PROCESS COOLING SOLUTIONS

AIR CONDITIONING SYSTEMS

FUNDAMENTALS OF AIR COOLED CHILLERS

HVAC 2

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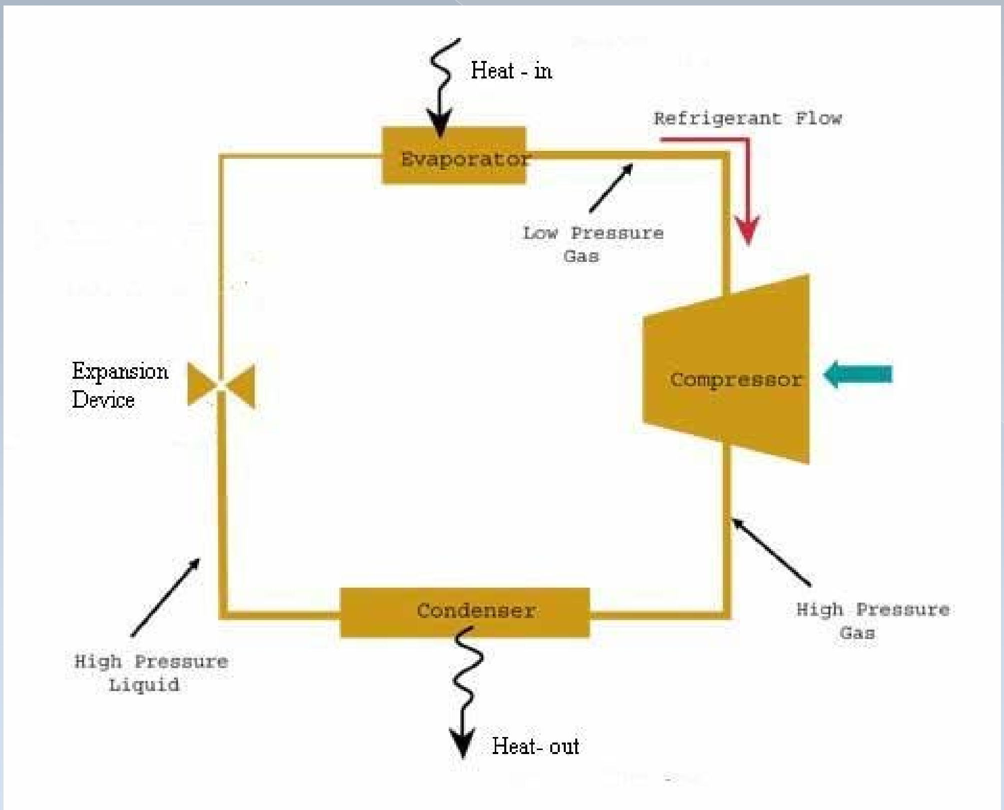
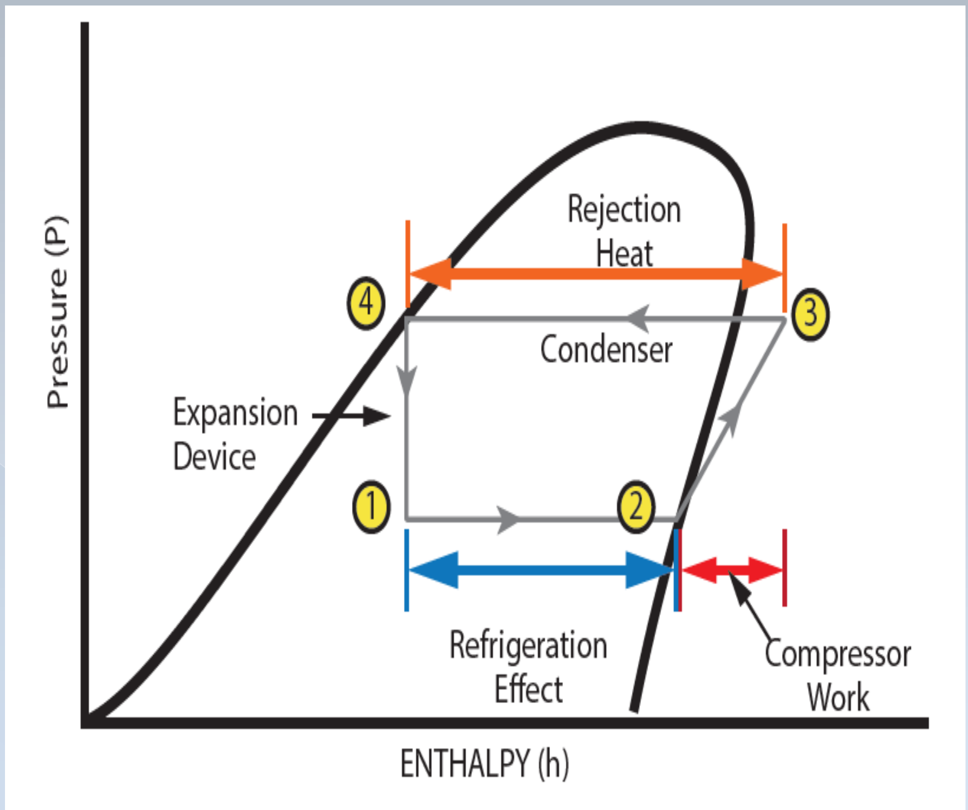
Refrigeration Cycle, P-H Diagram

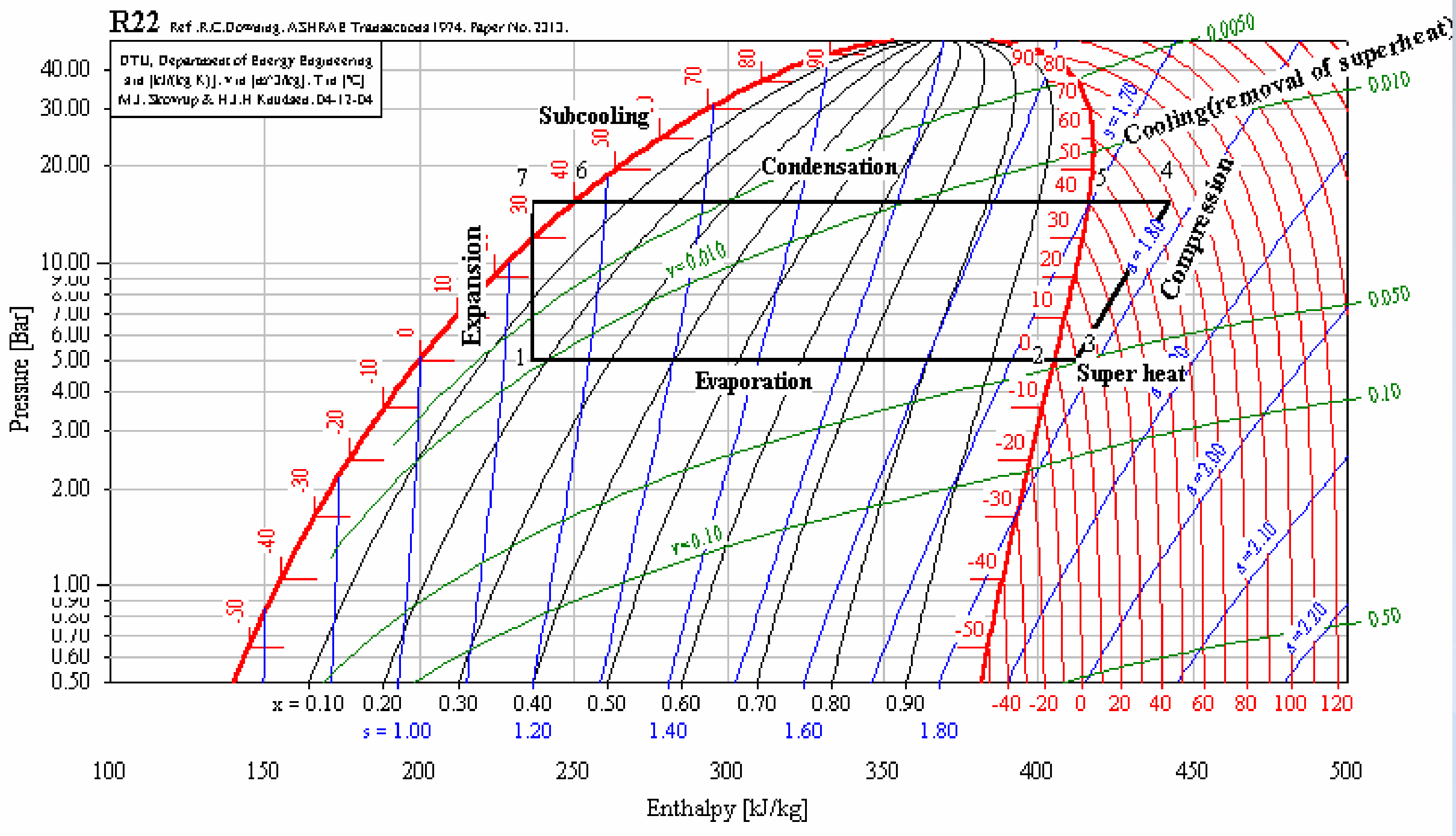




Refrigeration Cycle, P-H Diagram

Step 1-2-3: Absorption of heat by the liquid refrigerant and conversion to gas in the evaporator.
Step 3-4: Compression of low temperature, low pressure refrigerant gas from the evaporator to high temperature, high pressure gas in the compressor.
Step 4-5-6-7: Rejection of heat to the Air/Water in the condenser, resulting in condensation of the gaseous refrigerant to liquid at high pressure.
Step 7-1: Expansion of the liquid refrigerant from high condenser pressure to low evaporator pressure through a throttling valve, called expansion device or valve.

Pressure – Enthalpy Diagram for Vapor Compression System



Refrigeration System Efficiency

1 Ton of Refrigeration (TR) = 3023 kcal/h = 3.51 kW.thermal = 12000 Btu/hr

Coefficient of Performance (COP):

If both refrigeration effect and work done by the compressor (or the input power) are taken in the same units (TR or kcal/hr or kW or Btu/hr), the ratio is COP

$$\text{COP} = \frac{\text{Refrigeration Effect}}{\text{Work done}}$$

Energy Efficiency Ratio (EER):

If the refrigeration effect is quantified in Btu/hr and work done is in Watts, the ratio is

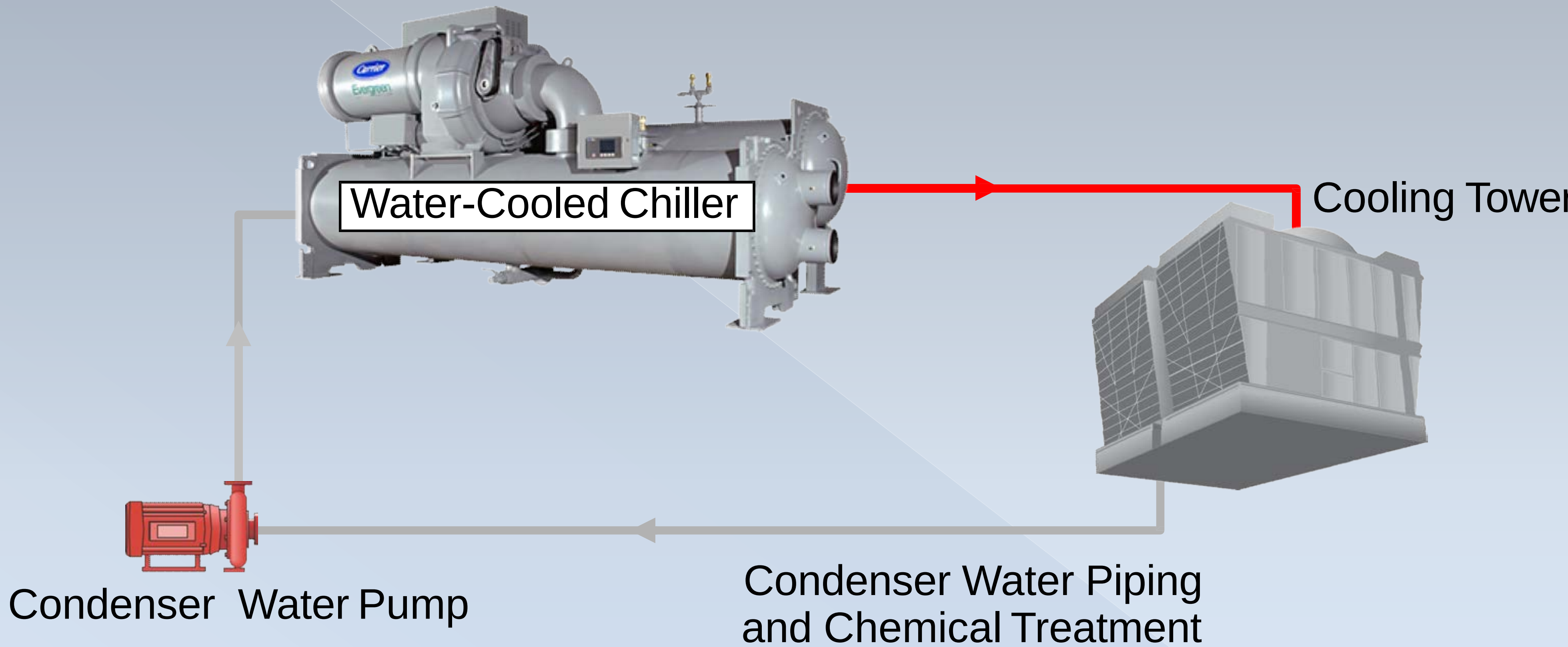
$$\text{EER} = \frac{\text{Refrigeration Effect (Btu/hr)}}{\text{Work done (Watts)}}$$

Higher COP or EER indicates better efficiency.

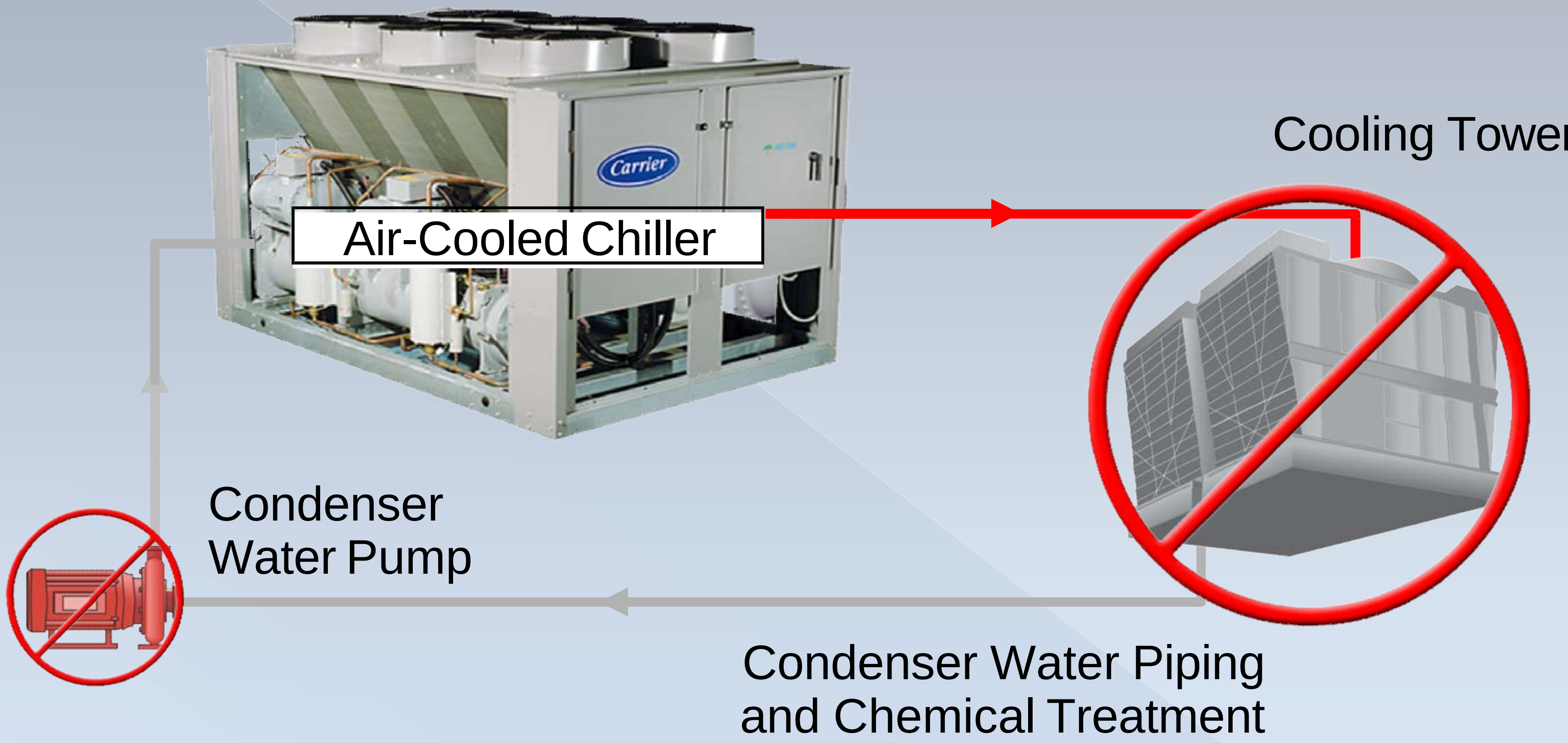
Specific Power Consumption:

$$\text{Specific Power Consumption} = \frac{\text{Power Consumption (kW)}}{\text{Refrigeration effect (TR)}}$$

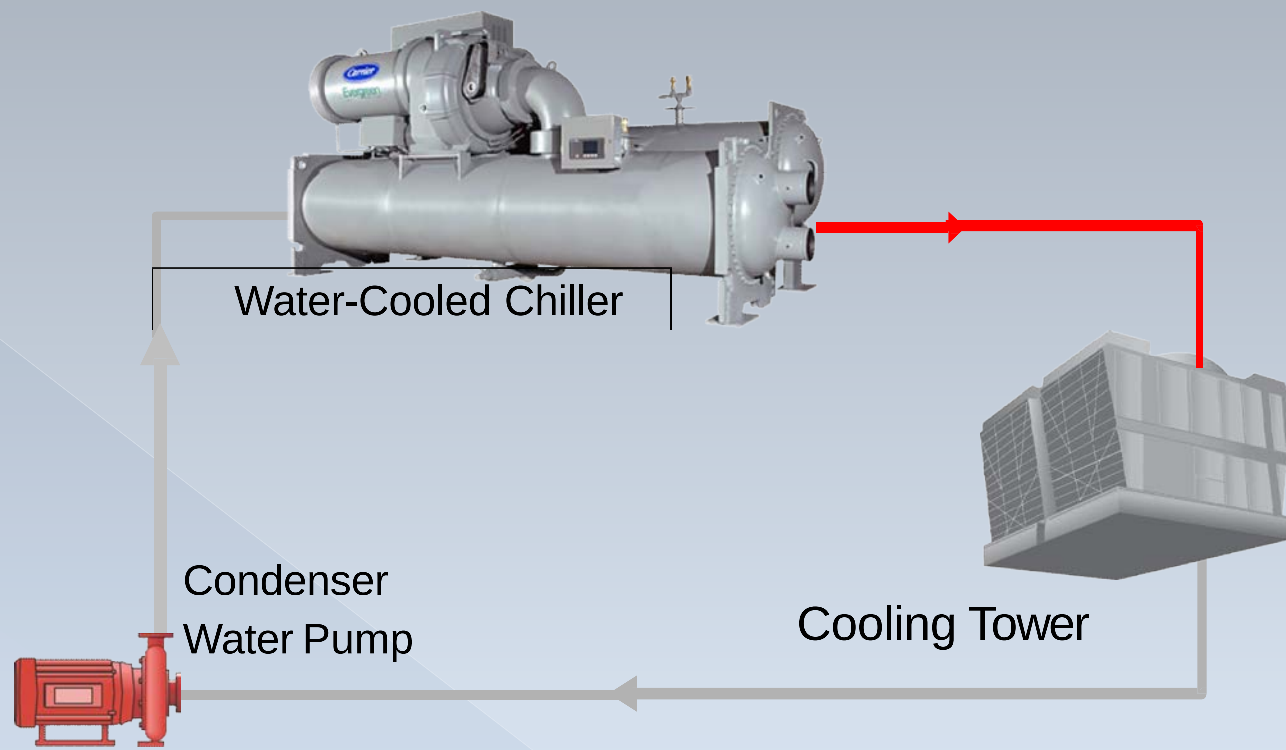
Water-Cooled Chiller System Requirements



Air-Cooled Chiller System Requirements



Air/Water-Cooled Chiller System Requirements



Air-Cooled Chiller

Water-Cooled Chiller

Air-Cooled vs. Water-Cooled Chillers

Air-Cooled Chiller Advantages

- Lower installed cost
- Quicker availability
- No cooling tower or condenser pumps required
- Less maintenance
- No mechanical room required

Water-Cooled Chiller Advantages

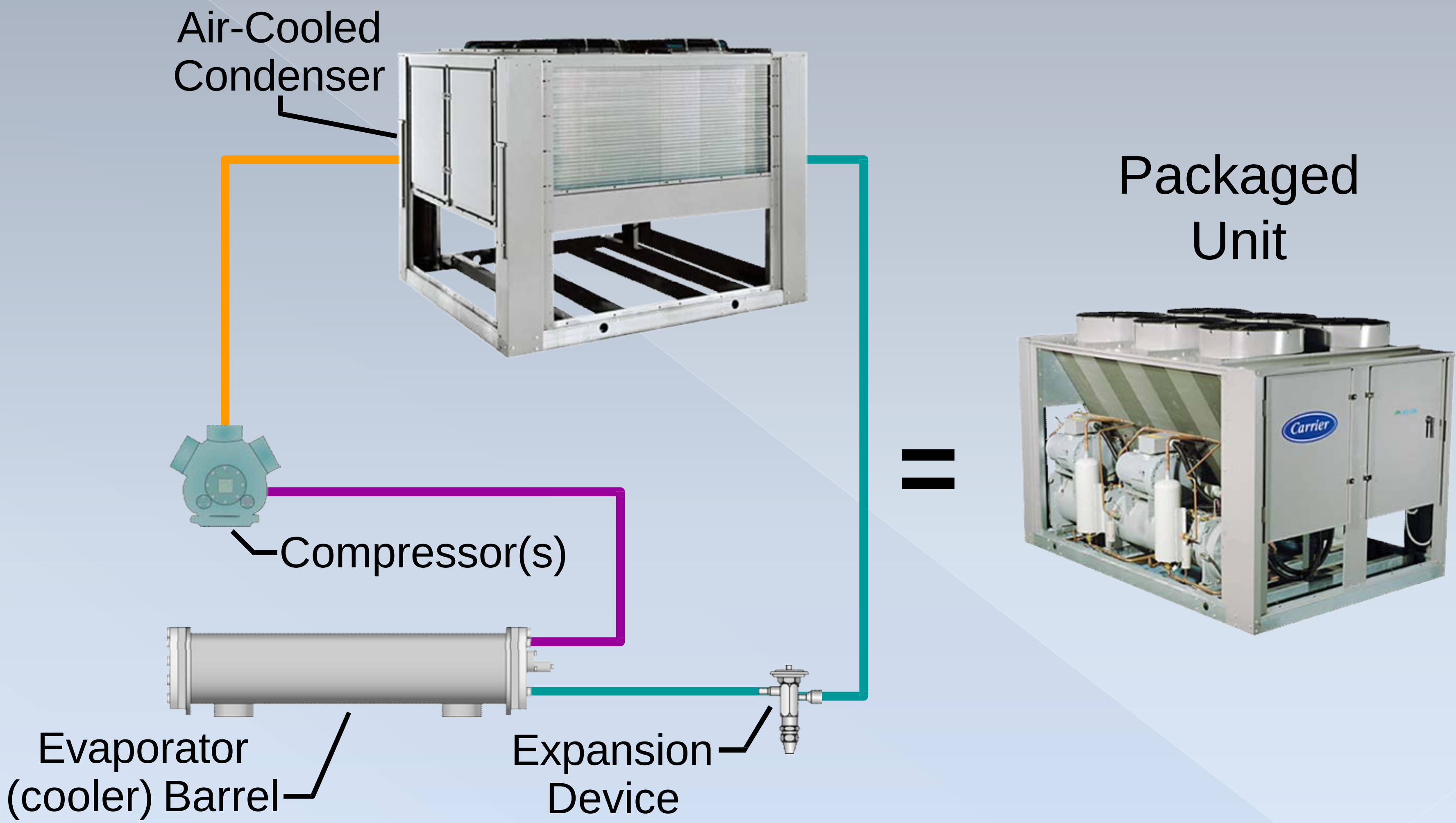
- Higher efficiency
- Custom selections in larger sizes
- Large tonnage capabilities
- Indoor chiller location
- Longer life

Air-Cooled vs. Water-Cooled Chillers

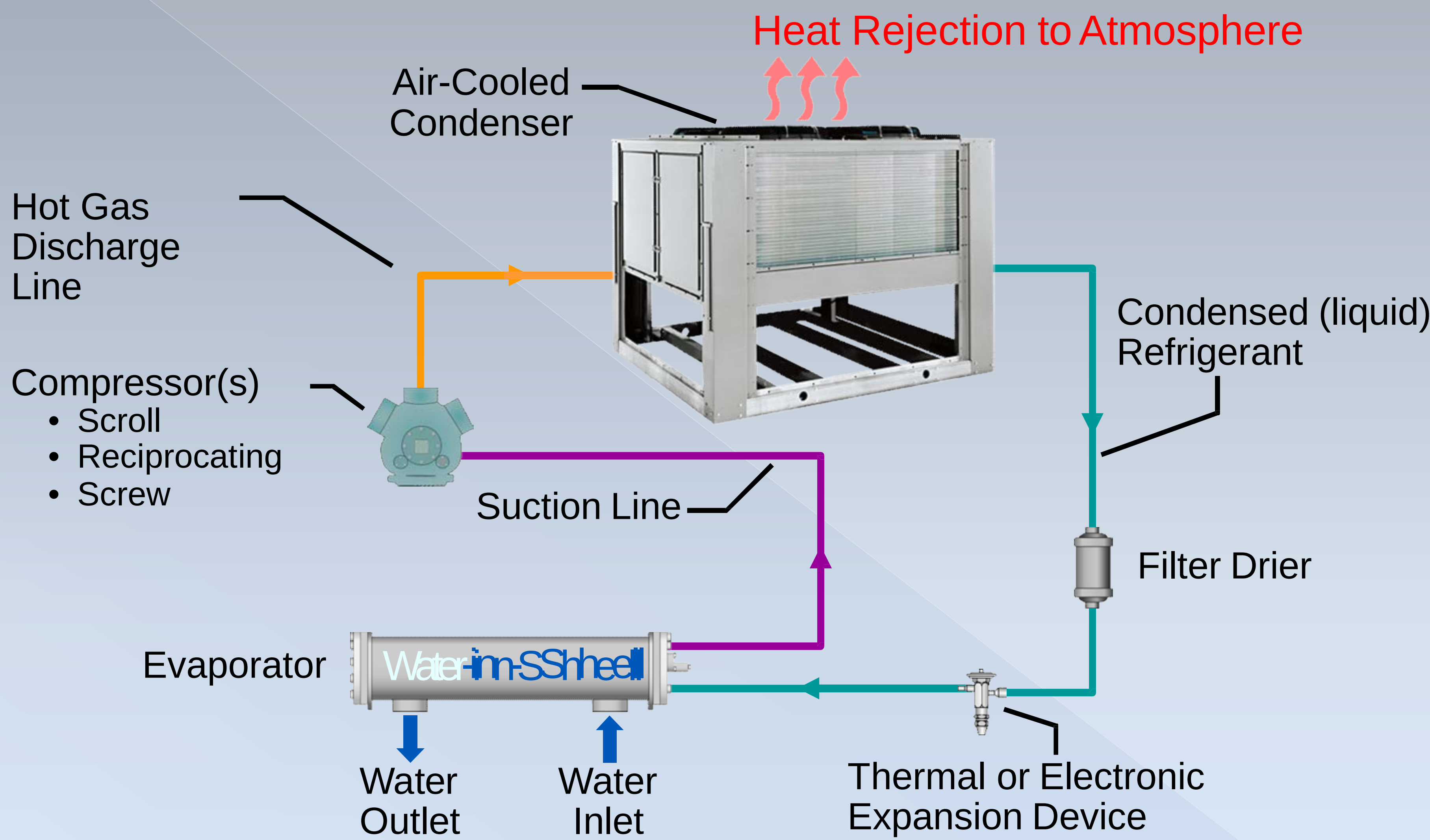
نوع		چیلر آب خنک DX	چیلر هوا خنک DX
ظرفیت	تن تبرید	100	100
دمای اشباع مکش	سانتیگراد	6.1	6.1
دمای اشباع دهش	ساتنیگراد	37.8	52.7
توان مصرفی کمپرسور	کیلووات	62.0	104.5
توان مصرفی پمپ آب	کیلووات	0	0
توان مصرفی فن کندانسور / پمپ برج	کیلووات	13.5	7.8
توان مصرفی کل سیستم	کیلووات	75.5	112.3
توان مصرفی ویژه	تن تبرید / کیلووات	0.76	1.12

Type	DX chiller (air cooled condenser)	DX chiller (water cooled condenser)
Capacity, TR	100	100
Saturated Suction temp, °C	6.1	6.1
Saturated Discharge temp, °C	52.7	37.8
Compressor power, kW (a)	104.5	62.0
Chilled water pump, kW (b)	0.0	0.0
Condenser cooling fan/pump (c)	7.8	13.5
Total power, kW (a) + (b) +(c)	112.3	75.5
Total Specific power, kW/TR	1.12	0.76

Air-Cooled Chiller Package

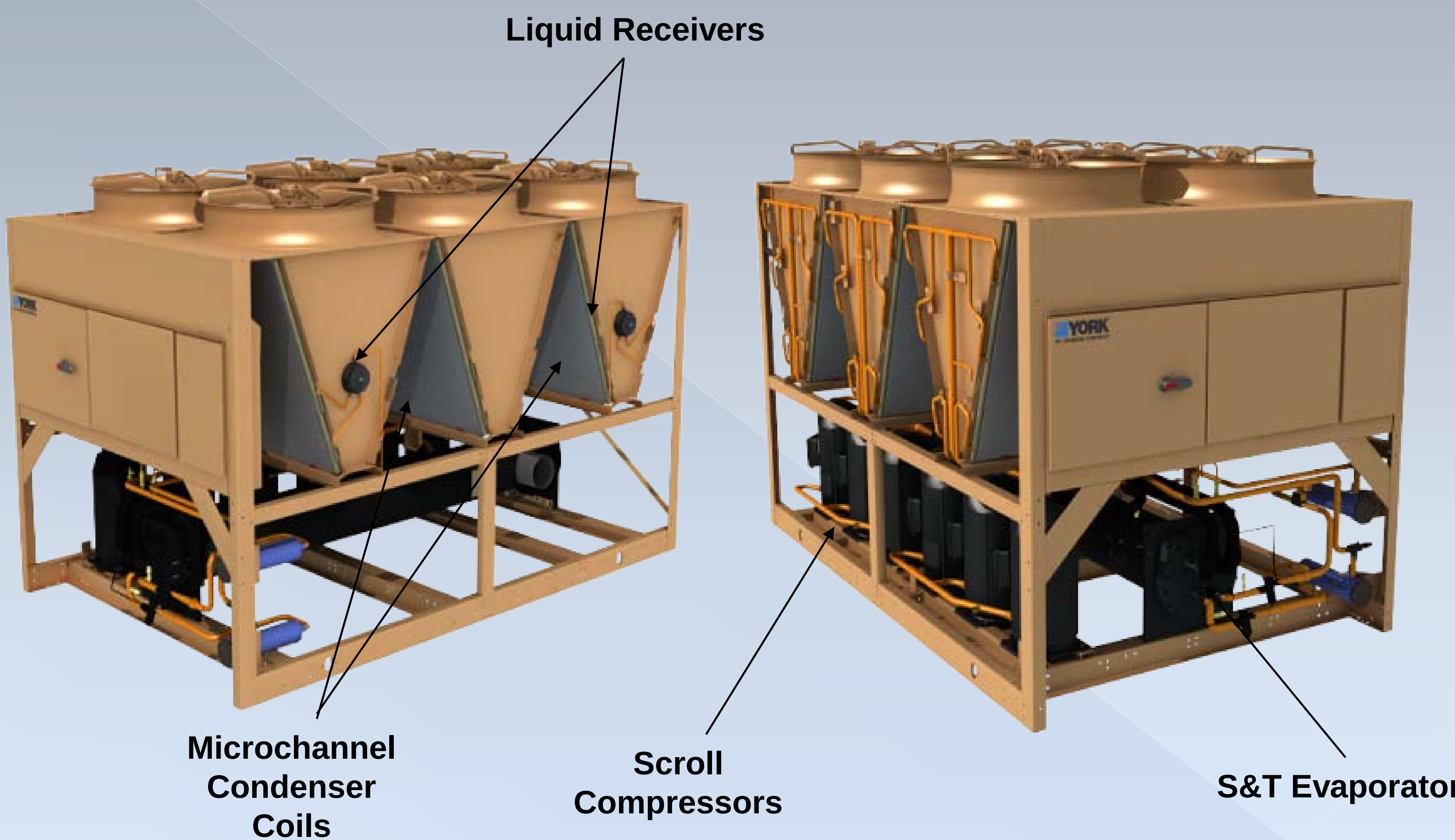


Air-Cooled Chiller Cycle

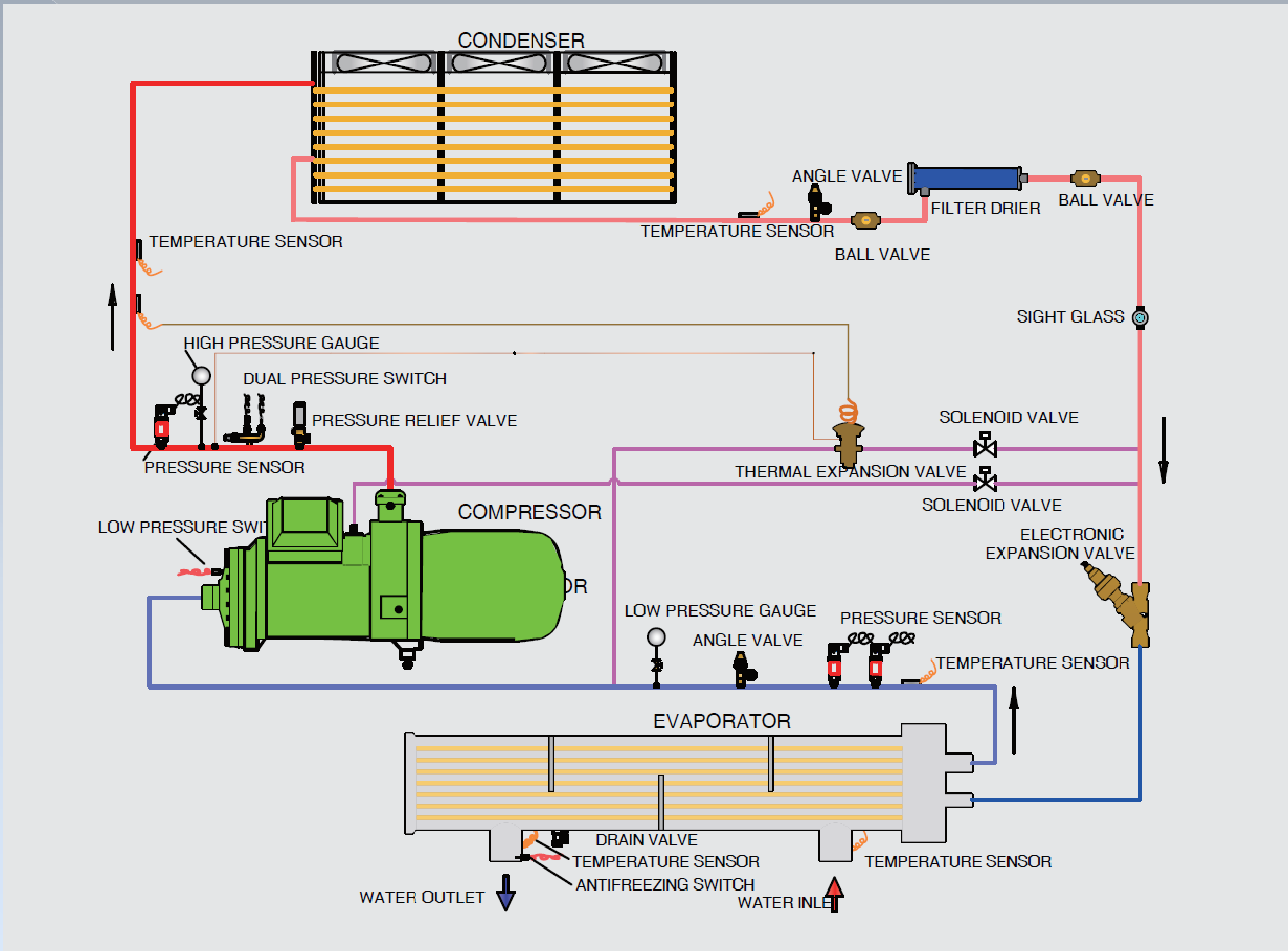


*Flooded cooler, which has water in the tubes, is also used

Air-Cooled Chiller Components



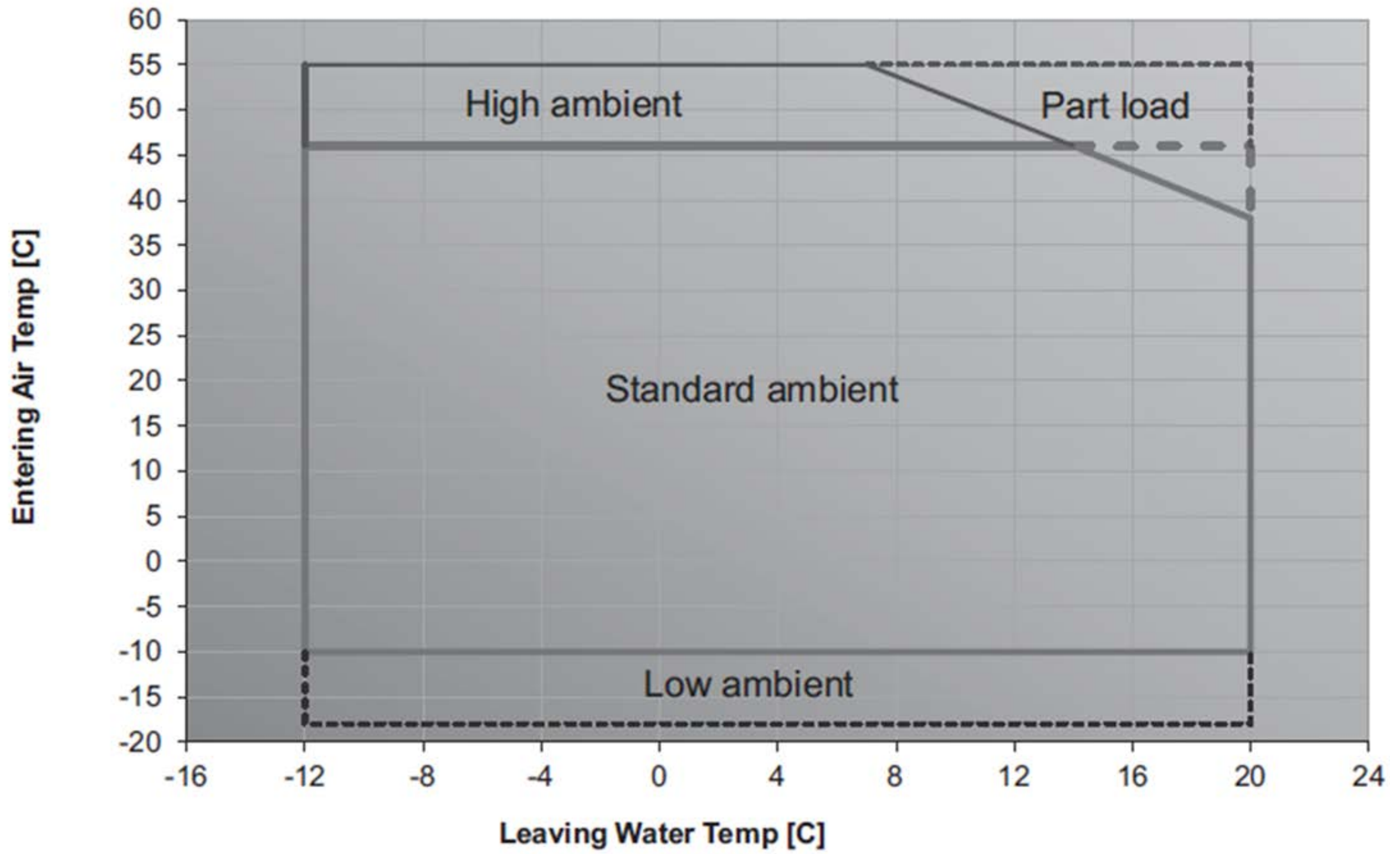
PIPING AND INSTRUMENTATION



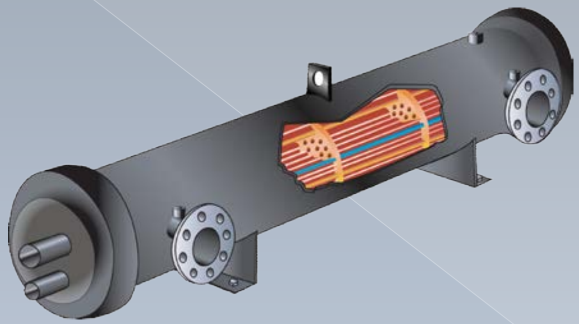
Air-Cooled Chiller Operating Map

* Standard ambient units:	-10°C ≤ Air temperature ≤ 46°C.
* Low ambient units:	-18°C ≤ Air temperature ≤ 46°C
* High ambient units:	-10°C ≤ Air temperature ≤ 55°C

Note: It is not possible to have a unit operate low and high ambient.

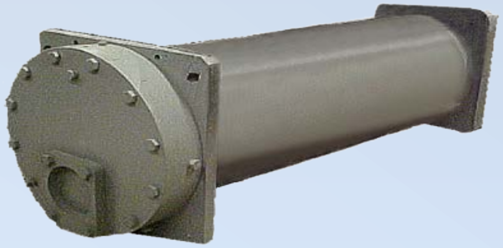


Three Types of Evaporators



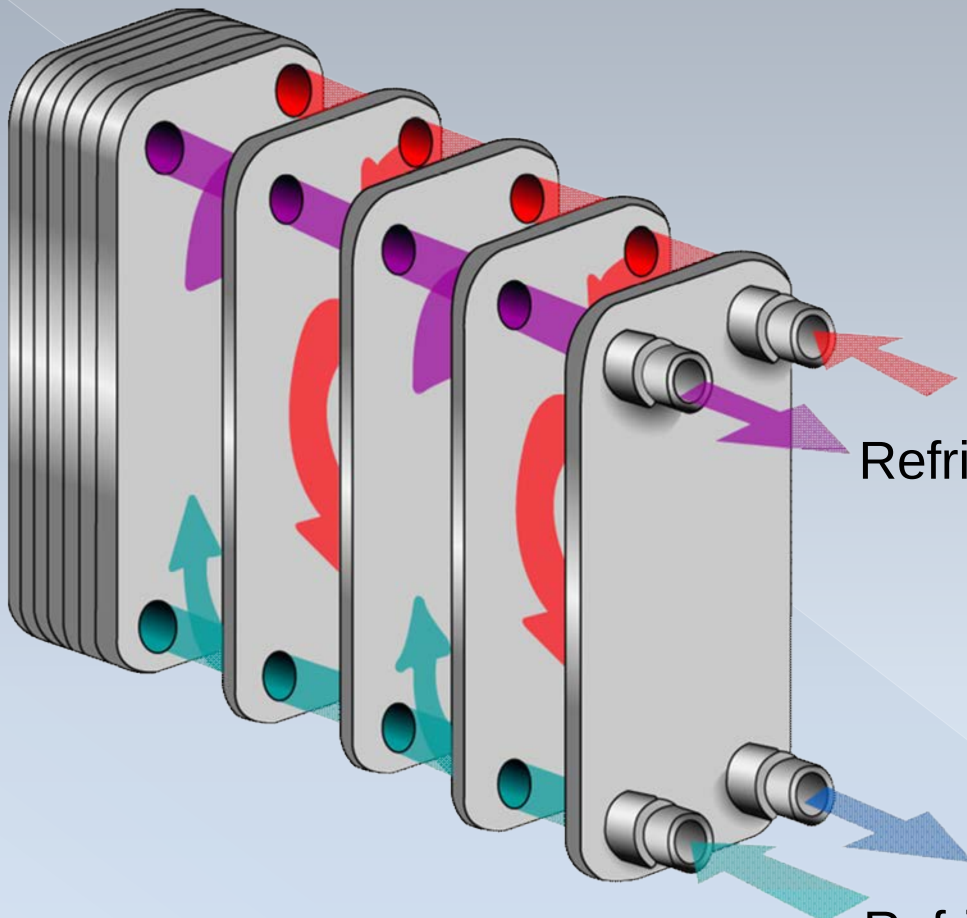
DX Shell-and-Tube

Brazed-Plate



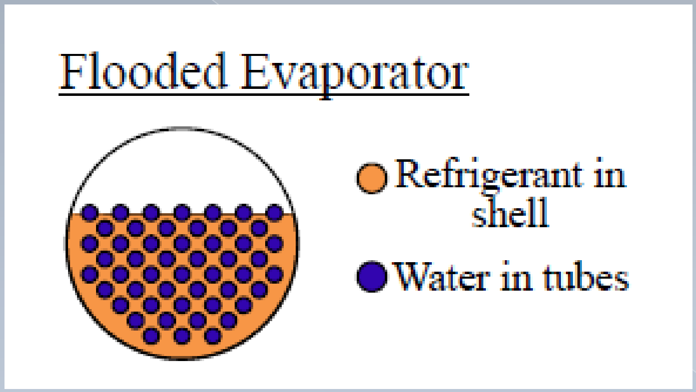
Flooded Shell-and-Tube

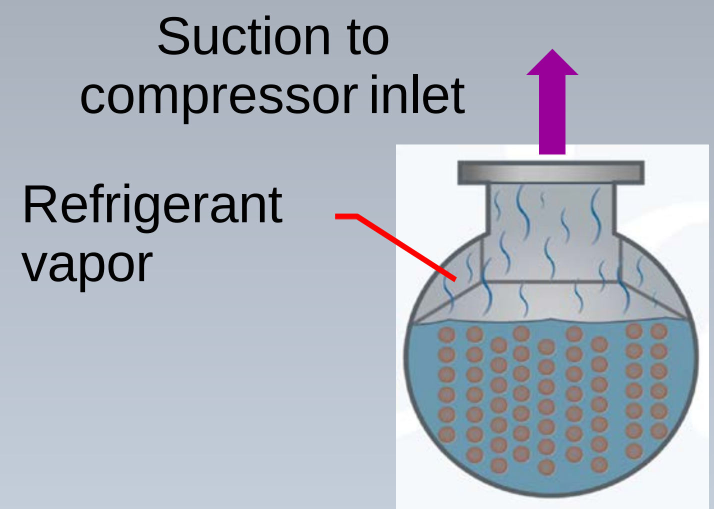
Brazed-Plate Evaporator

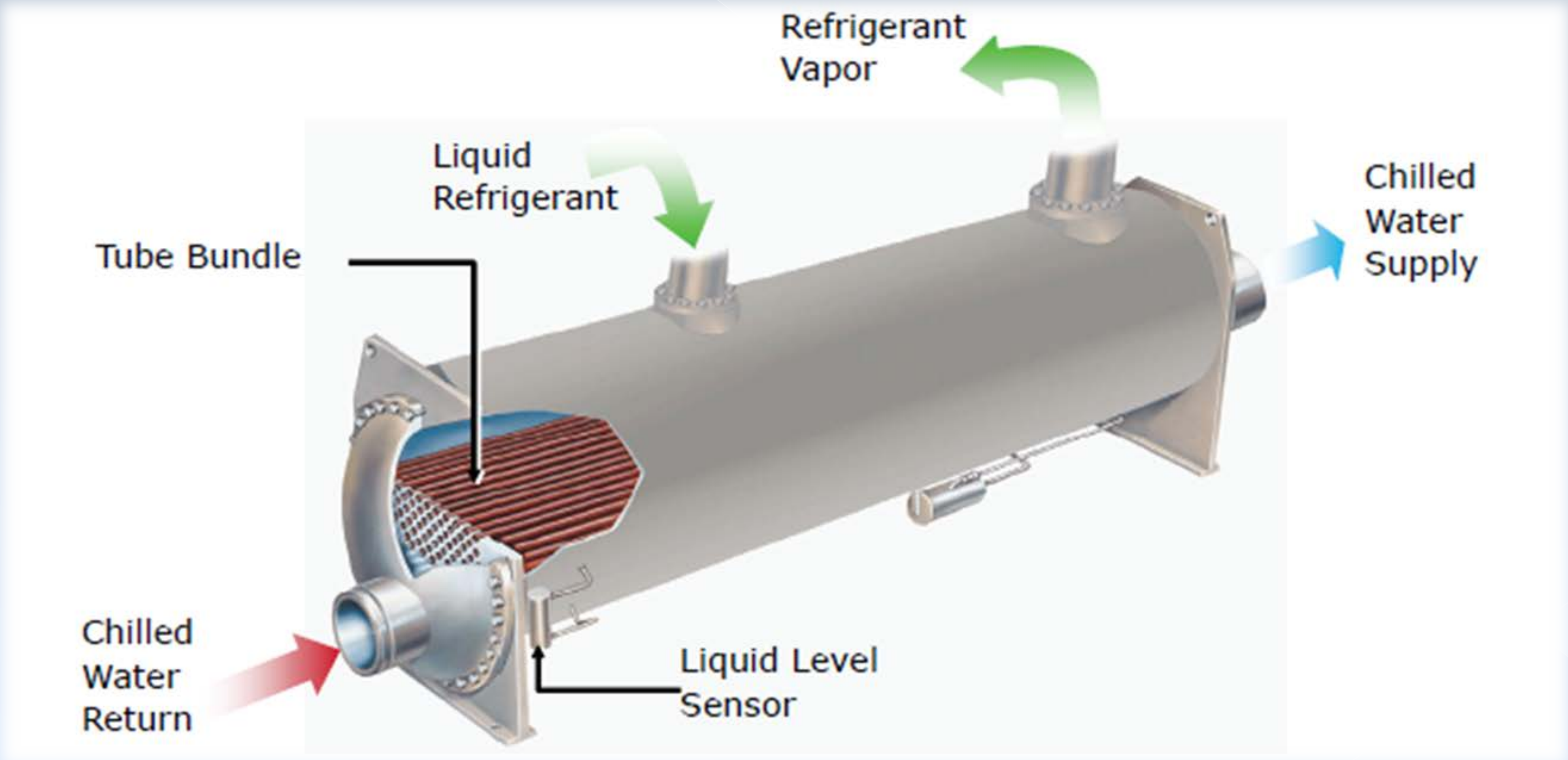


Note: Brazed-Plate Heat Exchangers are also used as condensers

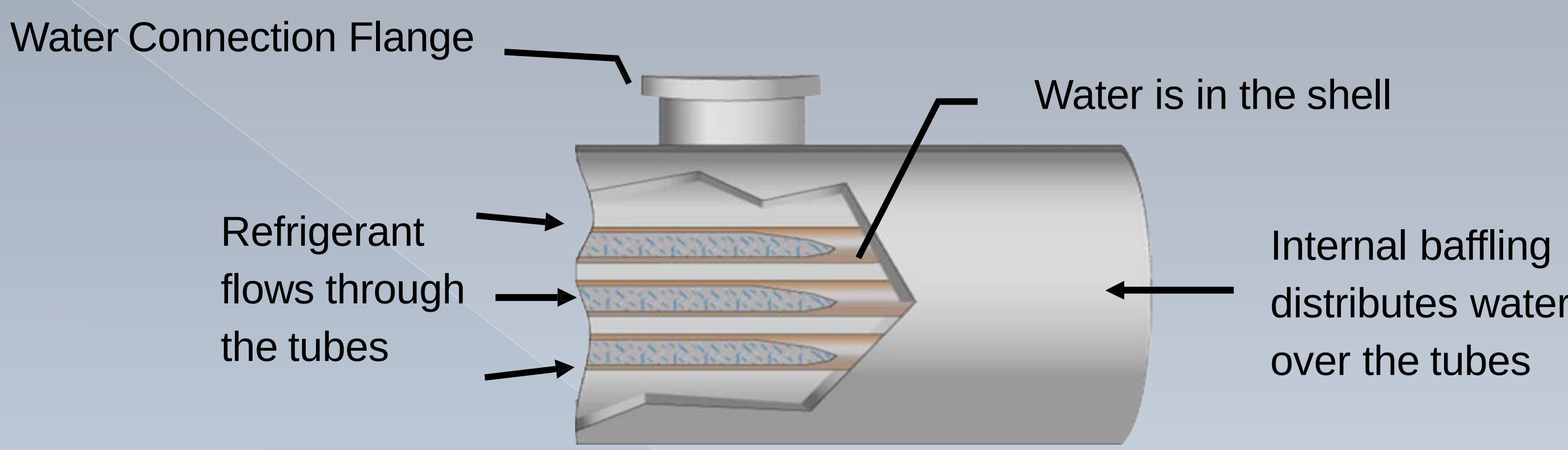
Flooded Shell-and-Tube Evaporator

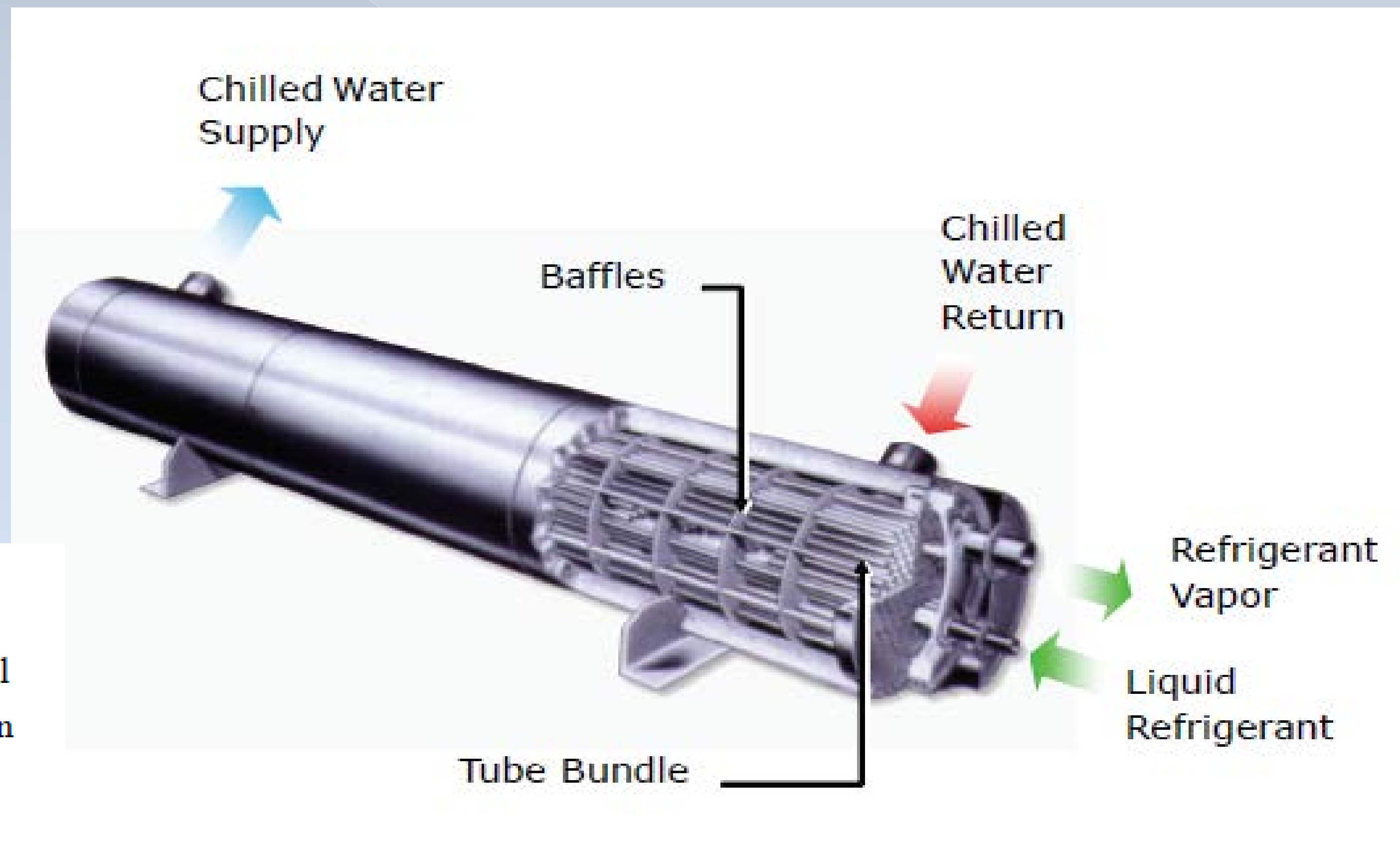


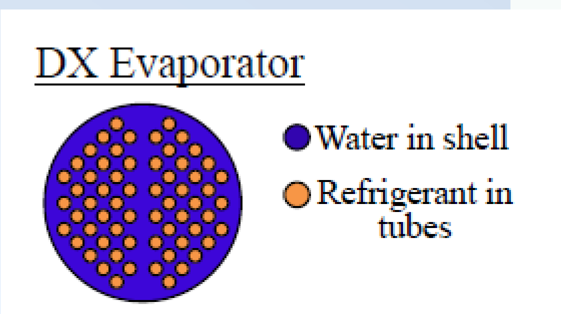




Direct Expansion Shell-and-Tube Evaporator







Variable Flow Minimum and Maximum Flow Rates

For variable flow, the maximum rate of change per minute is 10% of the design flow rate.

Flooded Cooler

Minimum flow is the gpm that corresponds to 3.0fps water velocity in the tubes

Maximum flow results in an approximate 5° F ΔT in cooler

Maximum flow is approximately 5 gpm/ton

DX Cooler

Minimum flow is the gpm that corresponds to 1.0fps water velocity in the shell

Maximum flow results in an approximate 5° F ΔT in cooler

Maximum flow is approximately 5 gpm/ton

Effects of Leaving Chilled Water Temperature

Typical Air-Cooled Chiller at 95° FAmbient

Leaving Chilled Water Temperature °F	kW / Ton	%Change Efficiency per °F	%Change Efficiency From 44° F
44	1.237	–	–
43	1.253	-1.1	-1.1
42	1.266	-1	-2.2
41	1.280	-1.1	-3.5
40	1.295	-1.2	-4.6

Effects of Ambient Air Temperature

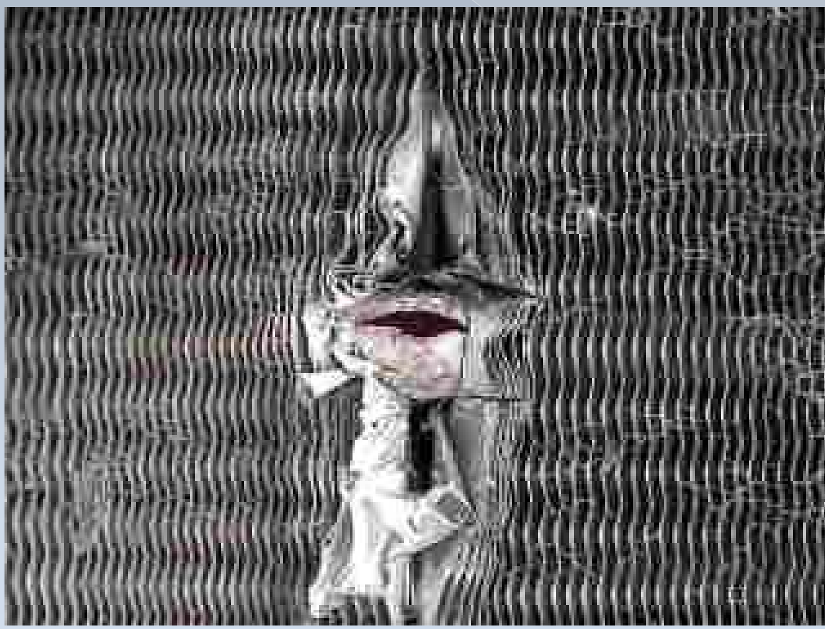
Typical Air-Cooled Chiller Full Load

Entering Air °F	Tons	kW/Ton	%Change Capacity	%Change Efficiency
75° F	112.1	0.952	+15	+20
85° F	105.5	1.069	+8	+11
95° F	97.5	1.208	–	–
105° F	89.5	1.384	-8	+15
115° F	81.2	1.621	-17	-35
125° F	73.1	1.923	-25	-60

Freeze Protection Methods

- **Drain the chiller loop**
- **Use cooler heater**
- **Circulate the water continuously**
- **Use antifreeze solution**
- **Combinations of the above**

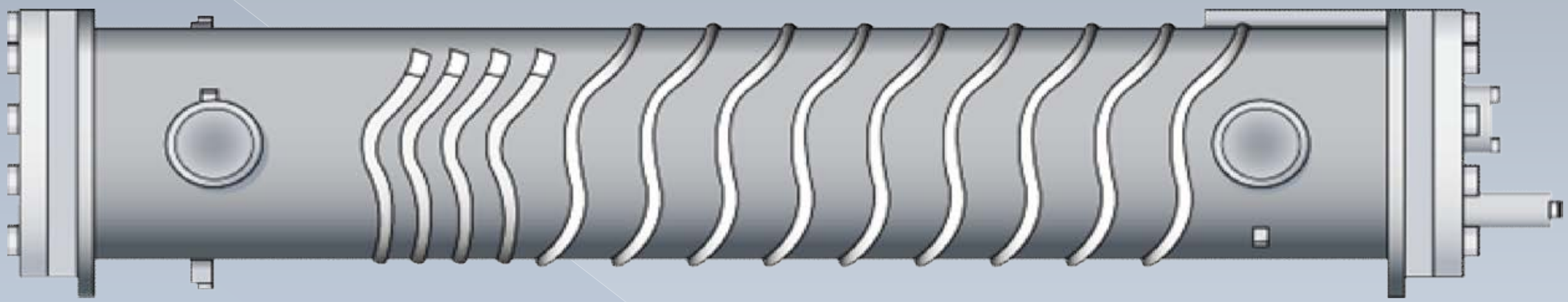
Freeze Damage



Burst Coil

Cracked Housing

Evaporator Barrel Heater



- Refrigerant in tubes
- Water (glycol) in shell
- Heater cable wrapped around the shell
- Factory or field-installed

Freeze vs. Burst Protection

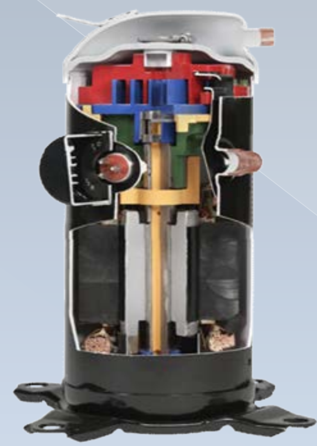
	Propylene Glycol	
Protection Temperature (°F)	For FREEZE protection **% by weight	For BURST protection **% by weight
+20	18	12
+10	29	20
0	35	25
-10	41	29
-20	45	30
-30	48	32
-40	52	34

**Confirm with the local glycol supplier

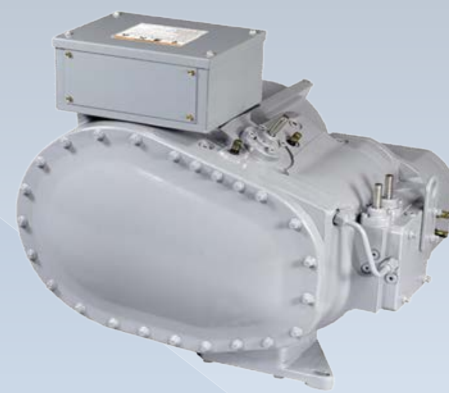
Compressor Types

Four types of compressors used in air-cooled chillers:

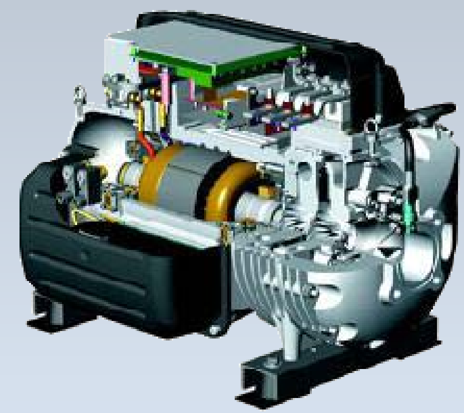
Reciprocating



Scroll

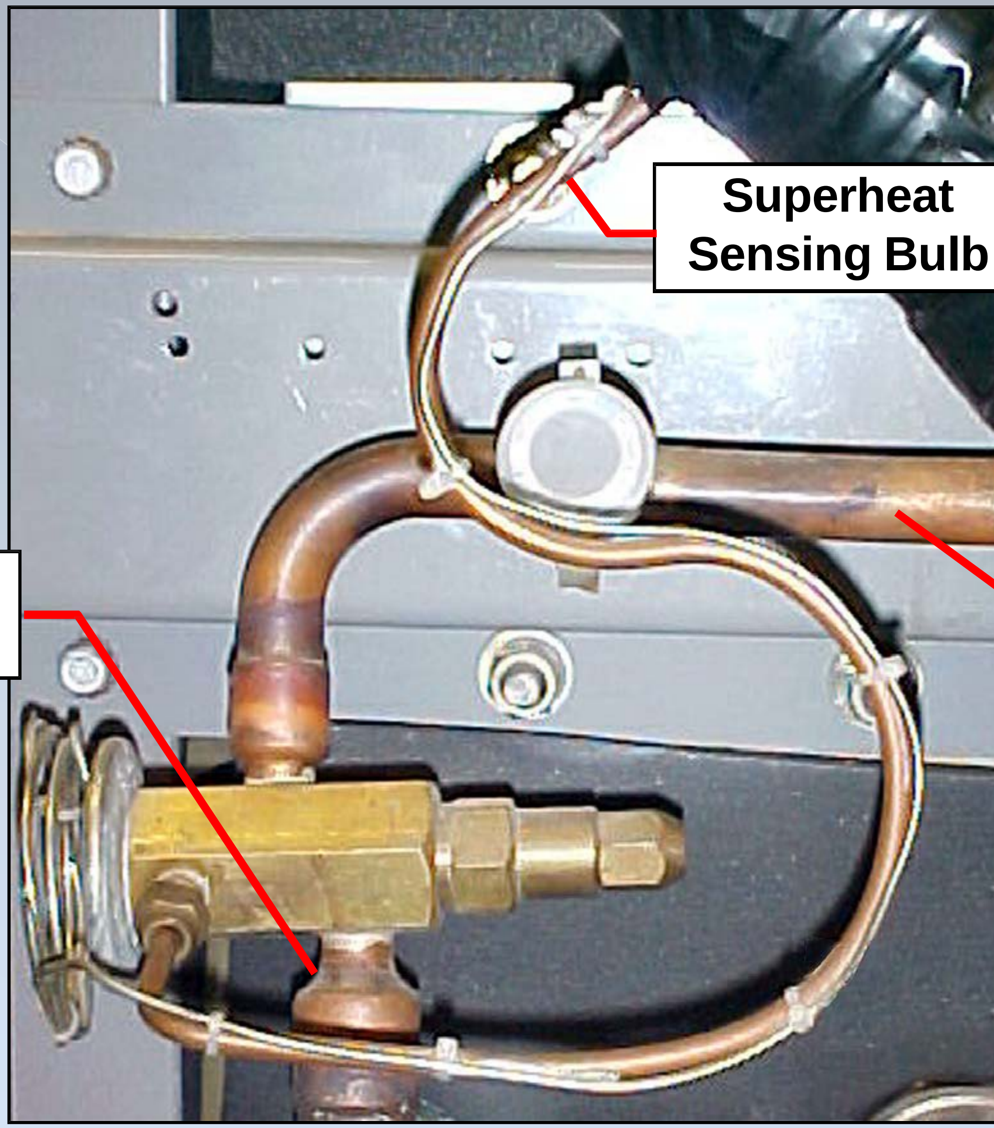


Screw

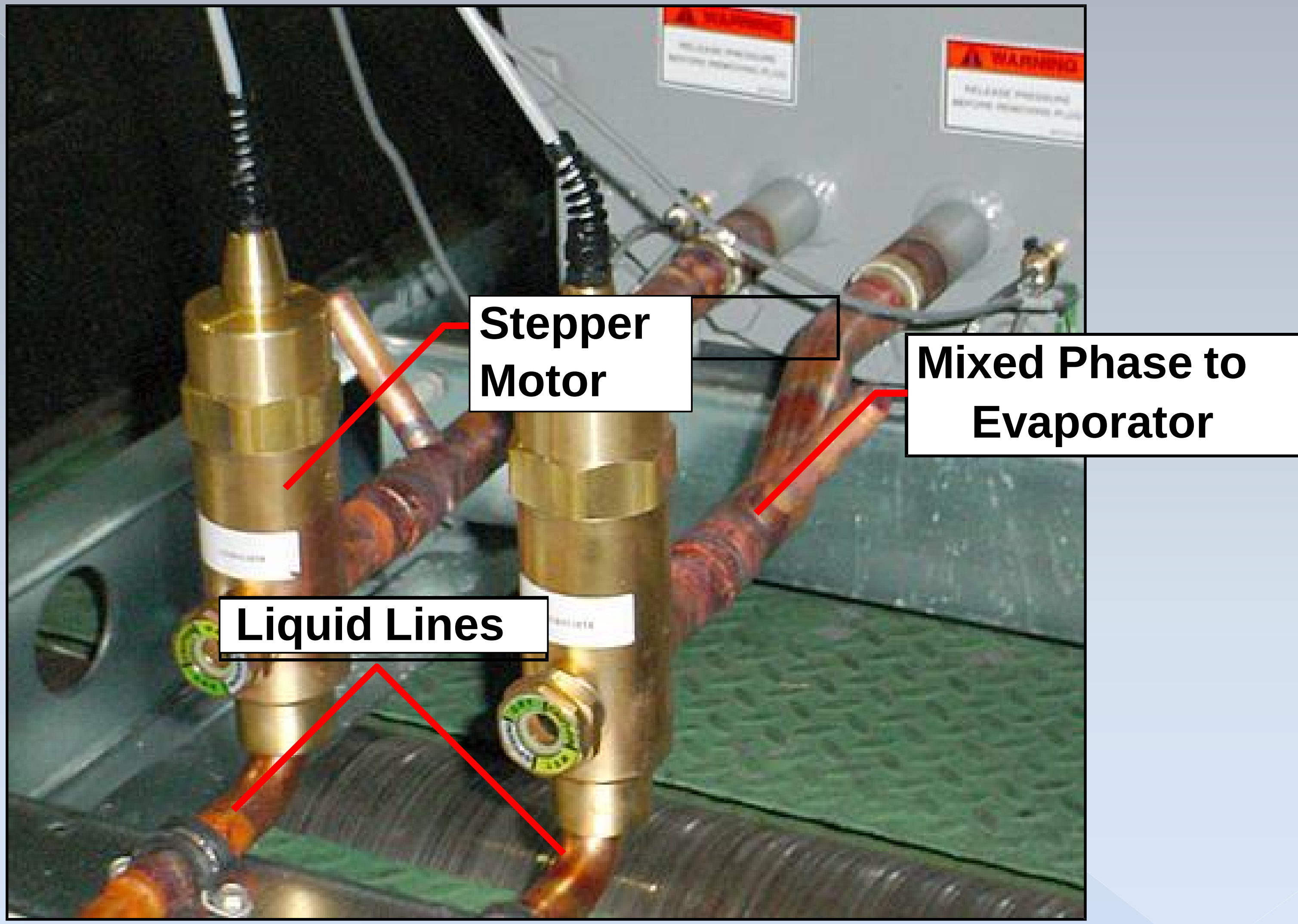


Centrifugal

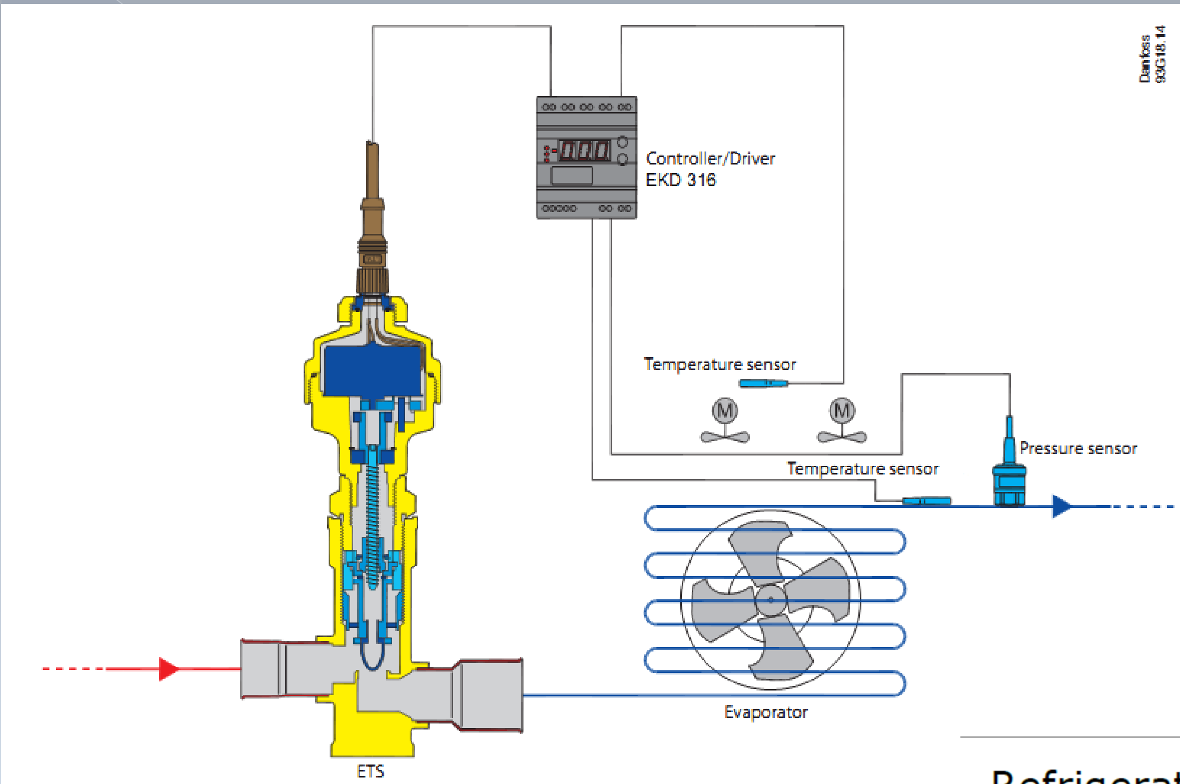
Horizontally Mounted TXV

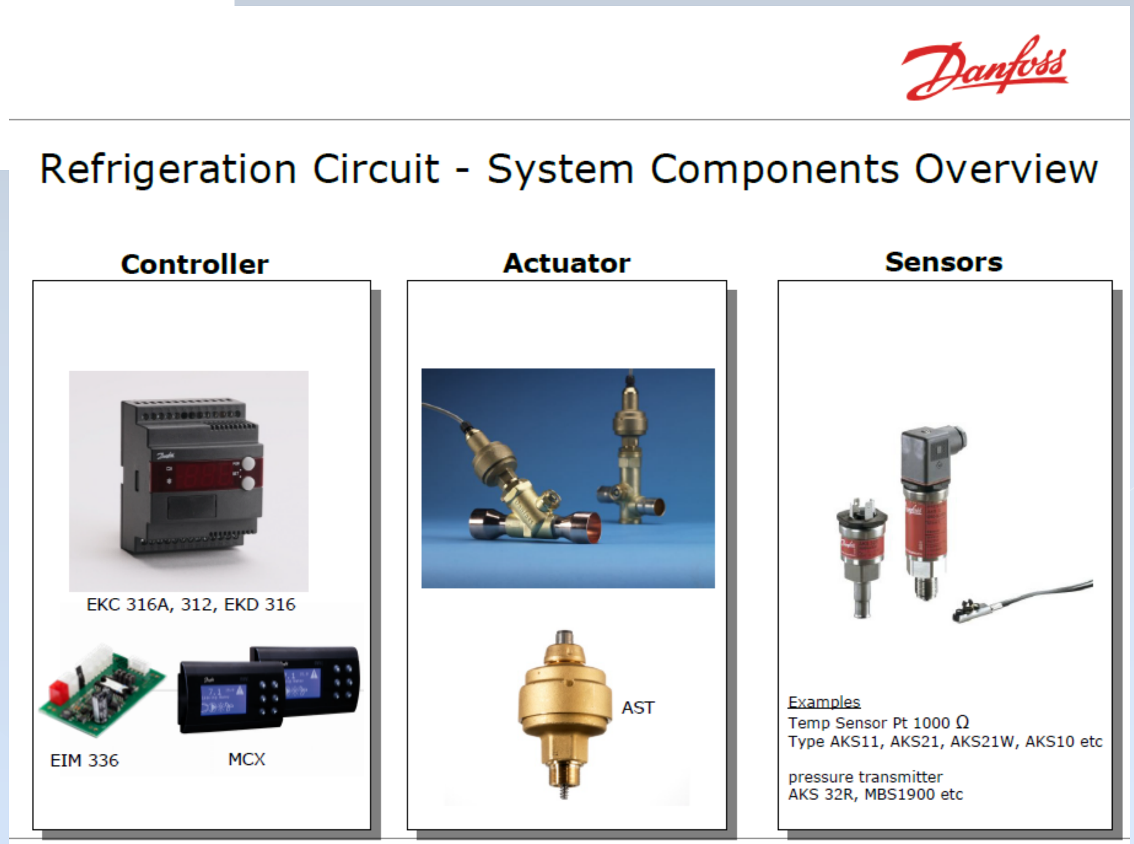


EXV Expansion Device



EXV Expansion Device





EXV Expansion Device Features & Benefits

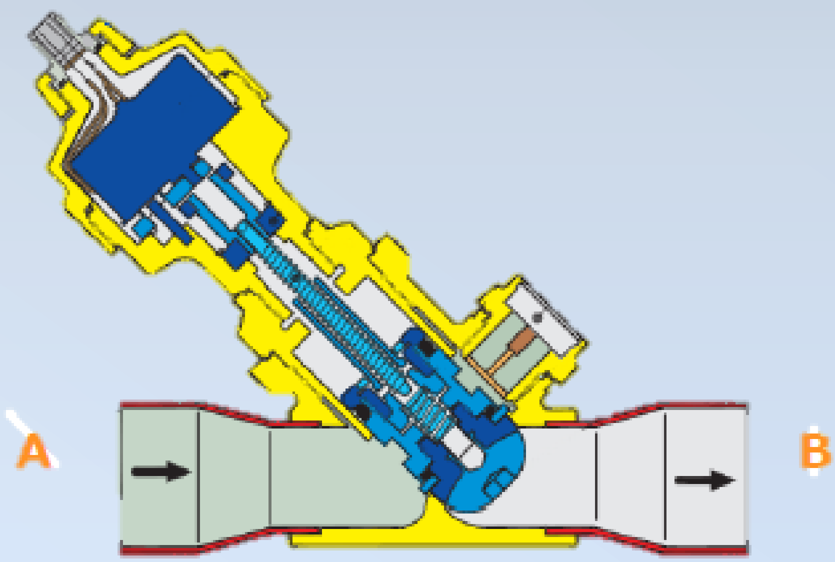
Features	Benefits	Installers	Wholesalers	End users
Precise control of liquid injection	Energy saving	Value selling	Value selling	Reduced running costs
Optimized for part loads	High flexibility		Stock optimization	Precise regulation – reduced running costs
Bi-flow operation and solenoid tight shut-off	Reversible systems	Save time (less components)	Stock optimization	
Wide range for all common Refrigerants, HFC/ HCFC	Multi refrigerant		Stock optimization	
Integrated sight glass with moisture indicator (ETS 50/100/250/400)	Refrigerant monitoring	System safety	Stock optimization	Reduced component costs
Bi-metal connections (ETS 50/100)	Waterless brazing	Save time	Value selling	Fast soldering
Corrosion resistant design	High quality			Improved life time
Low power consumption	Improved energy efficiency	Value selling	Value selling	Energy saving

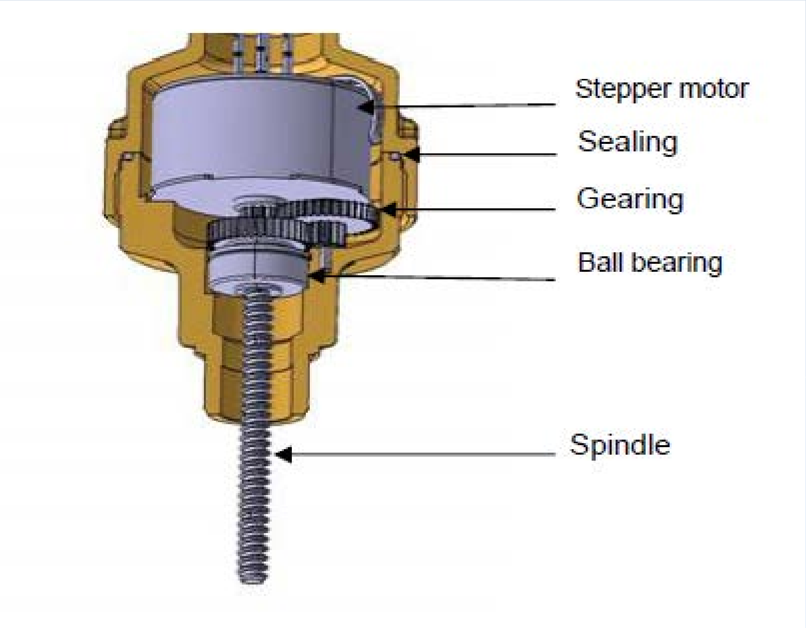
EXV Expansion Device Operation

Electrical pulses controls the activation of the stepper motor.

The direction of the rotation of the spindle depends on the phase relationship of the power pulses.

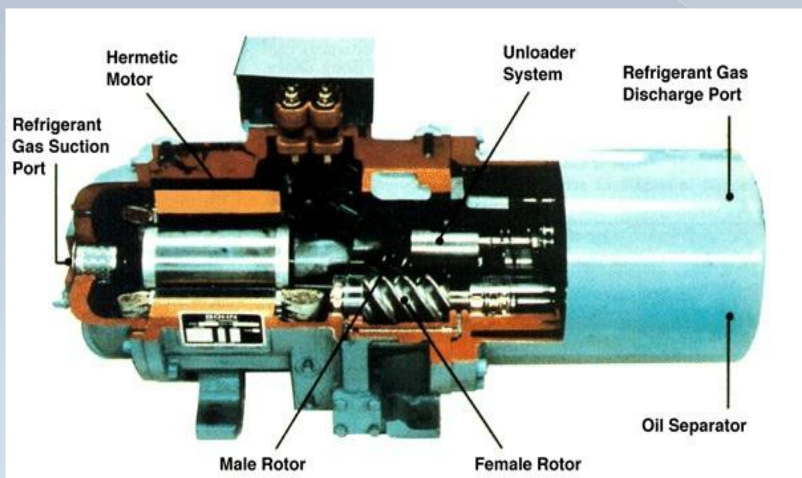
The rotation of the spindle is transformed into linear motion.





Capacity Control

Multiple Scroll Chiller Design
Cycling Compressors

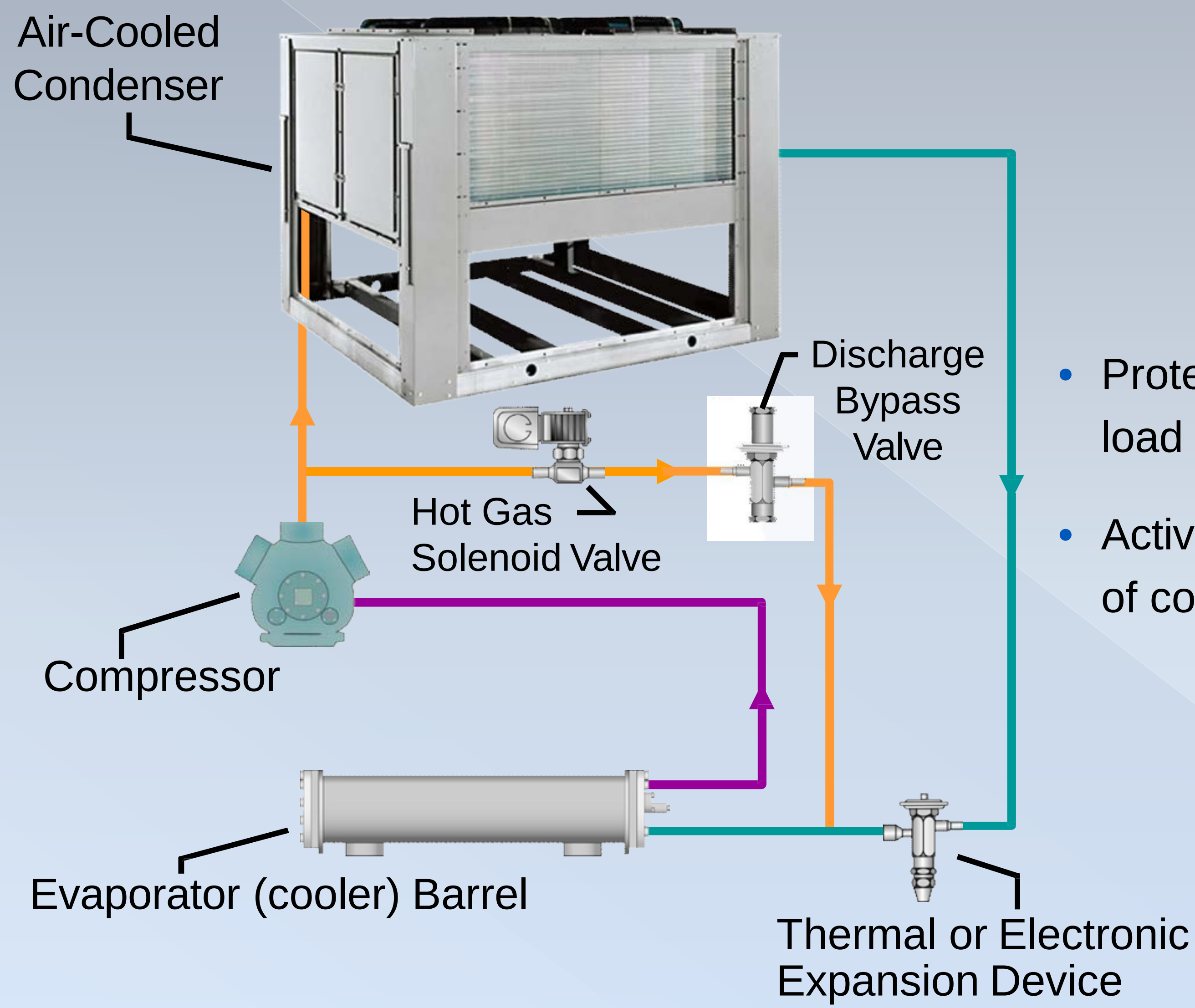


Capacity Control Slide-Valve

Capacity Control VFD

Capacity Control

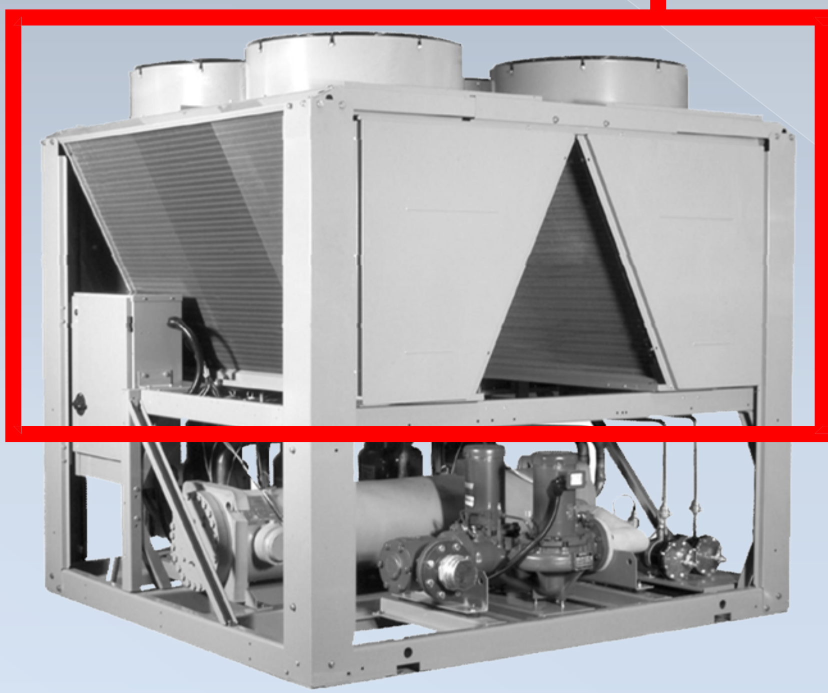
Hot Gas Bypass



- Protects system in low-load conditions
- Active at minimum step of cooling only

Condenser

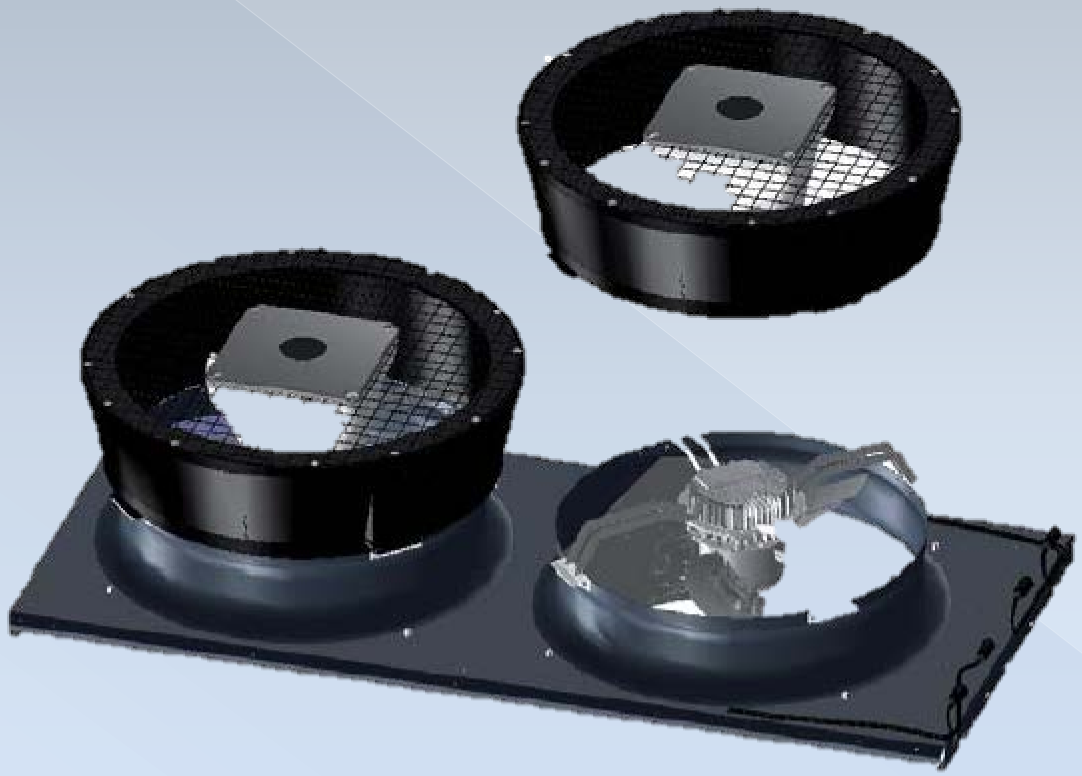
Vertical Discharge Propeller Fans



Aerodynamically designed condenser fan deck

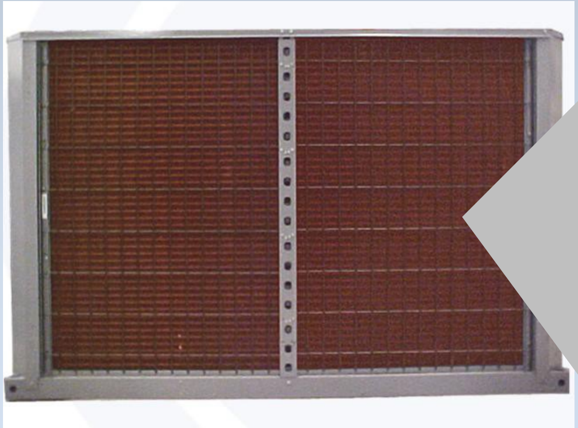
Condenser Fans

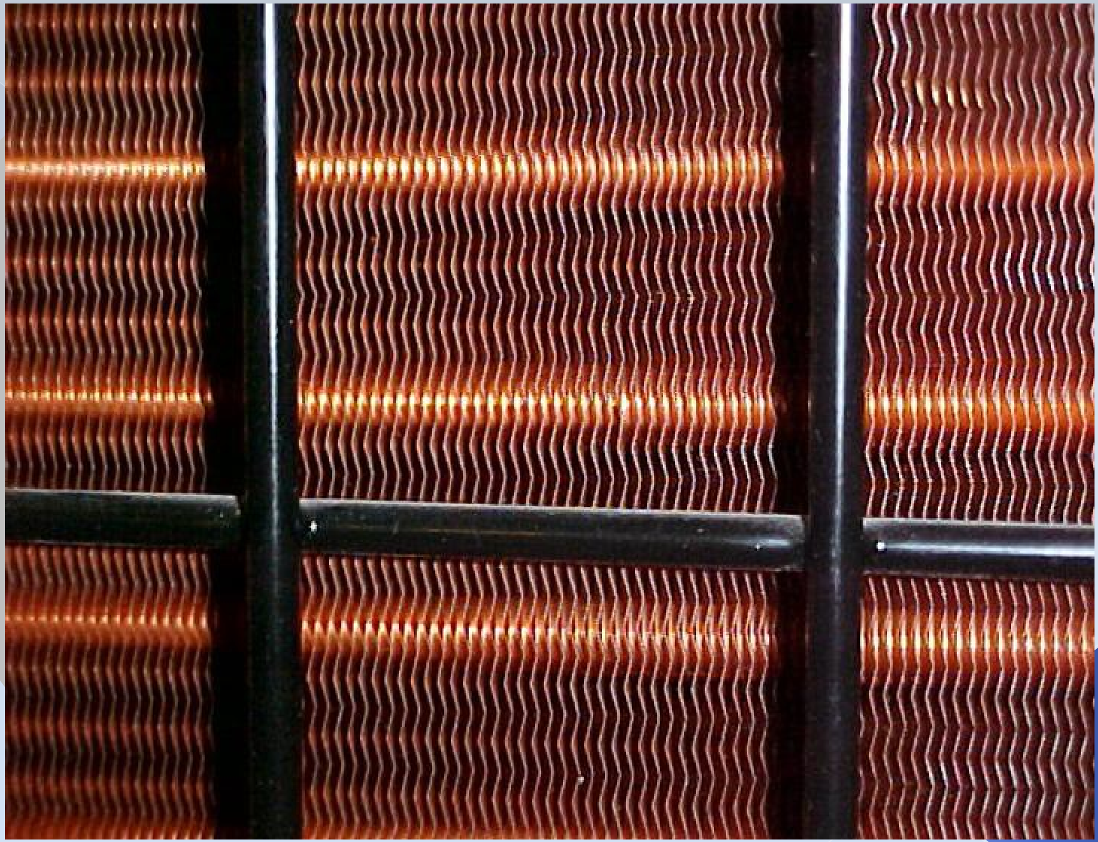
EC fans are equipped with a diffuser to get an air flow optimization and a quieter operation.



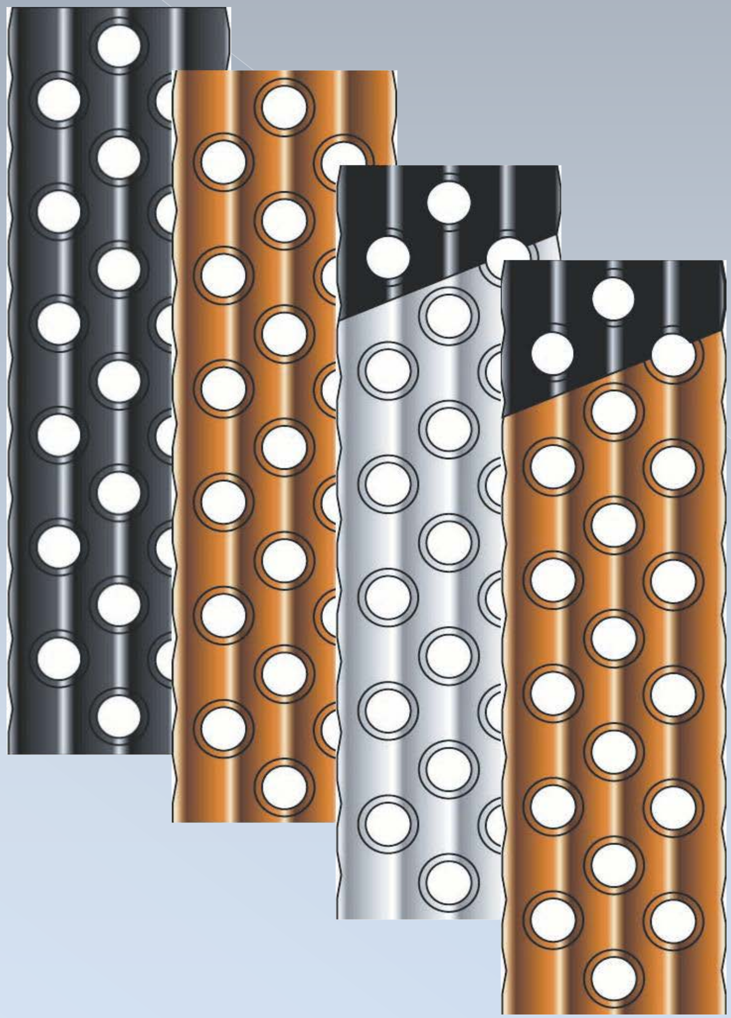
Copper-Fin Coils

Copper tube/copper fin coils are used for corrosion resistance in coastal areas.





Chiller Coil Corrosion Protection



Standard Coil

(majority of applications)

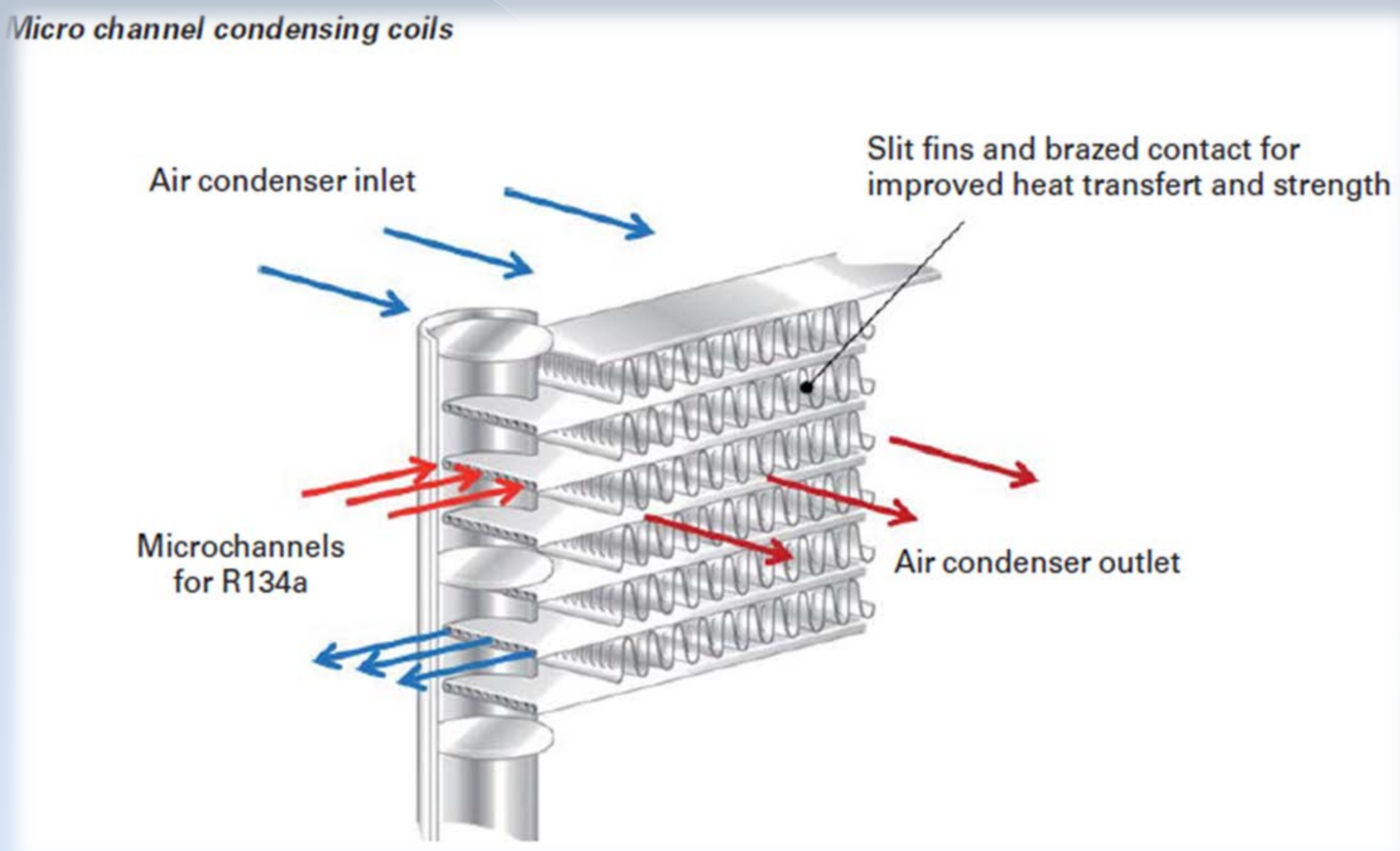
Plate fin coil options:

- Pre-Coated Aluminum Fins
  (moderate coastal protection)
- All Copper Coils
  (best coastal protection)
- Electro-Coated Aluminum Fins
  (best coastal and industrial protection)

Microchannel Condenser coils

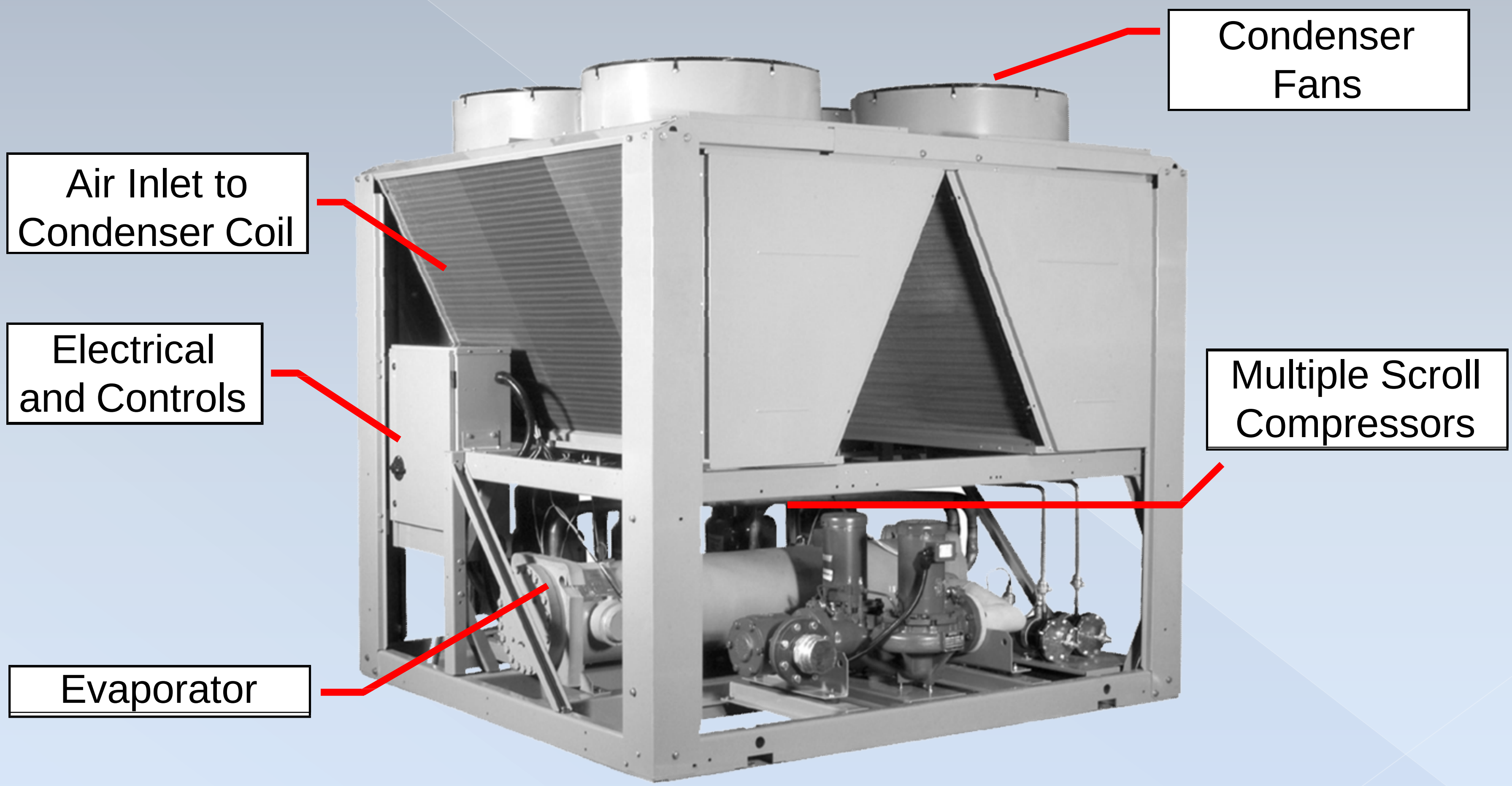
Microchannel all-aluminum construction provides several additional benefits:

- Lightweight(simplifies coil handling)
- Easy to recycle
- Minimize galvanic corrosion

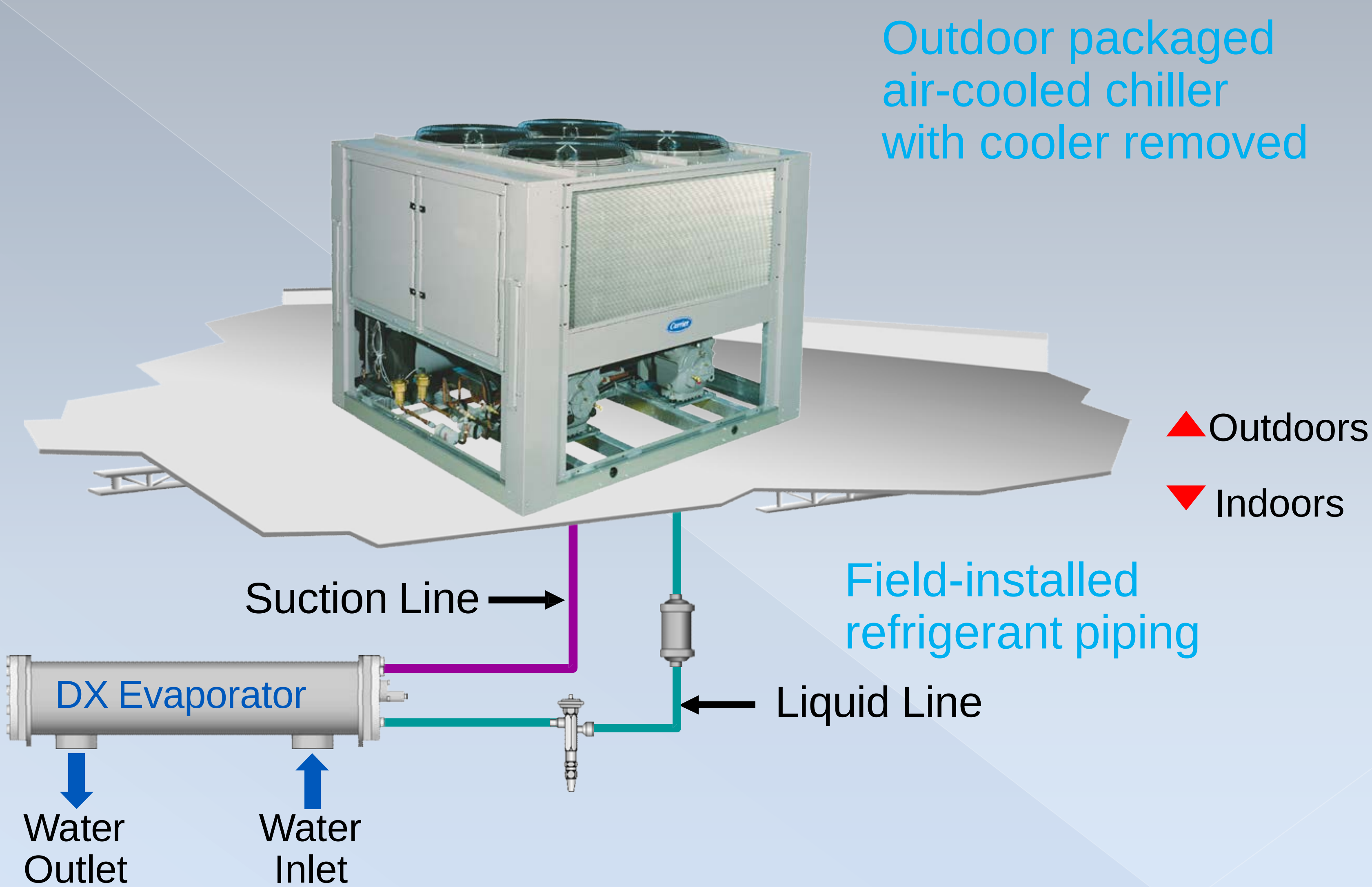


Air-Cooled Chiller Configurations

Ground or Roof-Mounted Chiller



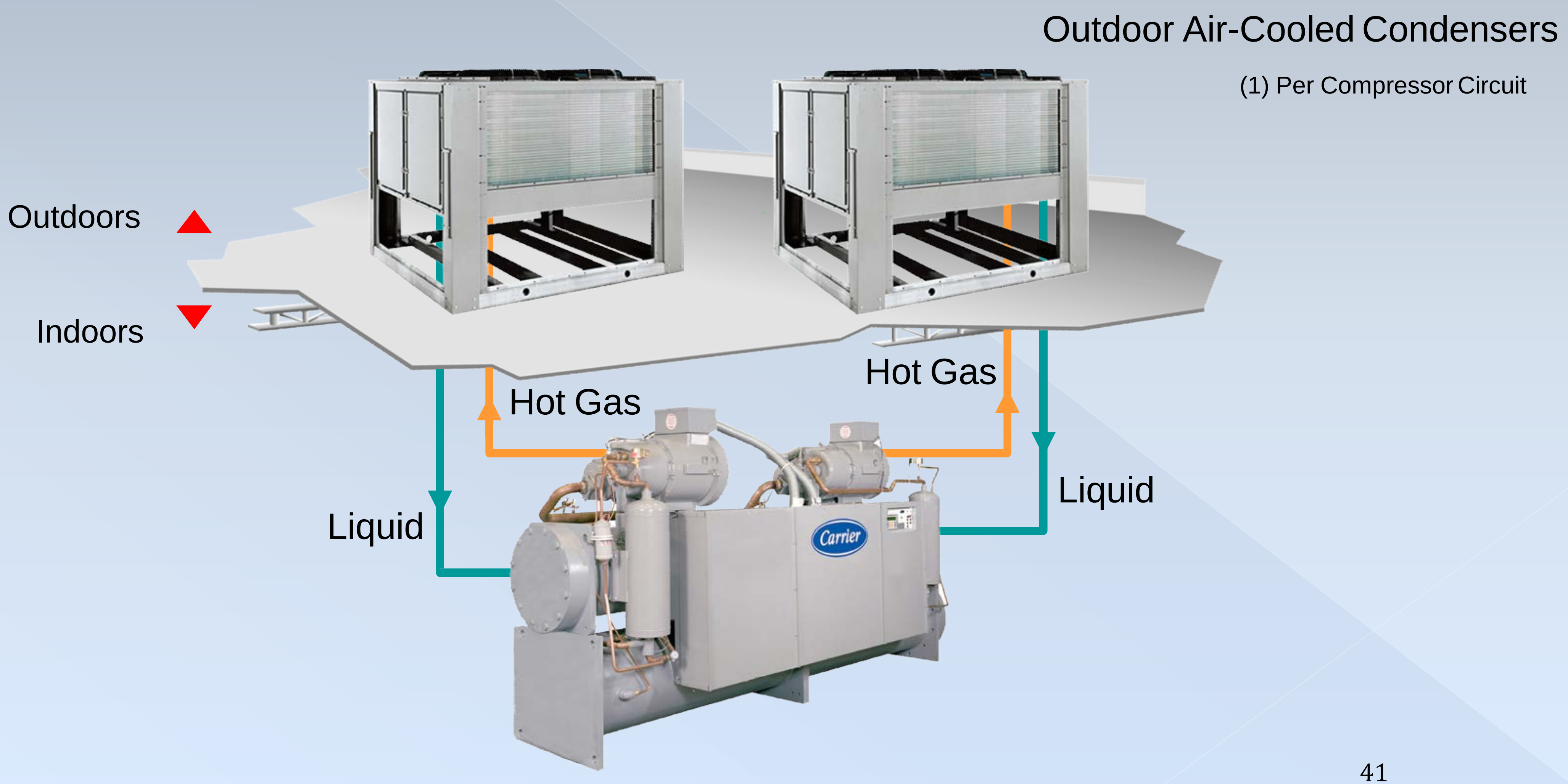
Remote Cooler Barrel



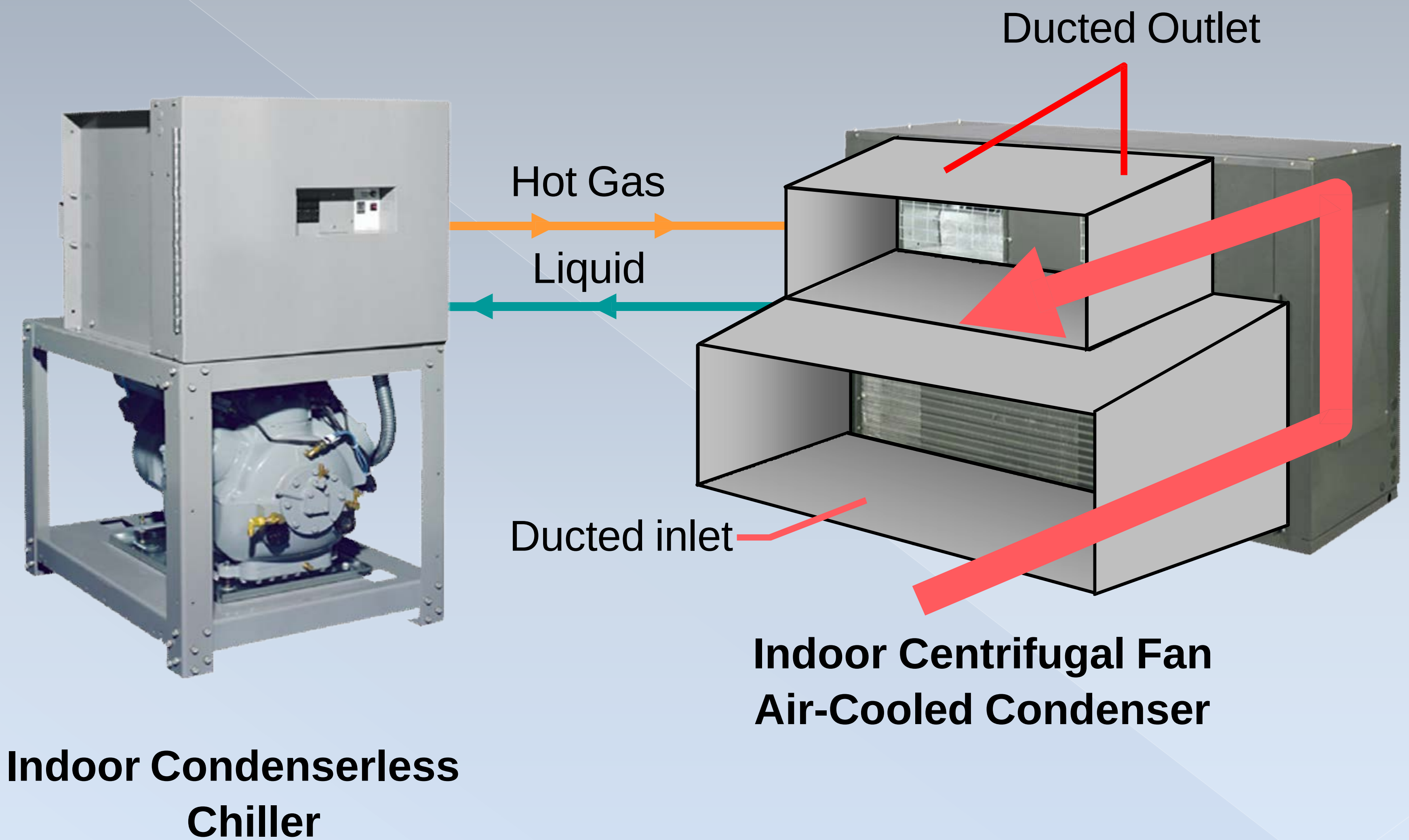
Condenserless Split-System Chiller

Benefits of Condenserless Chiller Configurations:

- Roof does not need to support the compressor(s)
- Lower electrical costs because the compressor is closer to the indoor electrical panel
- More options for noise control
- Reduced freeze-up potential

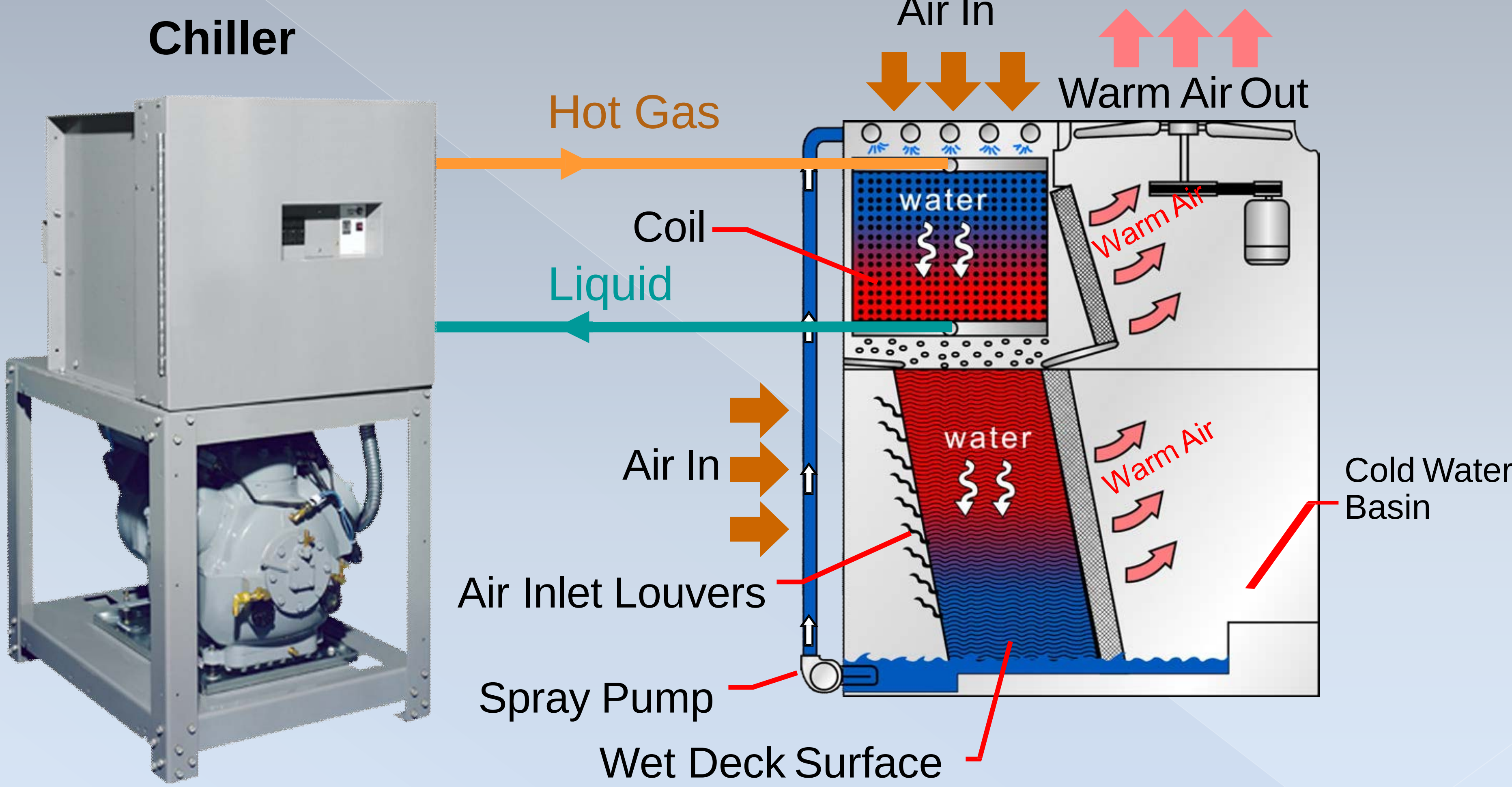


Indoor Chiller & Indoor Air-Cooled Condenser



Indoor Chiller - Evaporative Condenser

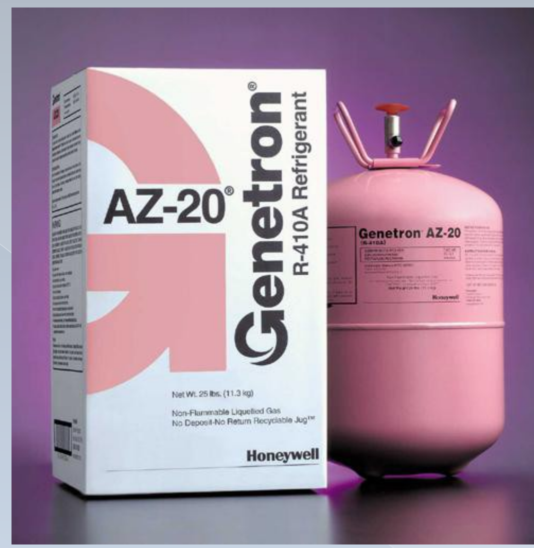
Indoor Condenser less Chiller



Refrigerants

New refrigerants not scheduled for phase-out:

R - 134a



R – 410a

R – 407c

R22 phase-out:

- 2010new equipment
- 2020service

Refrigerants

Summary of Status of Some Refrigerant Groups

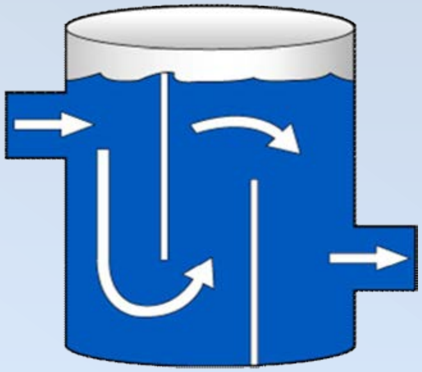
Type	Examples	ODP*	GWP**	Uses	Other Issues
CFC	R12 R502 R11	High	High	Widely used in most applications until 1990.	Now phased out of production
HCFC	R22 R409A R411B	Low	High	Widely used in many applications. Not recommended for us after 1999.	To be phased out of production in 2015. Their use is also regulated increasingly strictly.
NH_3 Ammonia	R717	Zero	Very low	Used in industrial systems since the birth of refrigeration.	Toxic and flammable, reacts with copper.
HFC	R134a R404A R407C R410C R507	Zero	High	Started to be used in place of CFCs from about 1990.	Different compressor oil needed performance of some HFCs not as good as CFCs. Some reliability problems.
HC E.G. propane, iso-butane, iso-pentane	R600a R290 Care 30 Care 50 R1270	Zero	Very low	R290 used in some industrial systems for decades. R600a now used in domestic systems. Care 30 and Care 50 now used in some commercial systems.	Flammable, but are very good refrigerants with few changes needed to a CFC/HCFC system.
CO_2		Zero	Very low	Widely used before the 1950s but superseded by halocarbons. Now being 'rediscovered' as a primary and secondary refrigerant.	Not yet widespread commercial use as a primary refrigerant, but an interesting prospect. (High operating pressures require special materials and construction.)

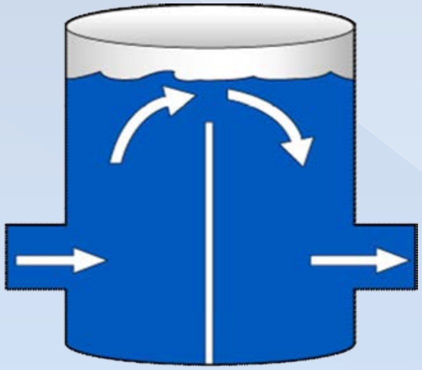
*ODP – Ozone Depleting Potential; **GWP – Global Warming Potential

Minimum Chilled-Water System Volume

Volume tank may be necessary

- 3gallons per ton of chiller for normal air-conditioning duty
- 6 to 10 gallons per ton of chiller for process duty or low ambient unit operation
- Mount tank on return line to chiller

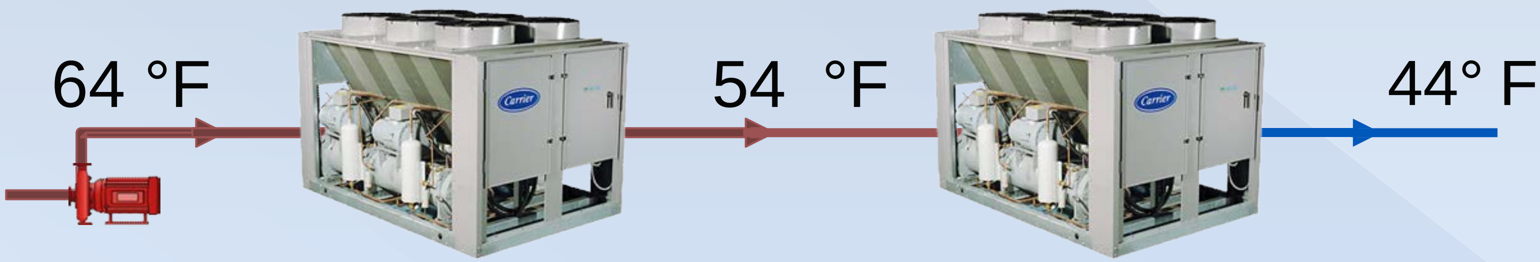




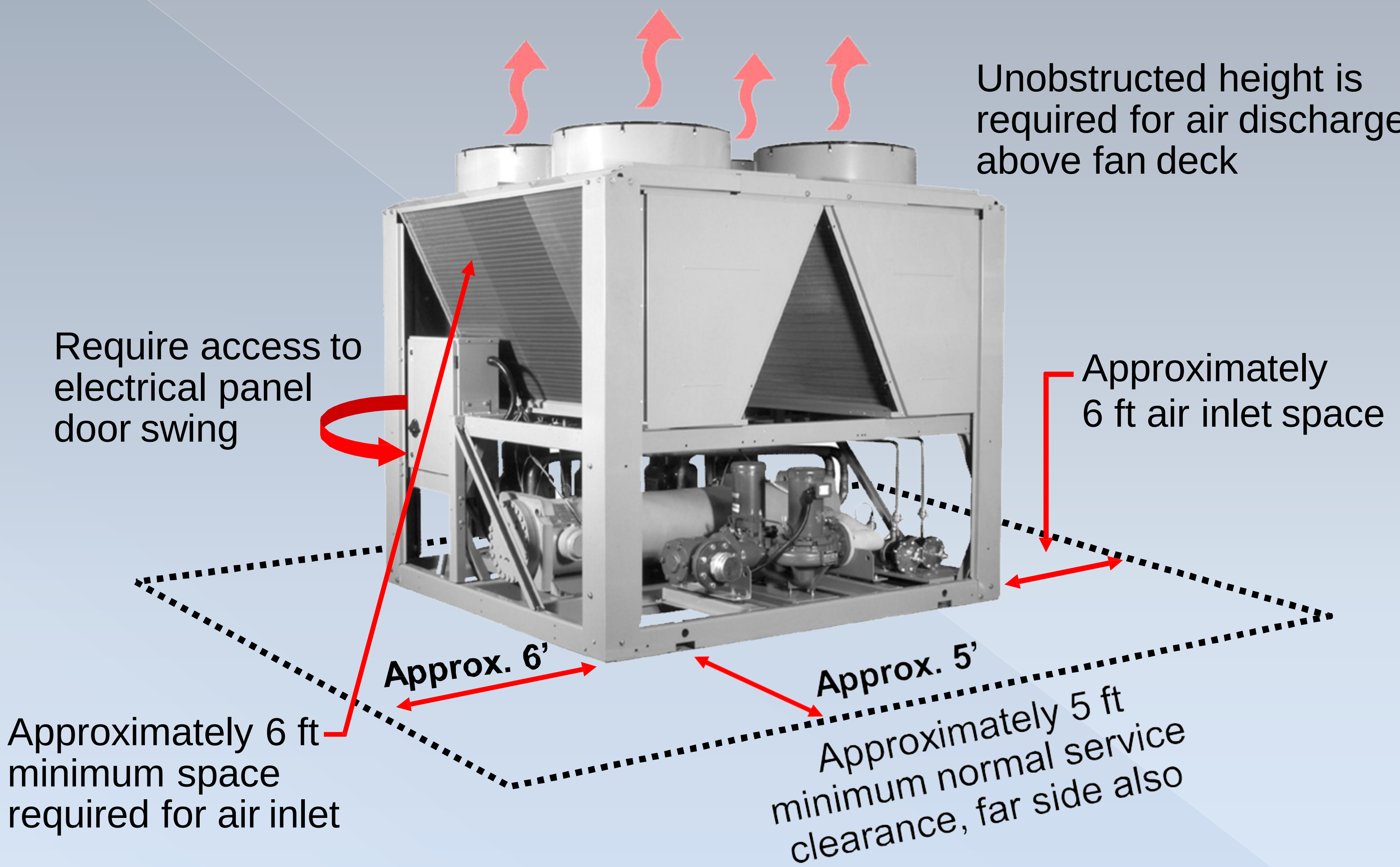
Parallel and Series Chillers

Parallel – (Typically 18° F drop or less)

Series – (Typically greater than 18° F drop)

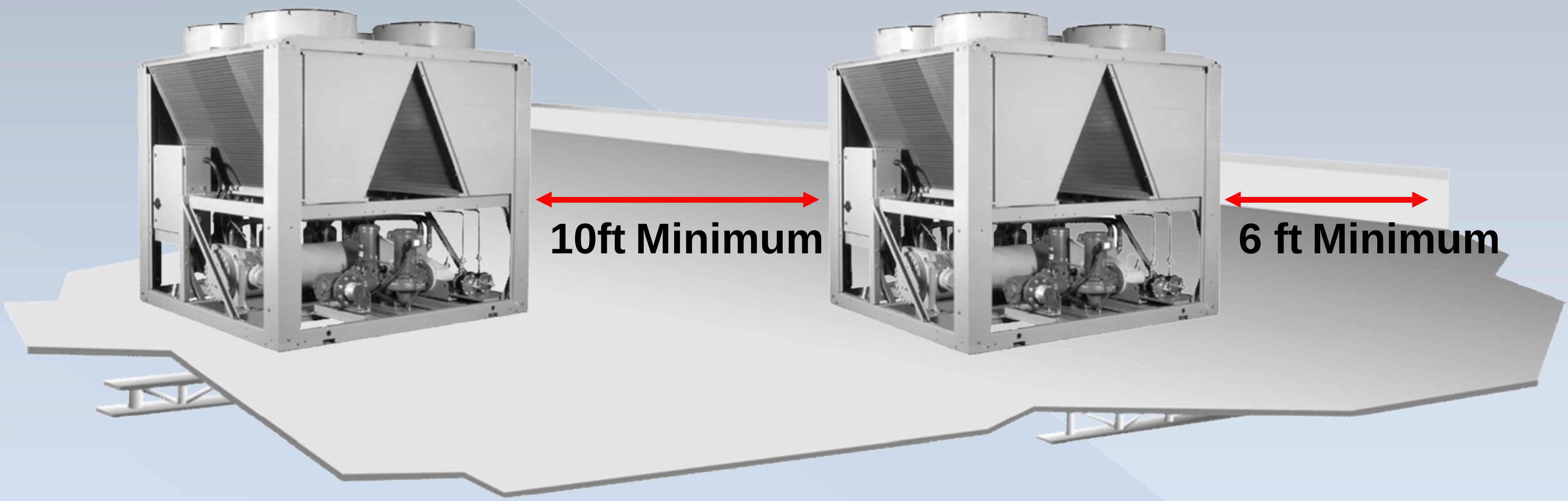


Clearances



Consult manufacturer's literature for exact requirements

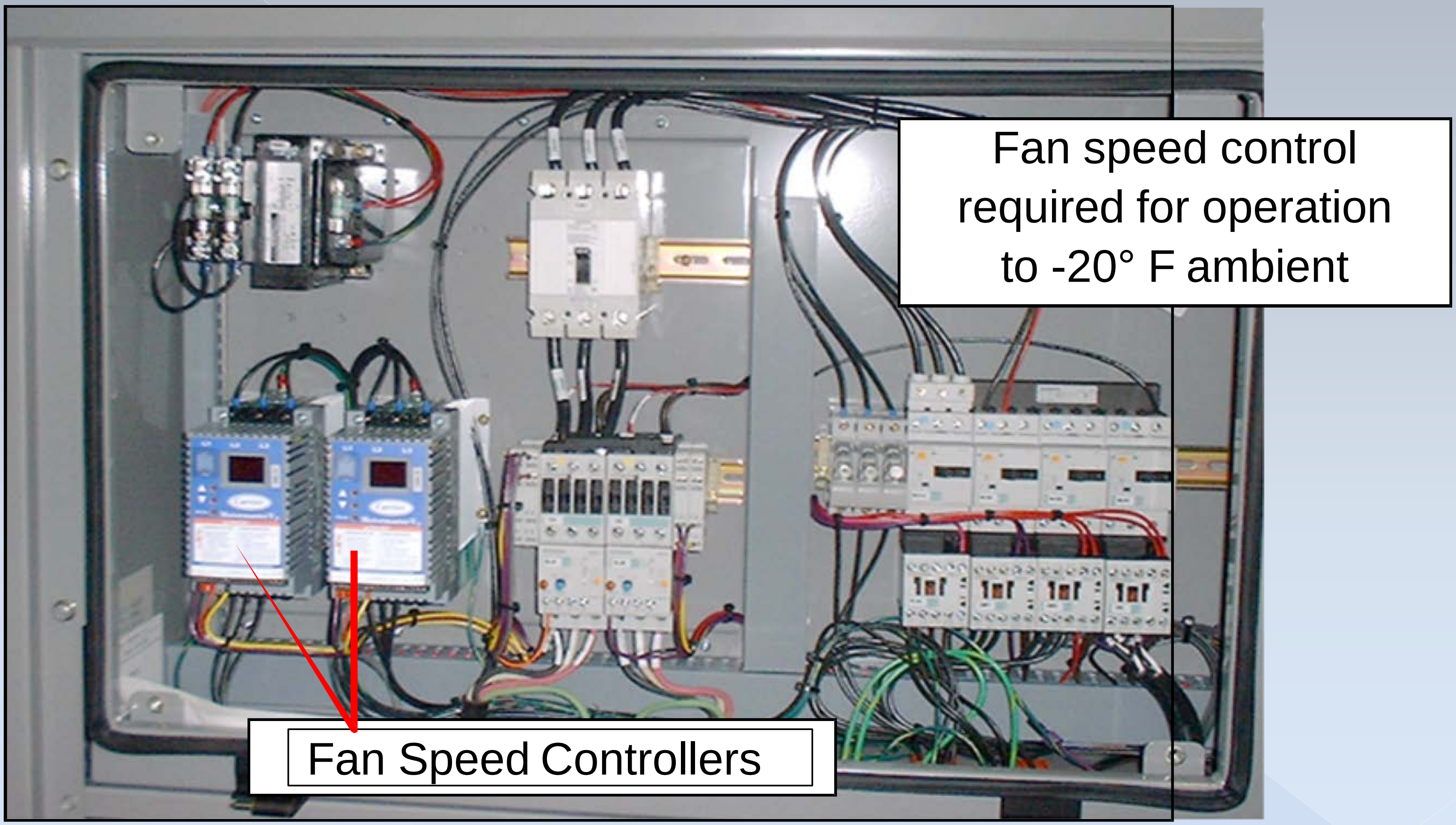
Multiple Unit Separation



Consult manufacturer's literature for exact requirements

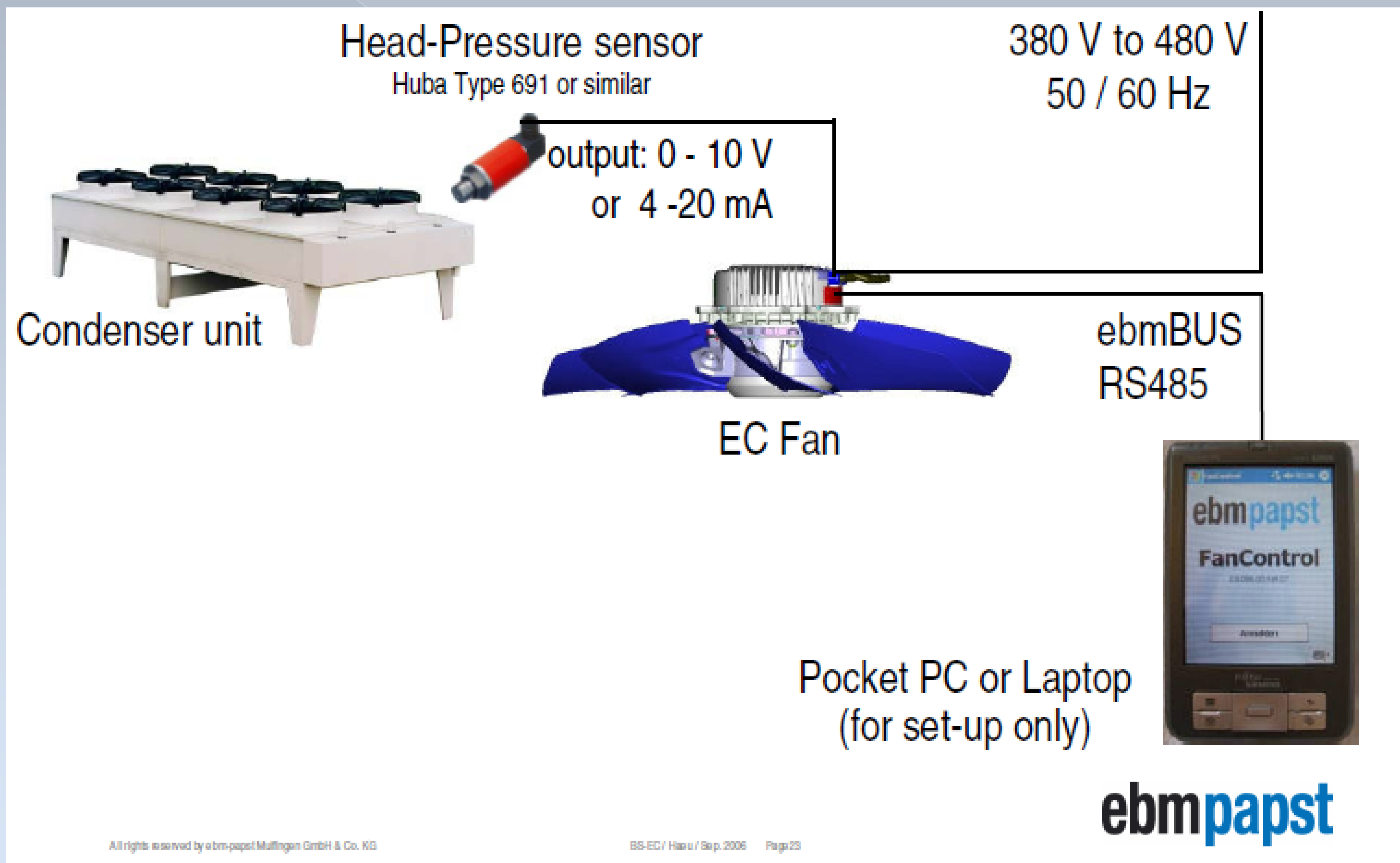
Low Ambient Operation

Control Section of Multi-Fan Air-Cooled Chiller

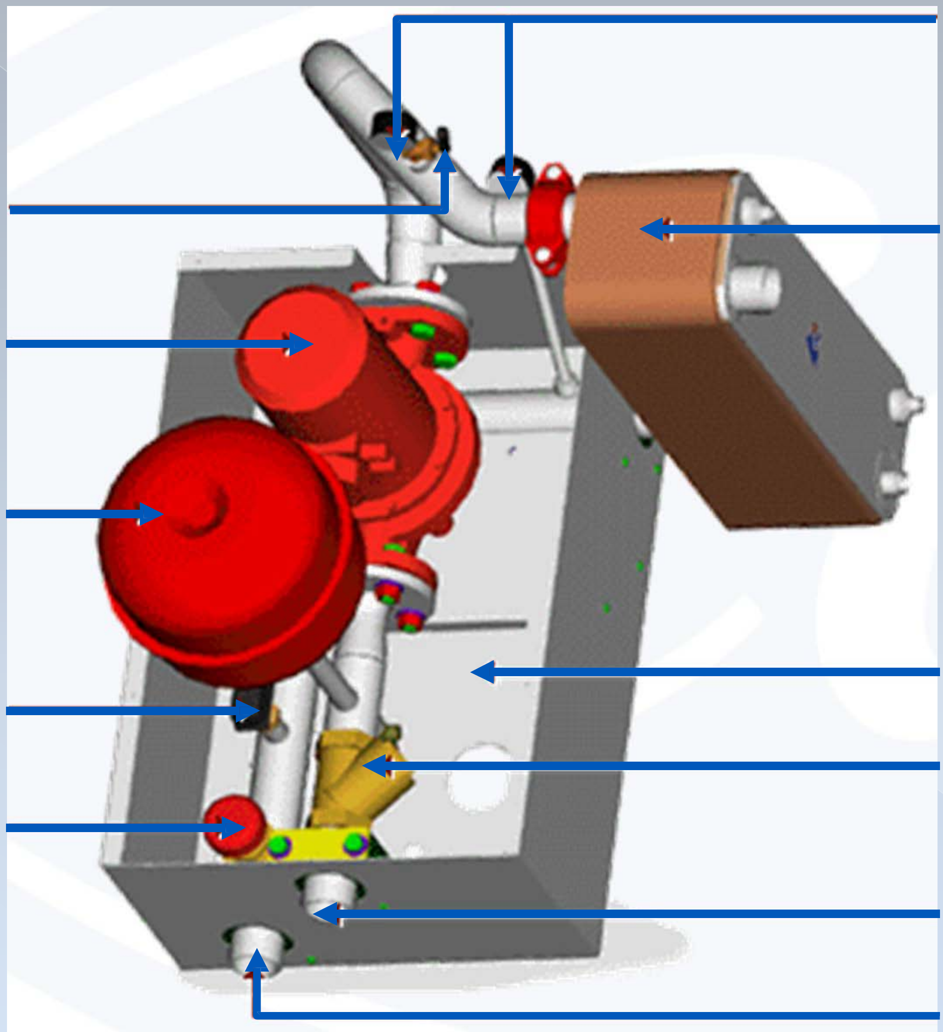


Low Ambient Operation

Speed Control with EC Fan



Hydronics Packages

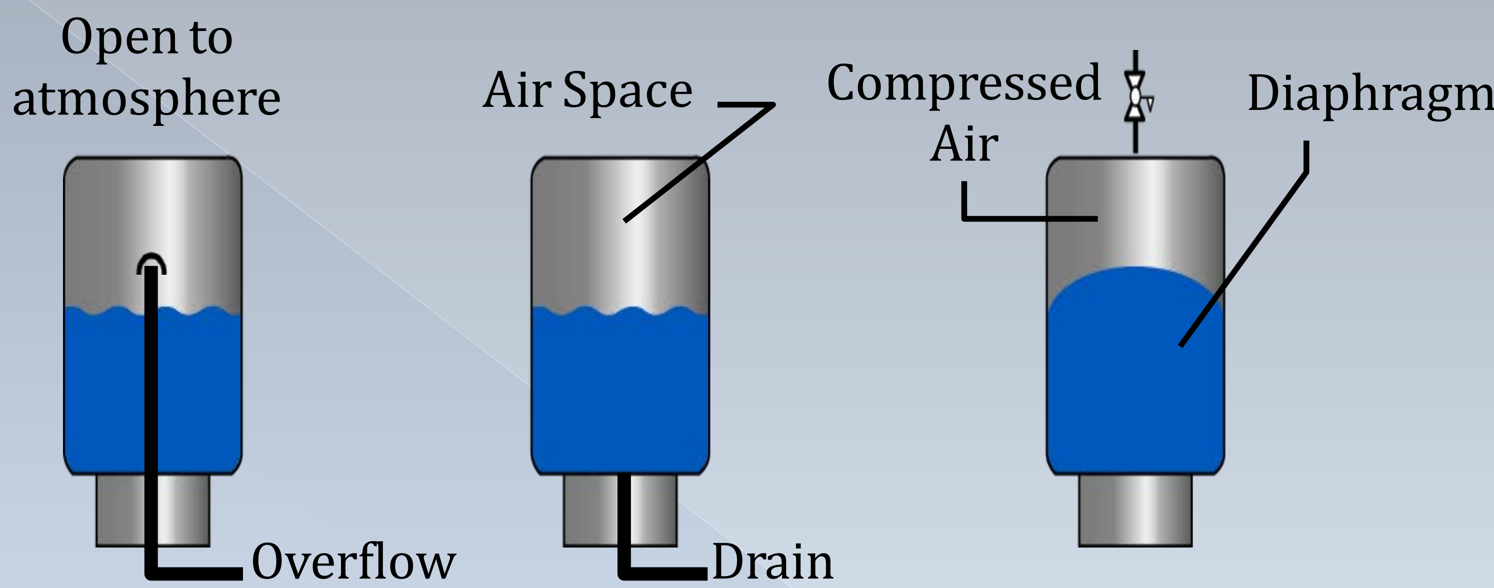


(Volume tank not shown)

Expansion Tank in Hydronics Package

The change in water system volume is about 1% for chilled- water systems

Expansion Tanks



Open Tank

- Open to air
- Air-water interface

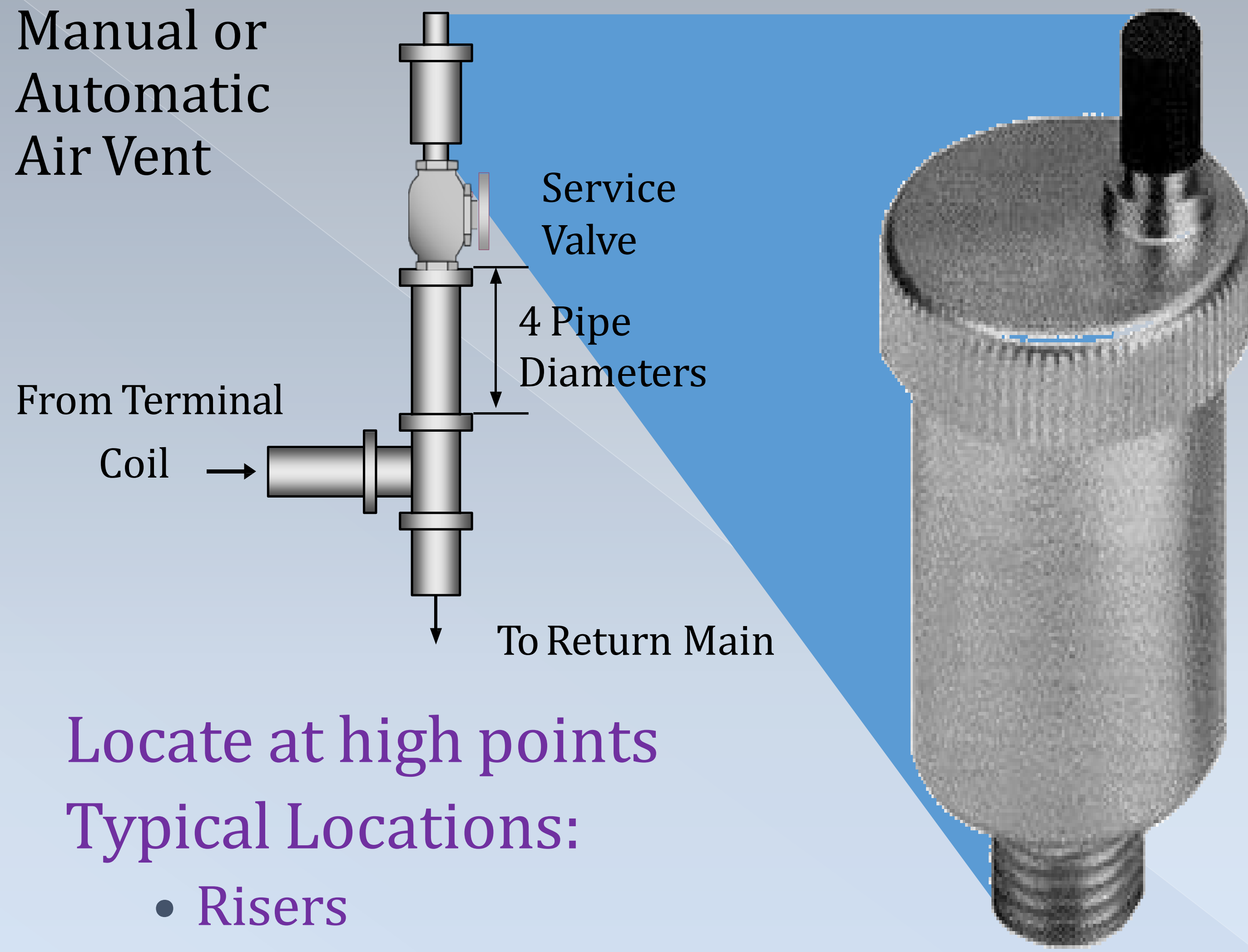
Closed Tank

- Very popular
- Captured air space
- Air-water interface

Closed Diaphragm Tank

- Flexible membrane
- No air-water interface
- Very popular

Air Vents



Locate at high points

Typical Locations:

- Risers
- Coils
- Terminals

GUIDE TO SELECTION

1. DESIGN COOLING CAPACITY KW
2. ENTERING AND LEAVING CHILLED WATER TEMPERATURES
3. CONDENSER ENTERING AIR DRY BULB TEMPERATURE
4. CHILLED WATER FLOW L/S IF ONE OF THE TEMPERATURES
5. CONDENSER WATER FLOW L/S IF ONE OF THE TEMPERATURES
6. COOLER AND CONDENSER FOULING FACTORS DETERMINE THE CAPACITY
7. AIR-COOLED CONDENSER, ENTERING AIR DRY BULB: 95°F [35.0°C]

Chiller Sizing

- DO NOT OVERSIZE BEYOND 15%
- IF FUTURE EXPANSION, ADD A SECOND CHILLER IN PARALLEL
- USE TWO SMALL CHILLERS VERSUS ONE LARGE CHILLER WHENEVER POSSIBLE

ARI Terms

Definitions

EER:

Measurement of a chiller's efficiency at full load capacity.

IPLV:

Calculation of a chiller's efficiency in addition to full load using weighted averages at various part load points.

ARI Conditions for Air-Cooled Chillers

ANSI/AHRI 550/590-2011:

Leaving chilled-water	=	44 °F
Chilled-water flow rate	=	2.4 gpm/ton
Cooler fouling factor	=	0.0001hr °F ft²/Btu
Entering air temperature	=	95 °F

Fluid Temperature change
&
Fluid mass flow rate

The temperature change in the fluid for either the condenser or the evaporator can be described using the following formula;

$$Q = W \times C \times \Delta TF$$

Where:

- Q = Quantity of heat exchanged (btu/hr or kw)
- W = mass flow rate of fluid (lb/hr or kg/hr)
- C = specific heat of fluid (btu/lb°F or kJ/(kg●K))
- ΔTF = temperature change of fluid (°F or °C)

Assuming the fluid is water;

Load (btu/hr) = Flow (USgpm) × (°Fin – °Fout) × 500

Or Load (tons) = Flow (USgpm) × (°Fin – °Fout) / 24

Using this equation and the AHRI design conditions, the temperature change in the evaporator is found to be 10°F. The water temperature entering the evaporator is then 54°F.

Minimum Efficiencies

ASHRAE Standard 90.1-2013
Energy Efficiency Standards For Air-Cooled Chillers.

Equipment Type	Size Category	Minimum Efficiency kW/Ton
Air-cooled with condenser	150 >tons	10.10 EER/ 13.7 IPLV
Air-cooled with condenser	150 ≤tons	10 EER/ 14 IPLV
Air-cooled without condenser	All	Must be rated with matching condensers and comply with same efficiency requirements.

Codes and Standards

ARI

Air Conditioning and Refrigeration Institute

- Chiller performance certification
- Random testing of manufactured units for verification
- ARI 550/590-98
  - Latest standard for electric chillers

ASHRAE

American Society of Heating, Refrigerating and Air-Conditioning Engineers

- ASHRAE 90.1
  - Chiller minimum efficiency requirements
- ASHRAE 15
  - Safety of installations using refrigerants

ASME

American Society of Mechanical Engineers

- Pressure vessel specifications

BSR/ASHRAE Standard 184P

Method of Test for Field Performance of Liquid-Chilling Systems

1. PURPOSE

The purpose of this standard is to prescribe methods of field performance testing for liquid-chilling systems.

2. SCOPE

2.1 This standard includes the following types of liquid-chilling systems. These system types are further described in Section 5, "Equipment Types."

2.1.1 Vapor compression cycle.

2.1.2 Absorption cycle.

2.2 This standard does not include systems with a net refrigeration capacity less than 10 Tons [35 kW].

2.3 This standard does not include a specification of standardized test conditions under which the liquid-chilling system must operate. Test conditions typically reflect the expected operating conditions and are customer specified.

Summary

- ✓ LISTED THE VARIOUS TYPES AND TONNAGES OF AIR-COOLED CHILLERS AND THEIR OPERATIONAL CHARACTERISTICS
- ✓ DESCRIBED THE CORRECT APPLICATIONS FOR AIR-COOLED CHILLERS
- ✓ IDENTIFIED THE AVAILABLE OPTIONS AND ACCESSORIES

THANK YOU