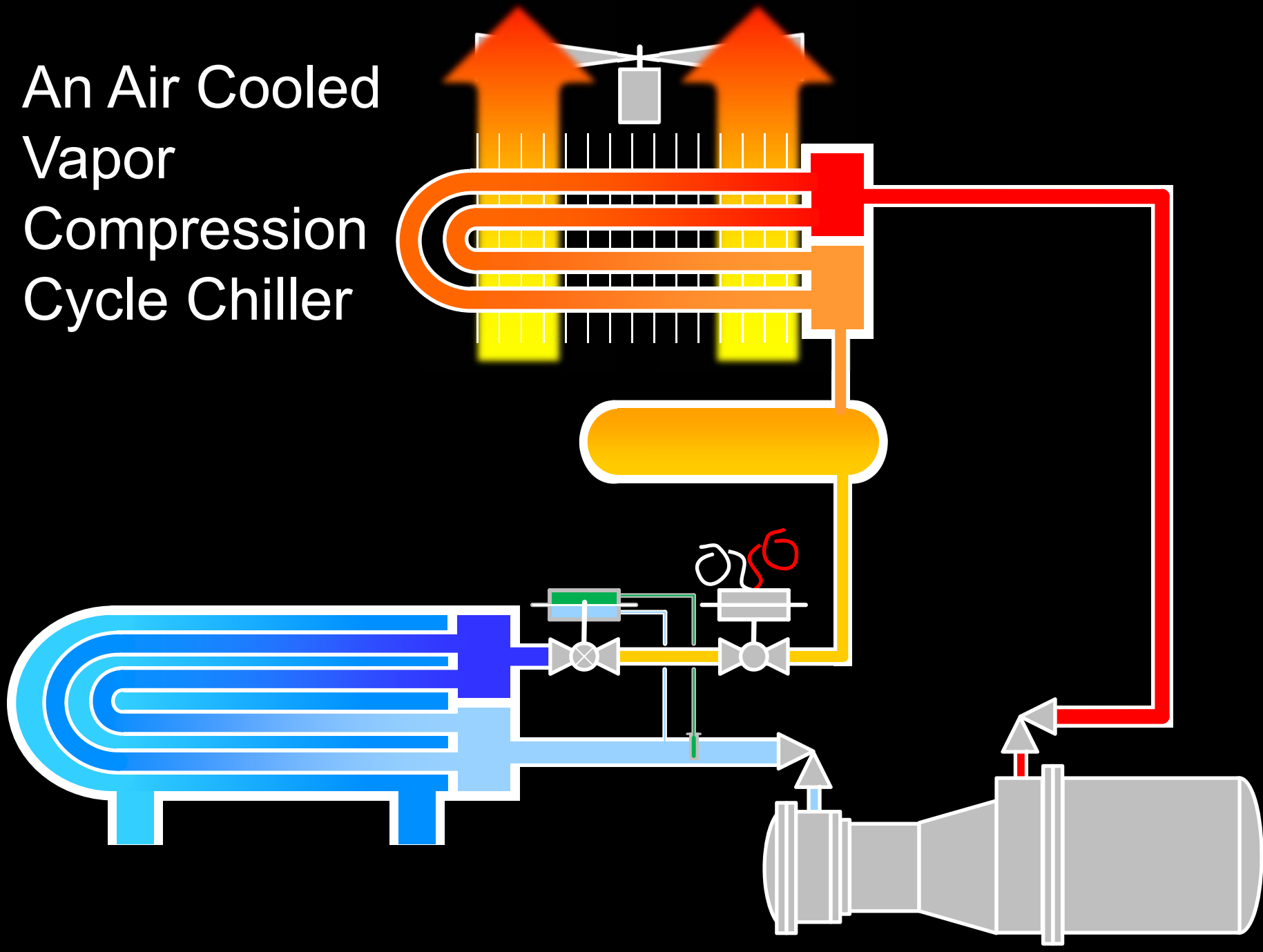
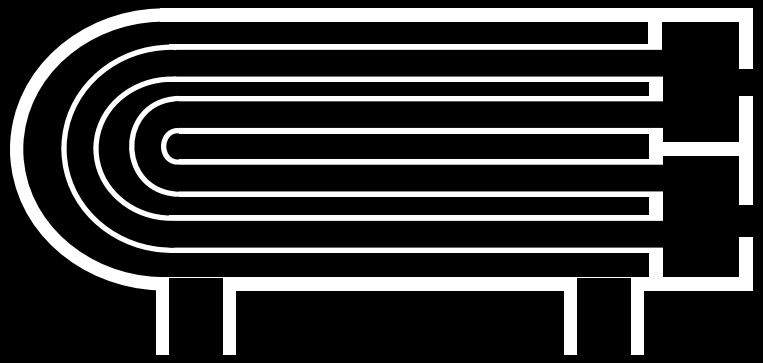
An Air Cooled Vapor Compression Cycle Chiller



An Air Cooled Vapor Compression Cycle Chiller

Start with a heat exchanger;
a.k.a the evaporator



An Air Cooled Vapor Compression Cycle Chiller

Start with a heat exchanger;
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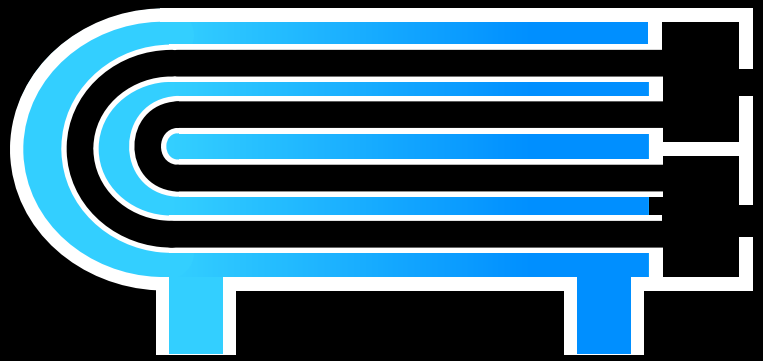


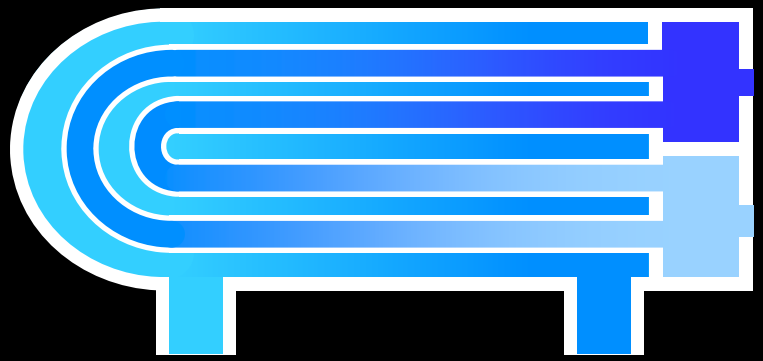
Add the fluid you want to cool on
one side of the heat transfer surface

An Air Cooled Vapor Compression Cycle Chiller

Refrigerant

- Substance used to absorb heat from the item or area to be cooled
- Vapor compression cycles leverage the latent heat of vaporization of the refrigerant
  - Energy that changes the liquid to a vapor
  - The evaporator functions as a saturated system

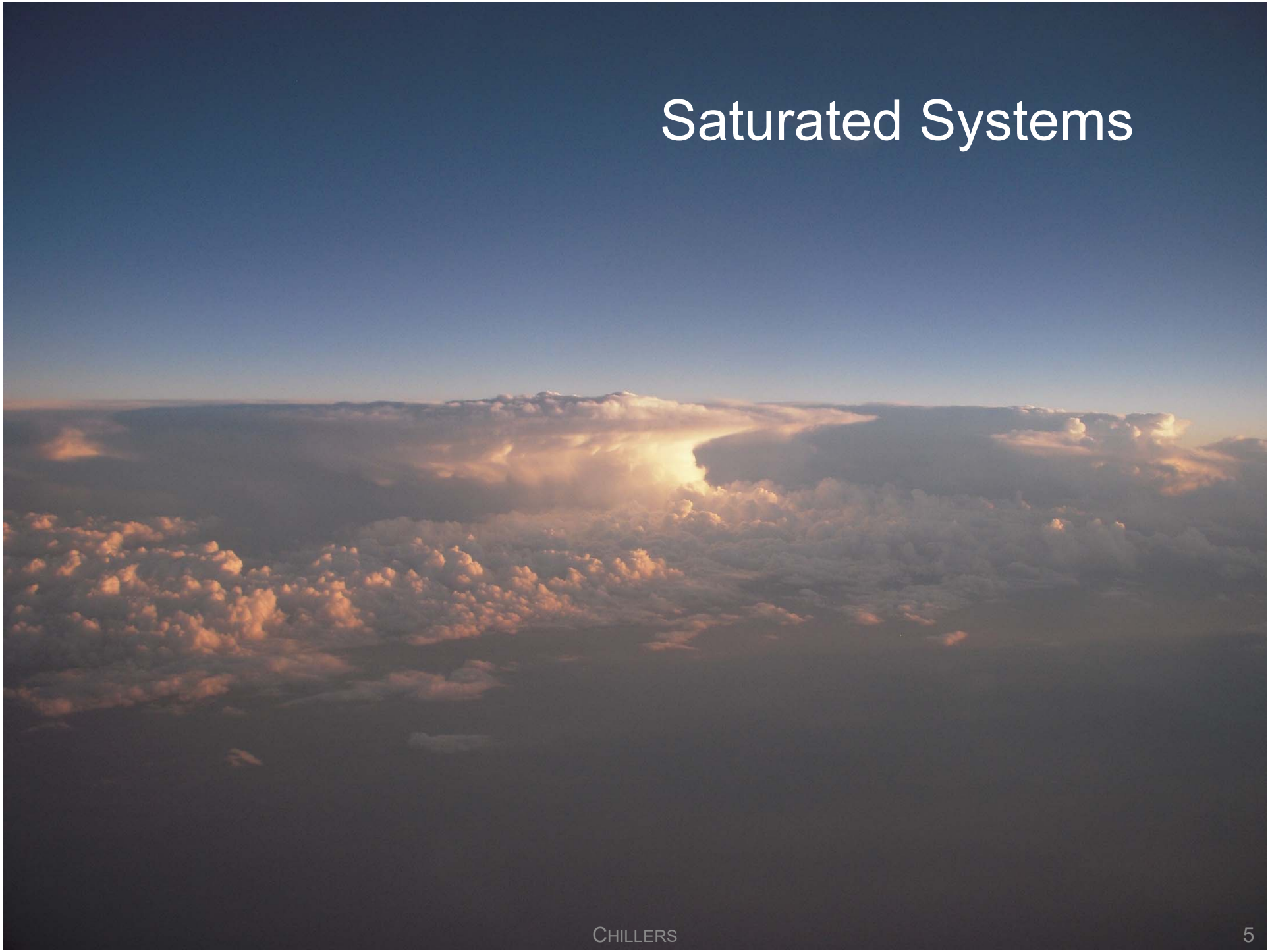
Start with a heat exchanger; a.k.a the evaporator



Place a refrigerant on the other side of the heat transfer surface

Add the fluid you want to cool on one side of the heat transfer surface

Saturated Systems




Saturated Systems

Saturated Systems

Saturated Systems

Saturated Systems

Saturated Systems

Phase Changes and Saturated Systems

Phase changes absorb a lot of energy

- Melting ice – 144 Btu/lb
- Heating water – 1Btu/lb-°F
- Converting water to steam – 971 Btu/lb
- Superheating steam – 0.5 Btu/lb

(all parameters are at atmospheric pressure)

Phase Changes and Saturated Systems

At saturation:

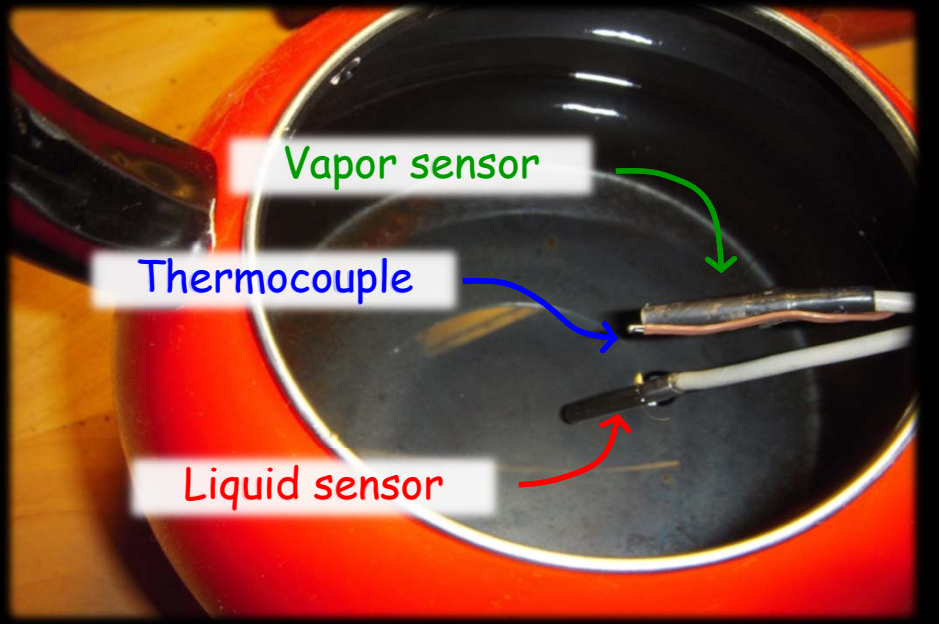
- The substance exists in both a liquid and vapor state
- At a constant pressure, the temperature of the substance will not change until:
  - It is fully converted to a liquid (removing energy), or
  - It is fully converted to a vapor (adding energy)

Phase Changes and Saturated Systems
An Experiment

- Heat water in a low pressure boiler
- Monitor:
  - Water temperature
  - Vapor temperature over the water surface
  - Power
- Plot the results

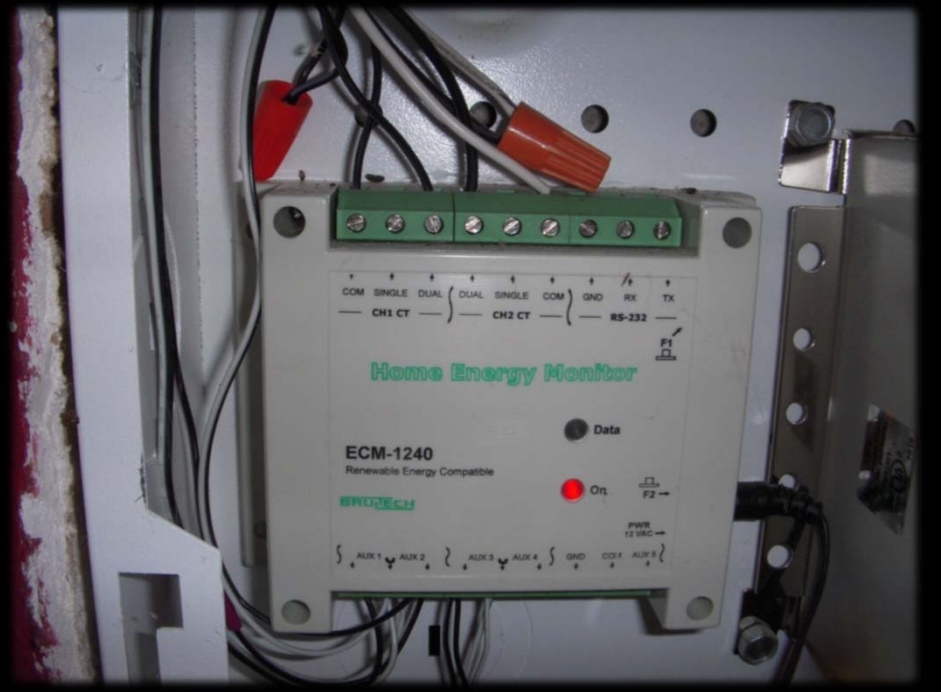
Phase Changes and Saturated Systems
An Experiment

- Monitoring temperature



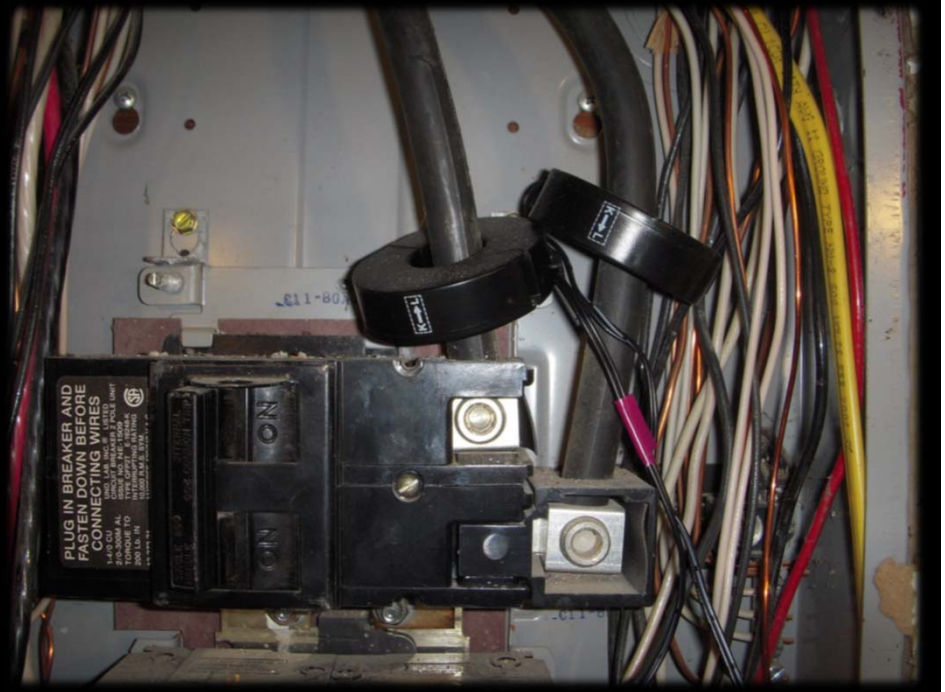
Phase Changes and Saturated Systems
An Experiment

- Monitoring power

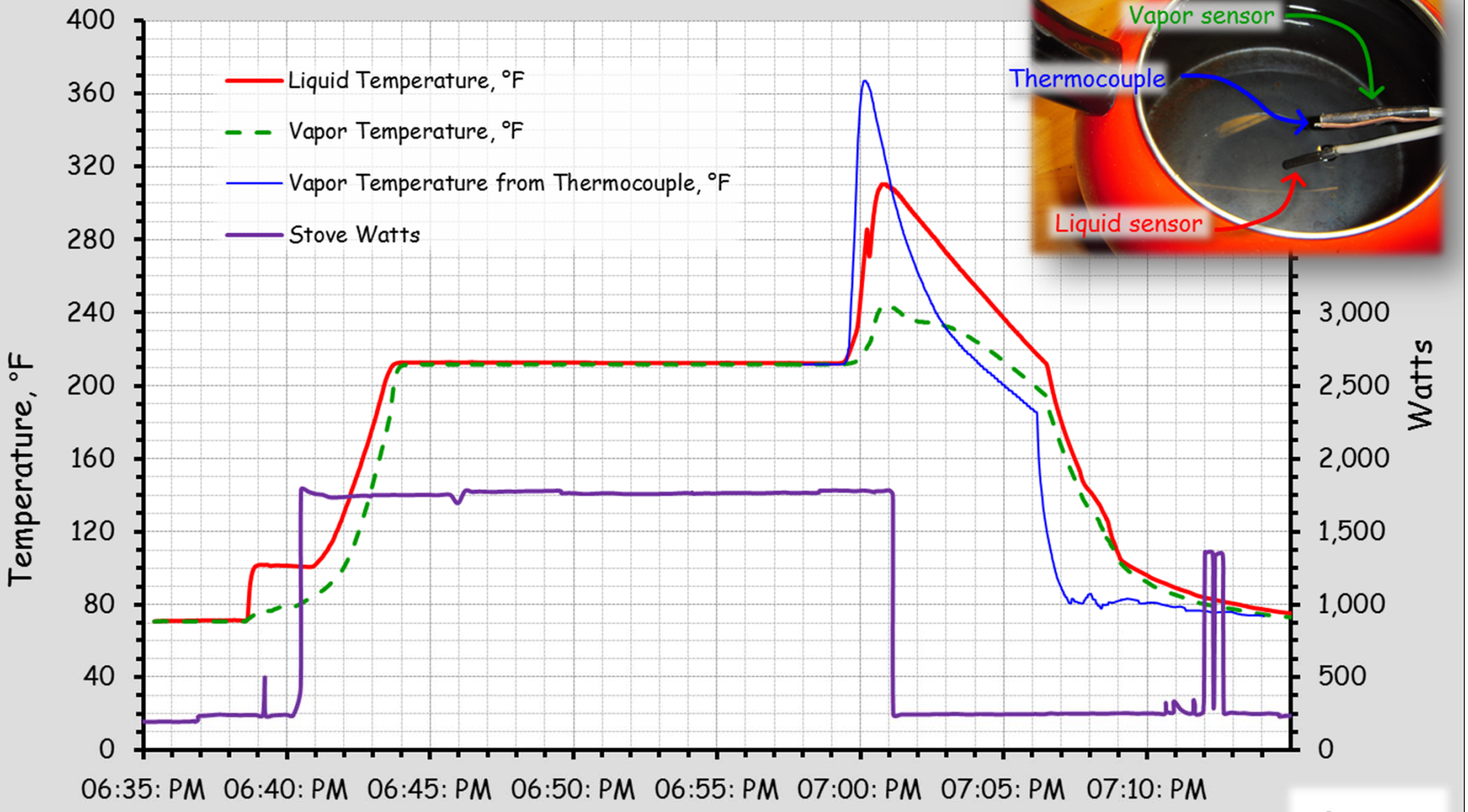


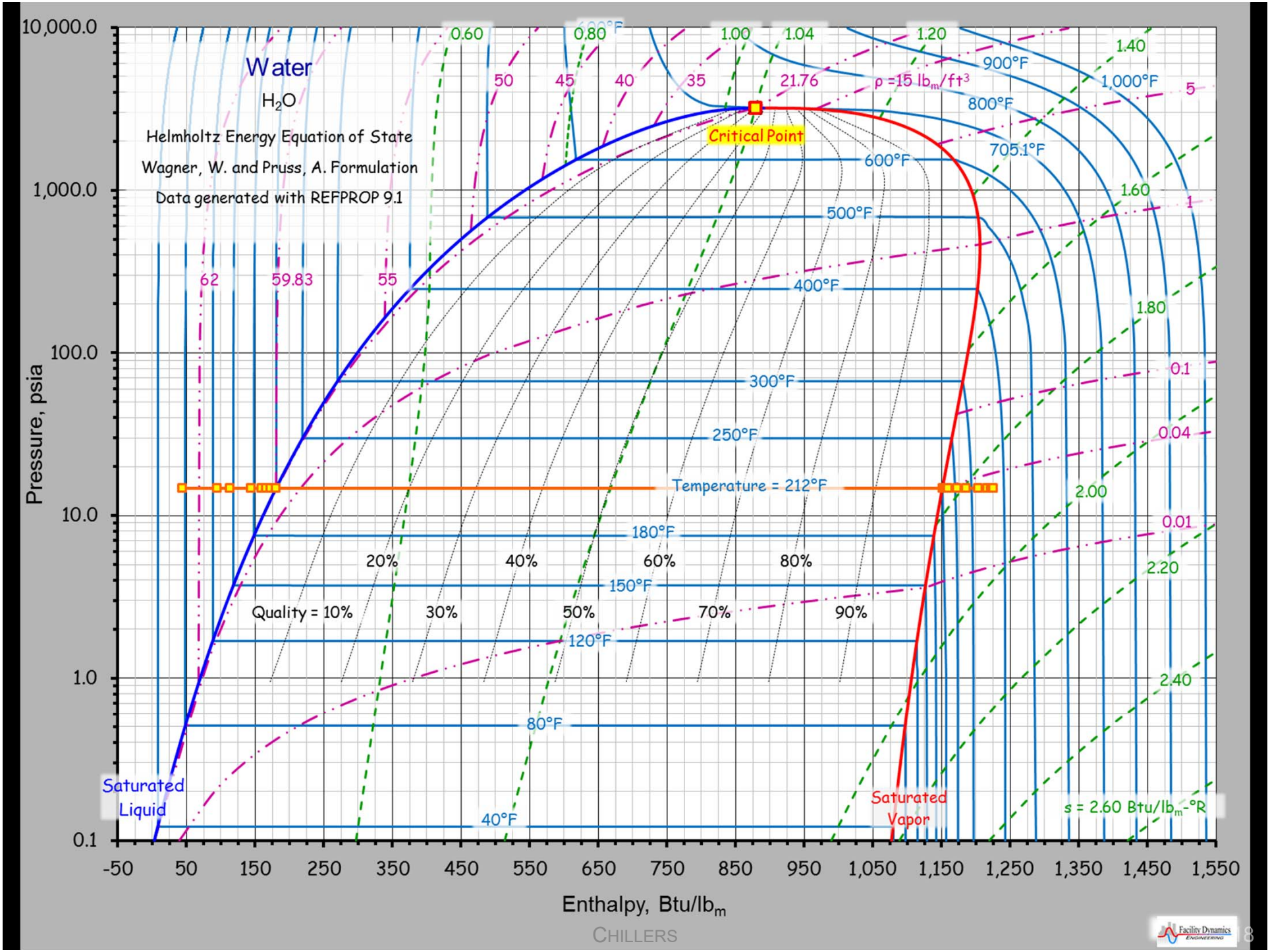
Phase Changes and Saturated Systems
An Experiment

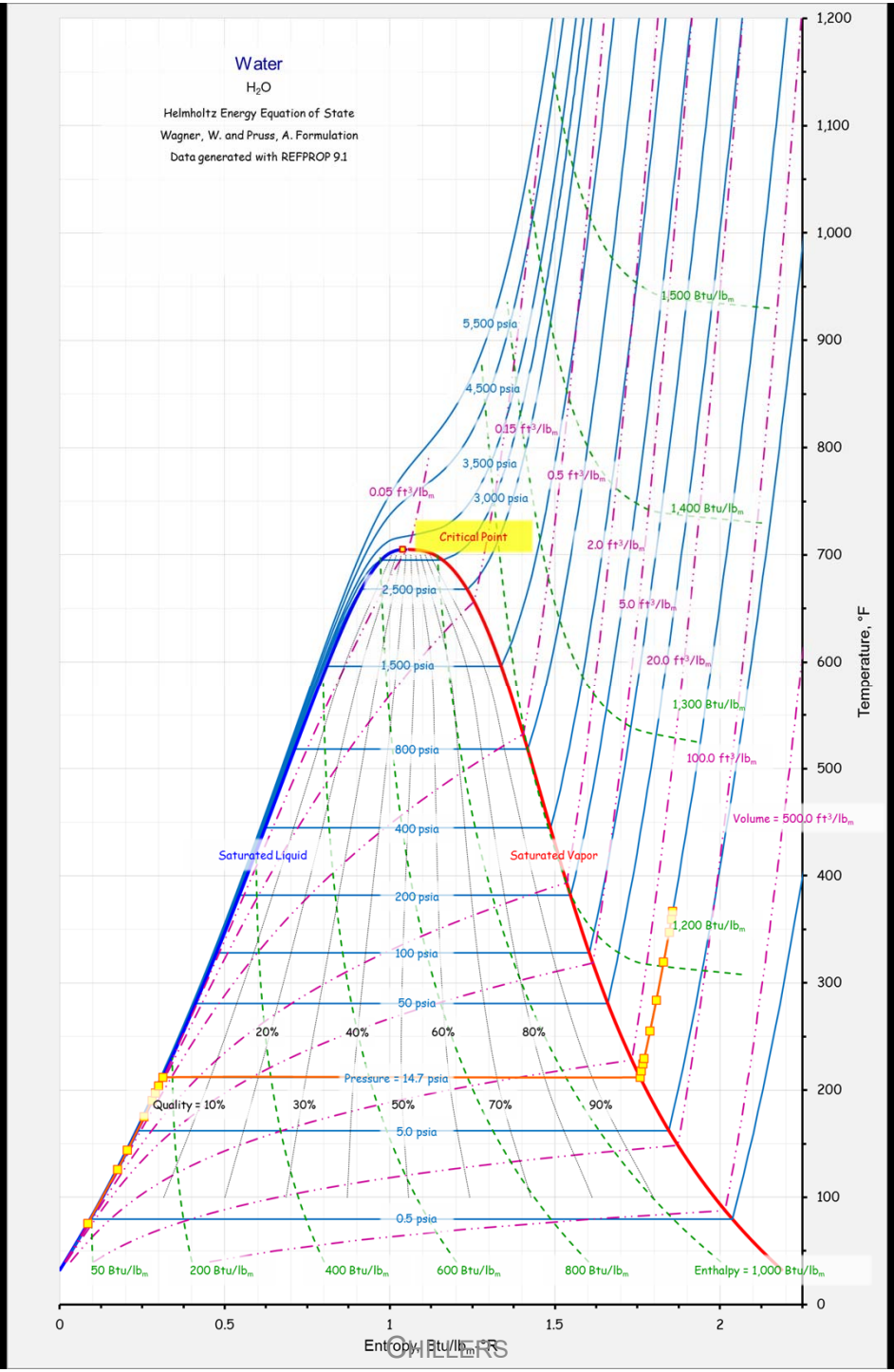
- Monitoring power

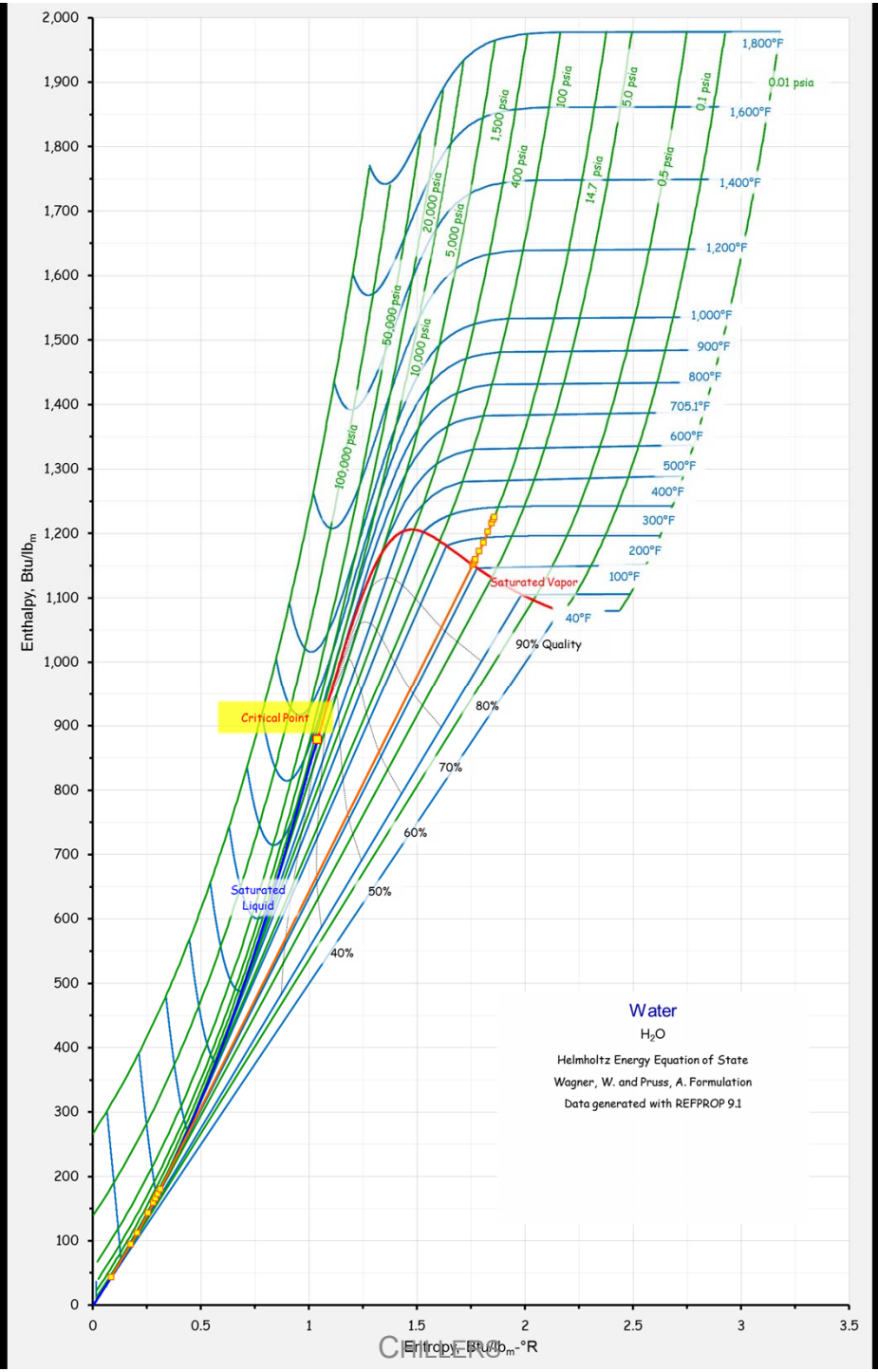


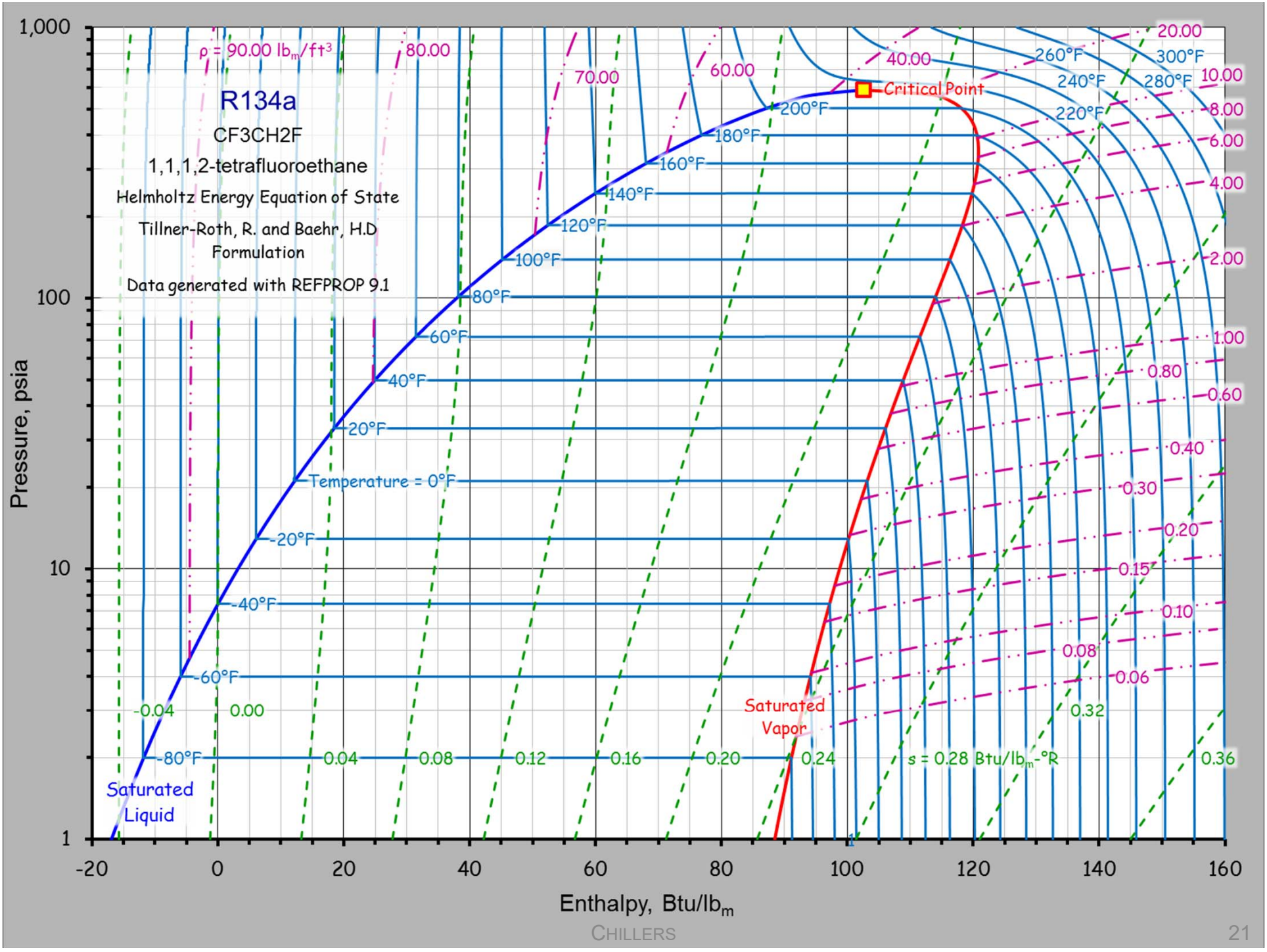
Temperatures in a Saturated System as it Transitions from Subcooled Liquid to Superheated Vapor




Water
H_2O
Helmholtz Energy Equation of State
Wagner, W. and Pruss, A. Formulation
Data generated with REFPROP 9.1
Critical Point
Saturated Liquid
Saturated Vapor
Temperature = 212°F
Quality = 10%
20%
30%
40%
50%
60%
70%
80%
90%
ρ =15 lbm/ft3
21.76
705.1°F
900°F
800°F
600°F
500°F
400°F
300°F
250°F
180°F
150°F
120°F
80°F
40°F
62
59.83
55
50
45
40
35
0.60
0.80
1.00
1.04
1.20
1.40
1.60
1.80
2.00
2.20
2.40
5
1
0.1
0.04
0.01
s = 2.60 Btu/lbm-°R
Pressure, psia
10,000.0
1,000.0
100.0
10.0
1.0
0.1
-50
50
150
250
350
450
550
650
750
850
950
1,050
1,150
1,250
1,350
1,450
1,550
Enthalpy, Btu/lbm

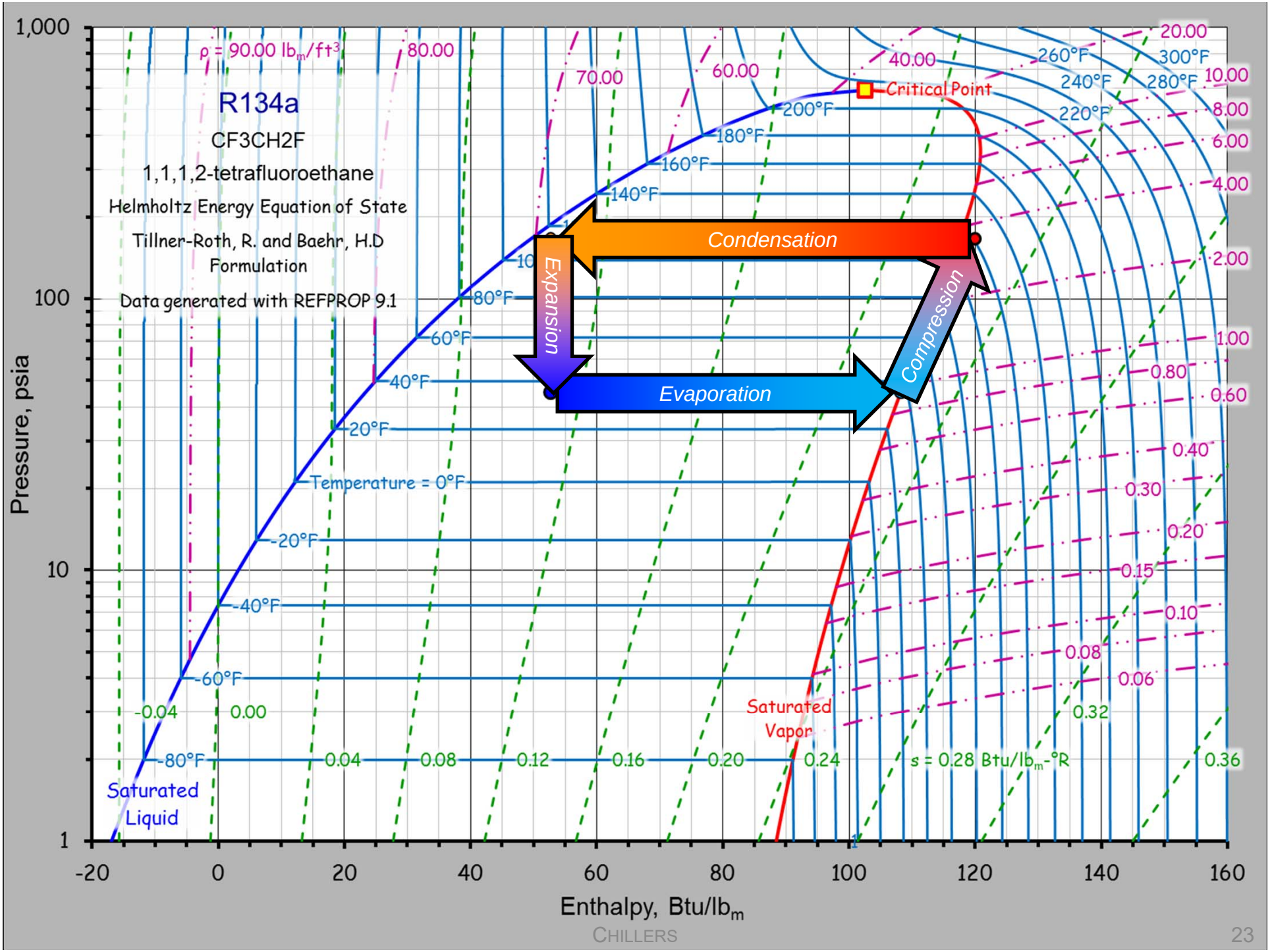

Water
H_2O
Helmholtz Energy Equation of State
Wagner, W. and Pruss, A. Formulation
Data generated with REFPROP 9.1
Critical Point
Saturated Liquid
Saturated Vapor
Pressure = 14.7 psia
5,500 psia
4,500 psia
3,500 psia
3,000 psia
2,500 psia
1,500 psia
800 psia
400 psia
200 psia
100 psia
50 psia
5.0 psia
0.5 psia
0.15 ft³/lbm
0.05 ft³/lbm
0.5 ft³/lbm
2.0 ft³/lbm
5.0 ft³/lbm
20.0 ft³/lbm
100.0 ft³/lbm
Volume = 500.0 ft³/lbm
1,500 Btu/lbm
1,400 Btu/lbm
1,300 Btu/lbm
1,200 Btu/lbm
20%
40%
60%
80%
Quality = 10%
30%
50%
70%
90%
50 Btu/lbm
200 Btu/lbm
400 Btu/lbm
600 Btu/lbm
800 Btu/lbm
Enthalpy = 1,000 Btu/lbm
Temperature, °F
Entropy, Btu/lbm°R
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
0
0.5
1
1.5
2


Enthalpy, Btu/lbm
Entropy, Btu/lbm-°R
2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
1,800°F
1,600°F
1,400°F
1,200°F
1,000°F
900°F
800°F
705.1°F
600°F
500°F
400°F
300°F
200°F
100°F
40°F
0.01 psia
0.1 psia
0.5 psia
1.0 psia
5.0 psia
14.7 psia
100 psia
400 psia
1,500 psia
5,000 psia
10,000 psia
20,000 psia
50,000 psia
100,000 psia
Saturated Vapor
90% Quality
80%
70%
60%
50%
40%
Critical Point
Saturated Liquid
Water
H2O
Helmholtz Energy Equation of State
Wagner, W. and Pruss, A. Formulation
Data generated with REFPROP 9.1


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
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
-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
Saturated
Liquid
Saturated
Vapor
Pressure, psia
1,000
100
10
1
-20
0
20
40
60
80
100
120
140
160
Enthalpy, Btu/lbm

Vapor Compression Refrigeration Machines

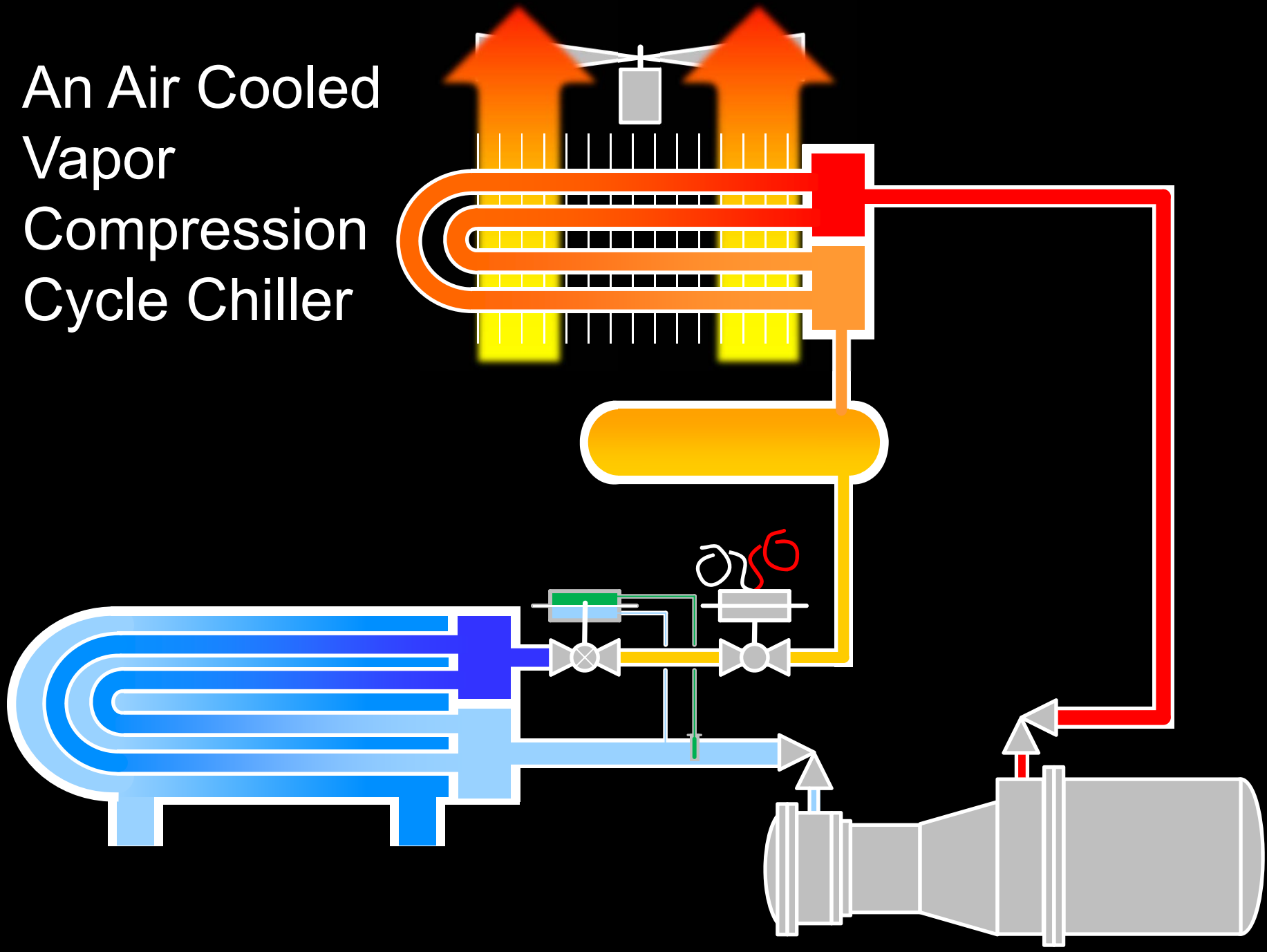
An application of saturated system and phase change principles and concepts

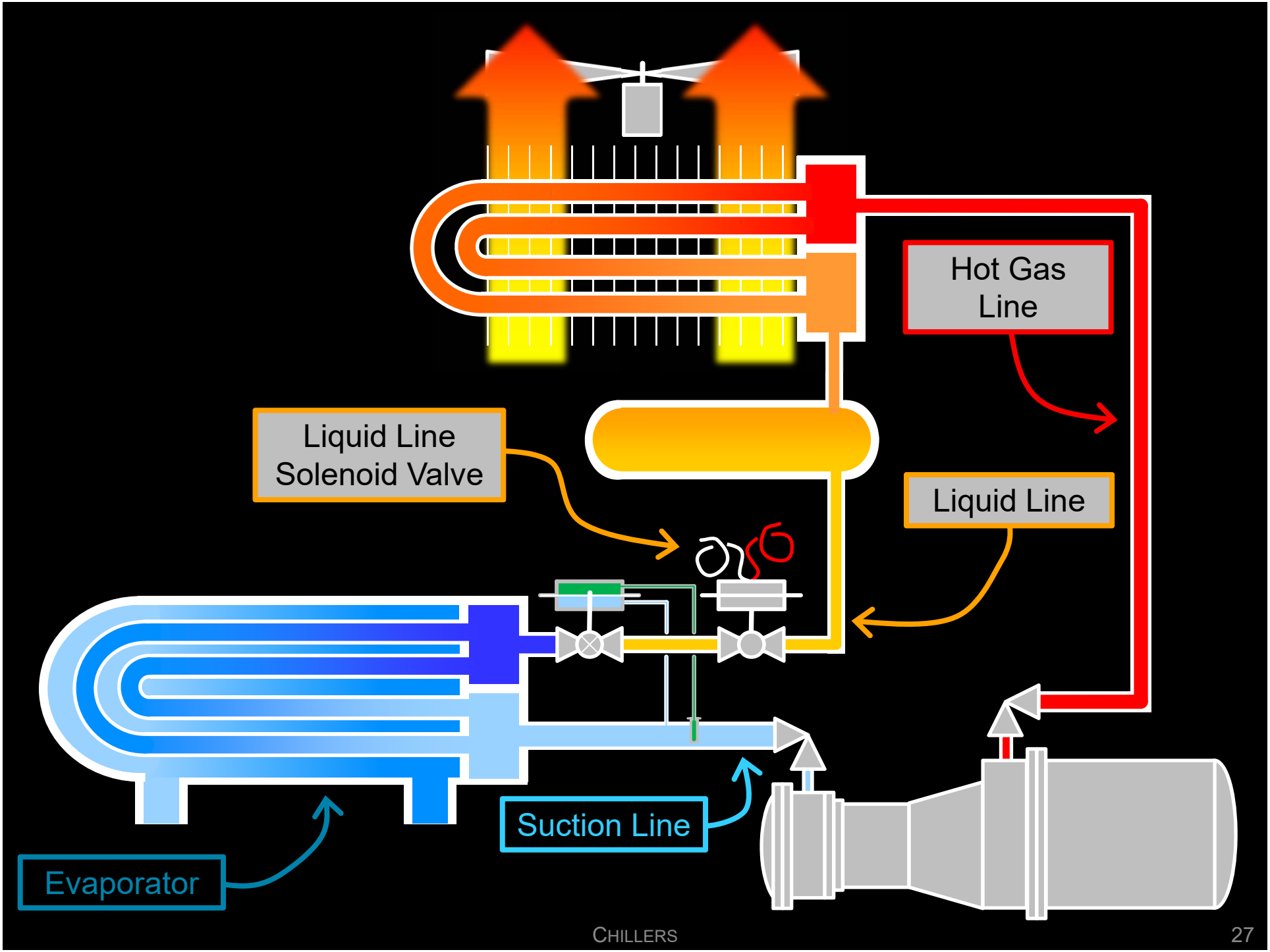

R134a
CF3CH2F
1,1,1,2-tetrafluoroethane
Helmholtz Energy Equation of State
Tillner-Roth, R. and Baehr, H.D
Formulation
Data generated with REFPROP 9.1
Critical Point
Condensation
Expansion
Compression
Evaporation
Saturated Liquid
Saturated Vapor
Pressure, psia
Enthalpy, Btu/lbm
1,000
100
10
1
-20
0
20
40
60
80
100
120
140
160

An Air Cooled Vapor Compression Cycle Chiller


CH-1
TECHNICAL
Black Jet

An Air Cooled Vapor Compression Cycle Chiller

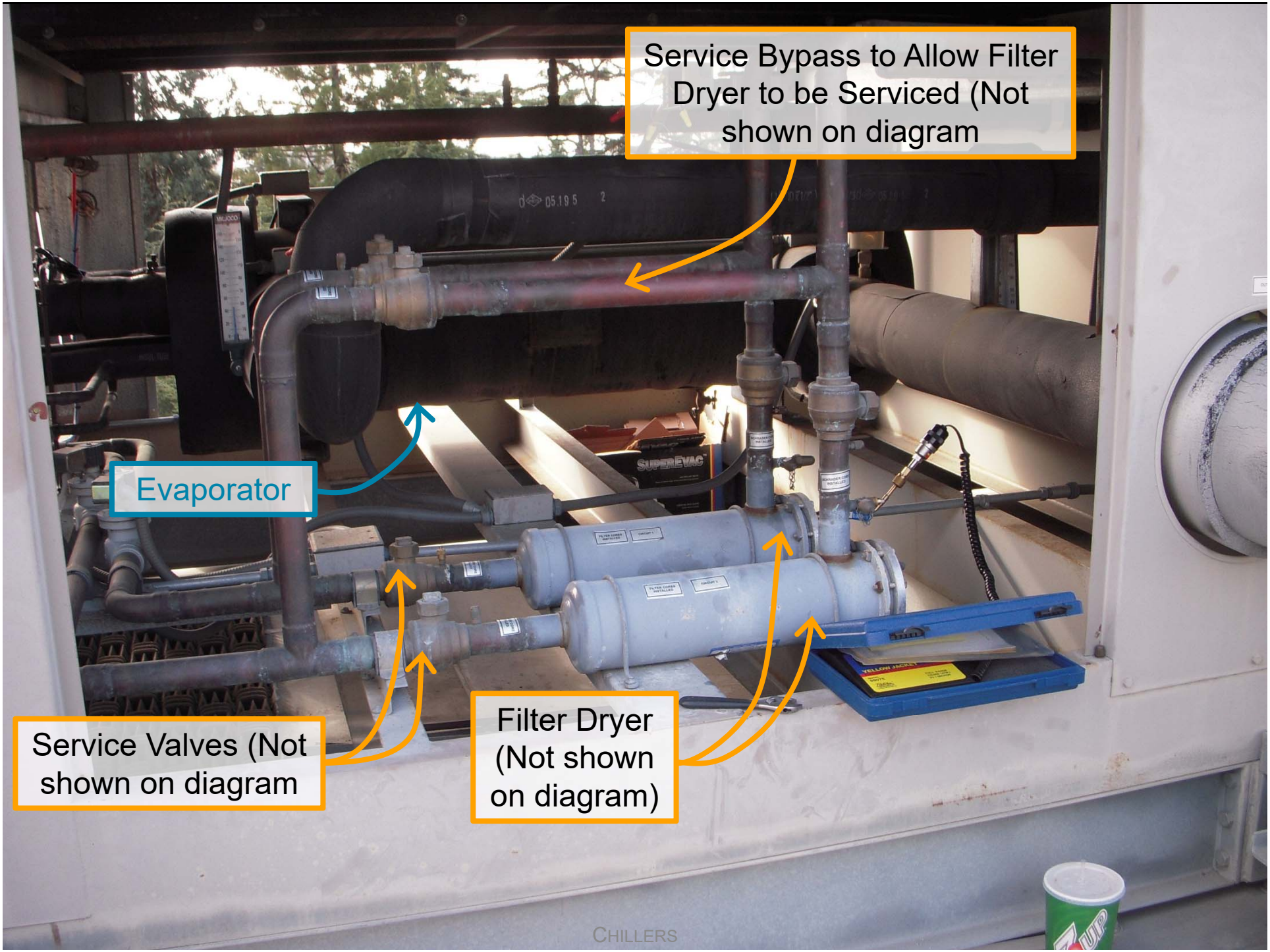


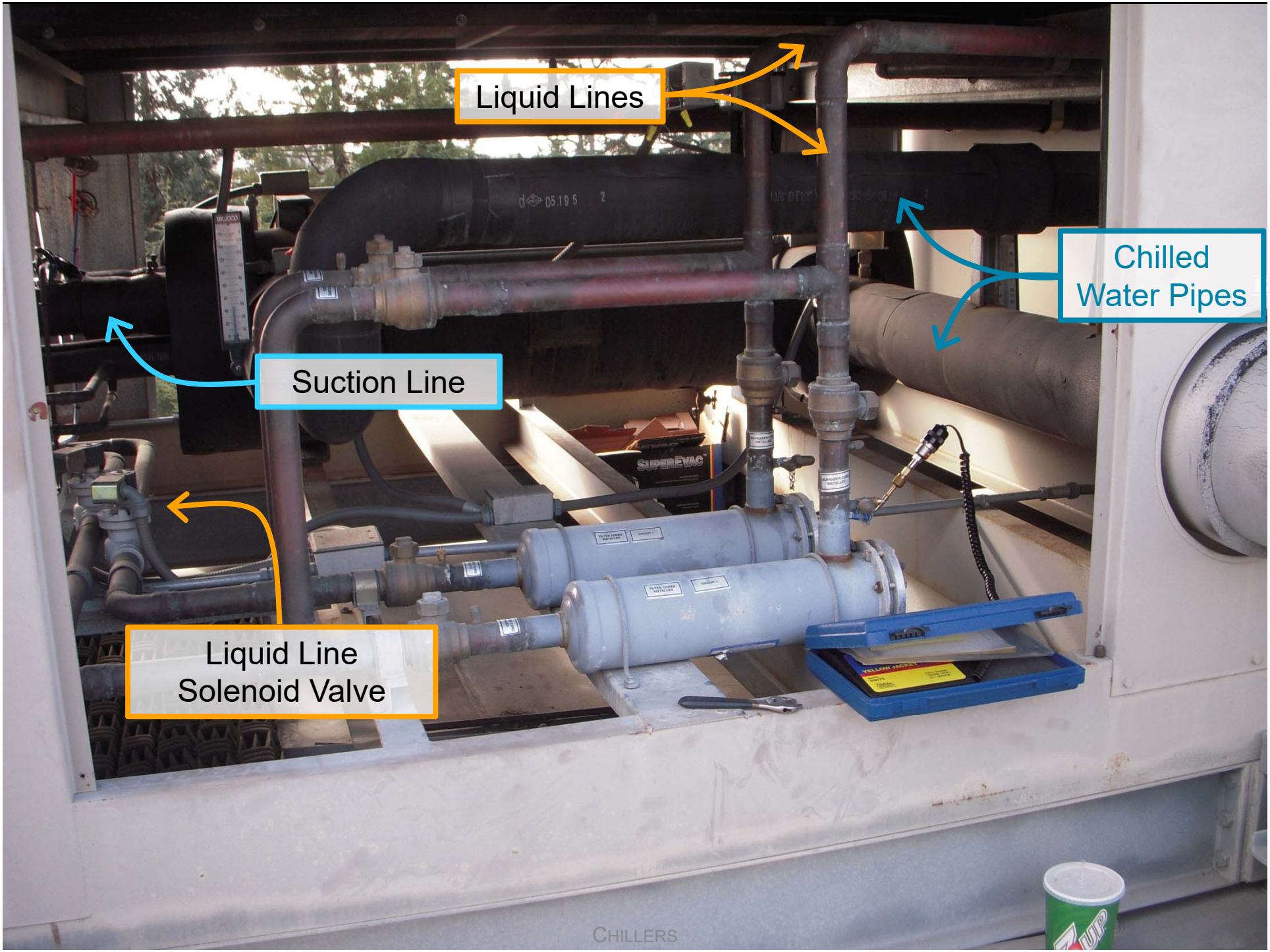

Hot Gas Line
Liquid Line Solenoid Valve
Liquid Line
Suction Line
Evaporator

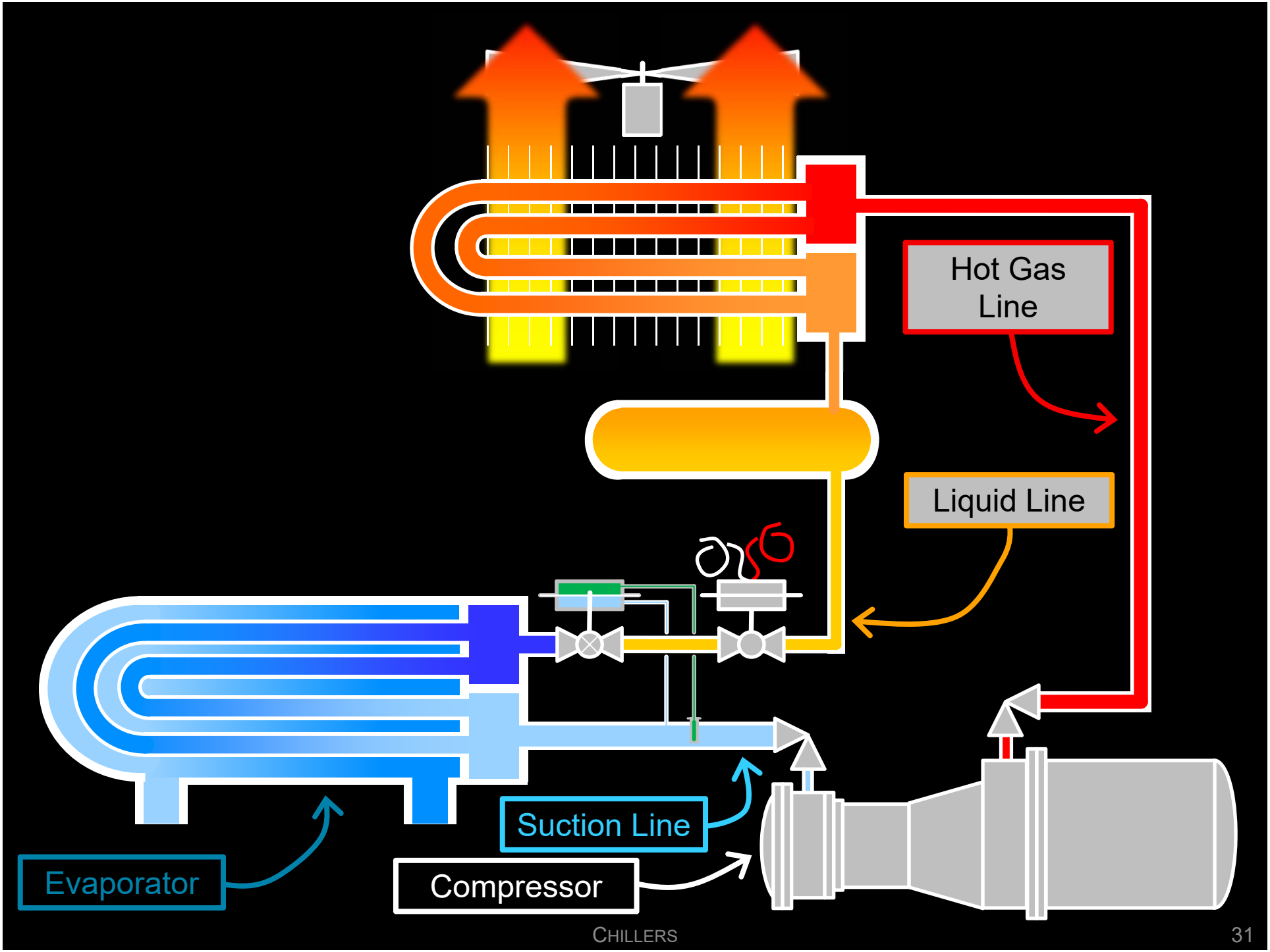
Which Pipe is Which

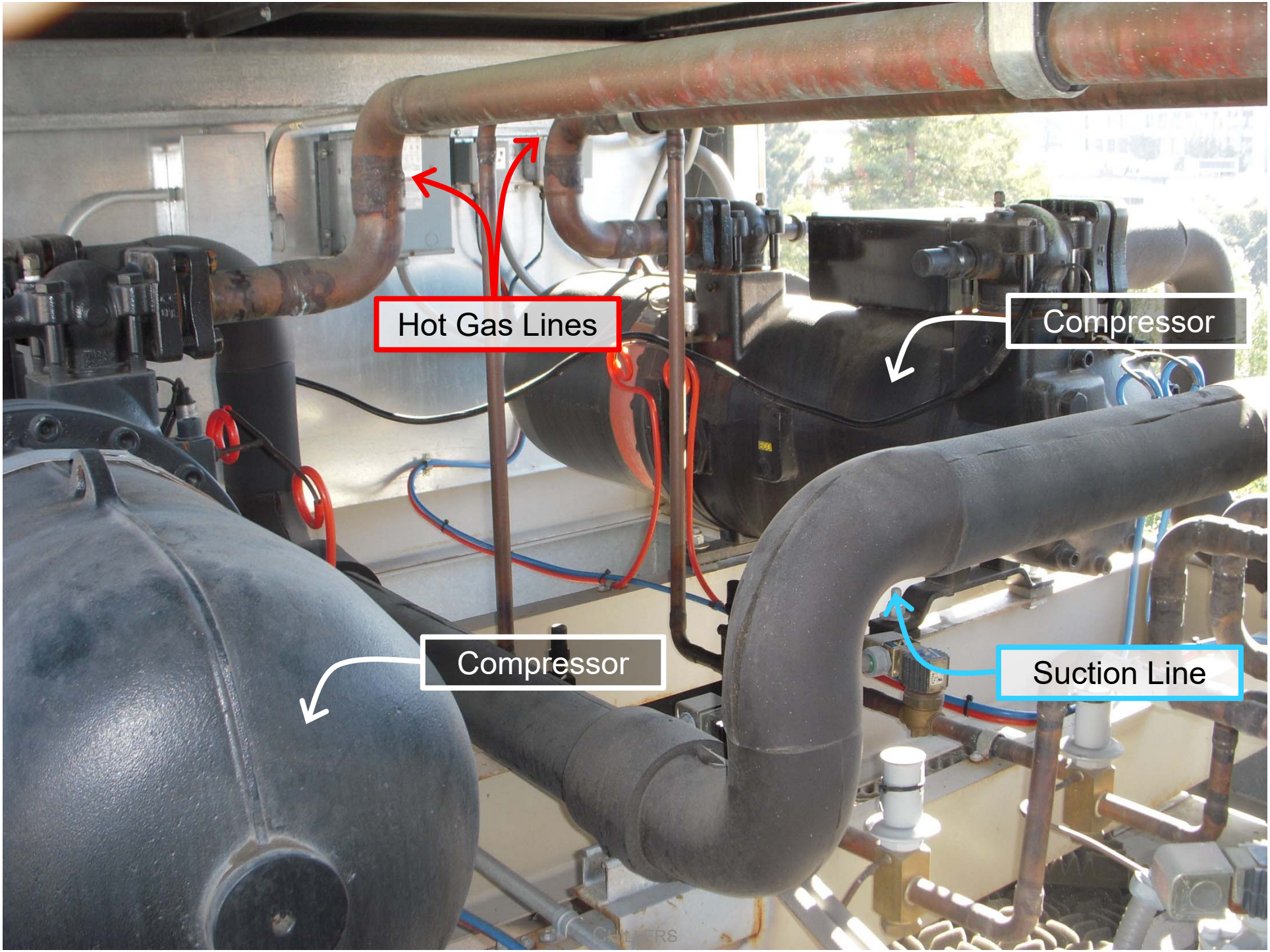
- Suction Line
- Liquid Line
- Hot gas line

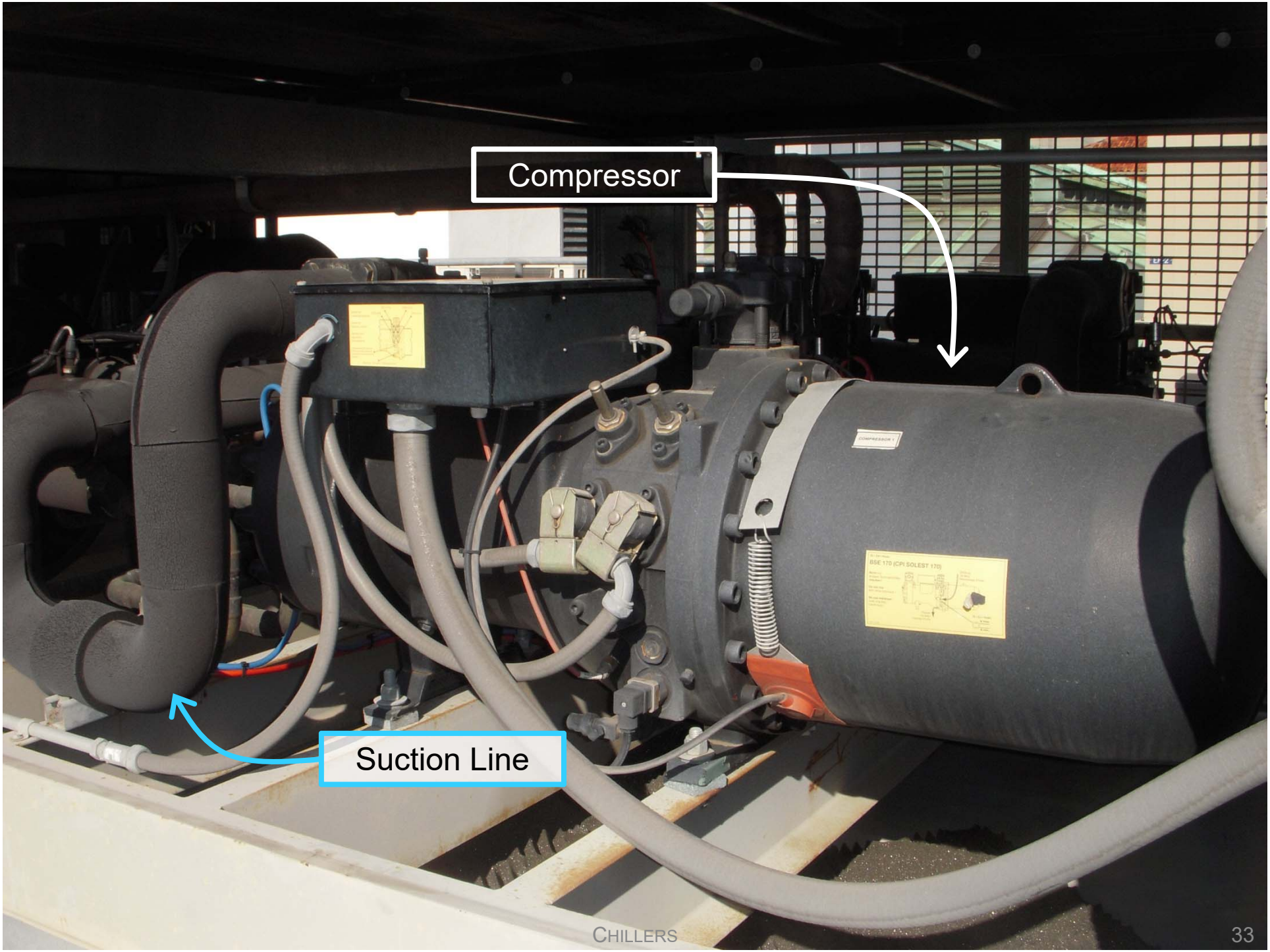
- Largest, coldest and insulated
- Smallest, warm, usually not insulated
- Size between suction and liquid line size, hot, typically not insulated

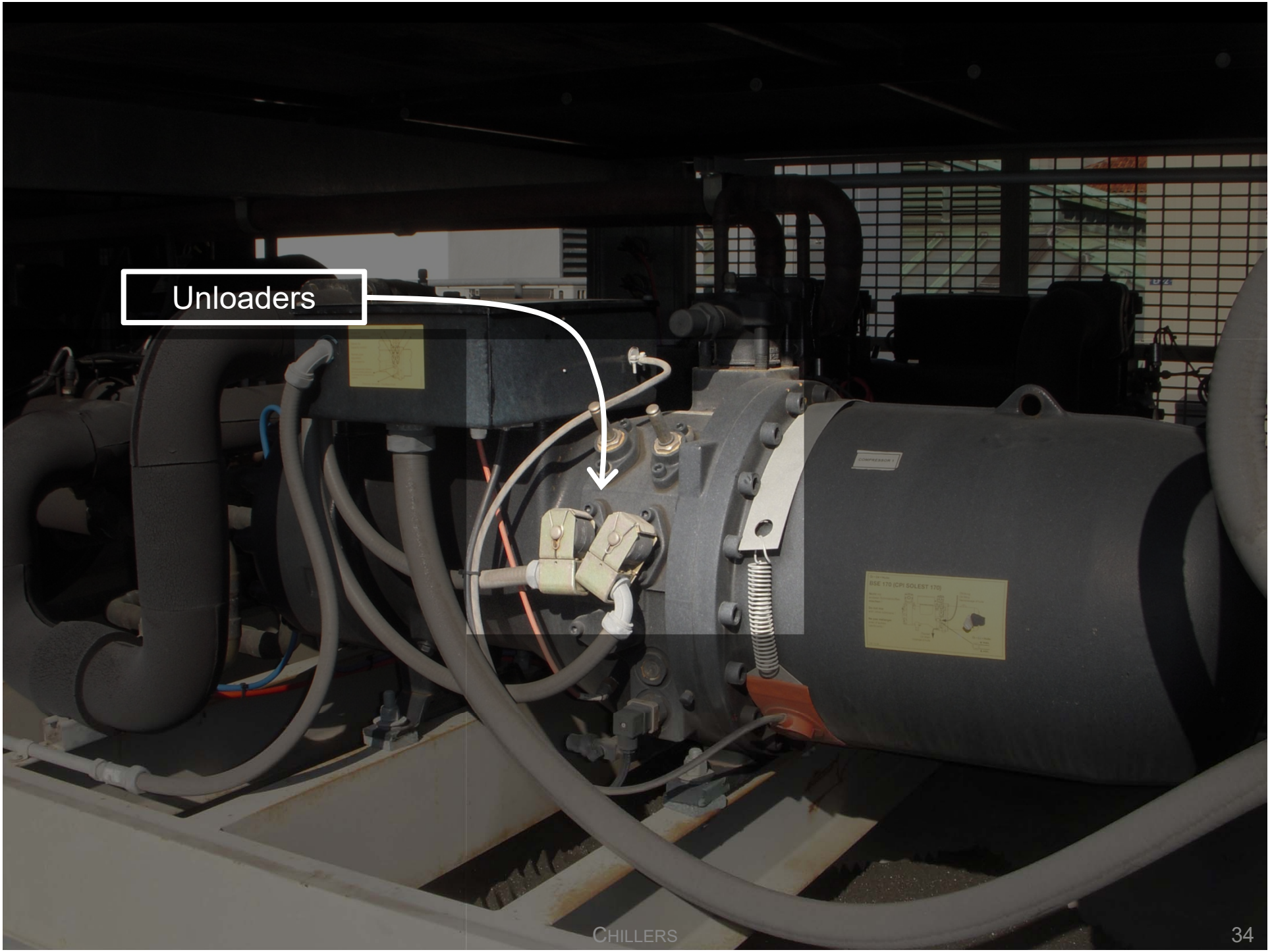

Service Bypass to Allow Filter Dryer to be Serviced (Not shown on diagram
Evaporator
Service Valves (Not shown on diagram
Filter Dryer (Not shown on diagram)

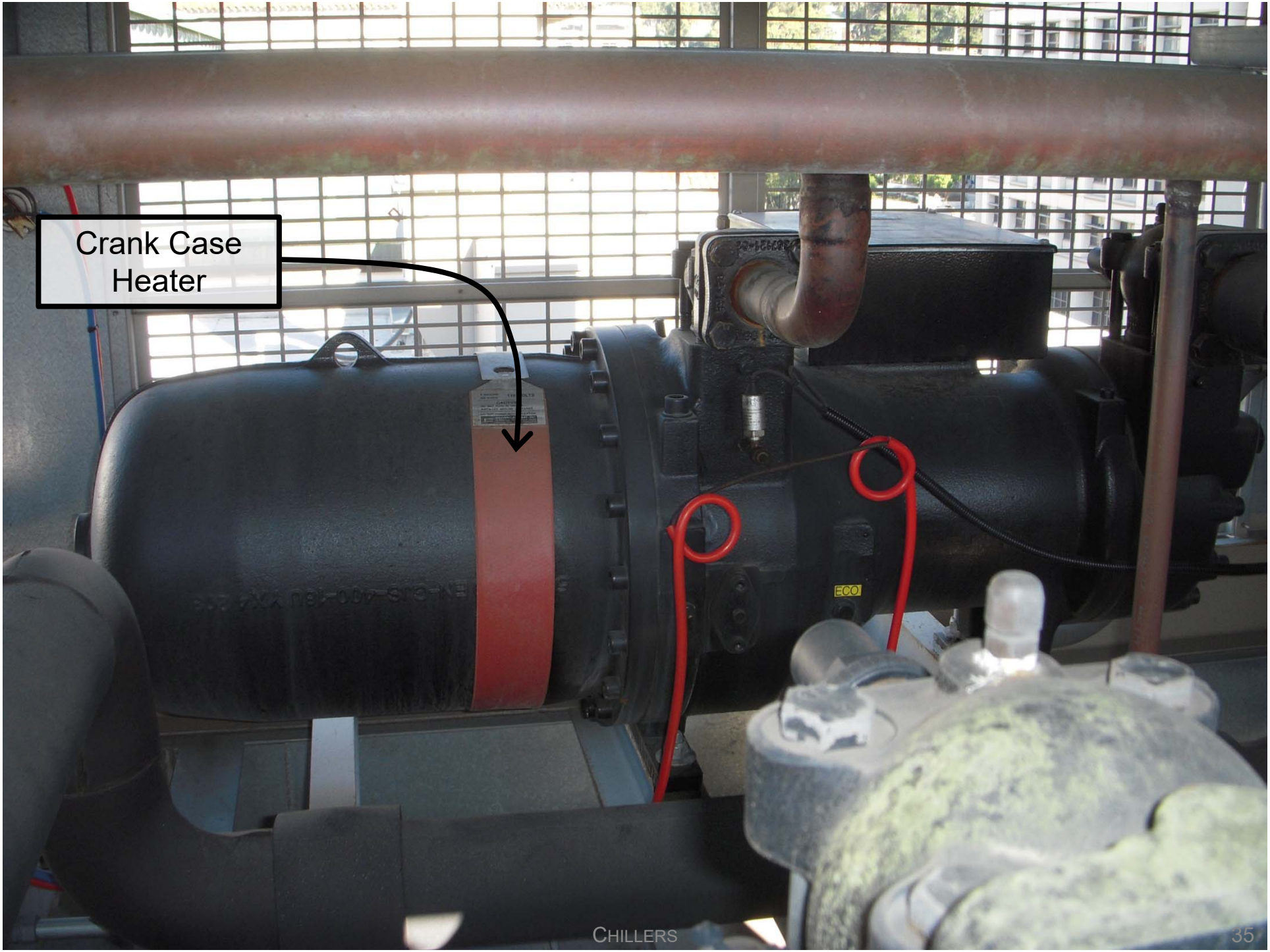

Liquid Lines
Chilled Water Pipes
Suction Line
Liquid Line Solenoid Valve

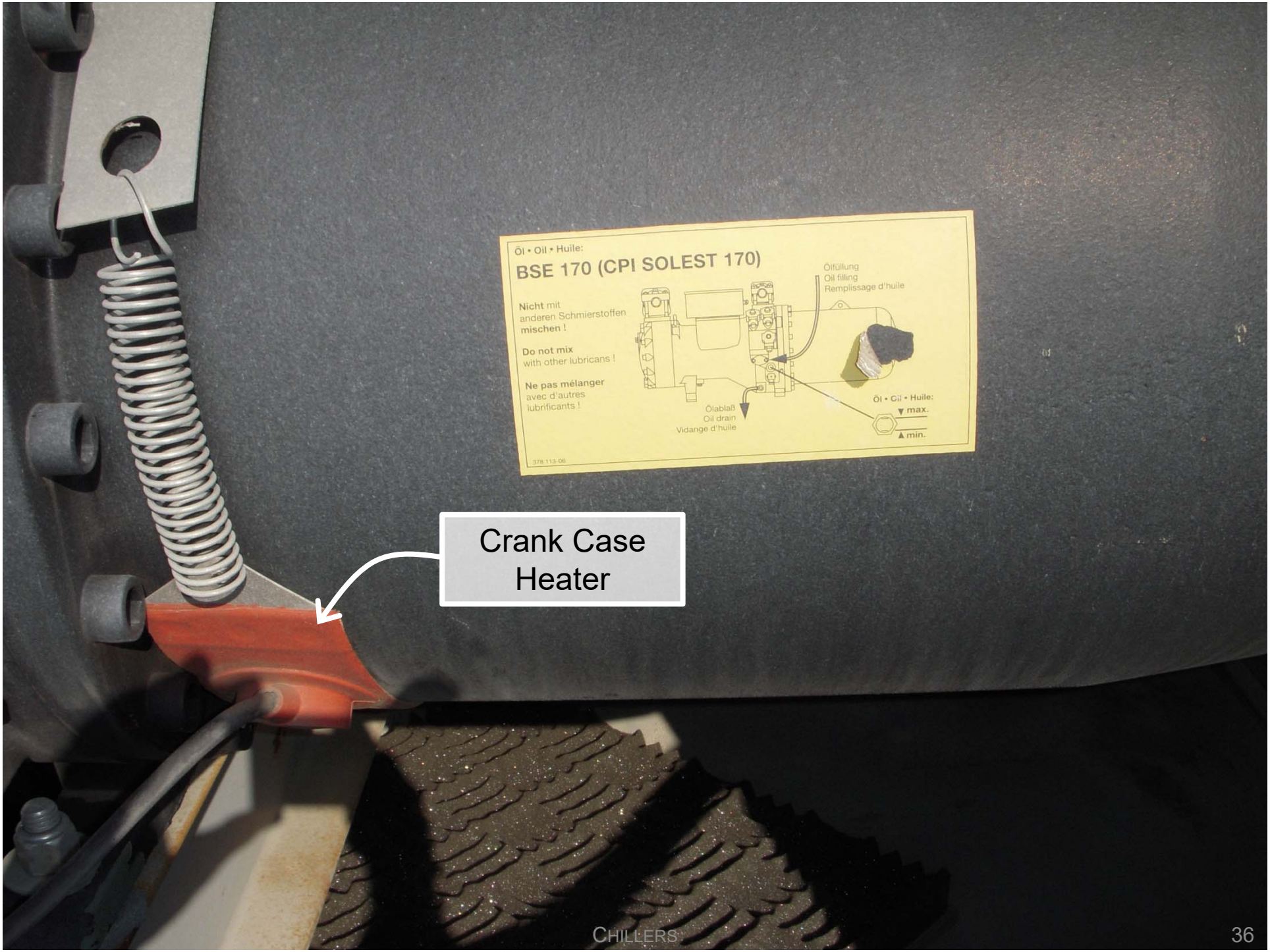

Hot Gas Line
Liquid Line
Suction Line
Evaporator
Compressor

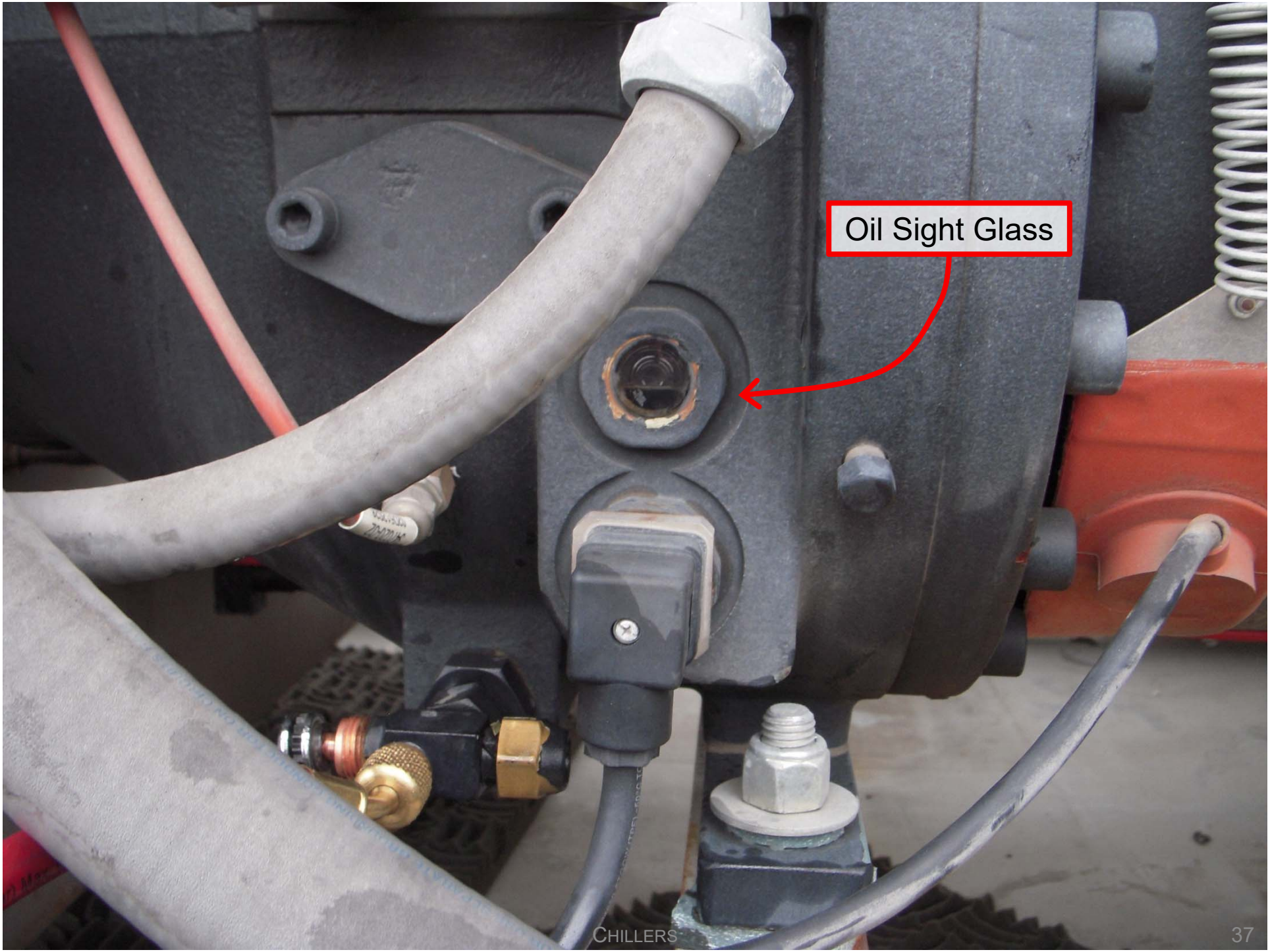

Hot Gas Lines
Compressor
Compressor
Suction Line


Compressor
Suction Line


Unloaders

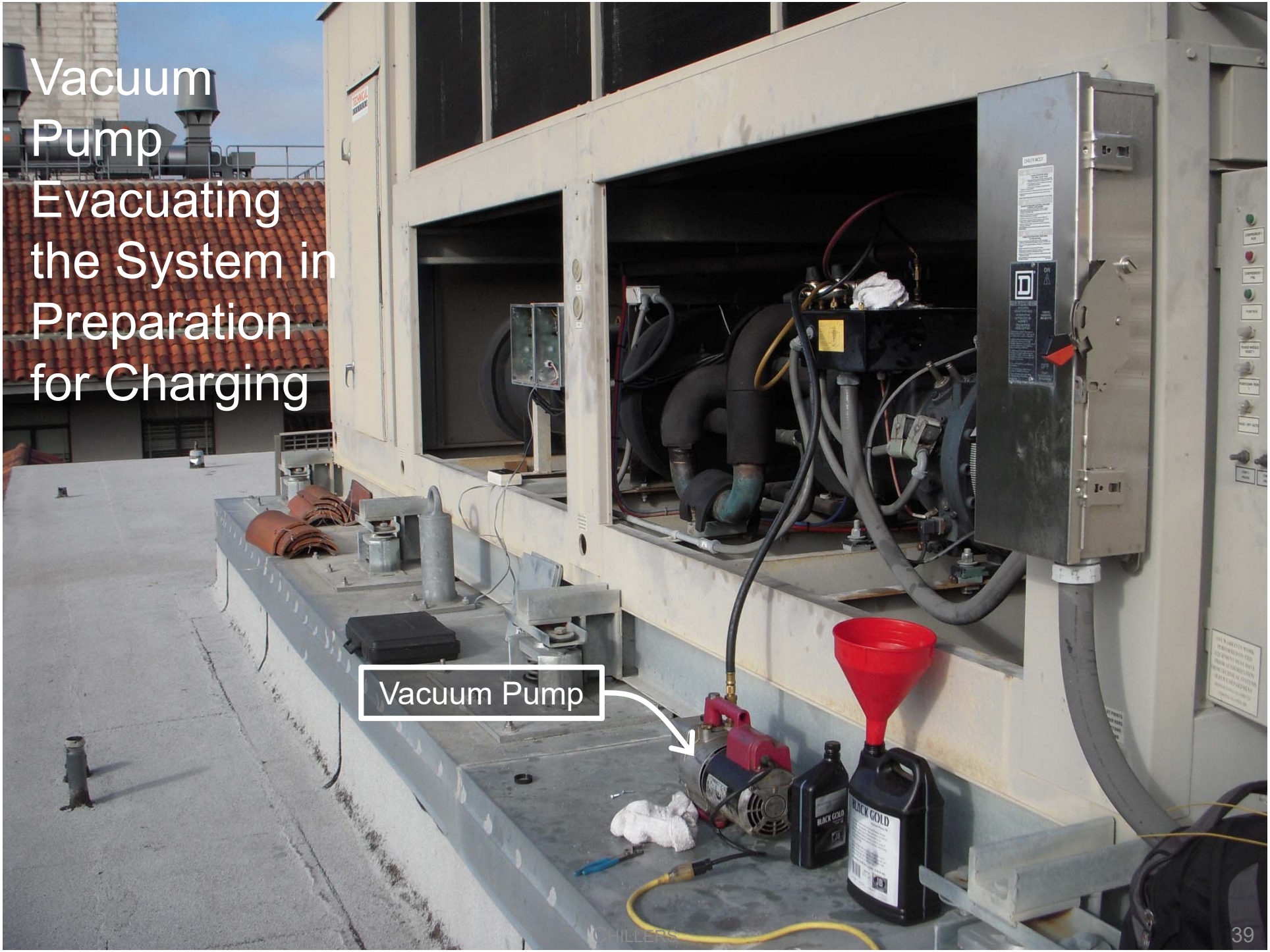

Crank Case
Heater

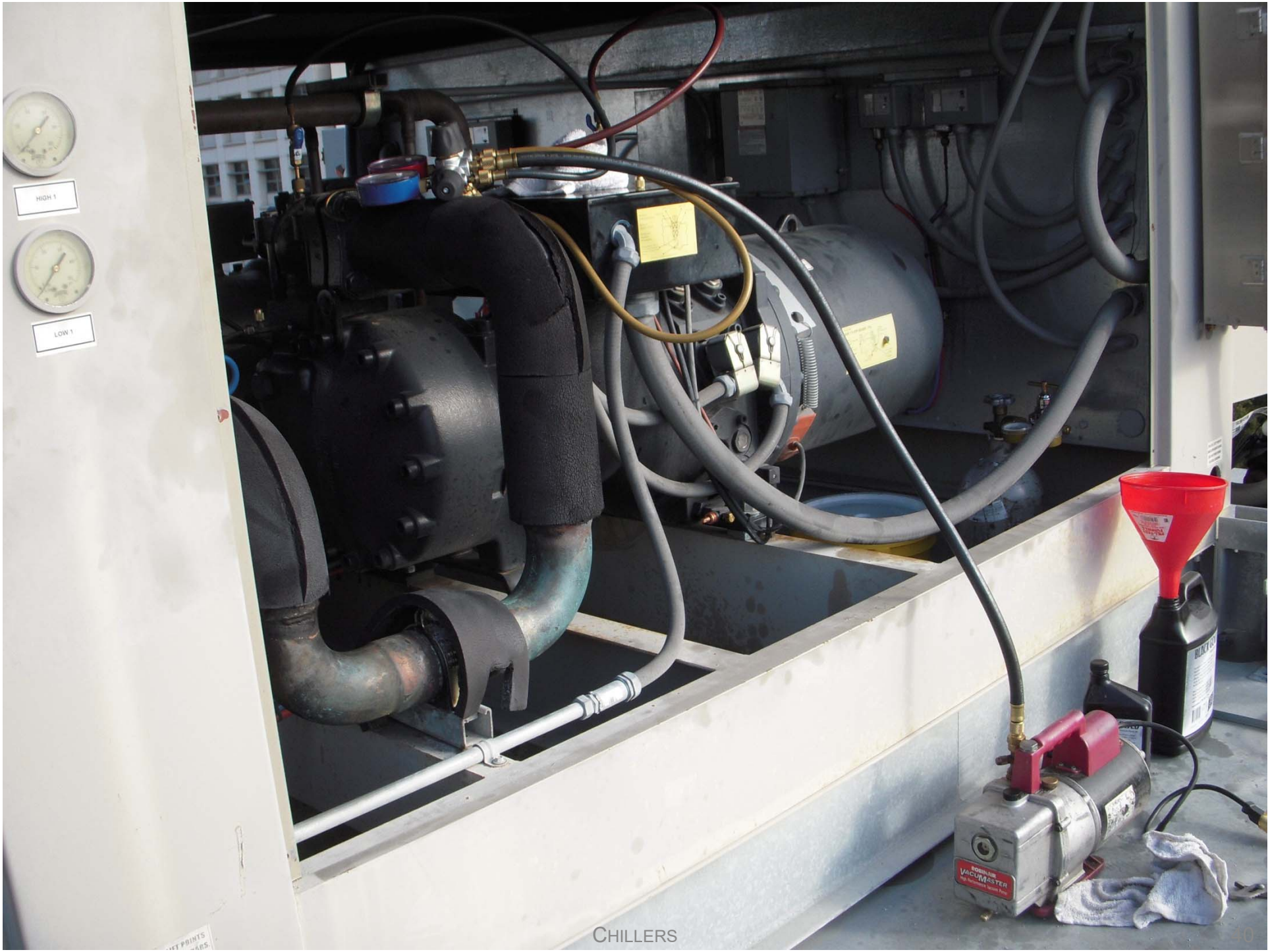

Öl • Oil • Huile:
BSE 170 (CPI SOLEST 170)
Nicht mit anderen Schmierstoffen mischen !
Do not mix with other lubricans !
Ne pas mélanger avec d'autres lubrificants !
Ölfüllung
Oil filling
Remplissage d'huile
Ölablaß
Oil drain
Vidange d'huile
Öl • Oil • Huile:
▼ max.
▲ min.
378 113-06
Crank Case Heater

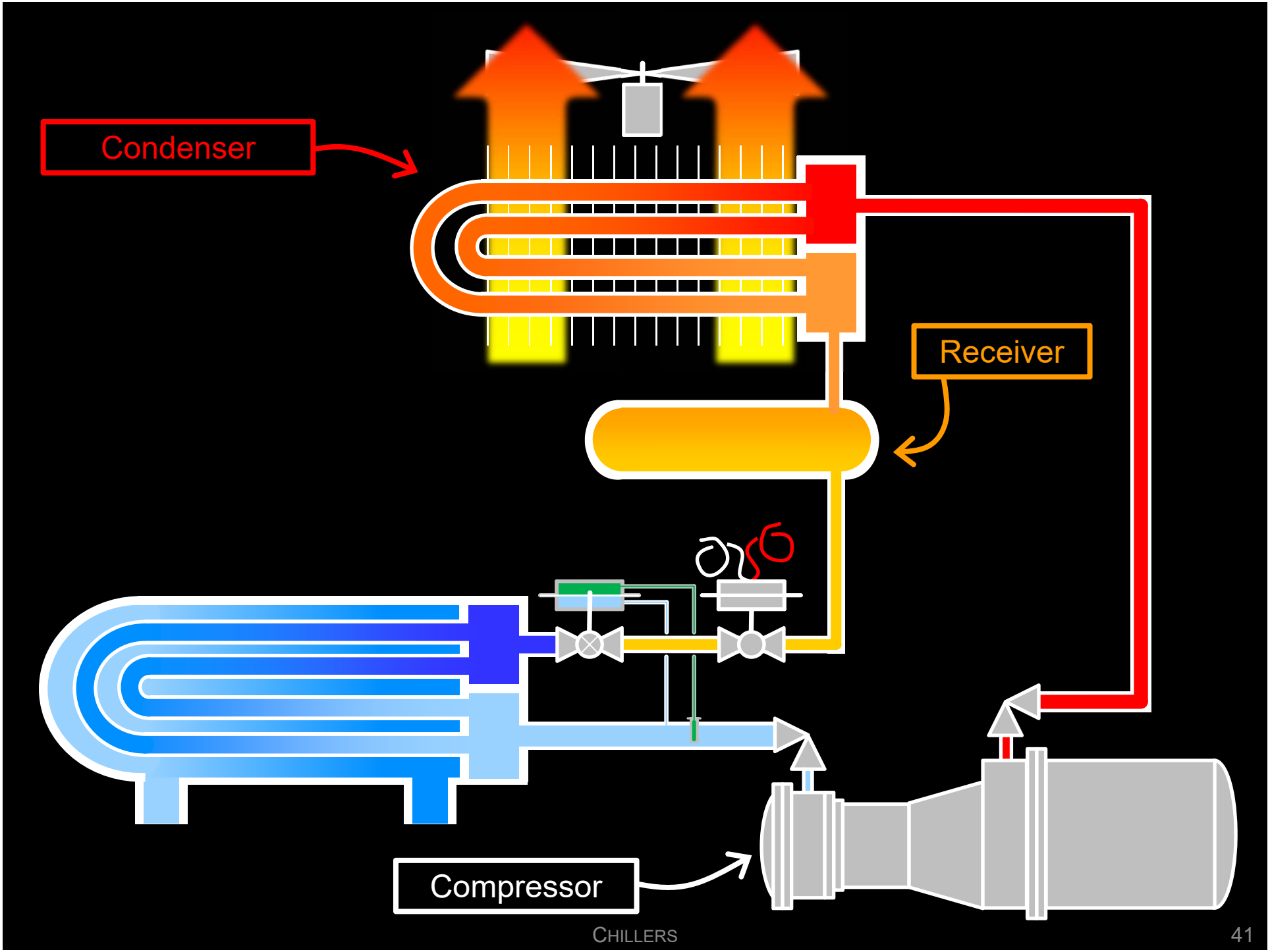

Oil Sight Glass

Hand Pump for Adding Oil

Vacuum Pump Evacuating the System in Preparation for Charging

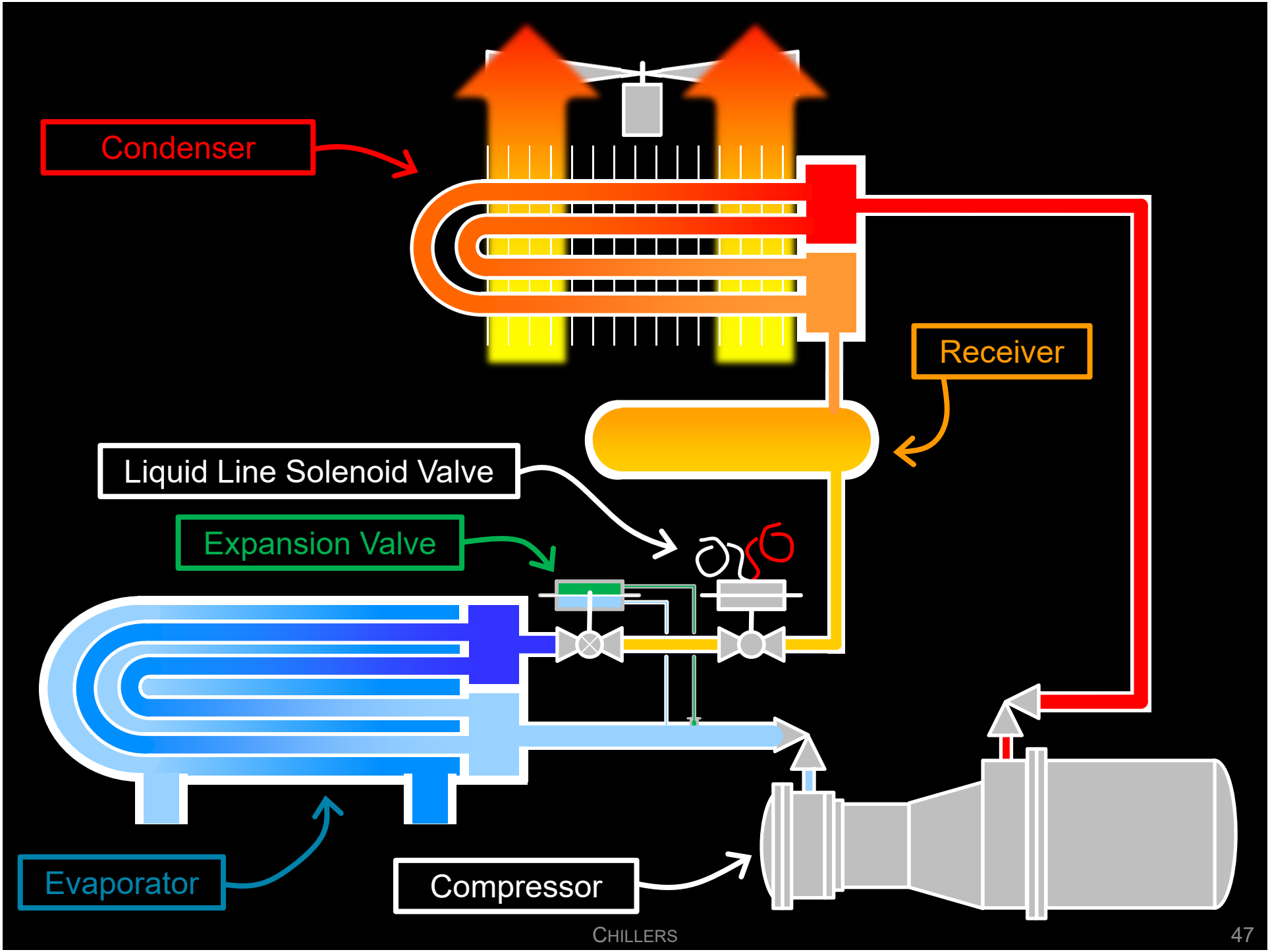


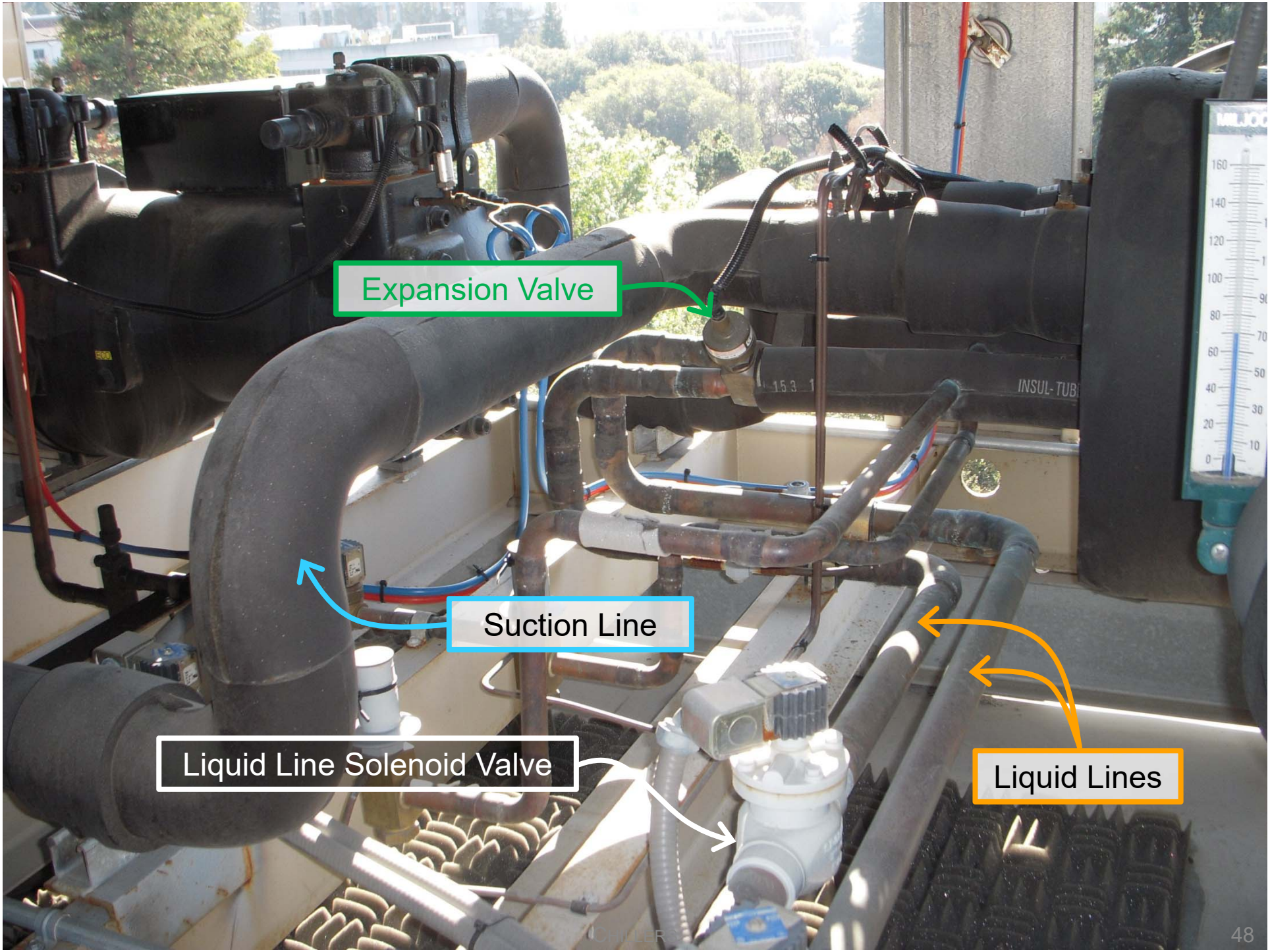

HIGH 1
LOW 1
VACUMASTER


Condenser
Receiver
Compressor

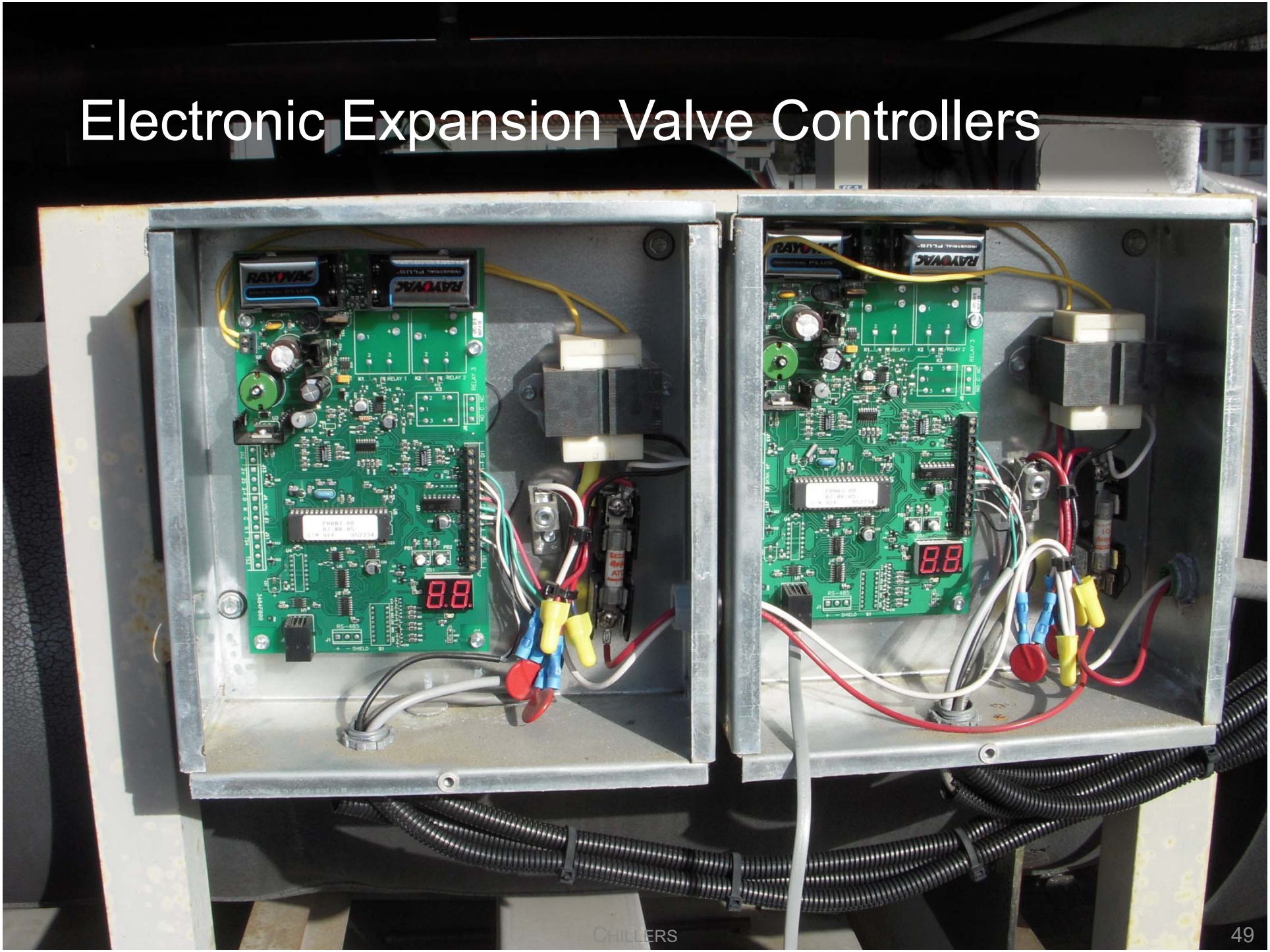

Condenser
CH-1
TECHNICAL

Failed Condenser Fan


Condenser
Receiver
Liquid Line Solenoid Valve
Expansion Valve
Evaporator
Compressor


Expansion Valve
Suction Line
Liquid Line Solenoid Valve
Liquid Lines

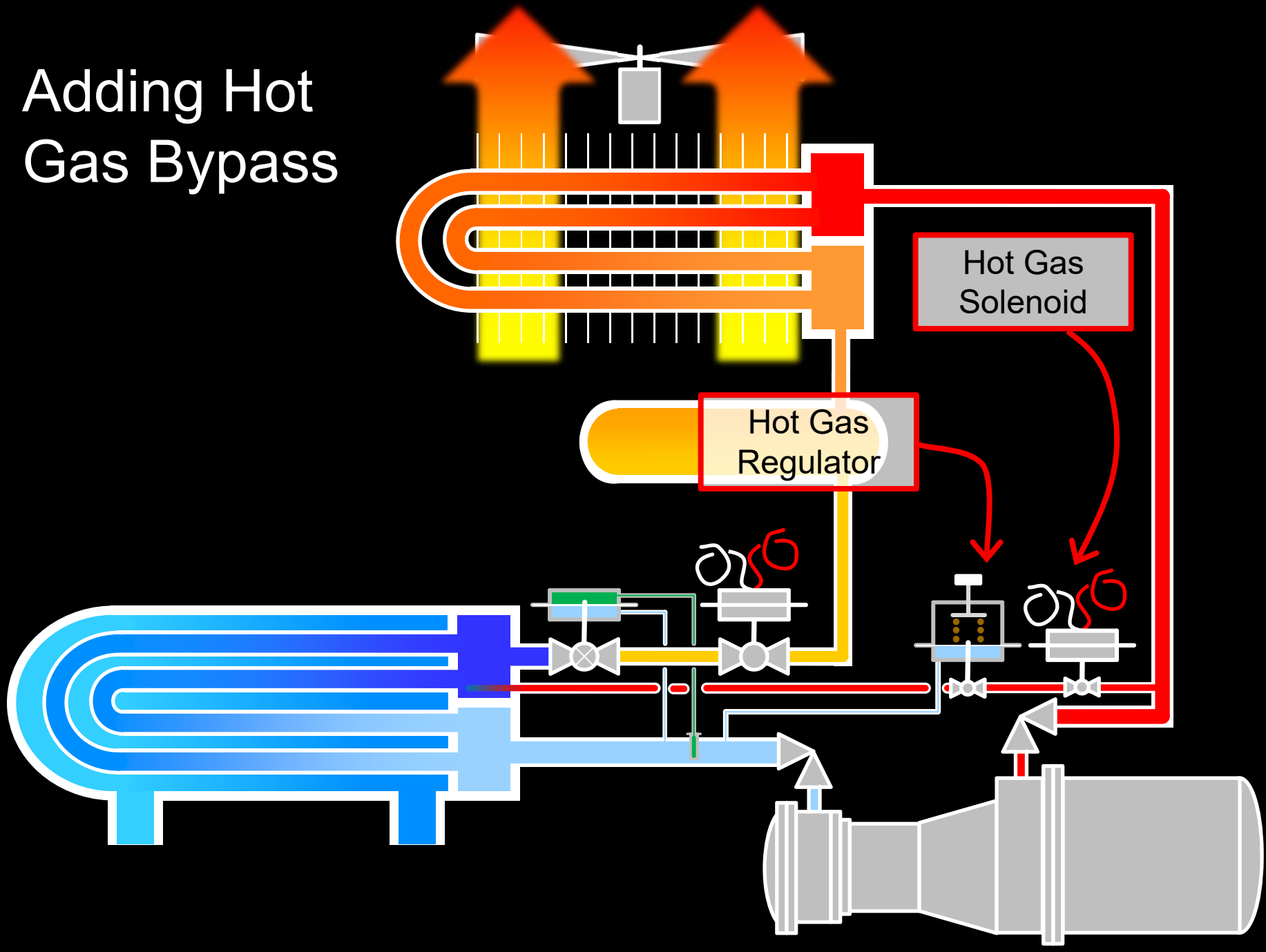
Electronic Expansion Valve Controllers

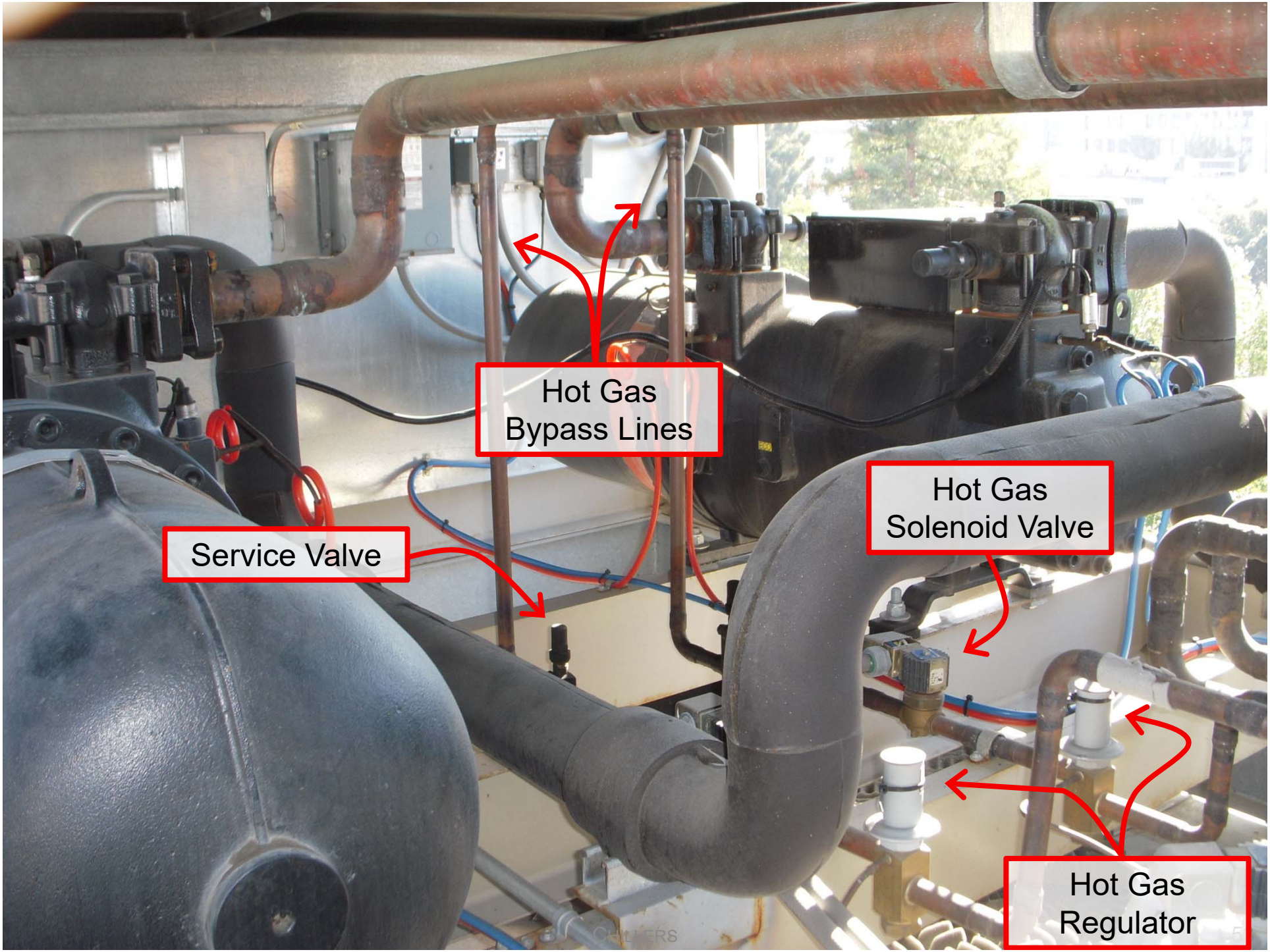


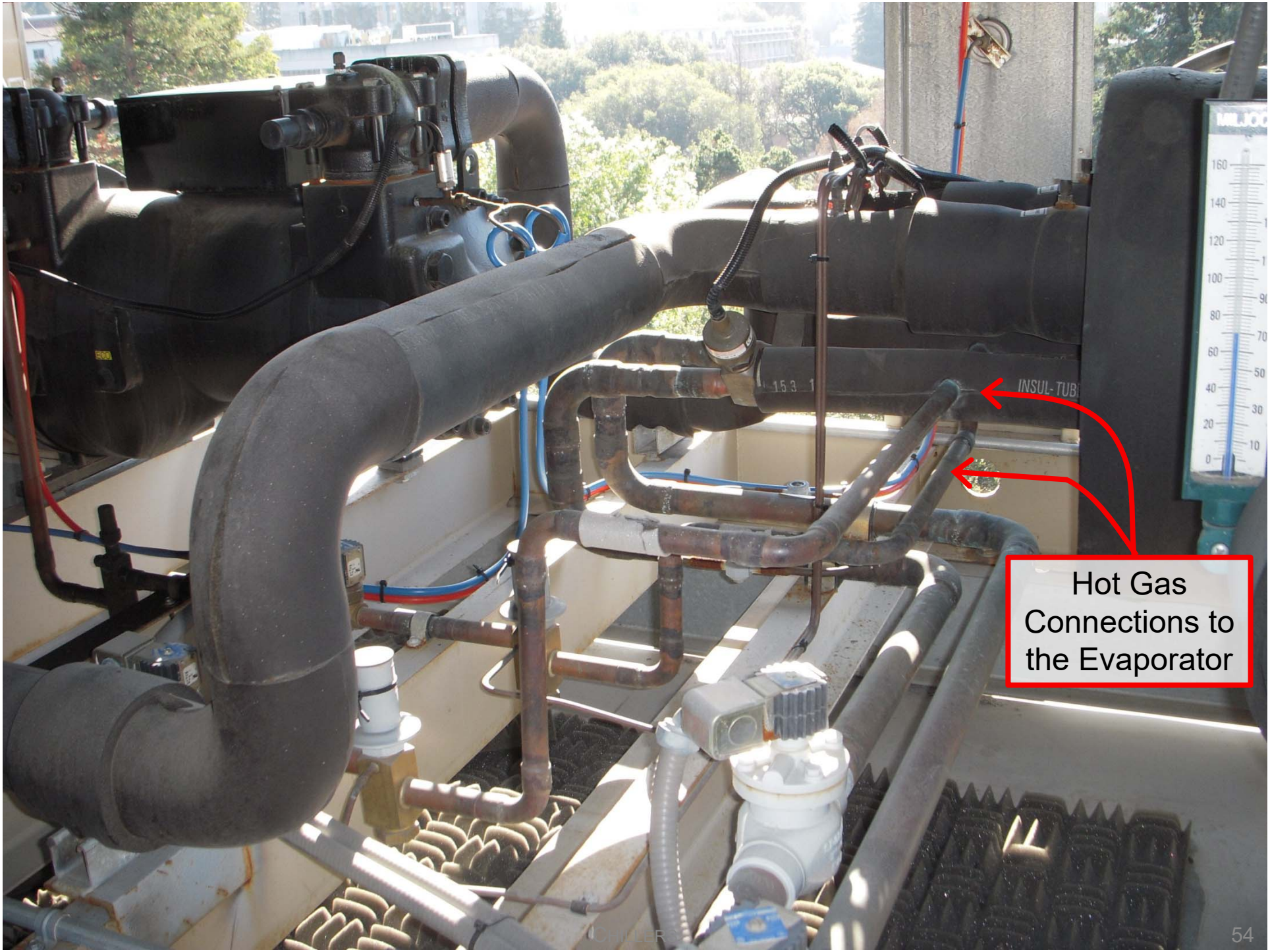
A Refrigerant Sight Glass

Typical Control Switches

Adding Hot Gas Bypass




Hot Gas
Bypass Lines
Service Valve
Hot Gas
Solenoid Valve
Hot Gas
Regulator


Hot Gas
Connections to
the Evaporator

Let’s Review

Name the Parts in the Diagram on the Next Slide

A. _____

B. _____

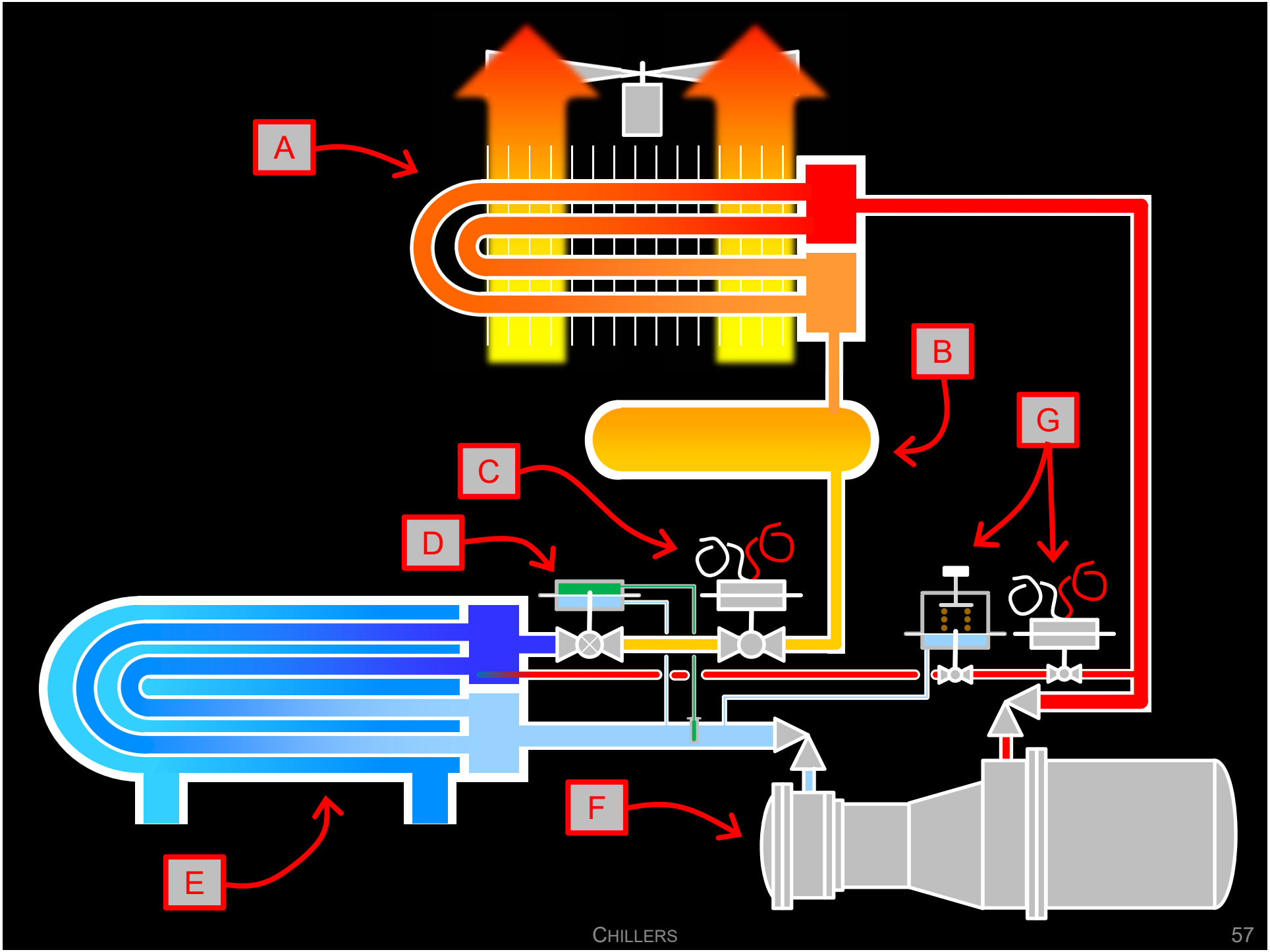
C. _____

D. _____

E. _____

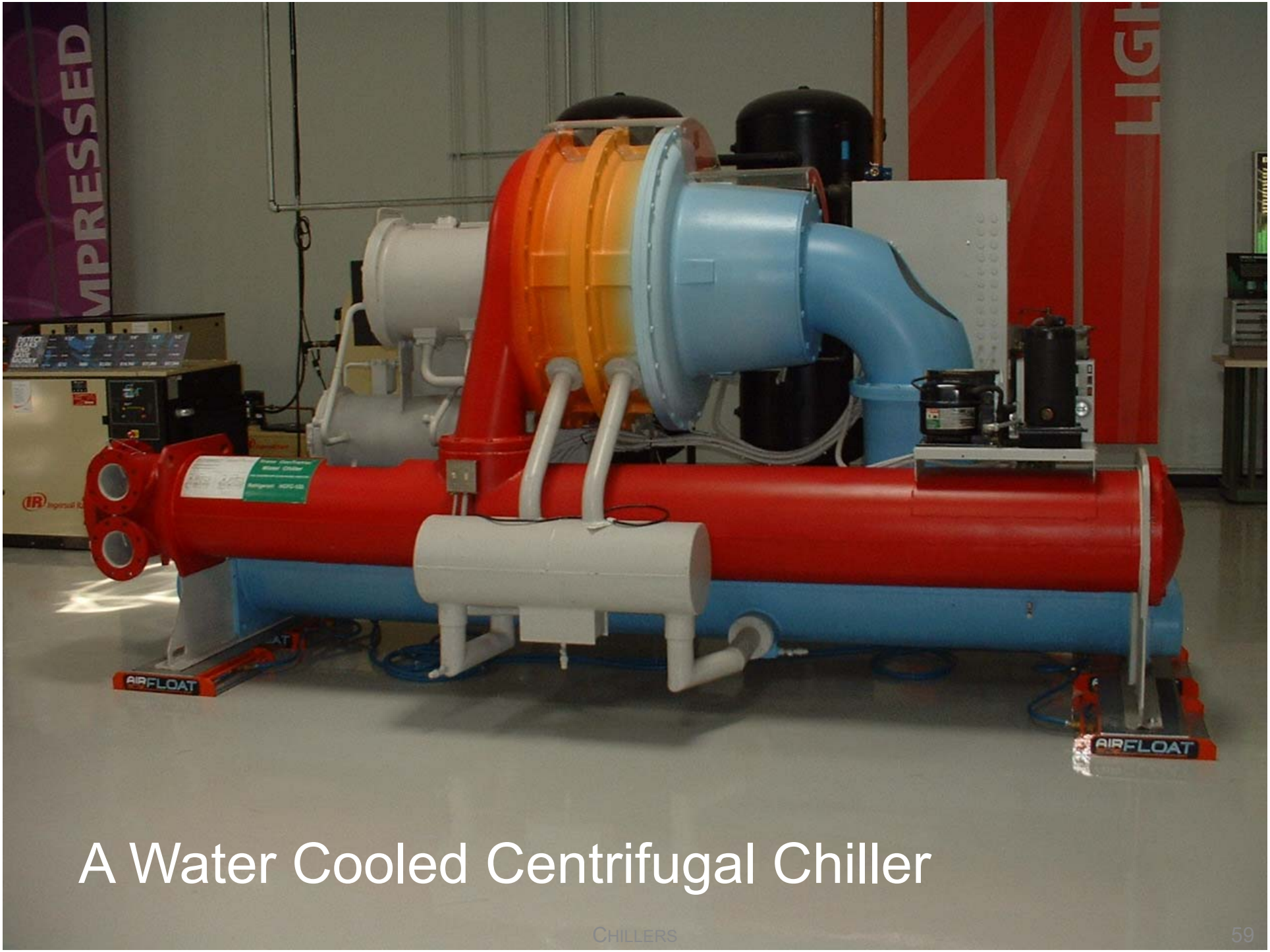
F. _____

G. _____

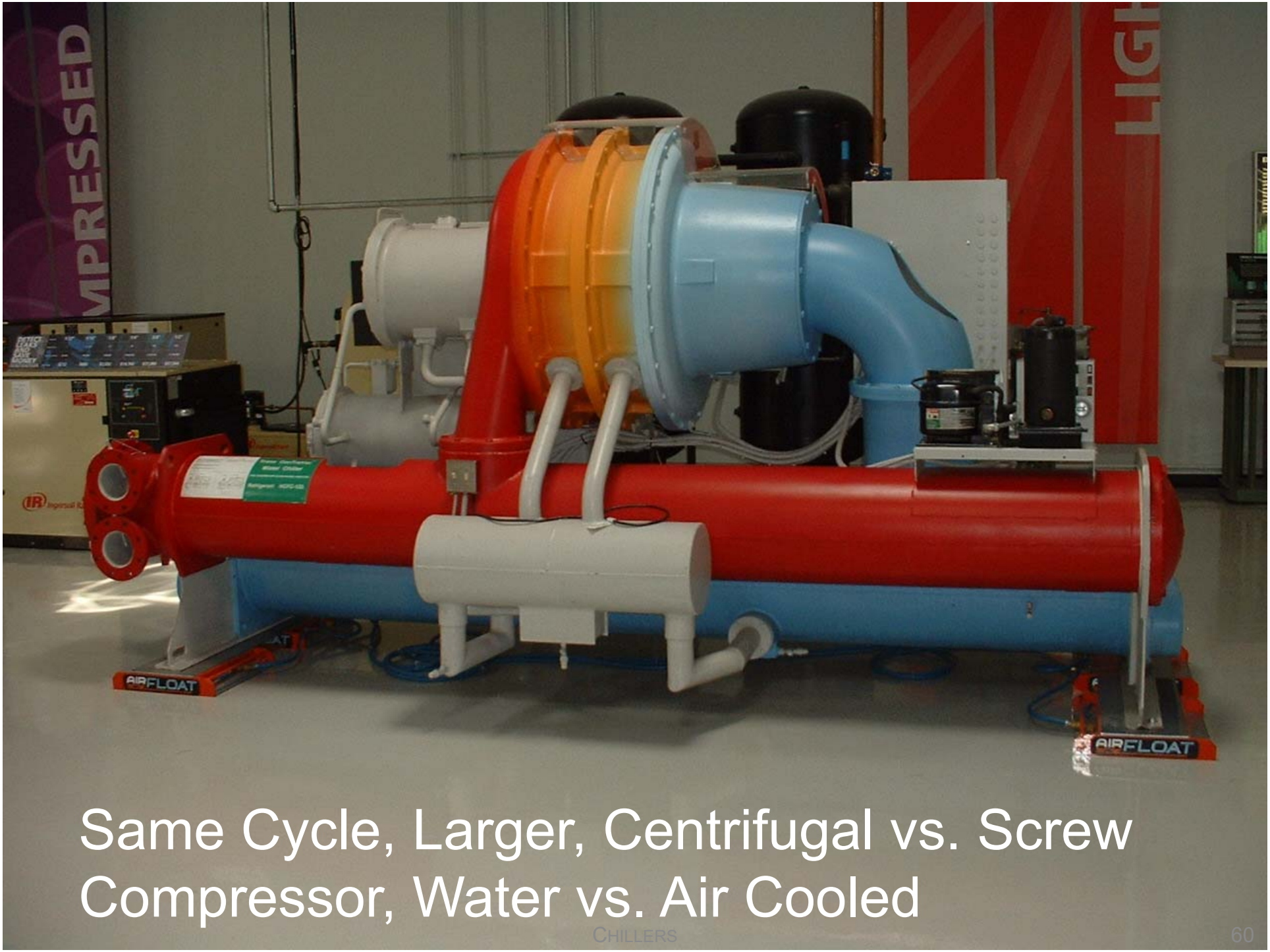

A
B
C
D
E
F
G

Name the Parts in the Diagram on the Next Slide

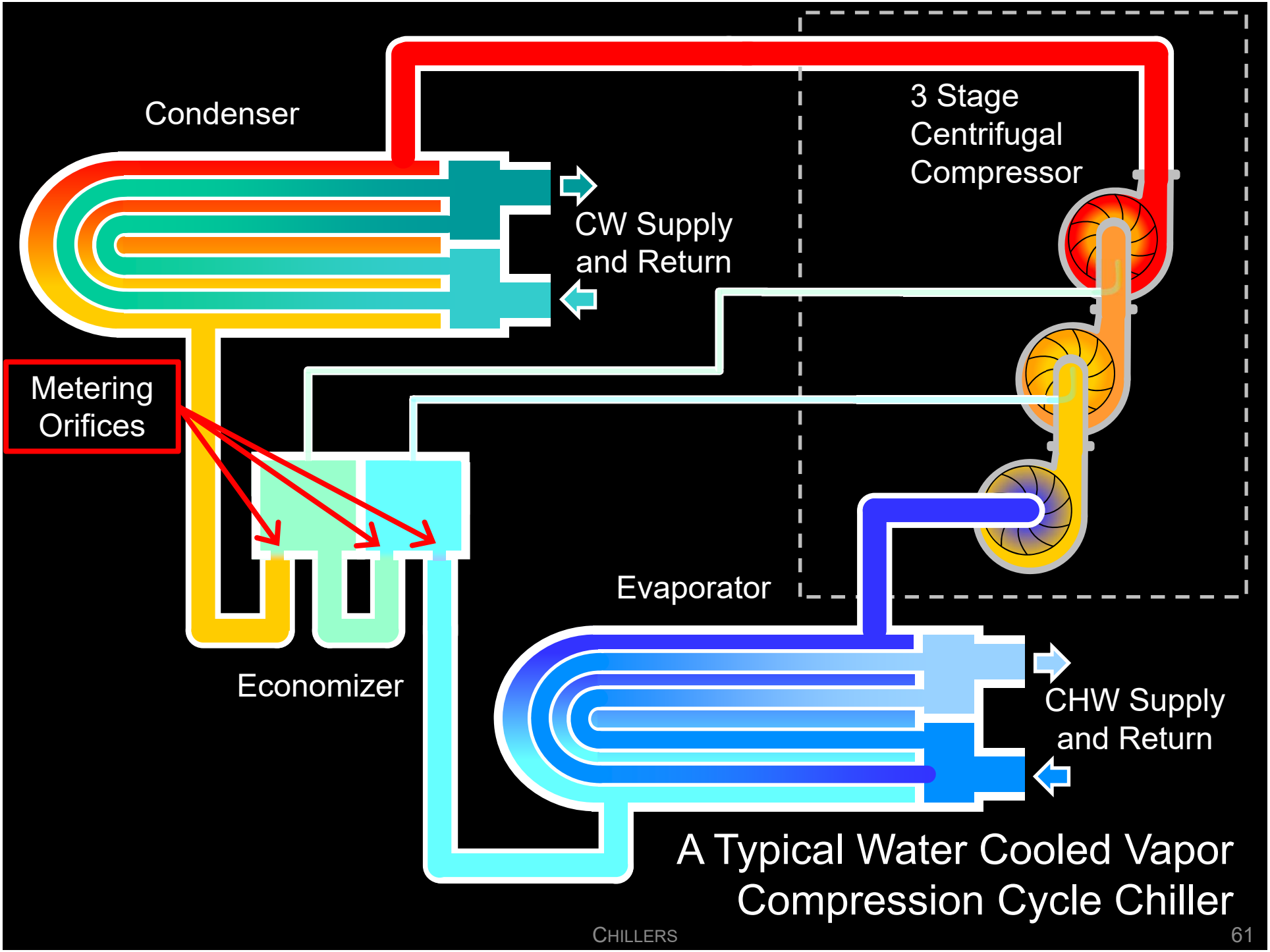
A. Air Cooled Condenser
B. Reciever
C. Liquid Line Solenoid Valve
D. Expansion Valve
E. Evaporator
F. Compressor
G. Hot Gas Solenoid Valve (Right) and Hot Gas Regulator (Left)



A Water Cooled Centrifugal Chiller

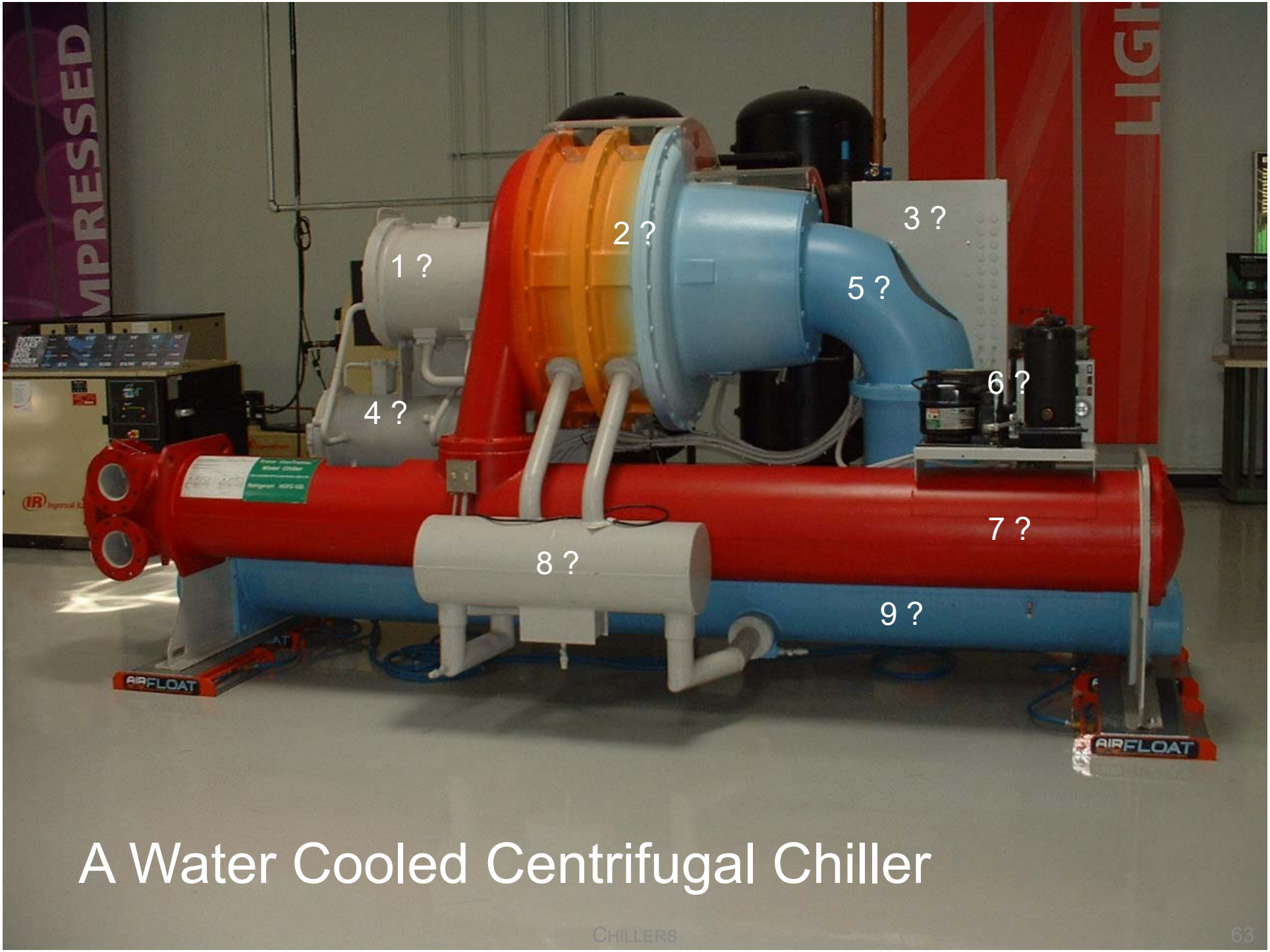


Same Cycle, Larger, Centrifugal vs. Screw Compressor, Water vs. Air Cooled

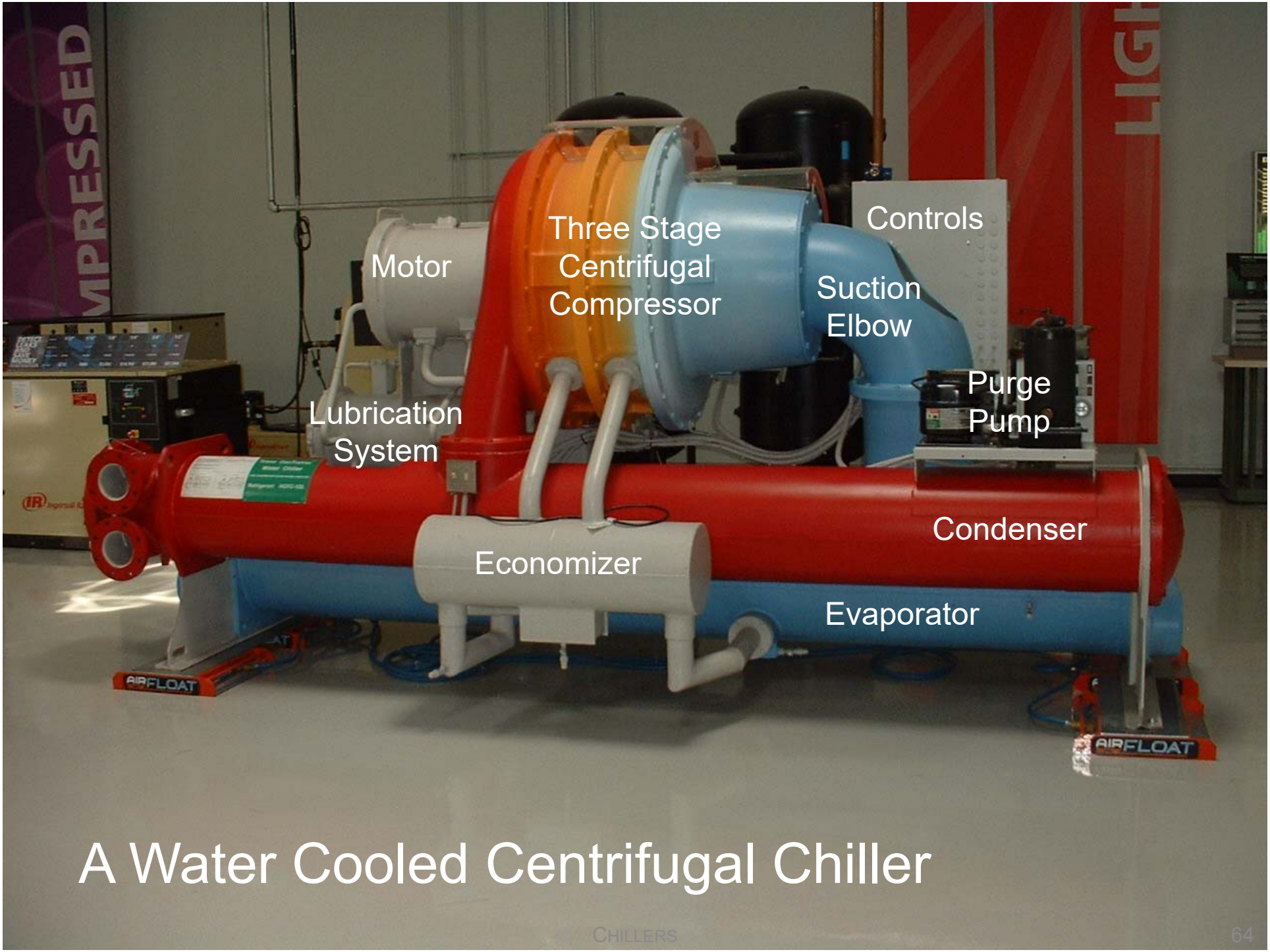


A Typical Water Cooled Vapor Compression Cycle Chiller

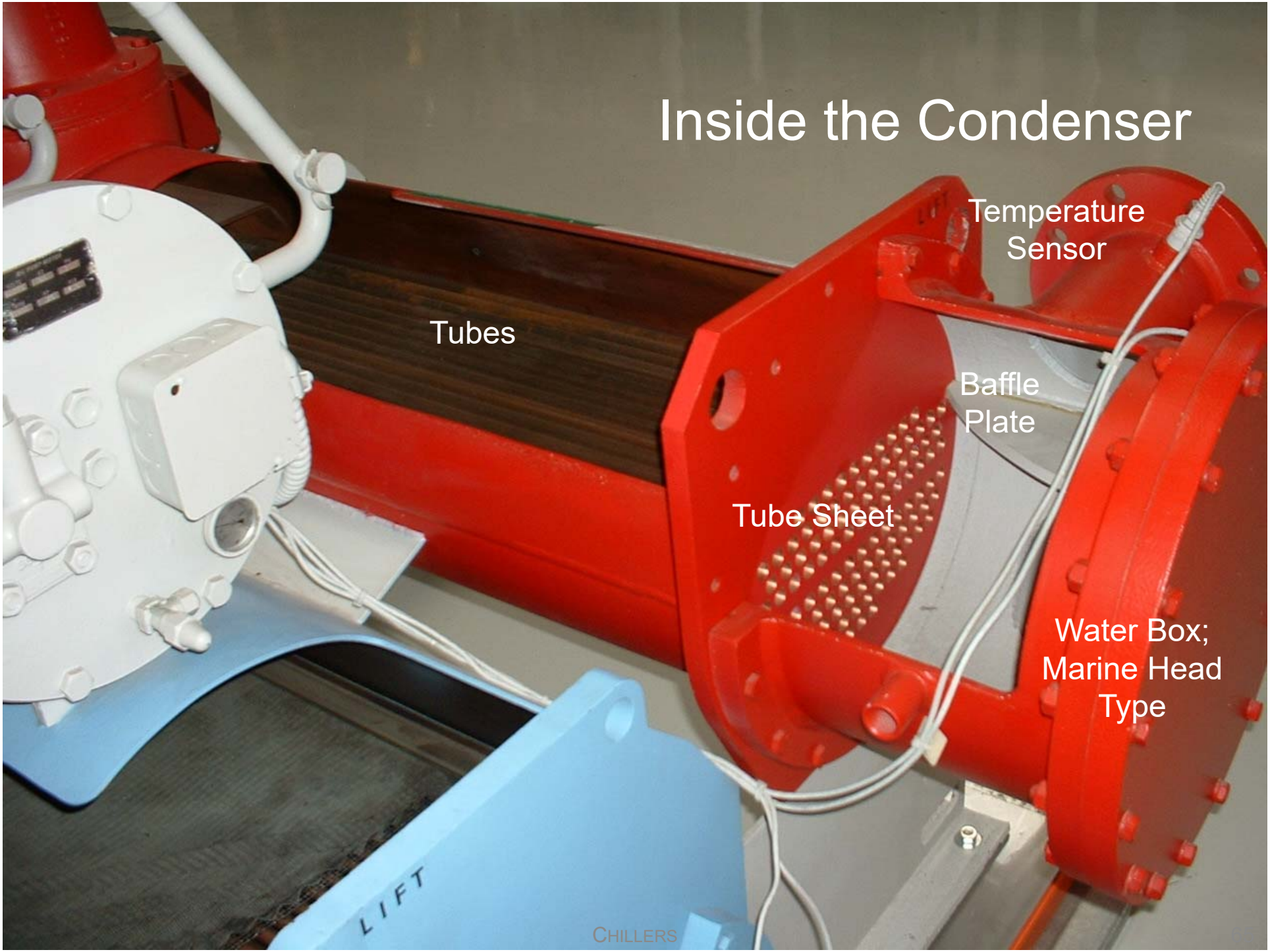
Try Your Hand At Identifying the Parts (Answers Follow)

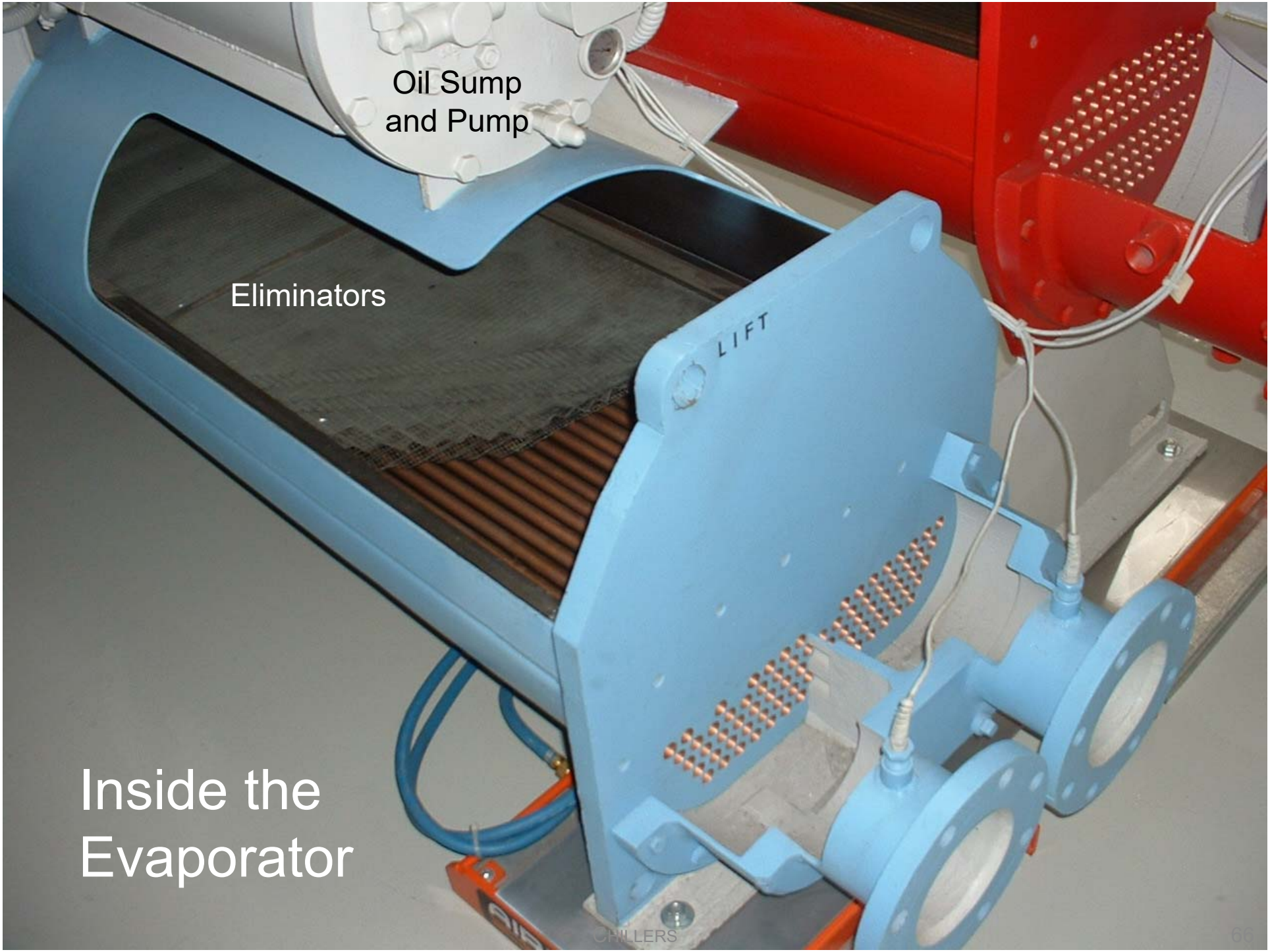


A Water Cooled Centrifugal Chiller



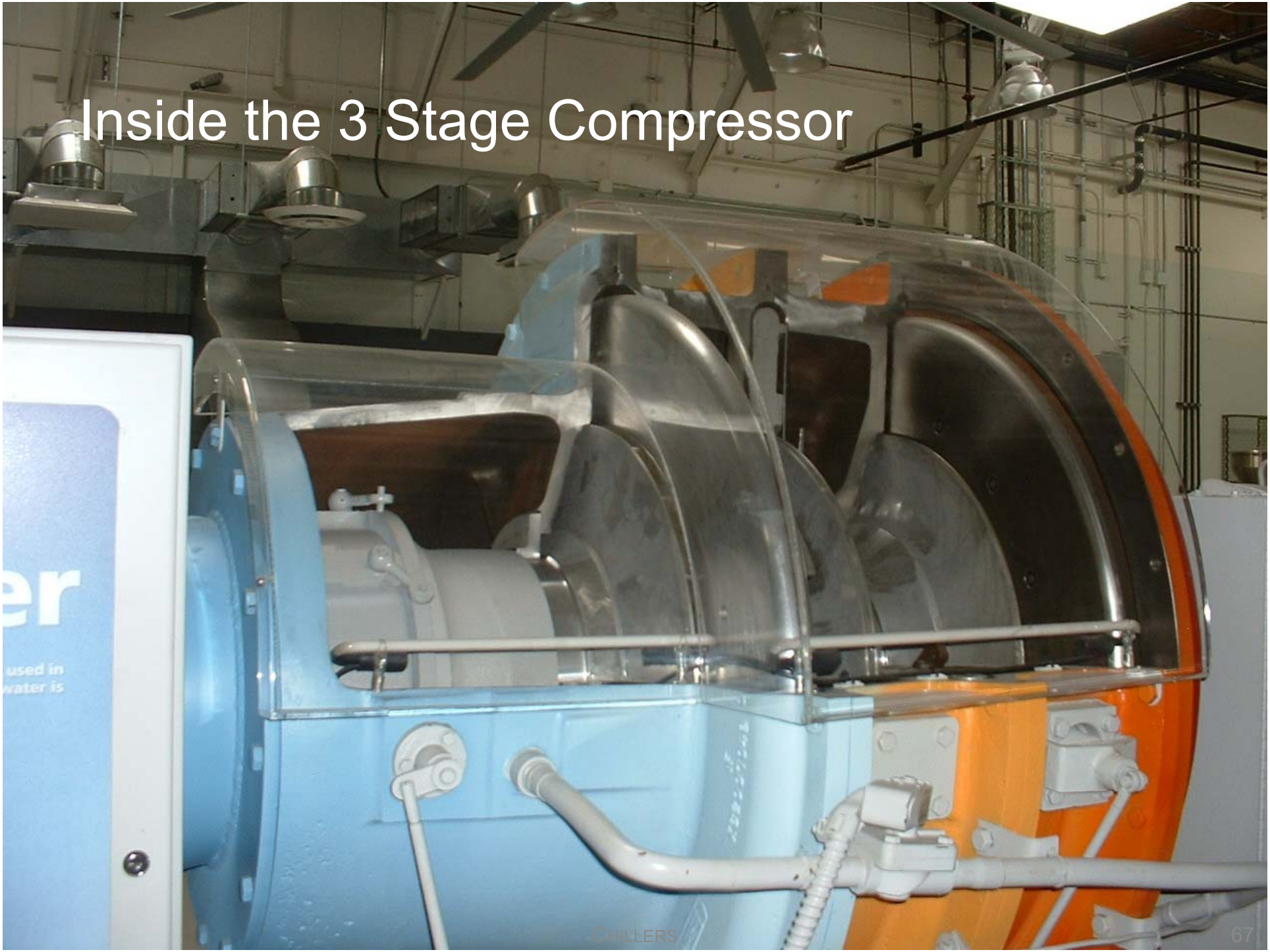
A Water Cooled Centrifugal Chiller

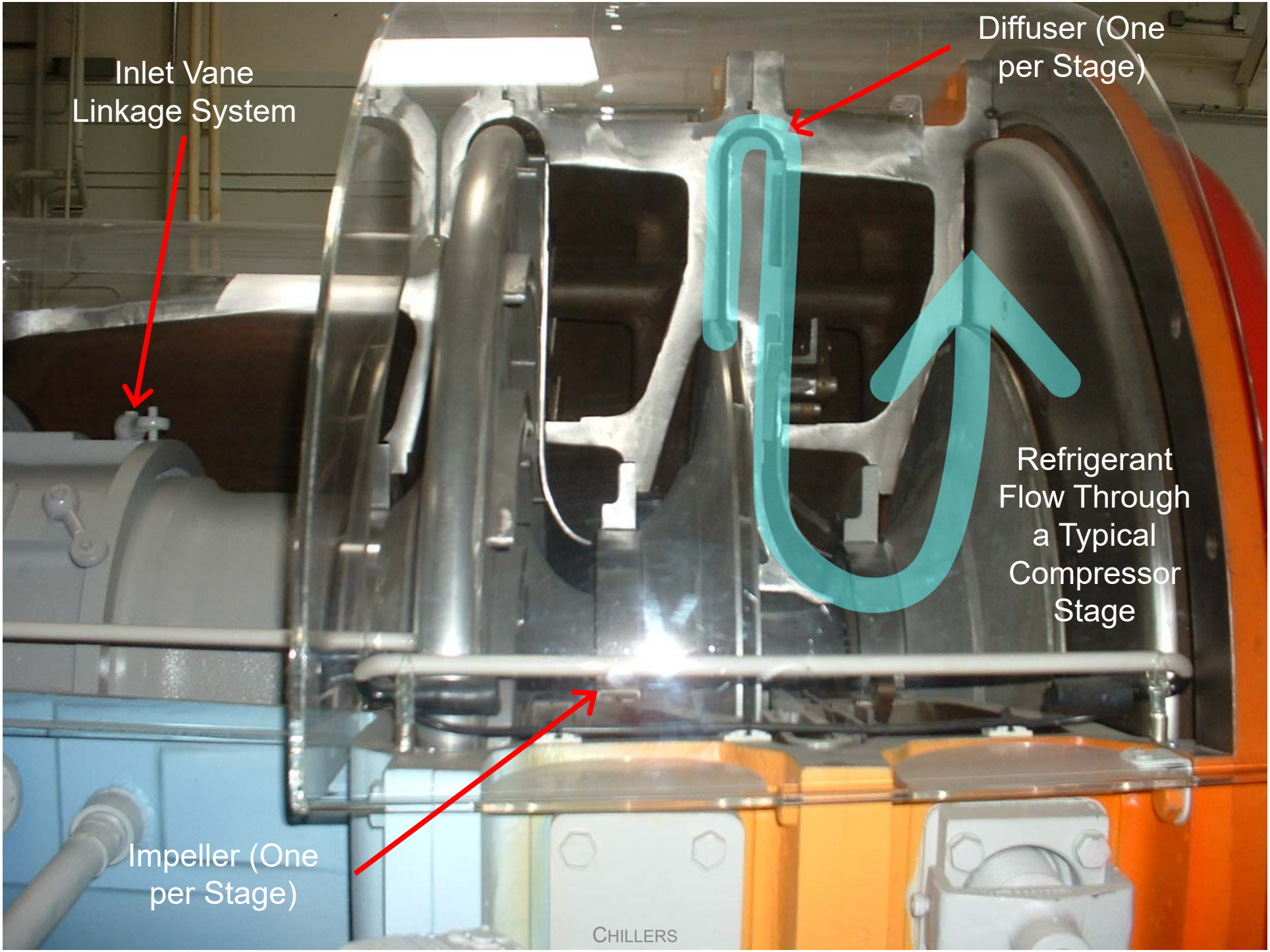

Inside the Condenser
Temperature Sensor
Tubes
Baffle Plate
Tube Sheet
Water Box; Marine Head Type
LIFT



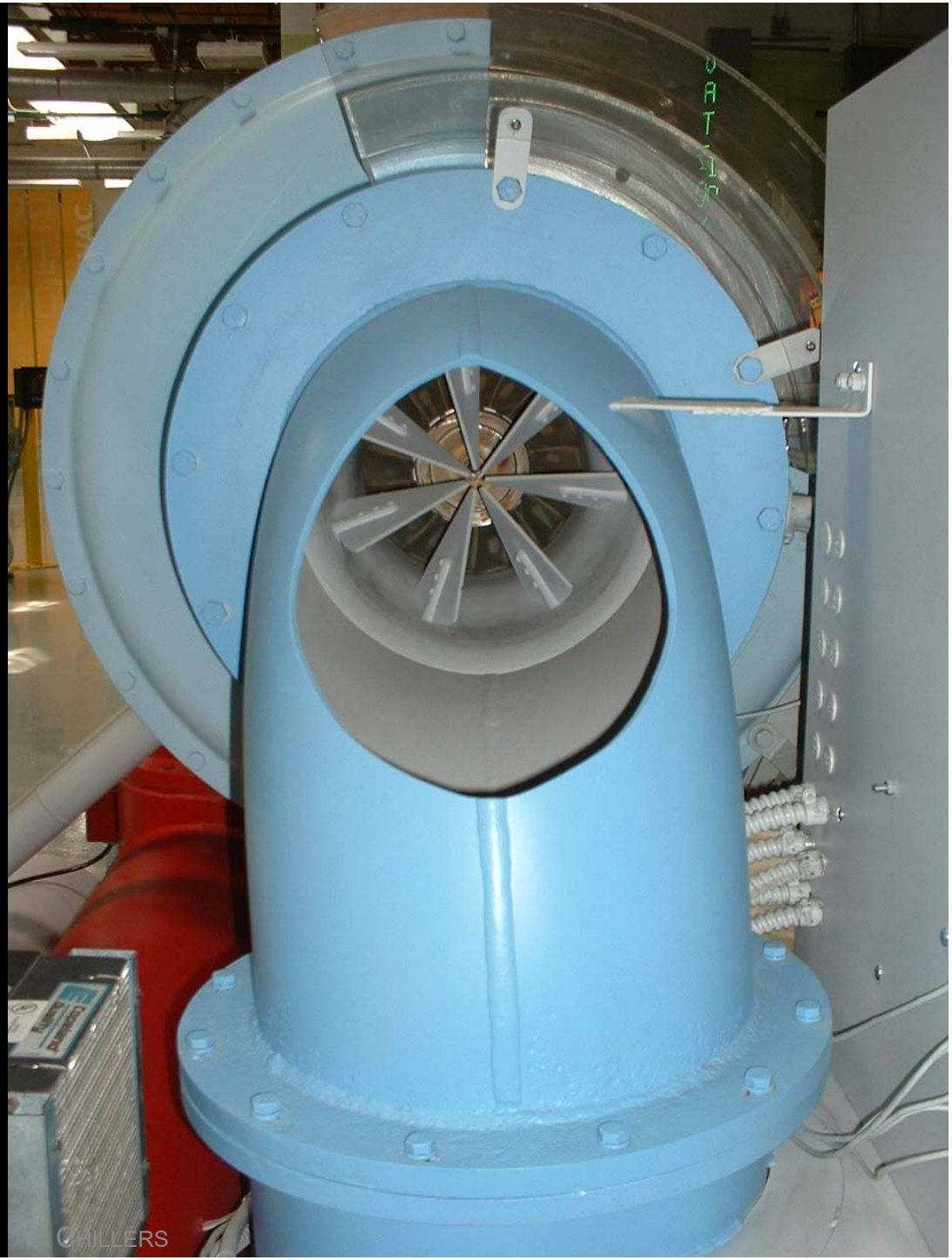
Inside the Evaporator

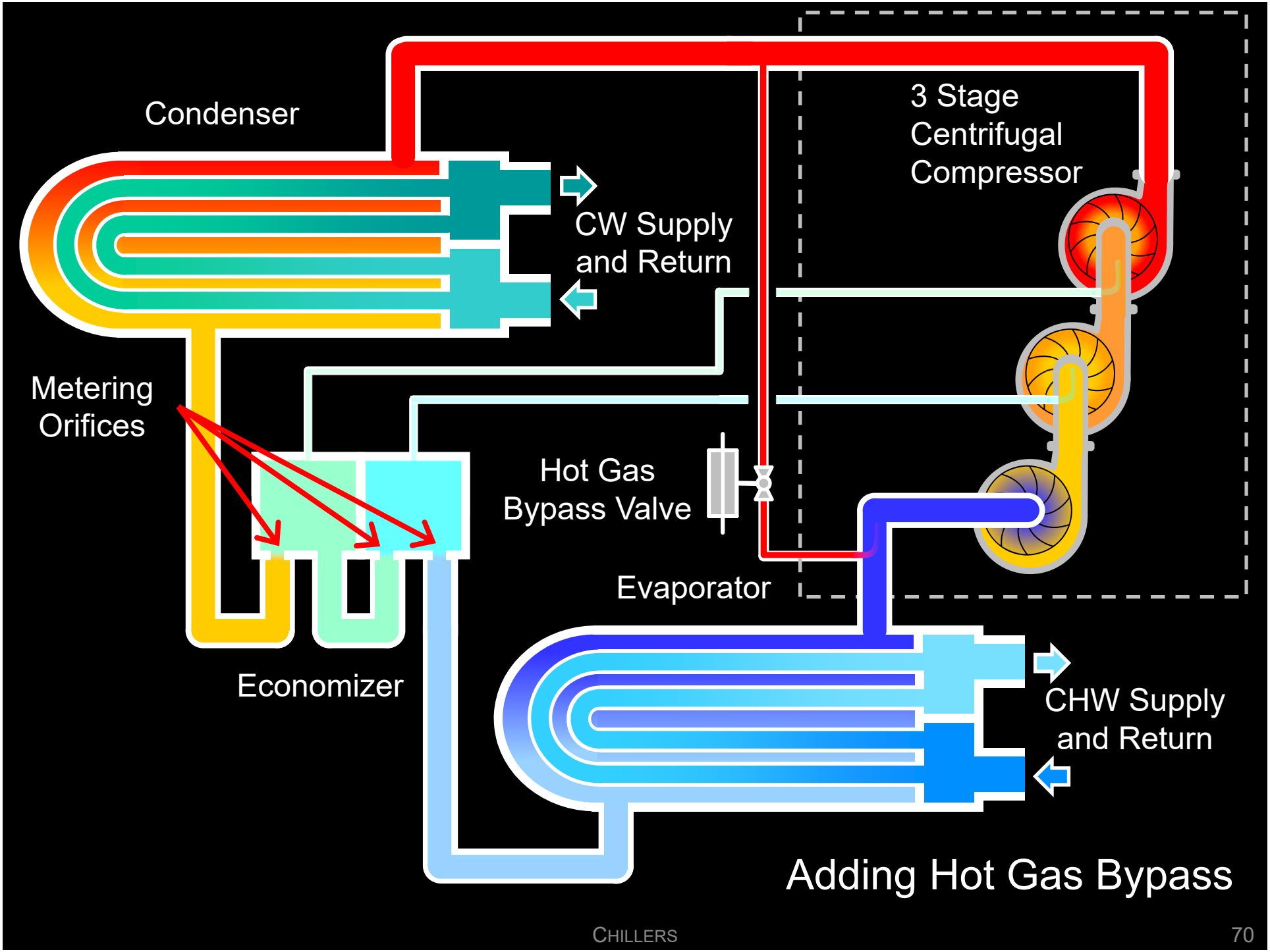
Inside the 3 Stage Compressor

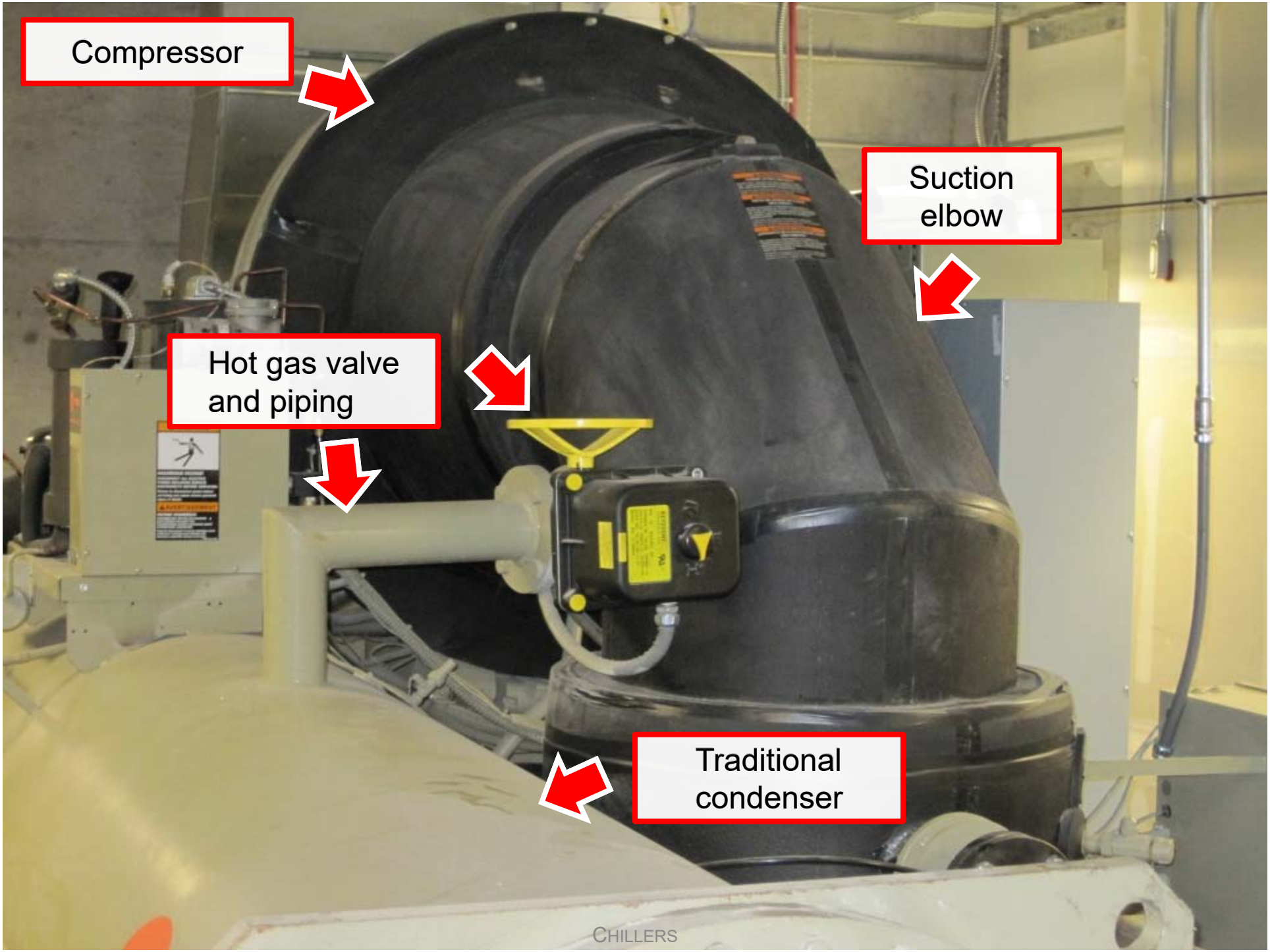



Inlet Vane
Linkage System
Diffuser (One
per Stage)
Refrigerant
Flow Through
a Typical
Compressor
Stage
Impeller (One
per Stage)

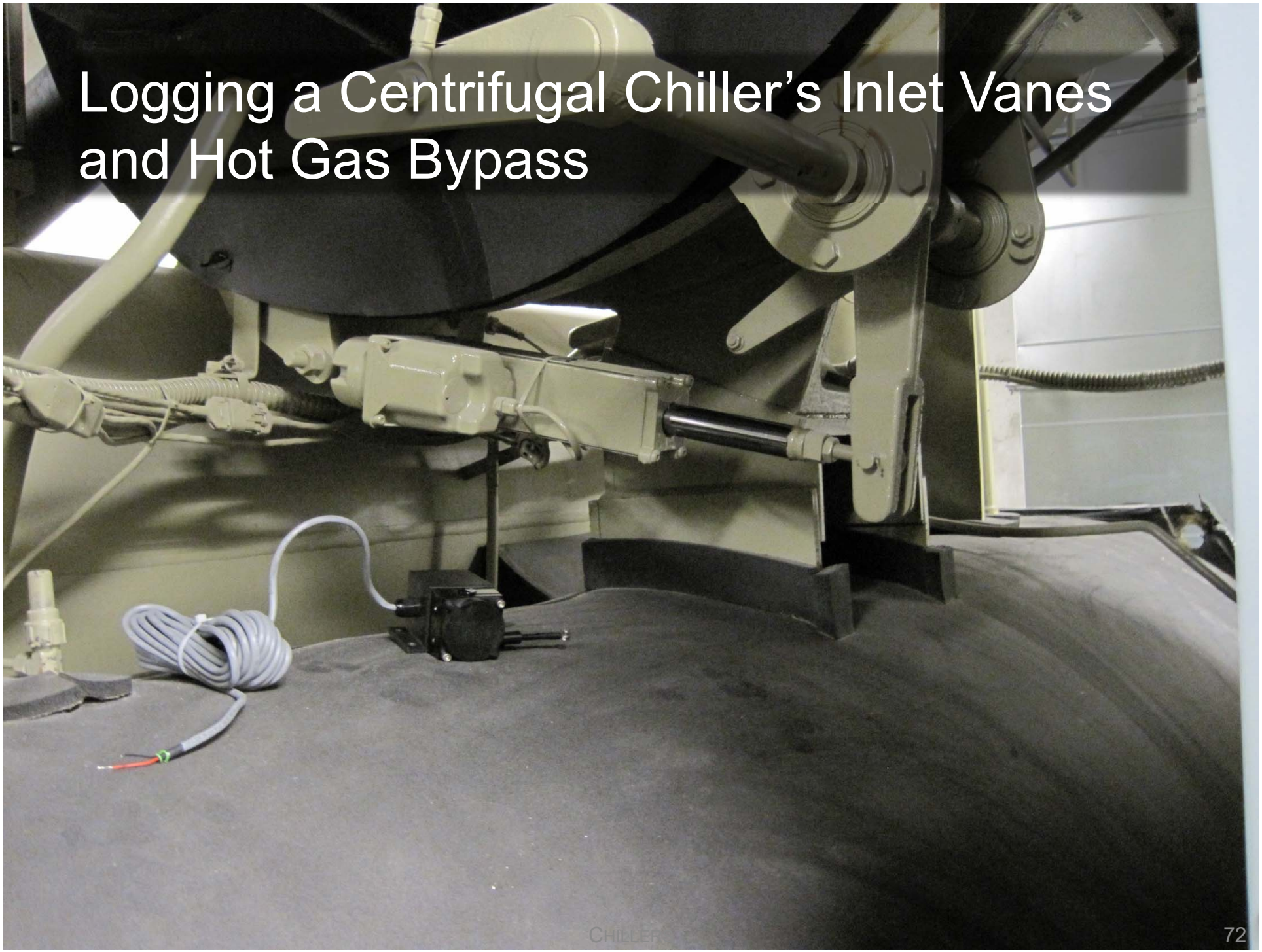
Inlet Vanes and Suction Elbow



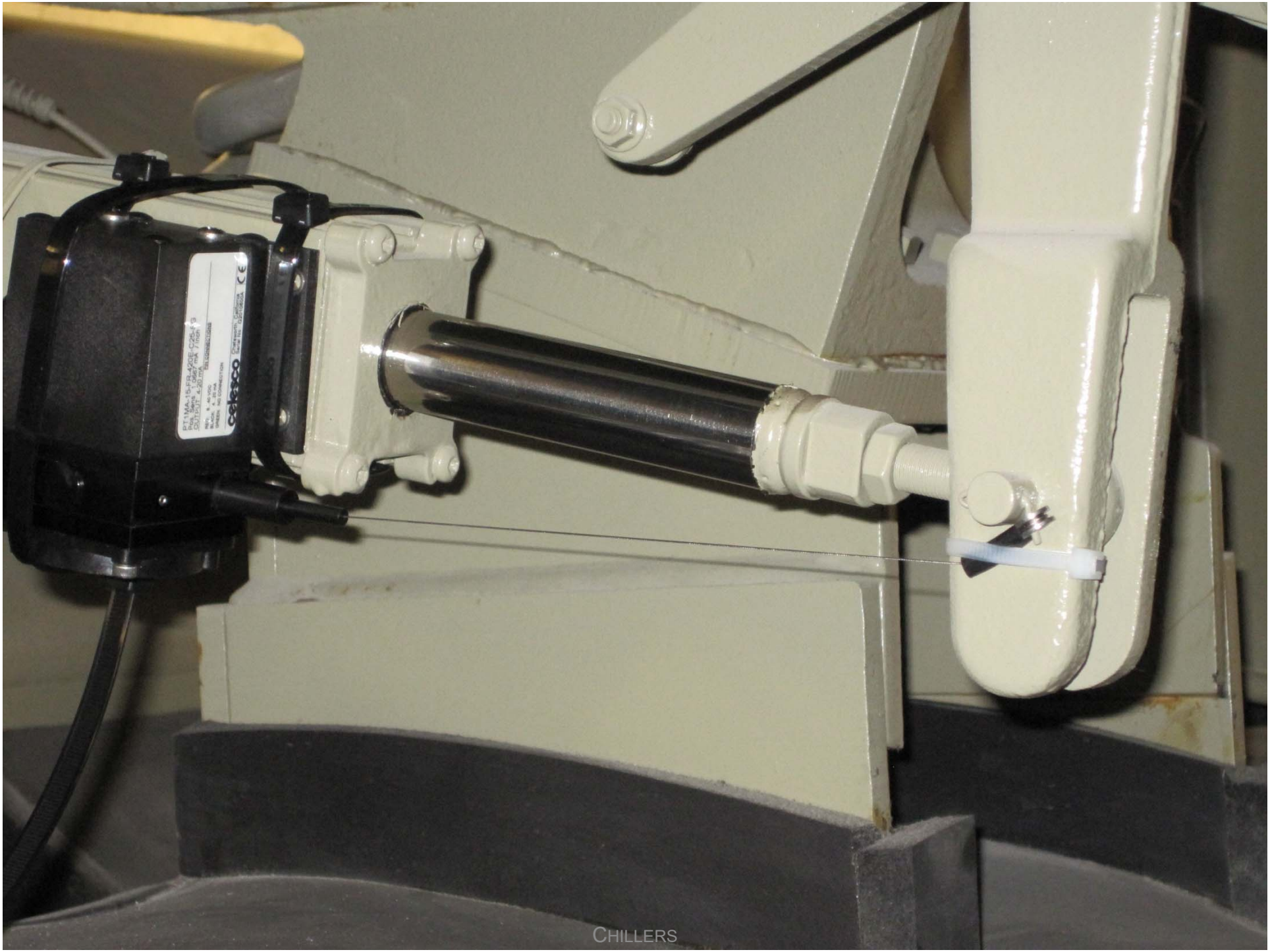

Condenser
3 Stage
Centrifugal
Compressor
CW Supply
and Return
Metering
Orifices
Hot Gas
Bypass Valve
Evaporator
Economizer
CHW Supply
and Return
Adding Hot Gas Bypass


Compressor
Suction elbow
Hot gas valve and piping
Traditional condenser

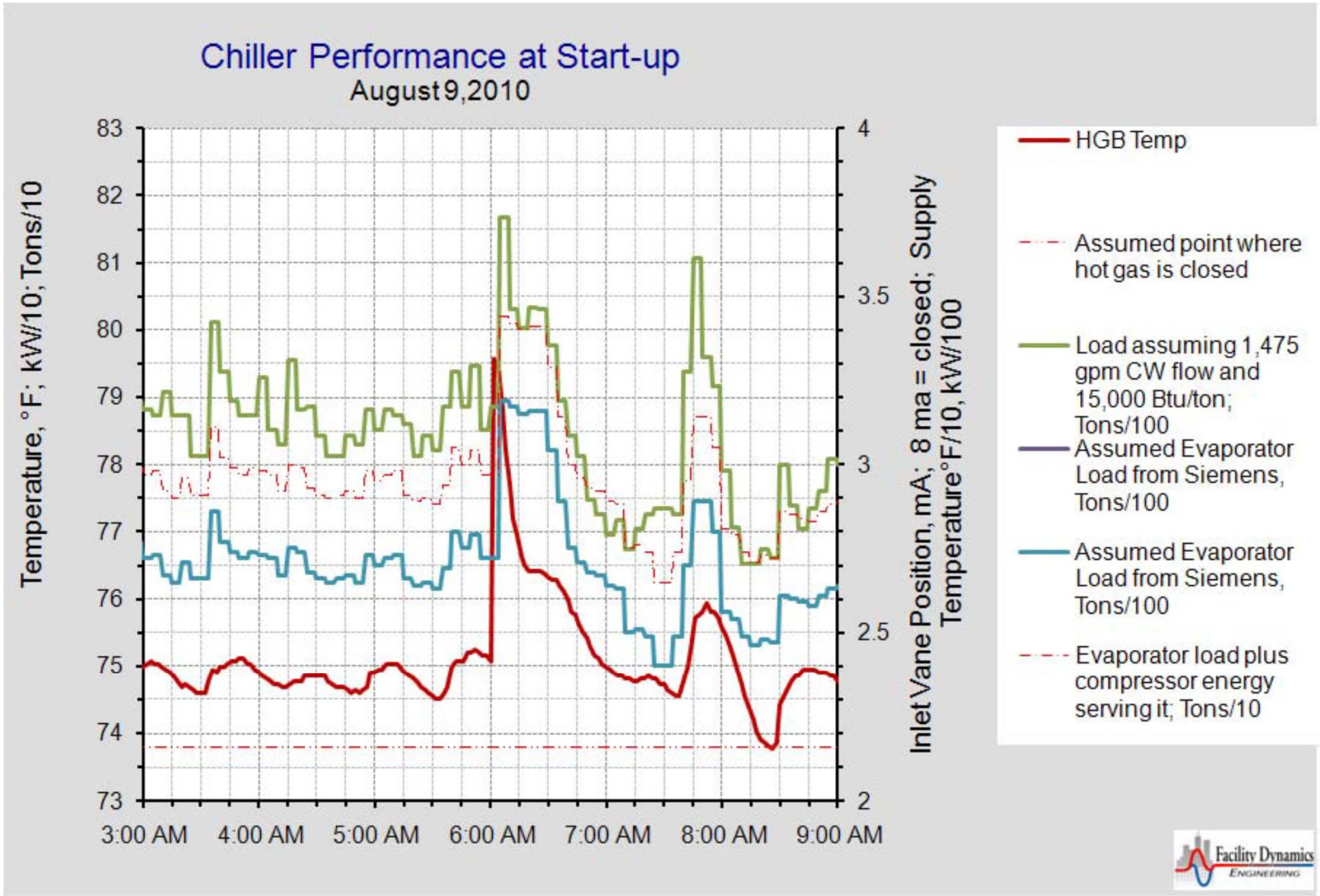
Logging a Centrifugal Chiller's Inlet Vanes and Hot Gas Bypass

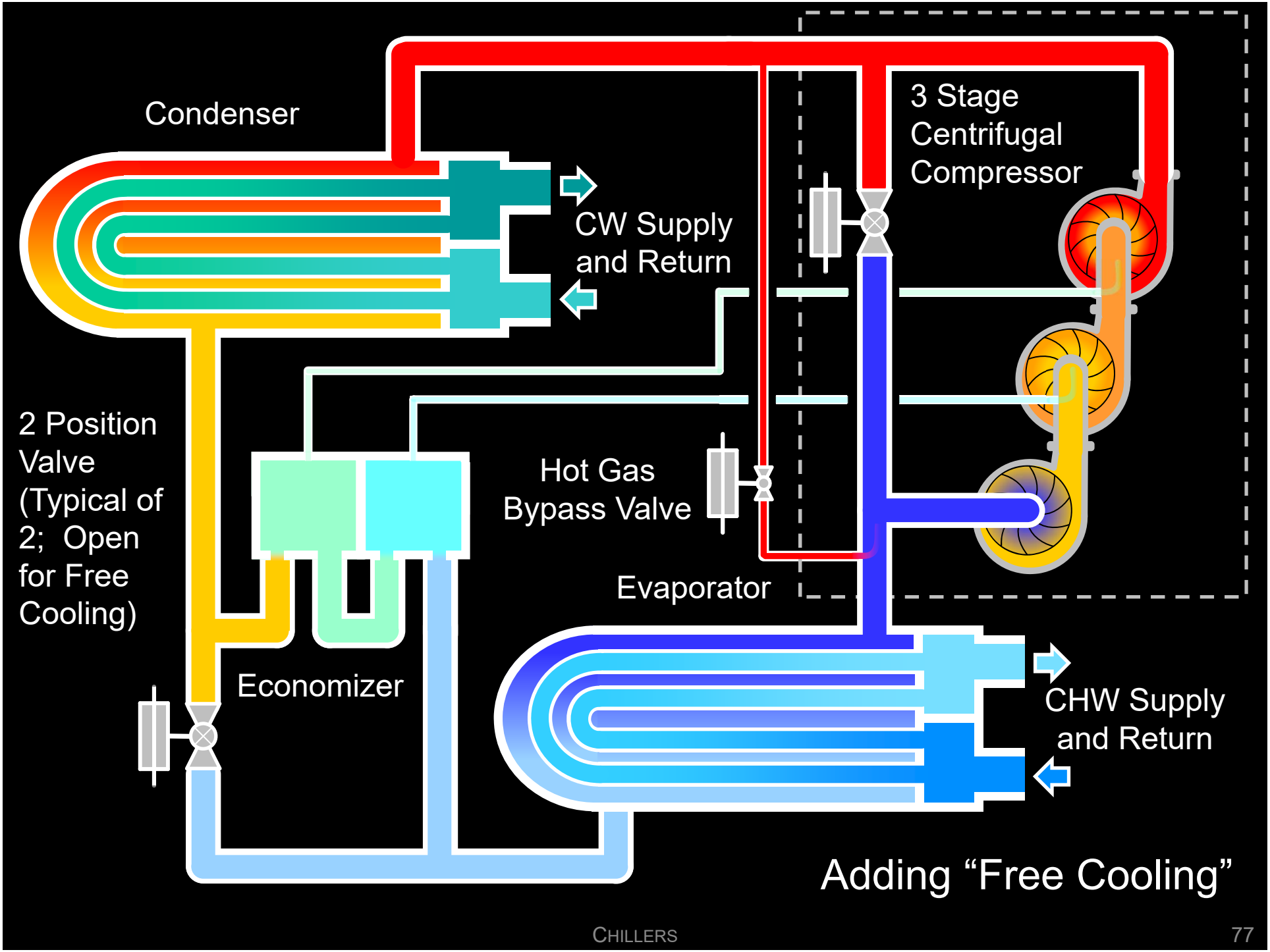


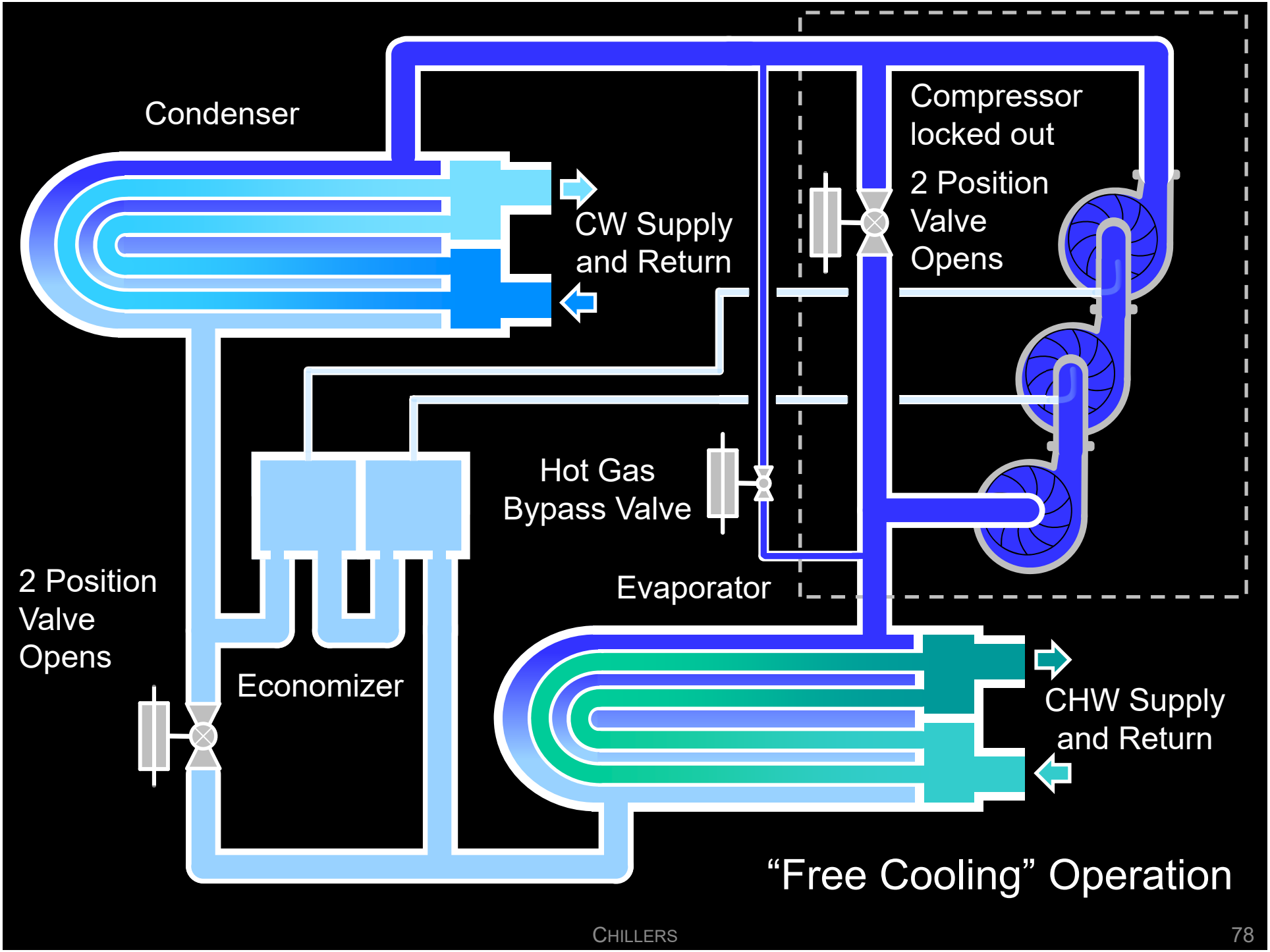

CHILLERS


CHILLERS


WARRANTY WILL BE DECLARED
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


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
Hot Gas
Bypass Valve
Evaporator
2 Position
Valve
Opens
Economizer
CHW Supply
and Return
“Free Cooling” Operation

Taking a Closer Look at a Centrifugal Chiller

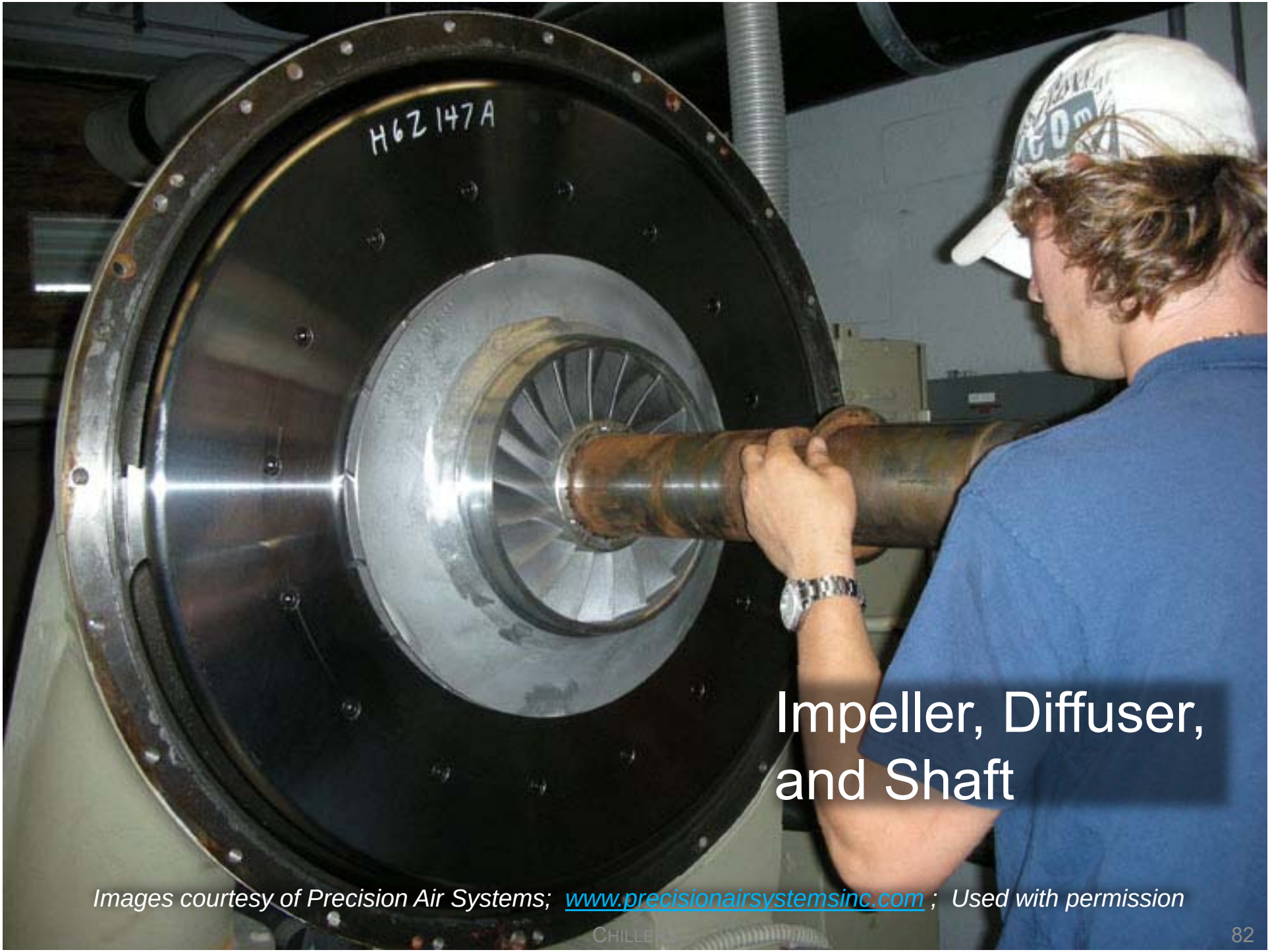
Images courtesy of Precision Air Systems; www.precisionairsystemsinc.com ; Used with permission

Suction Elbow and Inlet Vanes Removed

Images courtesy of Precision Air Systems; www.precisionairsystemsinc.com ; Used with permission

Between Compressor Stages

Images courtesy of Precision Air Systems; www.precisionairsystemsinc.com ; Used with permission



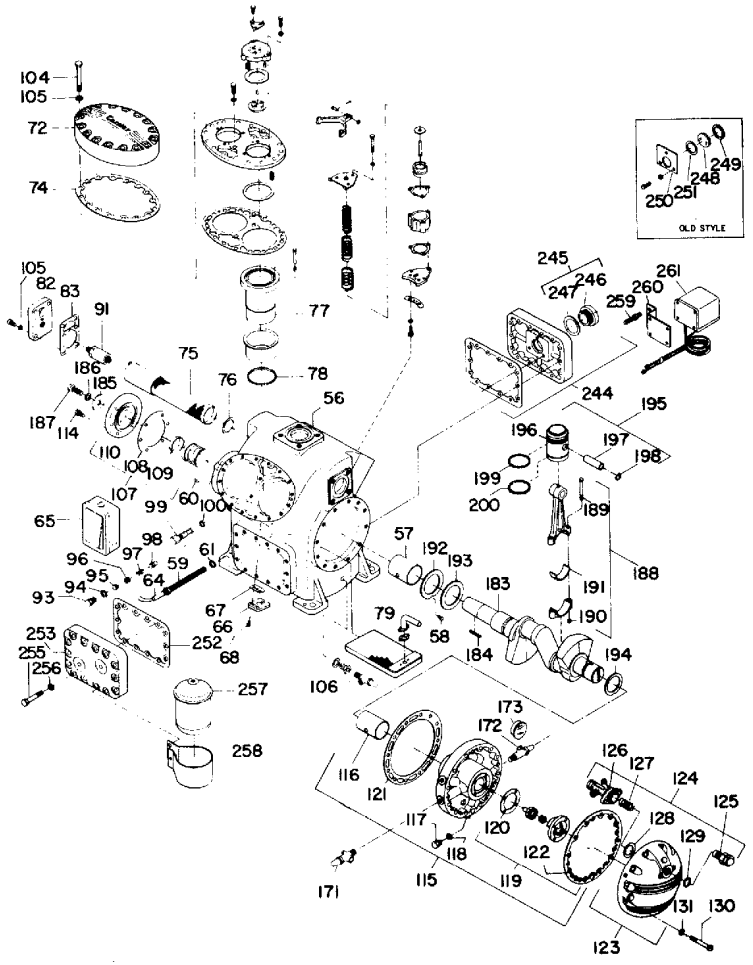
Impeller, Diffuser, and Shaft

Images courtesy of Precision Air Systems; www.precisionairsystemsinc.com ; Used with permission

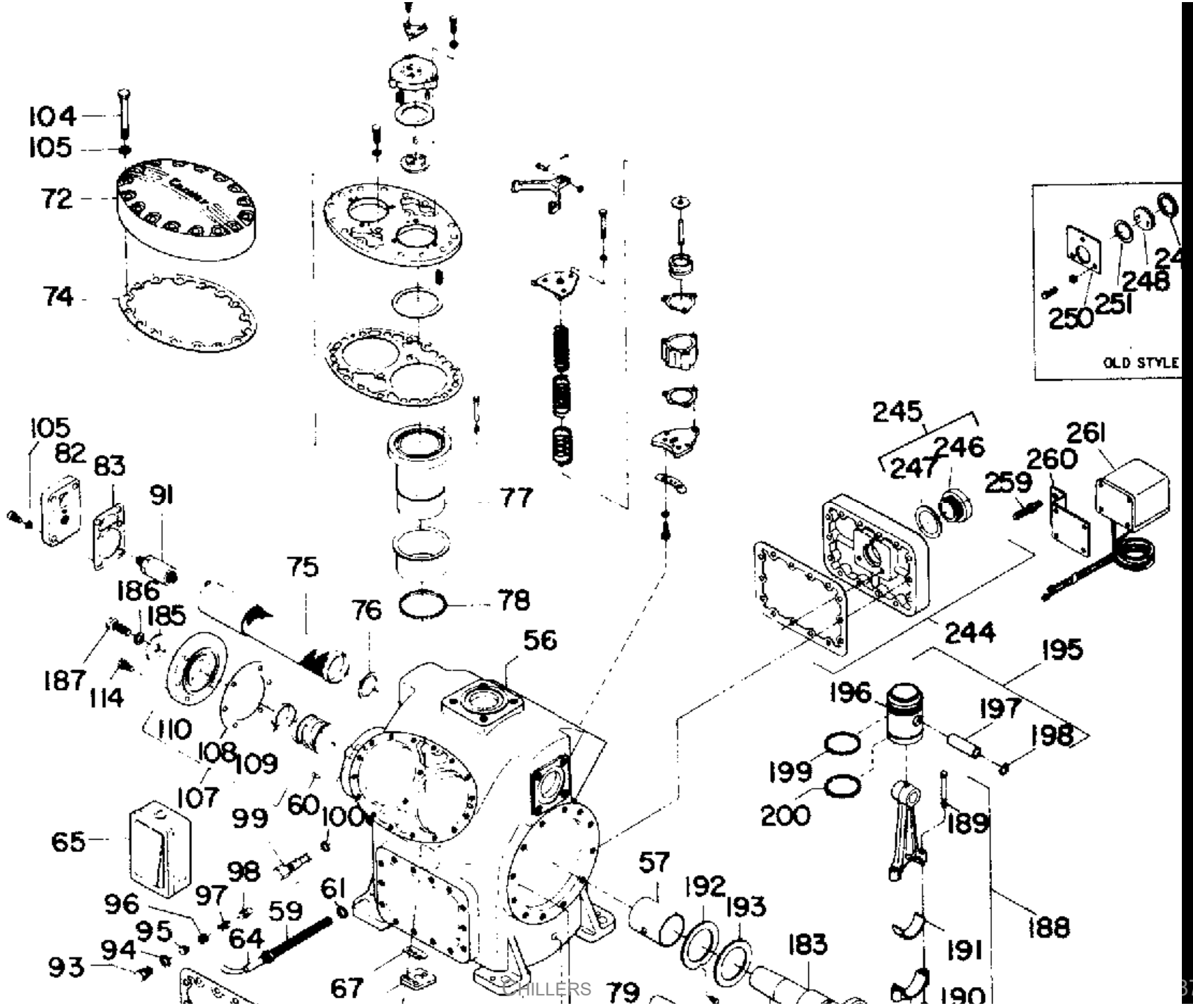
The Motor End

Images courtesy of Precision Air Systems; www.precisionairsystemsinc.com ; Used with permission

Reciprocating Compressors



COMPRESSOR
(5H40 shown)


104
105
72
74
105
82
83
91
186
185
187
114
75
76
77
78
56
110
108
109
107
99
60
100
65
98
97
96
95
94
93
64
59
61
67
57
192
193
183
79
245
246
247
261
260
259
244
195
196
197
198
199
200
189
188
191
190
250
251
248
OLD STYLE

Scroll Compressors

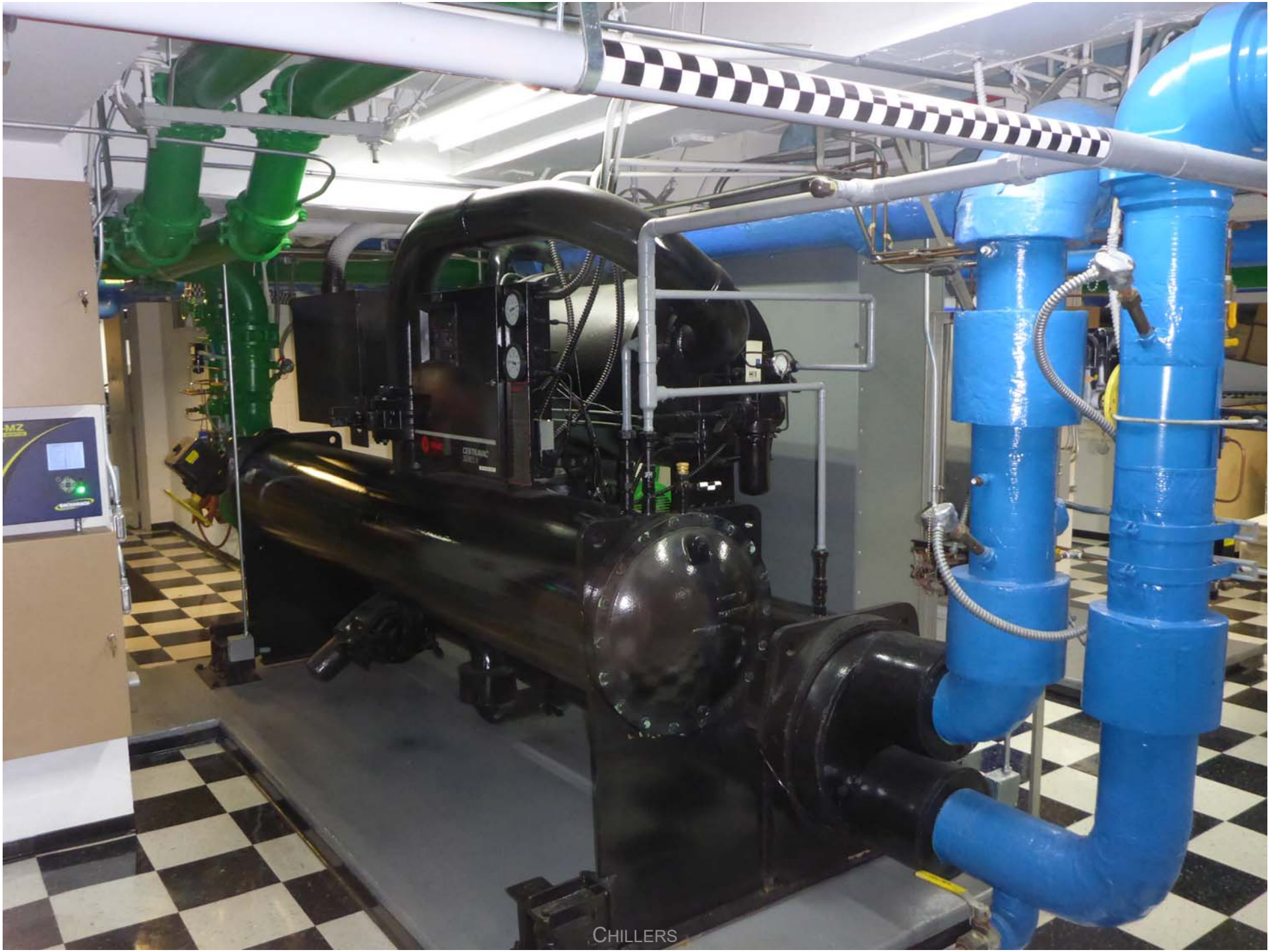
CHILLERS

Screw Compressors

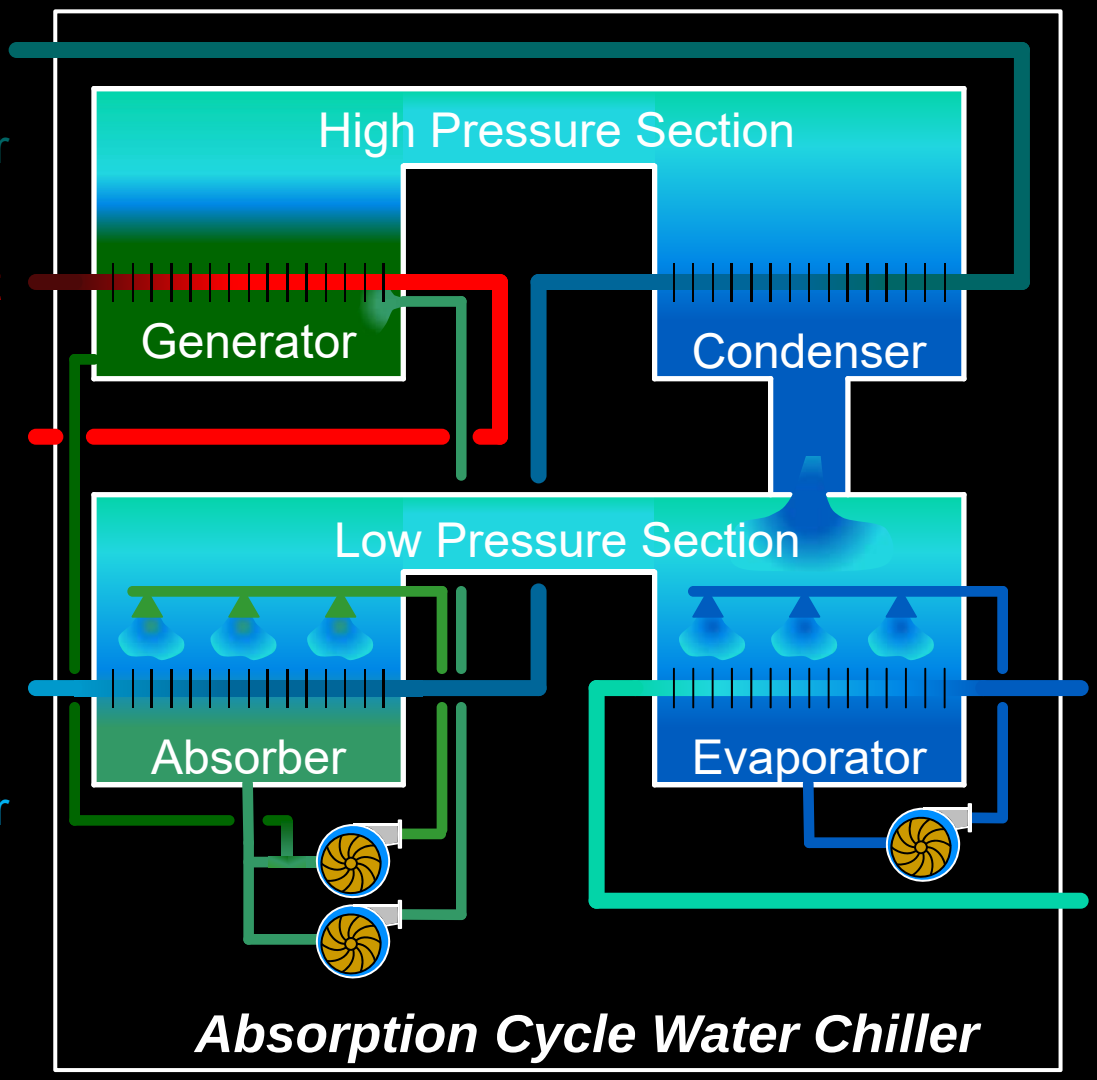

Carrier


CHILLED WATER SUPPLY
HGM-MZ


CONDENSER WATER SUPPLY



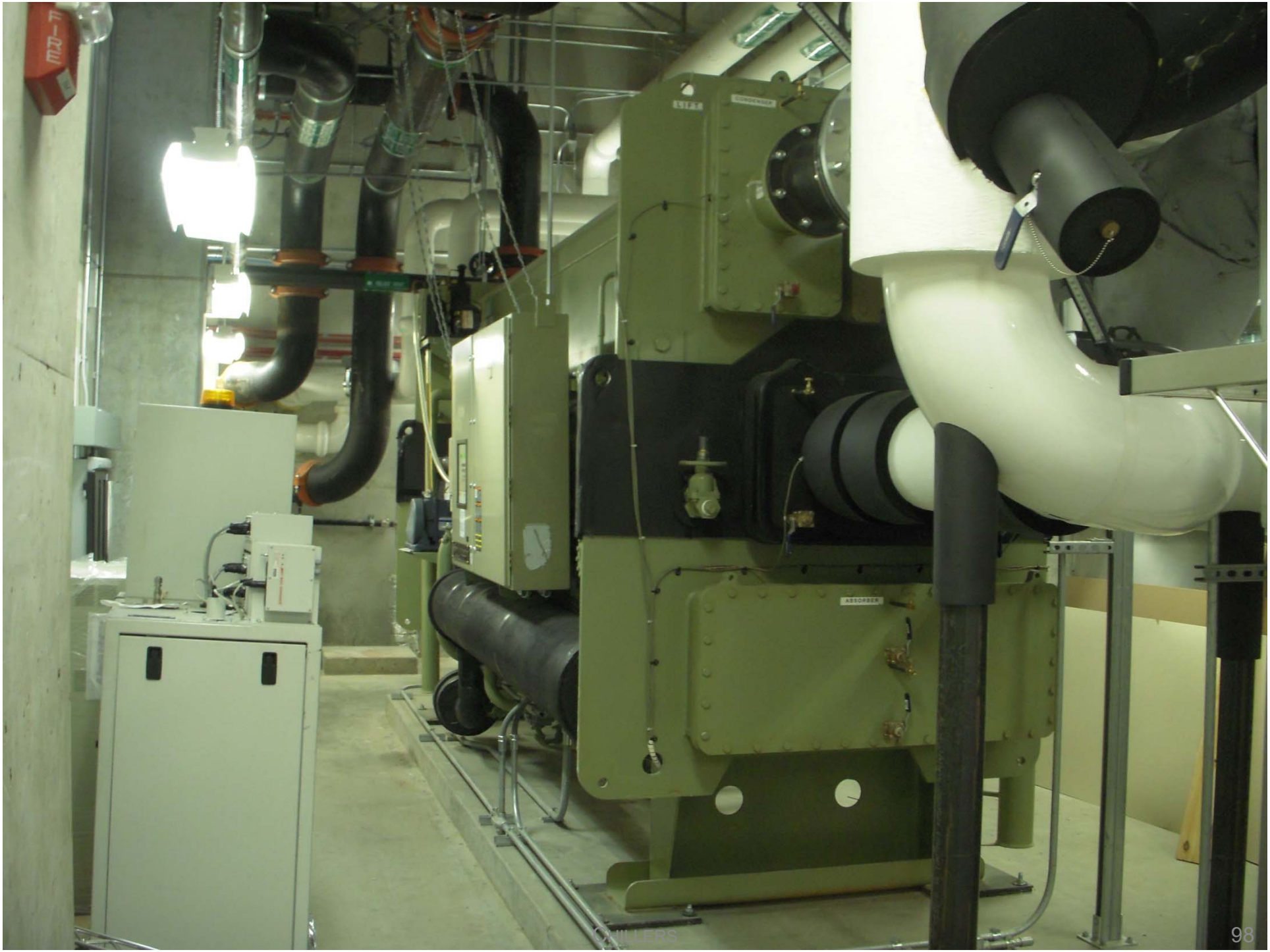
Absorption Chiller



The refrigerant is water

The absorbent is typically lithium bromide

Operates at a nearly perfect vacuum


FIRE


CHILLED WATER RETURN


TRANE
R1

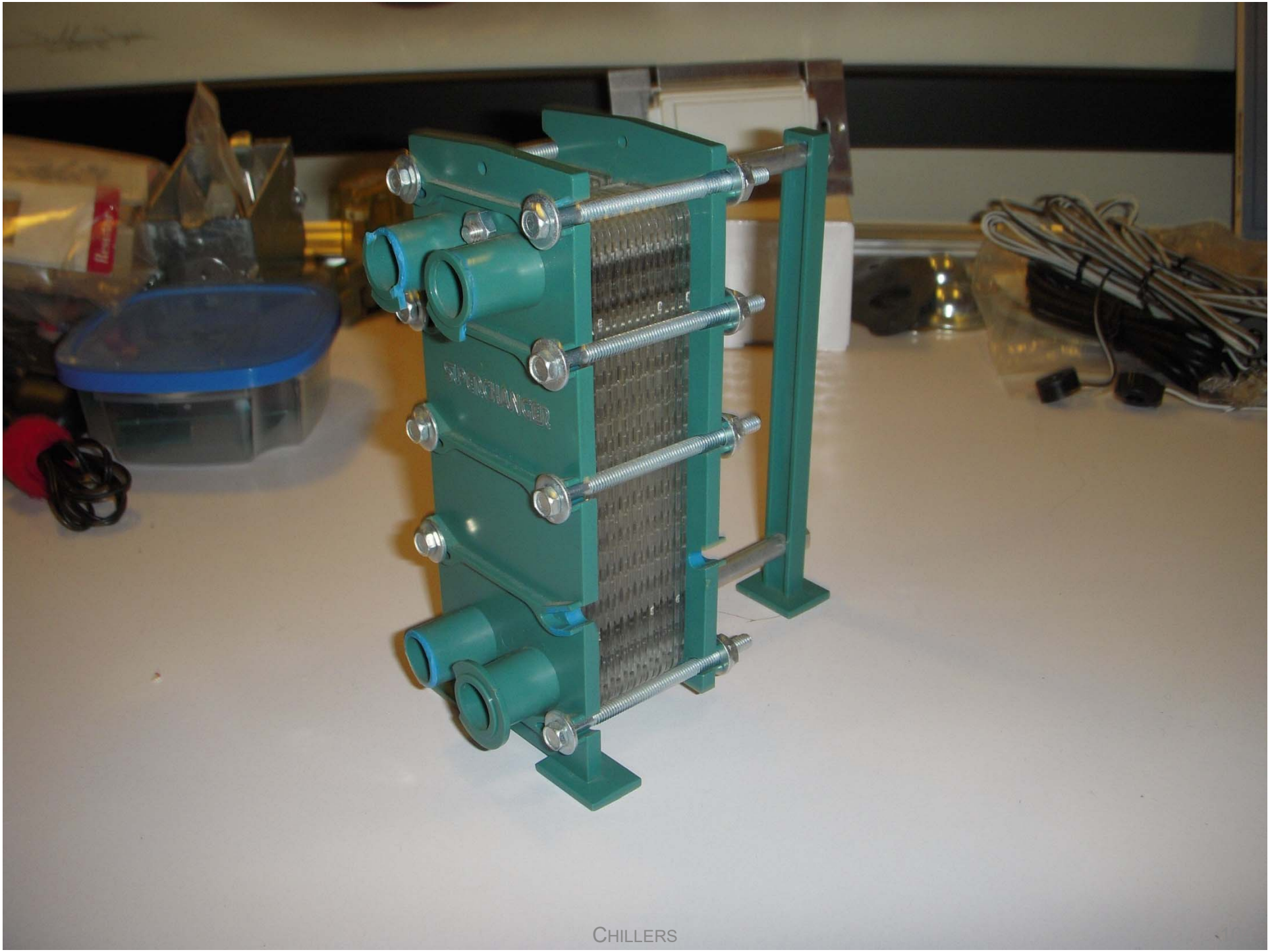
“Free Cooling”

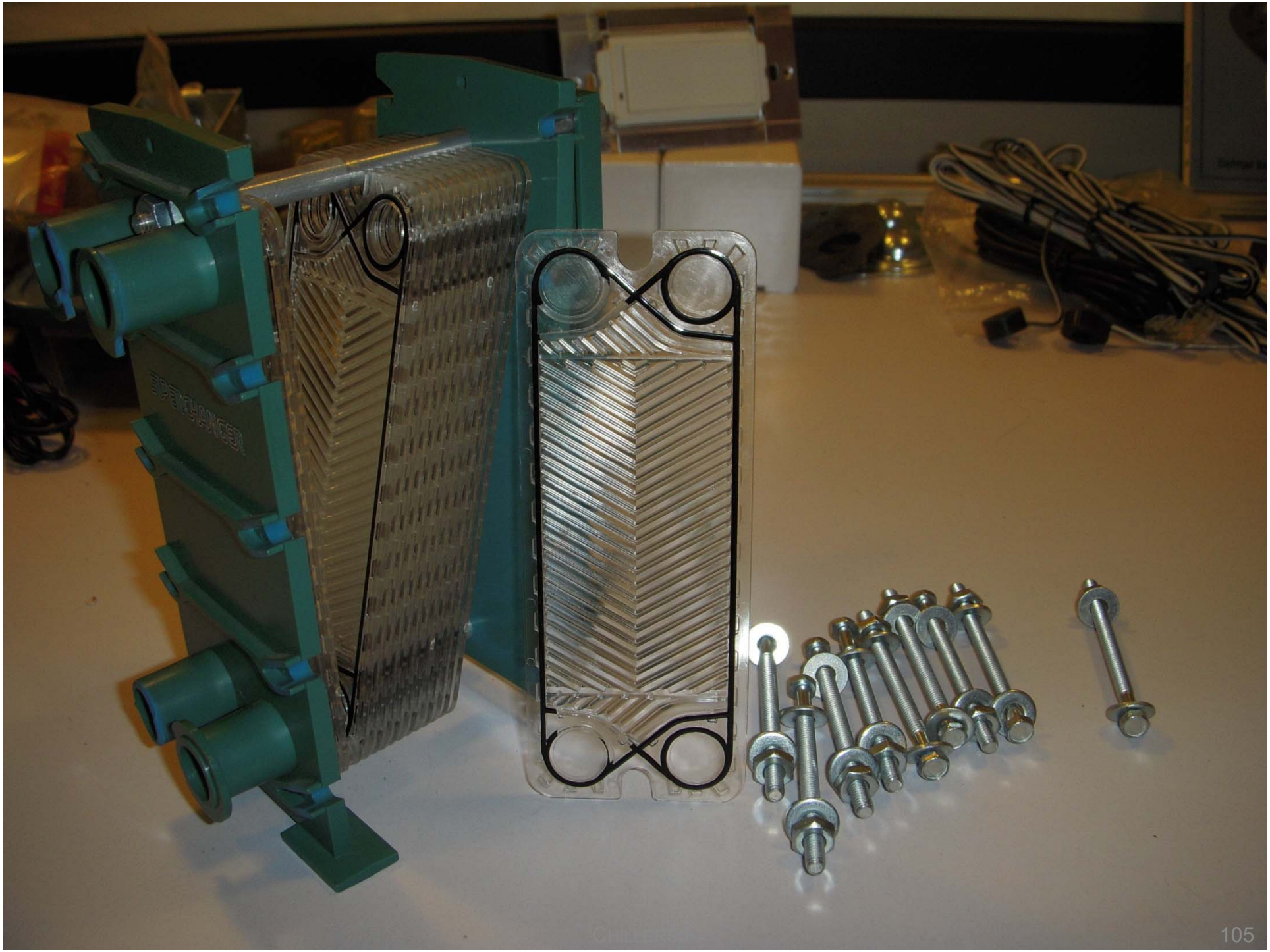
Option 1 – Plate and Frame Heat Exchanger

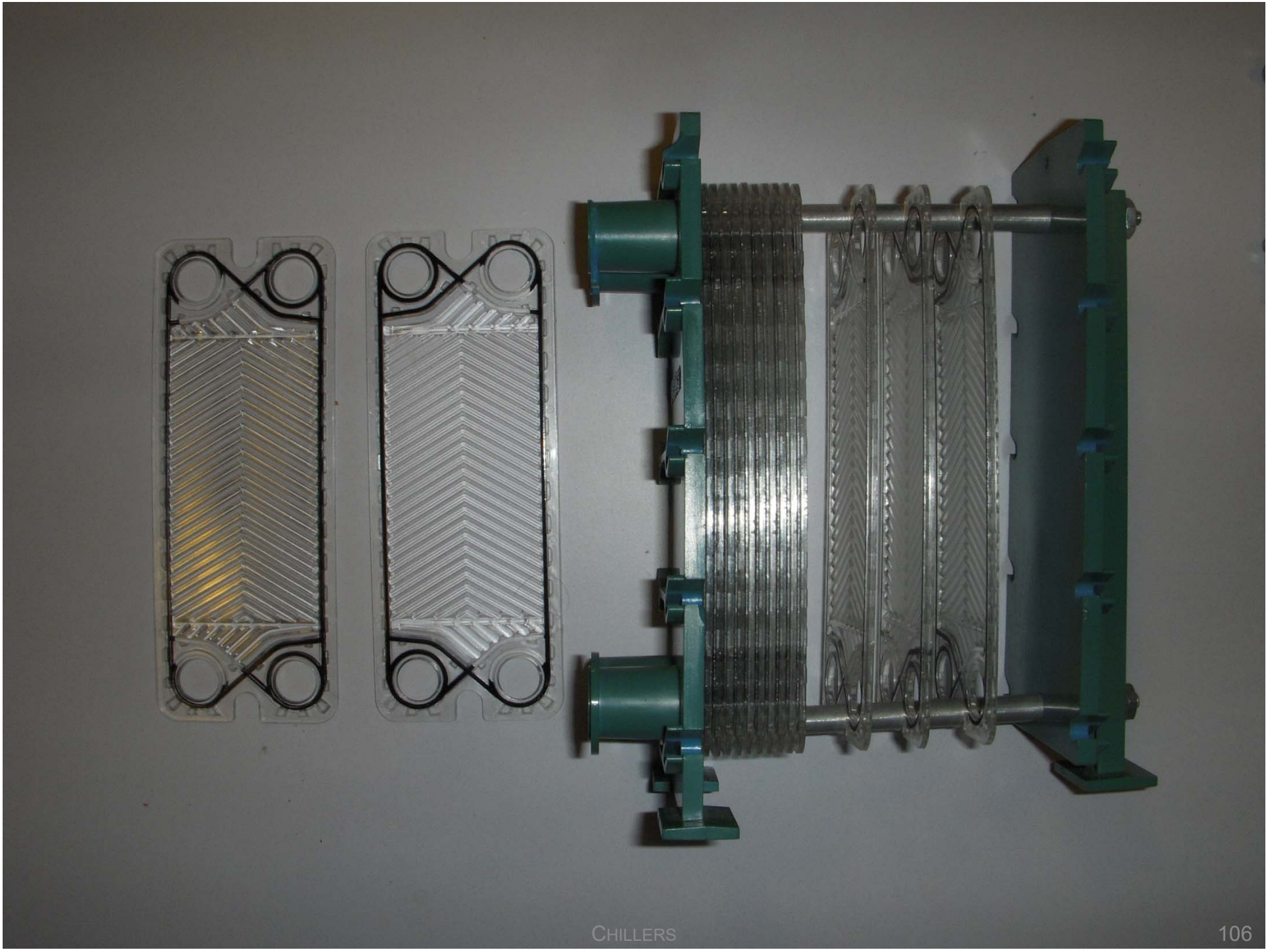
“Free Cooling” (Nothing is Free)

Option 1 – Plate and Frame Heat Exchanger


3.25.2003
URANUS
THERMAL
CHILLED WATER SUPPLY



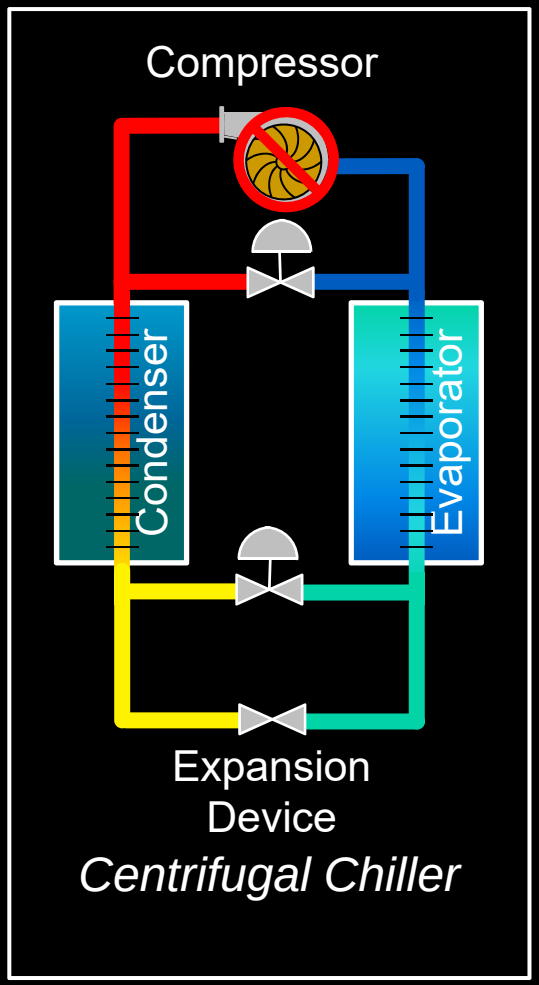


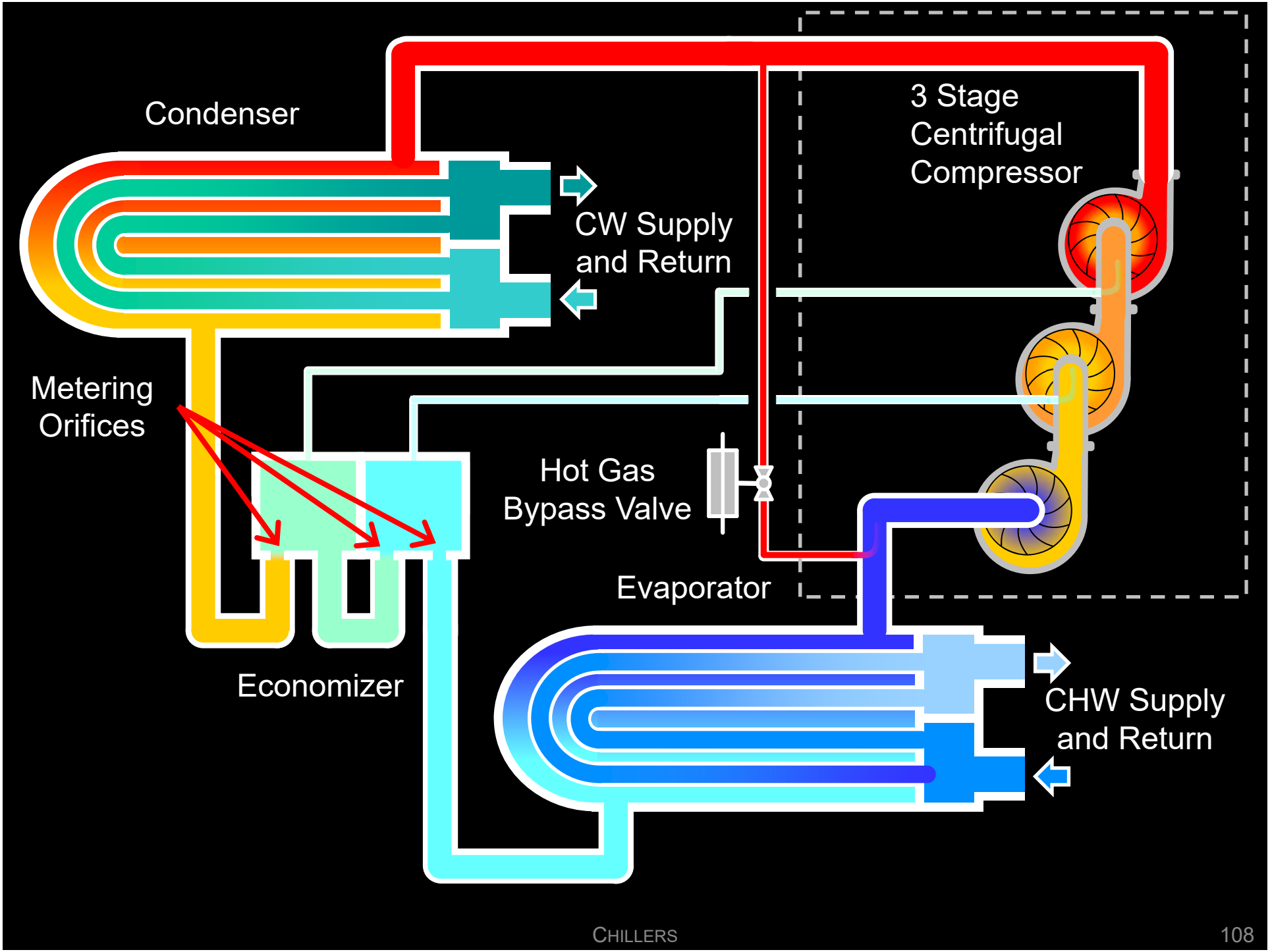


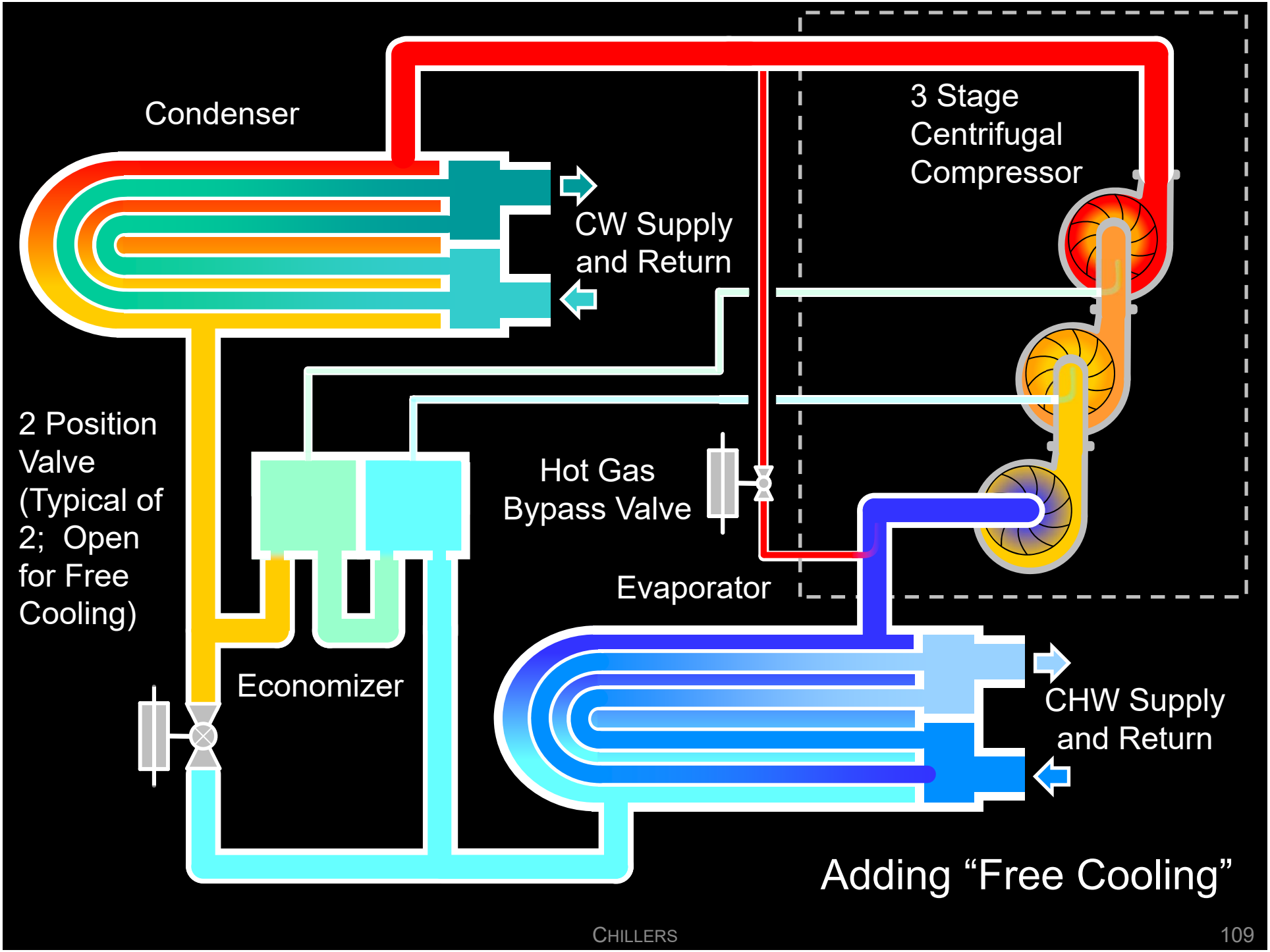
“Free Cooling” (Nothing is Free)

Option 1 – Plate and Frame Heat Exchanger

Option 2 – Thermo-syphon




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


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”

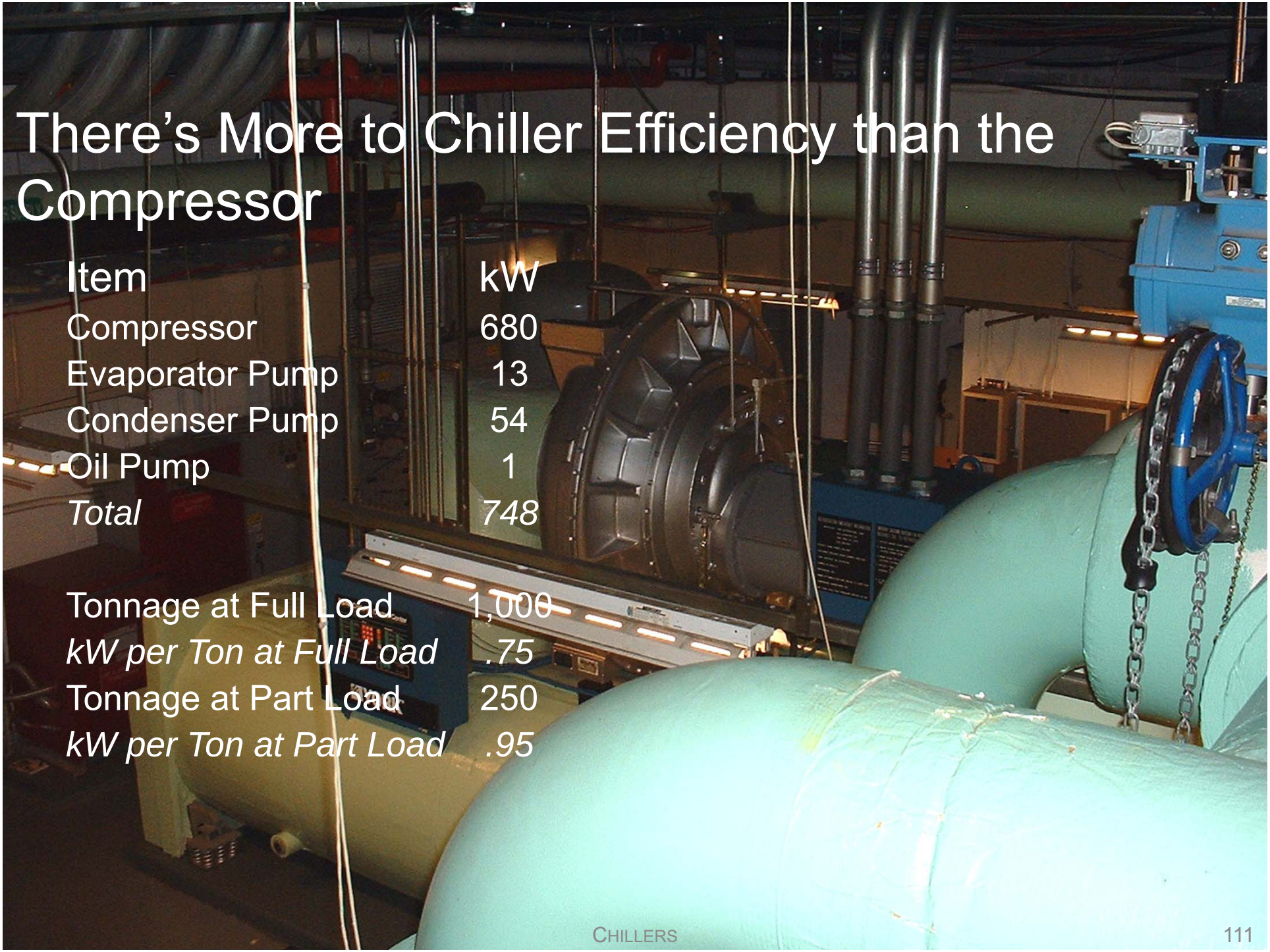
Different Cooling Sources = Different Operating Requirements

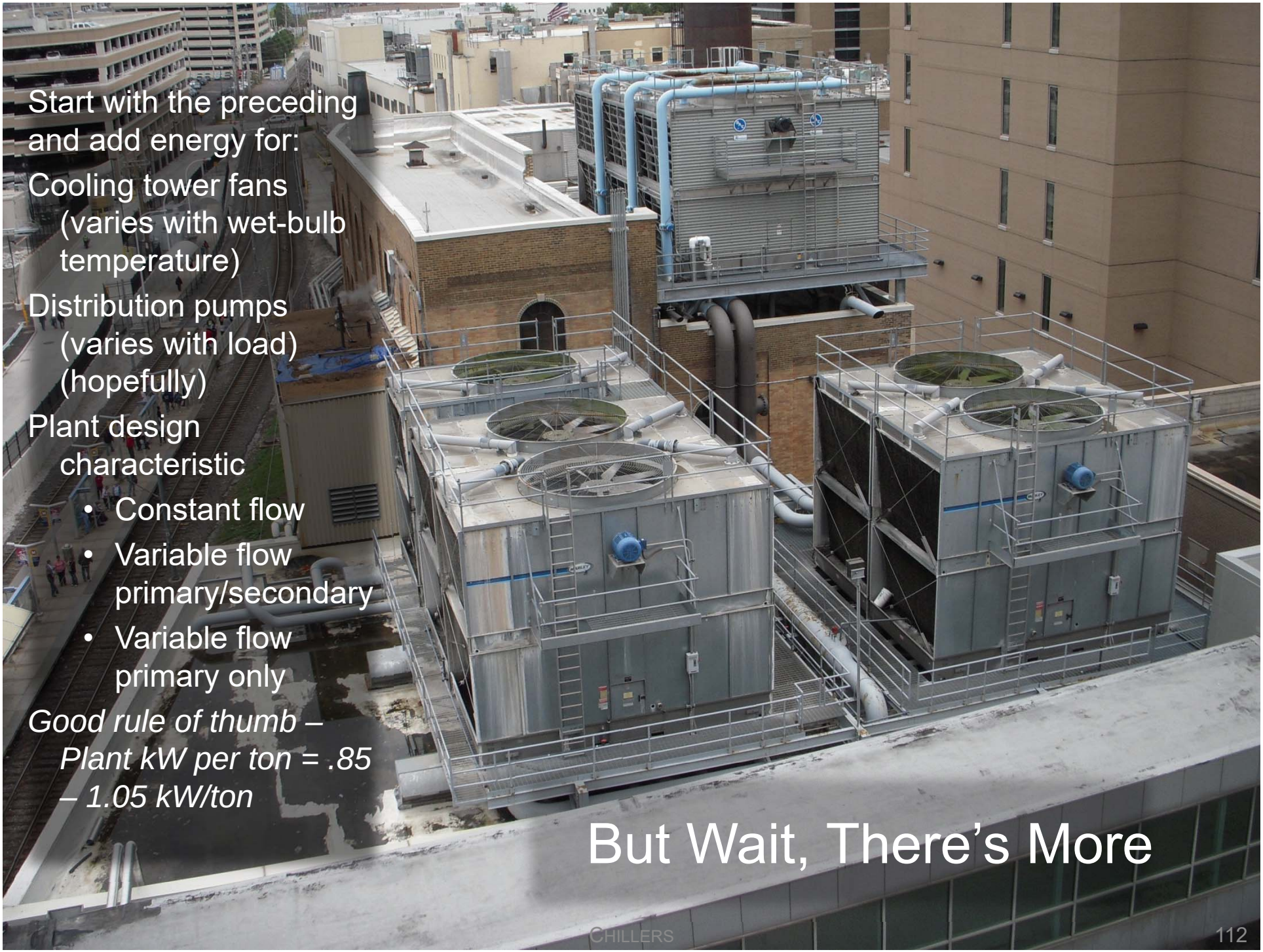
Vapor Compression Chiller	Absorption Cycle Chiller	Free Cooling Cycle
Cold condenser water = *Good*	Cold condenser water = *Bad*	Cold condenser water = *Relative thing*
Many moving parts; frequent or rapid cycling = *Compressor failure*	Fewer moving parts; frequent or rapid cycling = *Not gonna happen*	Some moving parts; frequent or rapid cycling = *Motor overheating*
Improper start/stop /sequencing = *Energy and demand penalty*	Improper start/stop /sequencing = *Angry boiler plant operators*	Improper start/stop /sequencing = *Cooling tower failure*
Set point fine tuning = *Performance and efficiency optimization*	Set point fine tuning = *Just fooling your self (you're lucky its running)*	Set point fine tuning = *Performance and efficiency optimization*

Monitoring operating data = *Ongoing performance optimization*

There's More to Chiller Efficiency than the Compressor

Item	kW
Compressor	680
Evaporator Pump	13
Condenser Pump	54
Oil Pump	1
Total	*748*
Tonnage at Full Load	1,000
kW per Ton at Full Load	*.75*
Tonnage at Part Load	250
kW per Ton at Part Load	*.95*





But Wait, There's More

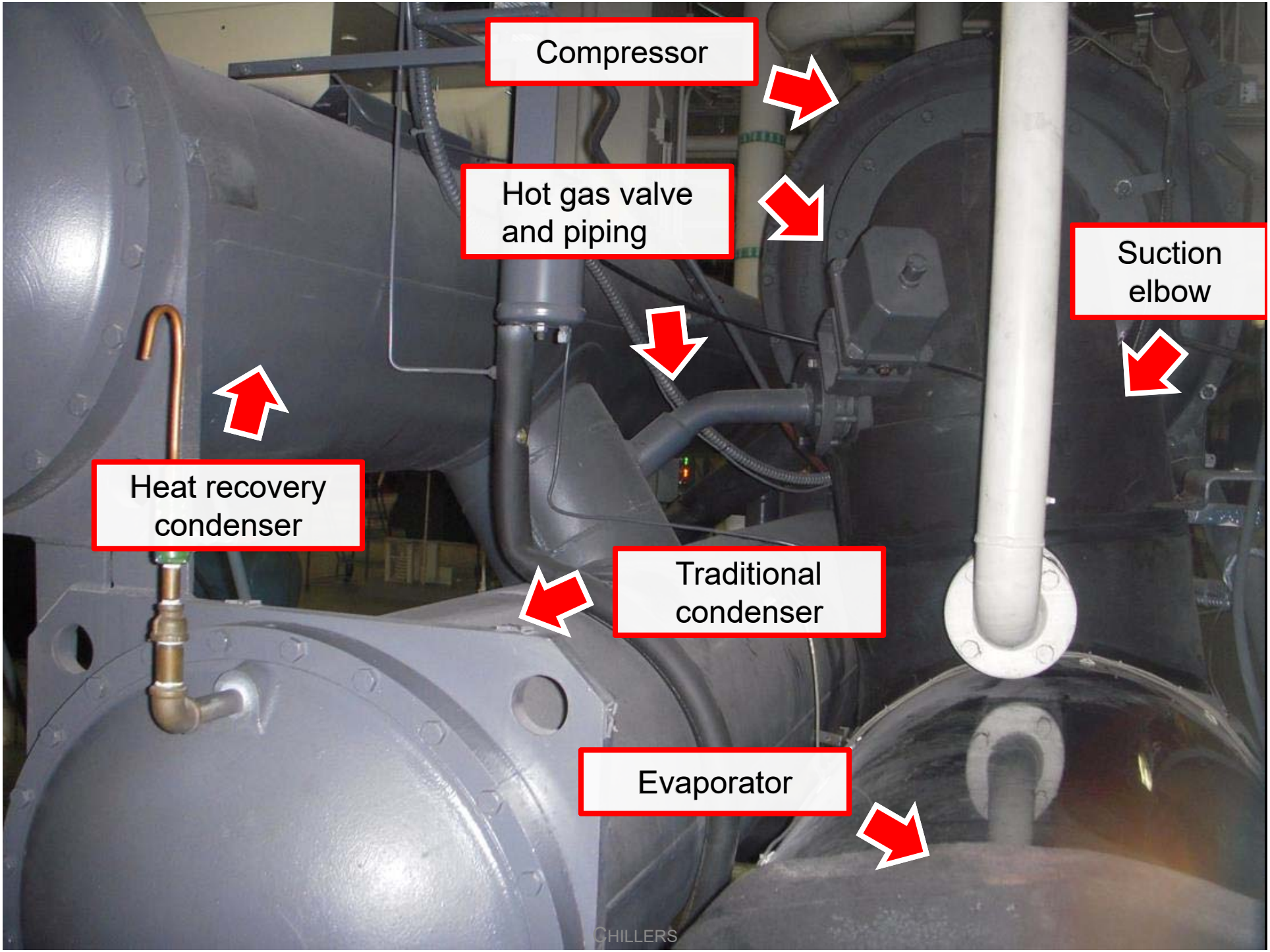
Start with the preceding and add energy for:

- Cooling tower fans (varies with wet-bulb temperature)
- Distribution pumps (varies with load) (hopefully)
- Plant design characteristic
  - Constant flow
  - Variable flow primary/secondary
  - Variable flow primary only

Good rule of thumb – Plant kW per ton = .85 – 1.05 kW/ton

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.


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