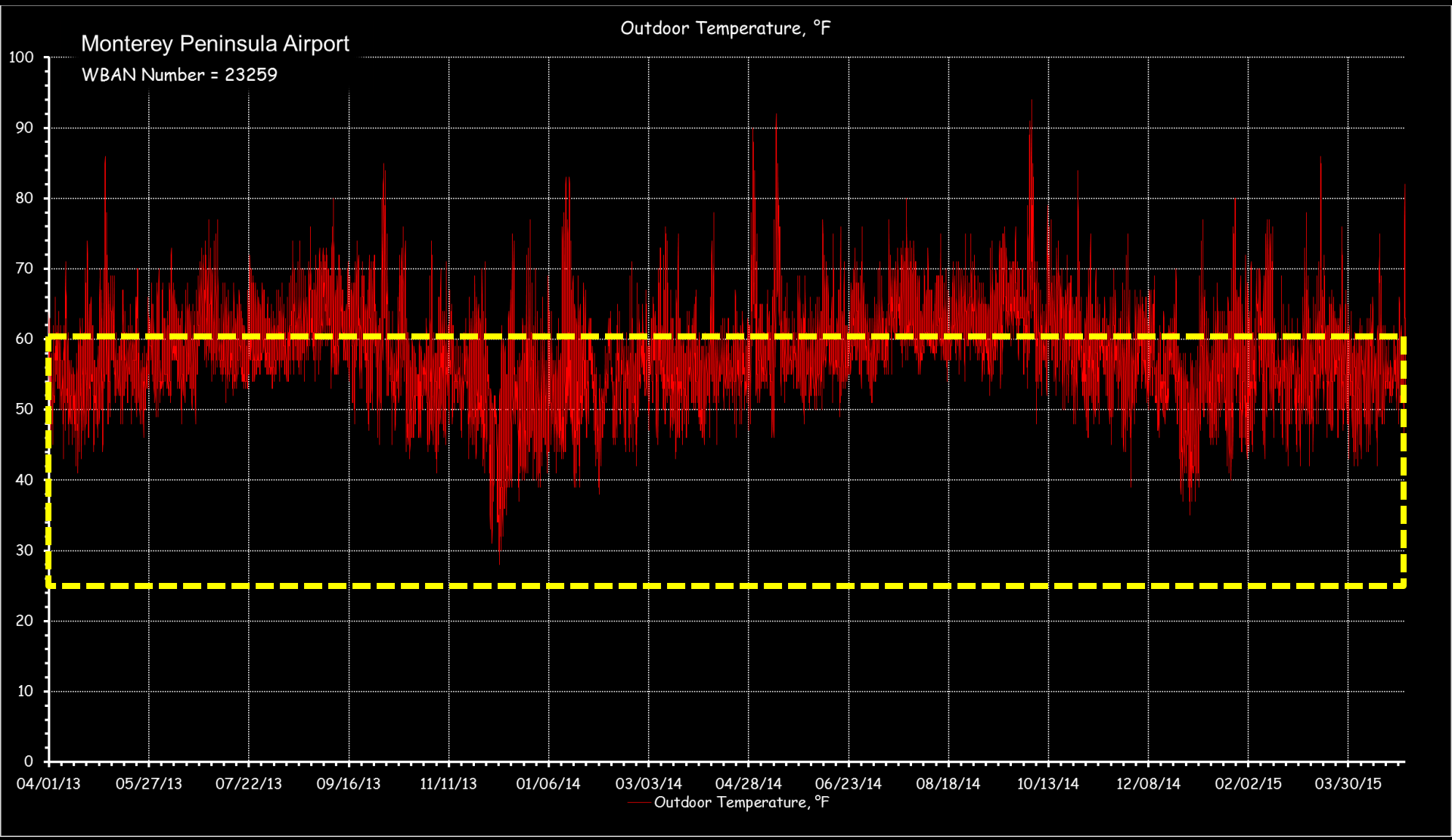
The Original Plant Configuration

UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS

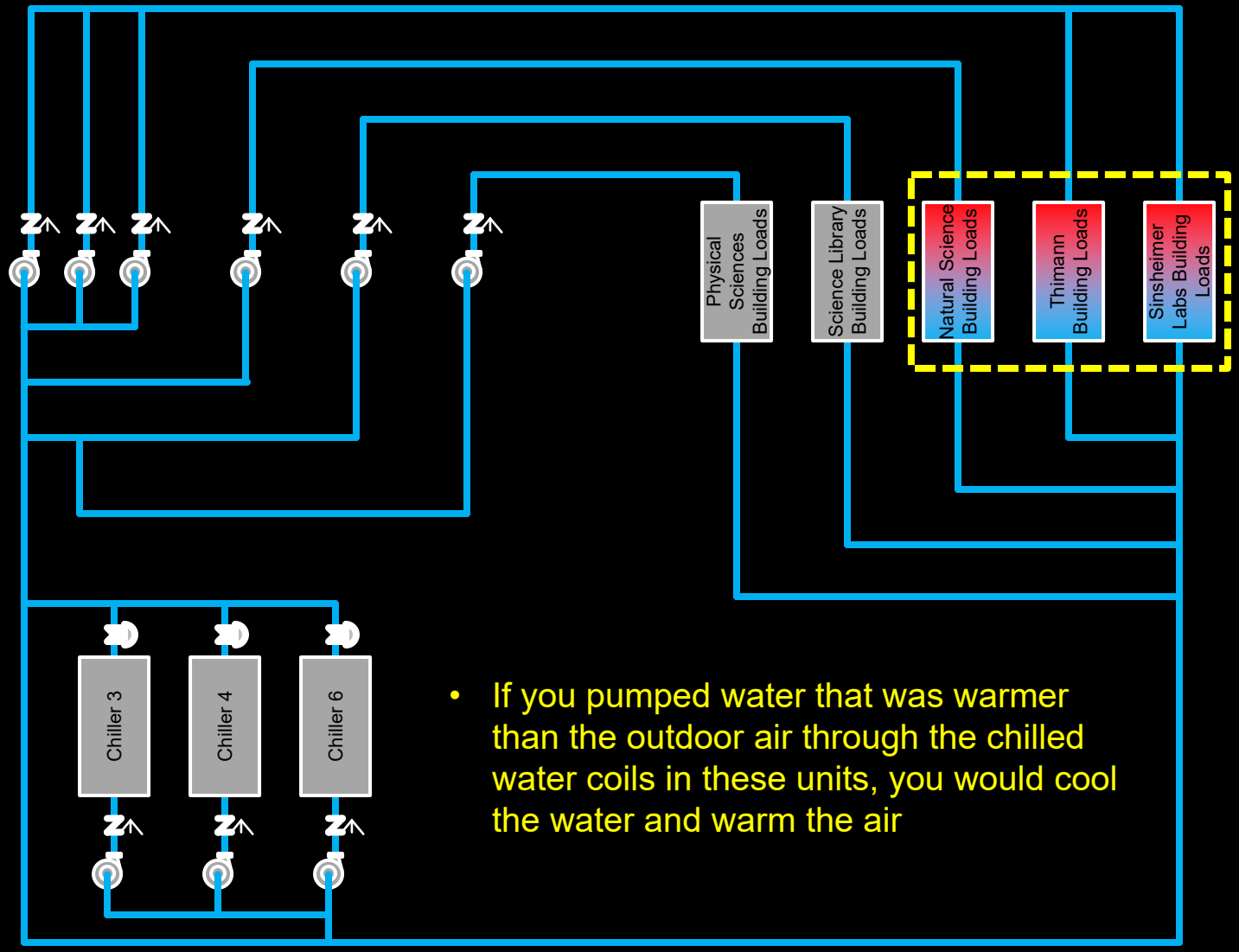


The Original Plant Configuration

UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS



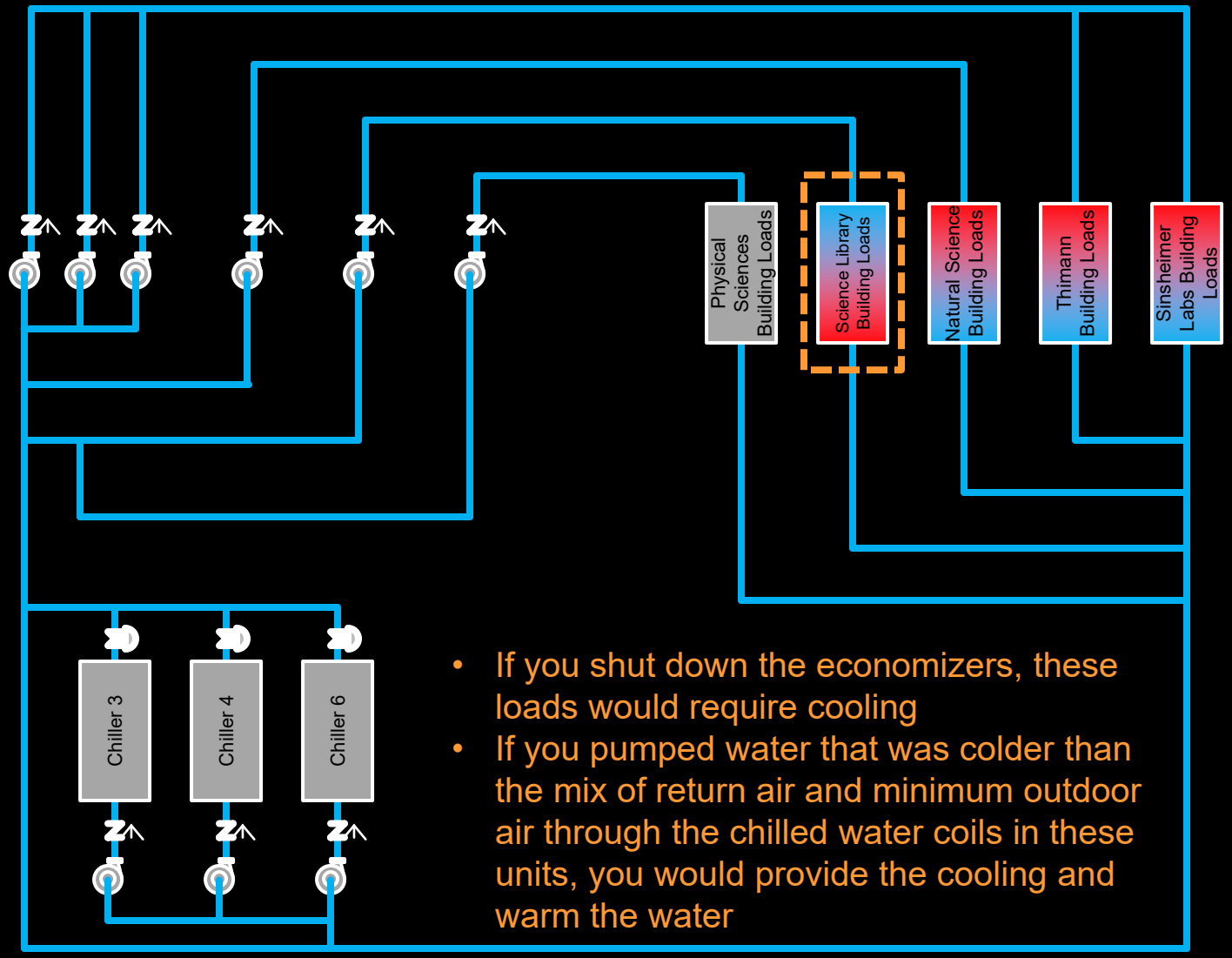
There Are A Lot of Hours When 100% Outdoor Air Systems Delivering 50-60°F Air will Need Preheat



- If you pumped water that was warmer than the outdoor air through the chilled water coils in these units, you would cool the water and warm the air

The Original Plant Configuration

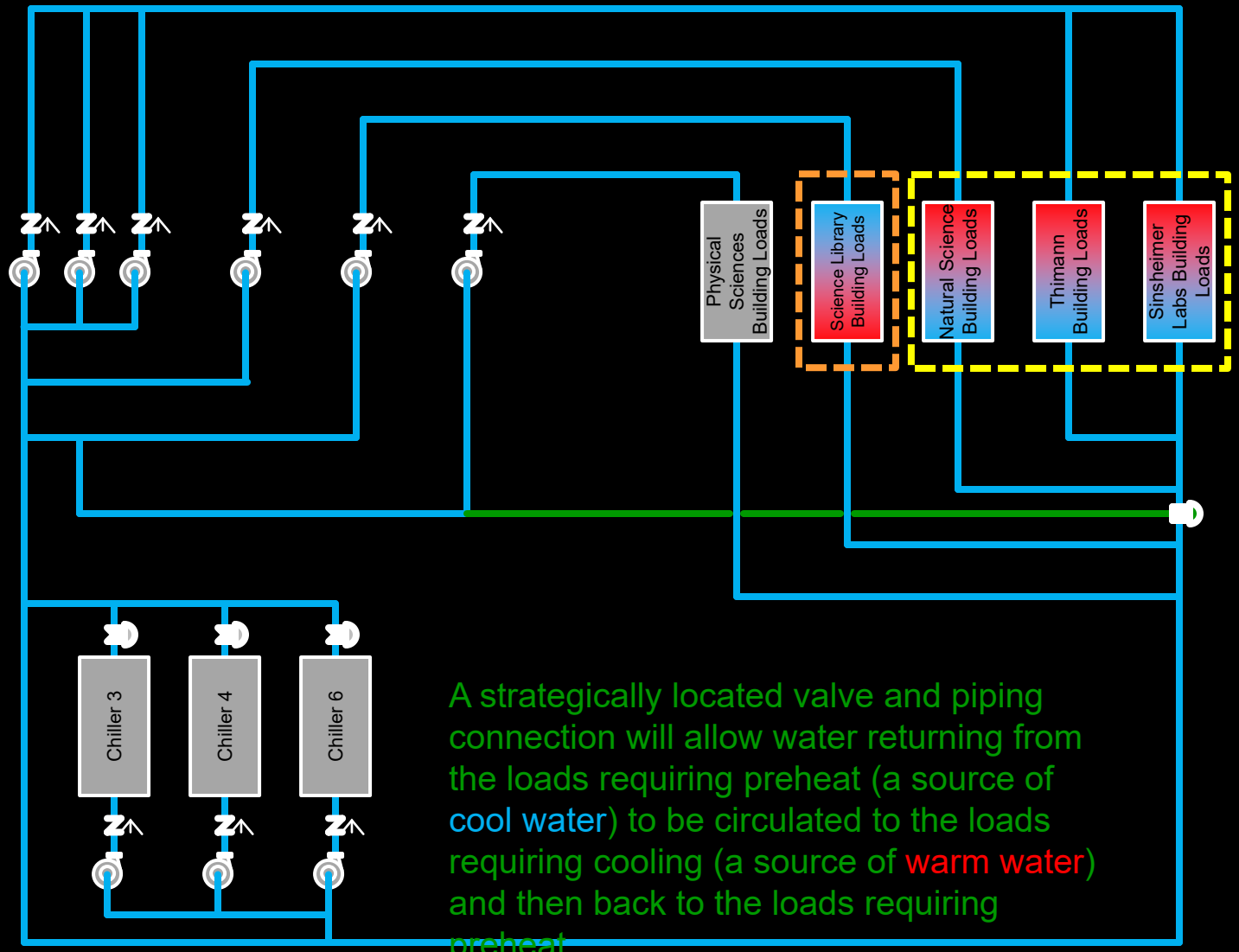
UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS



- If you shut down the economizers, these loads would require cooling
- If you pumped water that was colder than the mix of return air and minimum outdoor air through the chilled water coils in these units, you would provide the cooling and warm the water

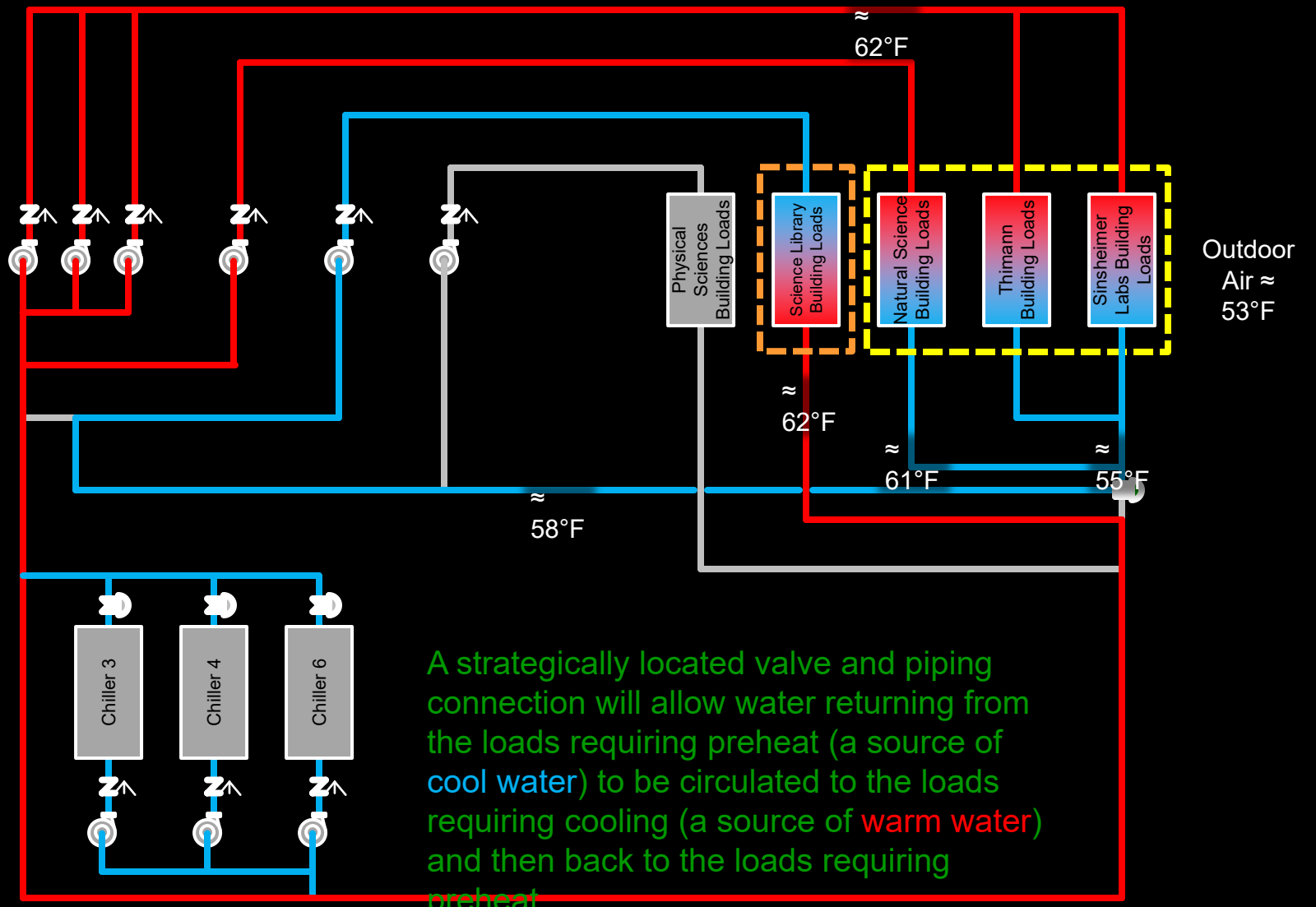
The Original Plant Configuration

UC Santa Cruz
Pre-Wet Economizer System
2016-01-29
Drawn By : DS



The Modification to Make the Wet Economizer

UC Santa Cruz
Wet Economizer System
2016-01-29
Drawn By : DS



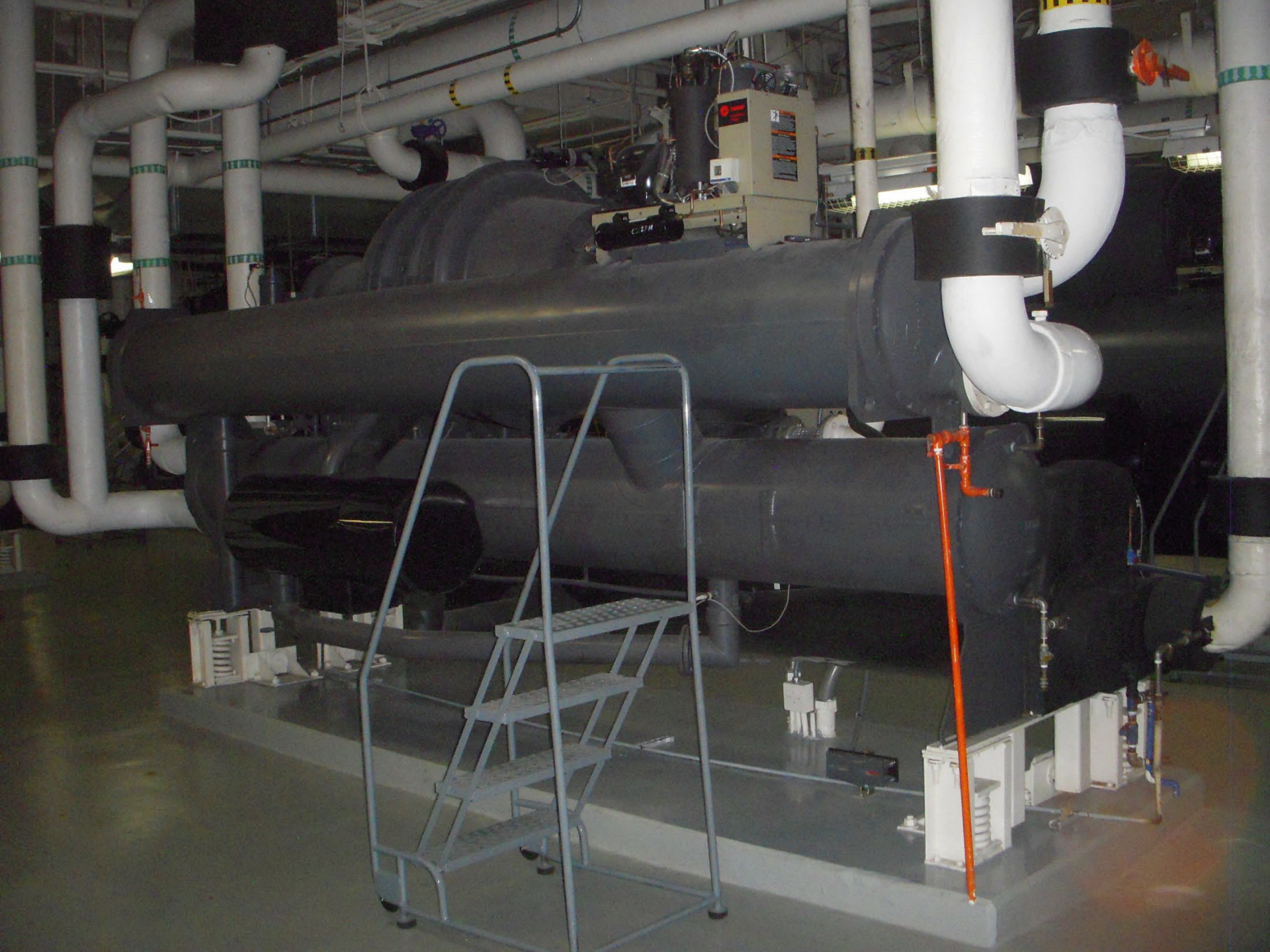
The Wet Economizer in Operation

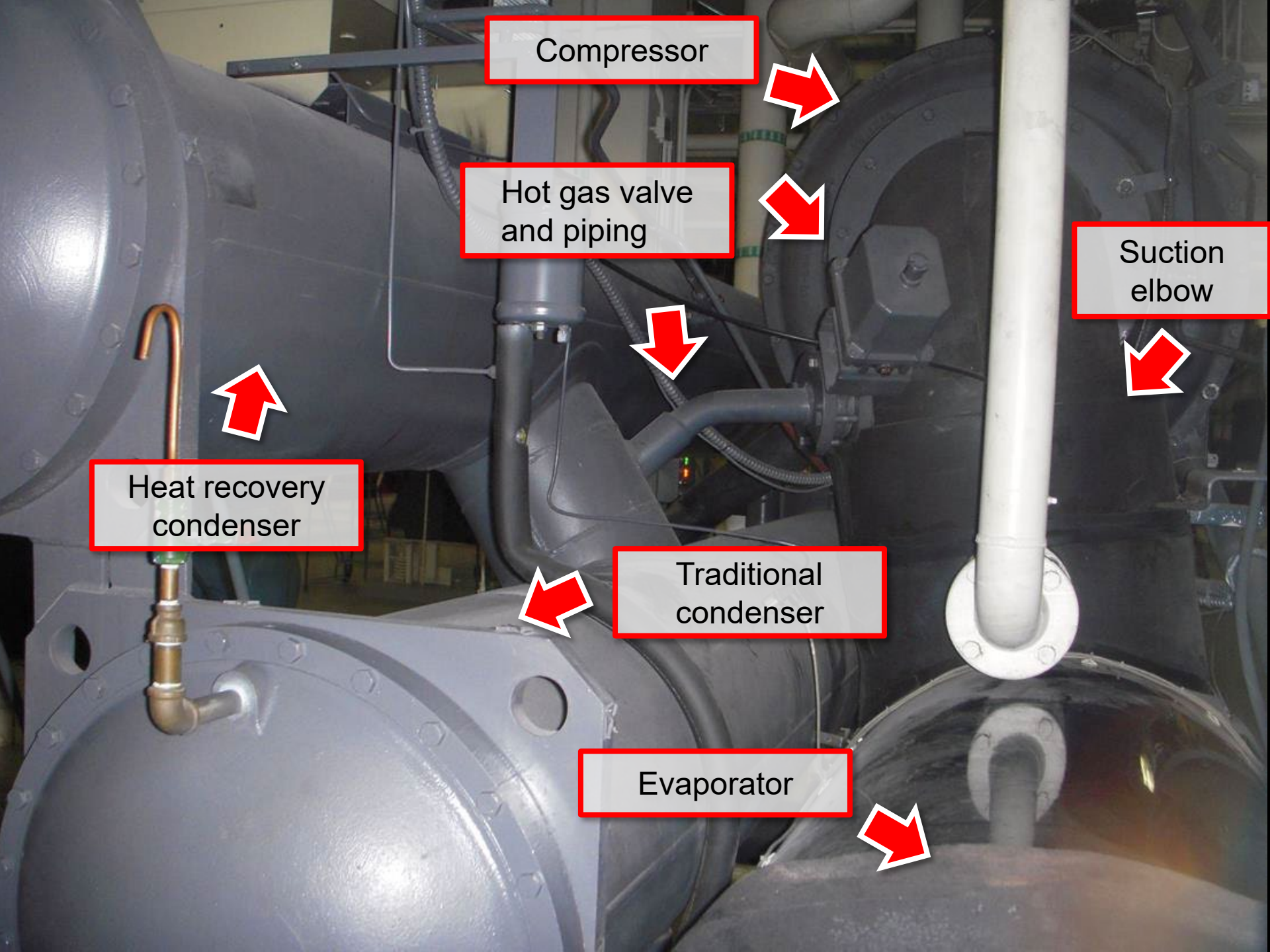
UC Santa Cruz
Wet Economizer System
2016-01-29
Drawn By : DS

A Heat Recovery Centrifugal Chiller

The chiller in the following slide has a second condenser tube bundle that is piped to the heating hot water system. This allows the hot gas off of the compressor to be used to generate hot water for reheat loads prior to having its heat rejected to the cooling tower via the traditional condenser.


CH-01
UCP2




Compressor
Hot gas valve and piping
Suction elbow
Heat recovery condenser
Traditional condenser
Evaporator