Water-Cooled vs. Air-Cooled Chillers Efficiency and Applications

Levi Hoiriis
Integrated Services Group
Keynote Speaker

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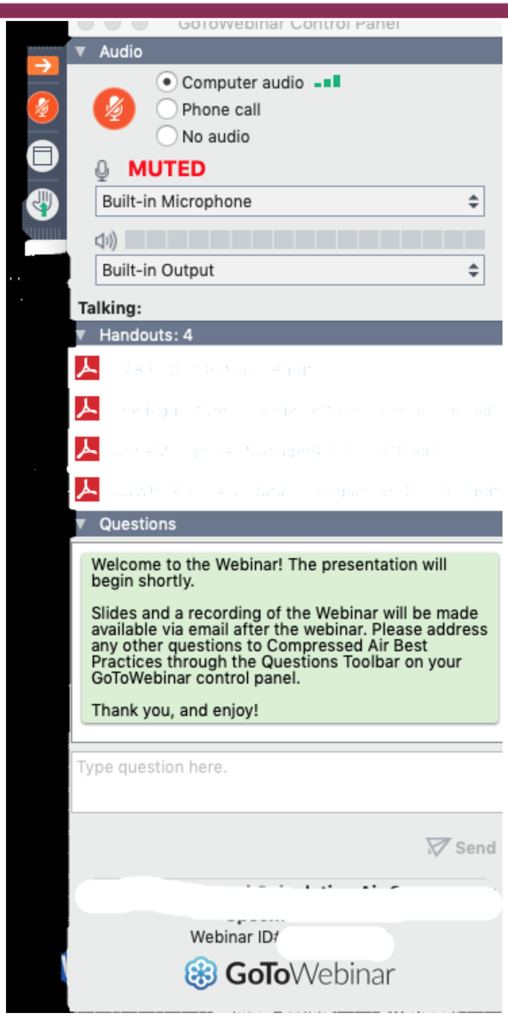
Q&A Format



- Panelists will answer your questions during the Q&A session at the end of the Webinar.
- Please post your questions in the Questions Window in your GoToWebinar interface.
- Direct all questions to Chiller & Cooling Best Practices® Magazine

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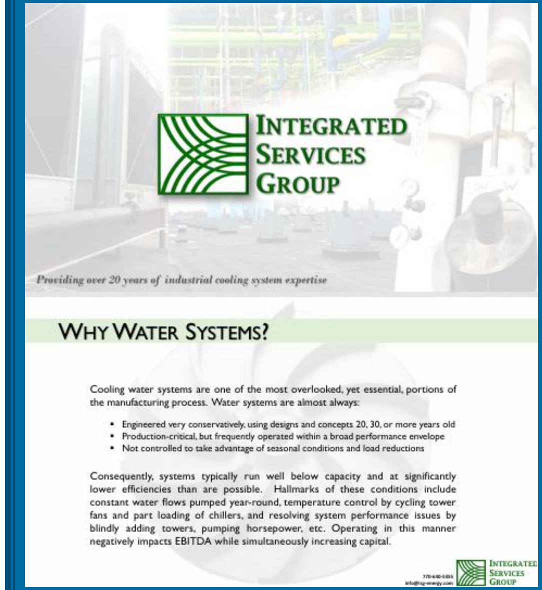

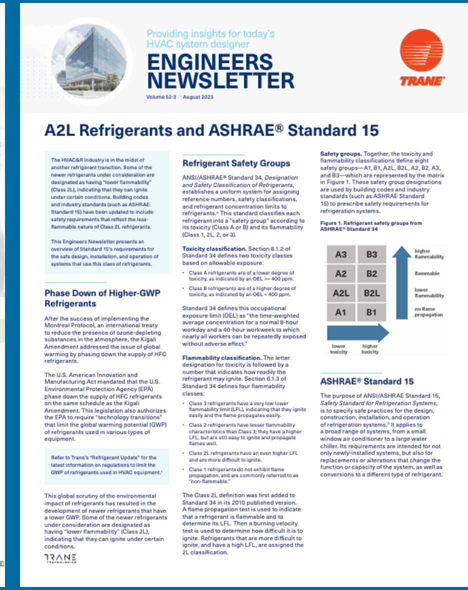

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Water-Cooled vs. Air-Cooled Chillers Efficiency and Applications

Introduction

Chiller & Cooling Best Practices® Magazine

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About the Speaker

Levi Hoiriis
Integrated Services Group

- Engineer, Integrated Services Group
- Expertise in thermal energy systems: chilled water, steam, and cogeneration
- Experience with industrial plants, campuses, and major US utilities
- Specializes in energy project planning, design, and economic modeling
- B.S. in Mechanical Engineering from Georgia Tech

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Presentation Outline

- Chiller technology choices
- Air vs Water Cooled Systems
- Impact of application specifics – industrial vs commercial applications

Chiller Technology Options

Scroll Compressor Chillers and Recommended Applications

Type	Condenser Cooling	Recommended Uses
Scroll compressors	Air	Smallest units only, limited hours of operation – replace compressors when failed (no repair)
Scroll compressors	Water	Not recommended for most applications

Air Cooled Scroll Compressor Chiller – 60 to 250 tons

Water Cooled Scroll Compressor Chiller – 10 to 240 tons

Screw Compressor Chillers and Recommended Applications

Type	Condenser Cooling	Recommended Uses
Oil-lubricated screw compressors	Air	Good choice for most applications – wide size range, economical with moderate power costs, rebuildable, multi-circuit designs available
Oil-lubricated screw compressors	Water	Good choice for smaller uses (<250 – 350 tons) – adequate size range (≈ 80 tons and up), economical with lower cost power, multi-circuit designs available, typically decades-long life with periodic rebuilds
VFD-controlled screw compressors	Air/Water	Higher efficiency than constant speed designs

Screw Compressor Chiller Examples

A-C VFD Screw Compressor
Chiller – 150 to 575 tons

W-C Single Screw Compressor
Chiller – 150 to 435 tons

W-C Multi-Screw Compressor
Chiller – 75 to 265 tons

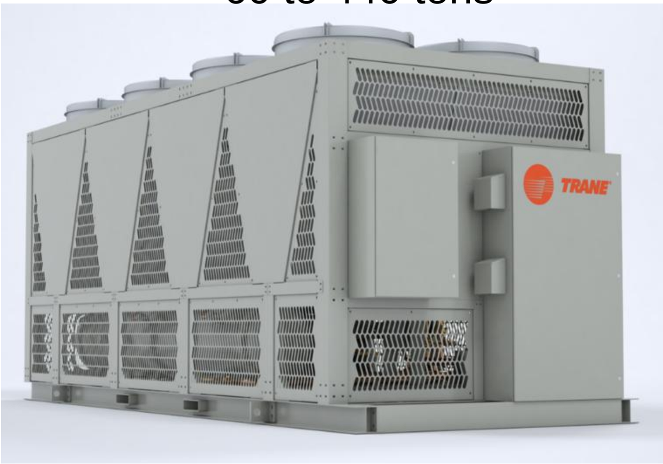
Centrifugal Chillers and Recommended Applications

Type	Condenser Cooling	Recommended Uses
Centrifugal compressors	Water	High efficiency for larger uses (300 – 1500+ tons) – core chiller design for many applications, typically decades-long life with rebuilds
Magnetic bearing centrifugal compressors	Air	Highest possible efficiencies (for Air-Cooled) across widest operating range – good choice for water constricted, high power cost locations
Magnetic bearing centrifugal compressors	Water	Highest possible efficiencies across widest operating range – good choice for all uses with higher energy costs, typically decades-long life w/ low maintenance

Centrifugal Compressor Chiller Examples

W-C VFD Centrifugal Compressor Chiller – 250 to 3000 tons

A-C Magnetic Bearing VFD Centrifugal Comp. Chiller – 60 to 440 tons



W-C Magnetic Bearing VFD Centrifugal Comp. Chiller – 300 to 700 tons

How to Choose Between Air-Cooled and Water-Cooled Systems?

Central Plant Chillers: Air-Cooled or Water-Cooled

Air-Cooled Chiller

Cooling Tower

Water-Cooled Chiller

Air-Cooled System Features, Pros & Cons

Advantages:

- Simple system design when only chilled water (CHW) required
- Fewer components overall
- Outdoor chillers minimize space requirements inside building
- Saves water in locations with limited availability or high costs

Air-Cooled System Features, Pros & Cons

Advantages:

- Simple system design when only chilled water (CHW) required
- Fewer components overall
- Outdoor chillers minimize space requirements inside building
- Saves water in locations with limited availability or high costs

Disadvantages:

- High capital cost per ton above cost crossover threshold
- Relatively poor chiller efficiency (for most chiller designs)
- Equipment life generally less than water-cooled chillers

Water-Cooled System Features, Pros & Cons

Advantages:

- Cooling tower water available for machine & non-CHW process cooling
- Highest possible system efficiencies – chiller & free cooling modes
- Lower or competitive total capital cost above crossover threshold
- Lowest energy costs, competitive maintenance costs

Water-Cooled System Features, Pros & Cons

Advantages:

- Cooling tower water available for machine & non-CHW process cooling
- Highest possible system efficiencies – chiller & free cooling modes
- Lower or competitive total capital cost above crossover threshold
- Lowest energy costs, competitive maintenance costs

Disadvantages:

- Requires dedicated space for system and installation of piping
- Effective operation requires higher operator knowledge, engineering support
- Consumes notable water amounts for tower, requires constant treatment vigilance

Air-Cooled or Water-Cooled Chillers?

Air-Cooled	Water-Cooled
Smaller total heat loads (<100 – 250 tons)	Higher total heat loads (500+ tons)
Simple water requirements (one temperature and / or all lines with TCUs[1]	Multiple water temp applications – CHW, tower-temp (85°F) uses
Significant concern about water supply	Free Cooling enabling climate (> ≈2000 hrs)
Limited plant staff resources	More capable staff or dedicated operators
Air-cooled auxiliaries (air compressors, dryers, vacuum pumps, process equipment, etc.	Water-cooled auxiliaries

[1]Temperature Control Units

Performance and Cost Distinctions Between Chiller and System Types

Central Plant Chillers Drive Overall System Performance

Chiller Type	Size Range	Nom. kW/ton	Annual kW/ton	System kW/ton*
Air-Cooled Screw	150 - 500	1.225	0.875	1.250
W-C Screw (1 comp)	150 - 650	0.675	0.525	1.050
W-C VFD Screw	150 - 650	0.625	0.475	0.950
Centrifugal (1 comp)	250 - 1350	0.575	0.435	0.900
VFD Centrifugal	250 - 1350	0.550	0.350	0.750
Mag. Brg. VFD Cent.	125 - 750	0.525	0.325	0.675
Free Cooling (seasonal)	0 – 1500+	0.075	0.05	0.400

** Assumes system controlled to leverage chiller efficiency*

Central Plant Chillers Installation & Operating Costs*

Chiller Type	Size Range	Installed Cost per Ton	Cost per 1000 ton -hrs @ 10¢ / kWh	Estimated Annual Maint. Per Ton
Air-Cooled Screw	150 - 500	$1280	$125	$50
W-C Screw (1 comp)	150 - 650	$1480	$105	$35
W-C VFD Screw	150 - 650	$1530	$95	$35
Centrifugal (1 comp)	250 - 1350	$1620	$91	$30
VFD Centrifugal	250 - 1350	$1670	$75	$30
Mag. Brg. VFD Cent.	125 - 750	$1830	$68	$20
Free Cooling (seasonal)	0 – 1500+	$2000	$40	$20

** Actual costs are widely variable based on site conditions, power costs, water quality & treatment, operating schedules, etc.*

Catalog vs Selection Chillers

Most smaller (air-cooled and water-cooled) chillers are “catalog” chillers

- Fixed range of sizes (rating based on standard conditions)
- May have high efficiency build options, low ambient (for A-C), etc.
- Essentially no ability to select specific features for application criteria
- May require either oversizing (e.g. for low ΔT use without high evap DP) or other sub-optimal choice to meet requirements

Larger chillers (screw, centrifugal, VFD and / or mag bearing) are typically engineered builds from a “selection” of available components

- Wide range of choices allows efficient tailoring of chillers to specific situations

Air-Cooled and Water-Cooled Systems
Application Example

Application Example Scenario – Typical Commercial Conditions

Requirements:

- 44° chilled water (CHW) required
- 500 tons running load average load, 750 tons peak load
- Standard 10° supply – return CHW temperature difference (“delta T”) with 2.4 GPM per ton required flow
- 2400 hours per year operating hours at average load

Note: Cooling system costs outside of central plant equipment assumed equal – plant piping, electrical infrastructure, mechanical room space value, etc.

Application Example Scenario – Typical Commercial Conditions

Requirements:

- 44° chilled water (CHW) required, 500 tons average load, 750 tons peak load
- 10° supply – return delta T, 2400 hours per year average load operating hours

Air-Cooled Capital & Operating Costs

- Two 400 ton A-C chillers, installed capital cost ≈ $1.02 mil.
- Annual operating cost @ 10¢ per kWh, 500 tons avg., 2400 hours - $150,000

Energy Cost Calculations @ 10¢ per kWh:

500 tons X 2400 hours / 1000 ton-hrs X $125 per 1000 ton-hrs

Use correct $ per 1000 ton-hrs value, prorate for actual cost per kWh

Application Example Scenario – Typical Commercial Conditions

Requirements:

- 44° chilled water (CHW) required, 500 tons average load, 750 tons peak load
- 10° supply – return delta T, 2400 hours per year average load operating hours

Air-Cooled Capital & Operating Costs

- Two 400 ton A-C chillers, installed capital cost ≈ $1.02 mil.
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Water-Cooled Capital & Operating Costs

- Two 400 ton W-C chillers, installed capital cost ≈ $1.34 mil.
- Annual operating cost @ 10¢ per kWh, 500 tons avg., 2400 hours - $90,000
- 5.33 year energy-only simple payback vs. A-C option, plus tower water costs

Application Example Scenario – Typical Industrial Conditions

Requirements:

- 50° chilled water (CHW) required
- 500 tons running load average load, 750 tons peak load
- 8° supply – return CHW delta T with 3.2 GPM per ton flow
- 6800 hours per year operating hours at average load

Note: Cooling system costs outside of central plant equipment again assumed equal – plant piping, electrical infrastructure, mechanical room space value, etc.

Application Example Scenario – Typical Industrial Conditions

Requirements:

- 50° chilled water (CHW) required, 500 tons average load, 750 tons peak load
- 8° supply – return delta T, 6800 hours per year average load operating hours

Air-Cooled Capital & Operating Costs

- Two 500 ton A-C chillers due to reduced delta T – ***"Catalog chillers"***
- Installed capital cost ≈ $1.275 mil.
- Annual operating cost @ 10¢ per kWh, 500 tons avg., 6800 hours - $425,000

Application Example Scenario – Typical Industrial Conditions

Requirements:

- 50° chilled water (CHW) required, 500 tons average load, 750 tons peak load
- 8° supply – return delta T, 6800 hours per year average load operating hours

Air-Cooled Capital & Operating Costs

- Two 500 ton A-C chillers, installed capital cost ≈ $1.275 mil. ***"Catalog chillers"***
- Annual operating cost @ 10¢ per kWh, 500 tons avg., 6800 hours - $425,000

Water-Cooled Capital & Operating Costs

- Two 400 ton W-C chillers, installed capital cost ≈ $1.34 mil. ***"Selection chillers"***
- Annual operating cost @ 10¢ per kWh, 500 tons avg., 6800 hours - $255,000
- 0.38 year energy-only simple payback vs. A-C option, plus tower water costs

Industrial Application Analysis Criteria Distinctions

Required CHW temperature(s)

- Frequently 50 - 60°F vs. AHRI standard 44°F
- May require multiple temperatures at significant enough condition differences to warrant system capabilities vs. using TCUs

Hours of operation – typically much higher in industrial applications

Seasonal implications – many process loads substantially unaffected by outdoor conditions, potential for seasonal optimization (adjusted setpoint)

Known or potential future load growth – very common in industry, often unlikely in commercial applications

Known or potential changes in required temperatures – design for adaptability

Summary

- Chiller type (and system design) driven by cooling load characteristics and application details (location, total size, power costs, water availability, etc.)

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- Air-Cooled central plant system is least cost option for small plant systems with no other need for tower water

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- Air-Cooled central plant system is least cost option for small plant systems with no other need for tower water
- Water-Cooled central plant system is least cost option for medium to larger systems with typical application details – operating hours, power costs, water cost / availability, etc.

Summary

- Chiller type (and system design) driven by cooling load characteristics and application details (location, total size, power costs, water availability, etc.)
- Air-Cooled central plant system is least cost option for small plant systems with no other need for tower water
- Water-Cooled central plant system is least cost option for medium to larger systems with typical application details – operating hours, power costs, water cost / availability, etc.
- Specific situations may benefit from other choices or hybrids (e.g. air-cooled chillers with cooling tower for other uses), refer to unbiased technical consultants for help with system development and equipment specification

Water-Cooled and Air-Cooled Chillers: Selection for Efficiency and Applications

March 20, 2025

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About the Speaker

Ben Sykora
Trane

- Applications Engineer at Trane Commercial (since 2024).
- Specialist in hydronic systems, heat pumps, and VFDs.
- Former power electronics engineer for Trane Commercial HVAC.
- Certified Professional Engineer with a master’s in Electrical Engineering and 13 patents.
- Served 6 years in the US Navy as a “nuke electrician's mate.”

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March 20, 2025

Advancements in Industrial Chiller Technology:

Exploring Modern Trends and Innovations

Ben Sykora
Applications Engineer, Trane®

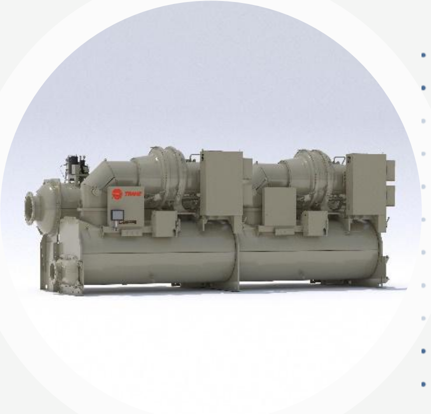
Agenda

What trends will affect decision making for industrial users in the next 2-5 Years?

- New Refrigerant Types
- Chiller Applications
  - Compressor "lift"
  - Vapor injection
  - Multistage
  - Cascaded compressors or chillers
- Chiller Efficiency Tradeoffs
  - Efficiency vs lift

Distributed Process Chillers
1-50T

Air-Cooled Chillers
20-650T



Water-Cooled Chillers
80-4000T+

New Refrigerant Types

Why Refrigerants are Transitioning and “Decarbonization is the New Trend”

ODP
Ozone Depletion Potential - *Past Concern*

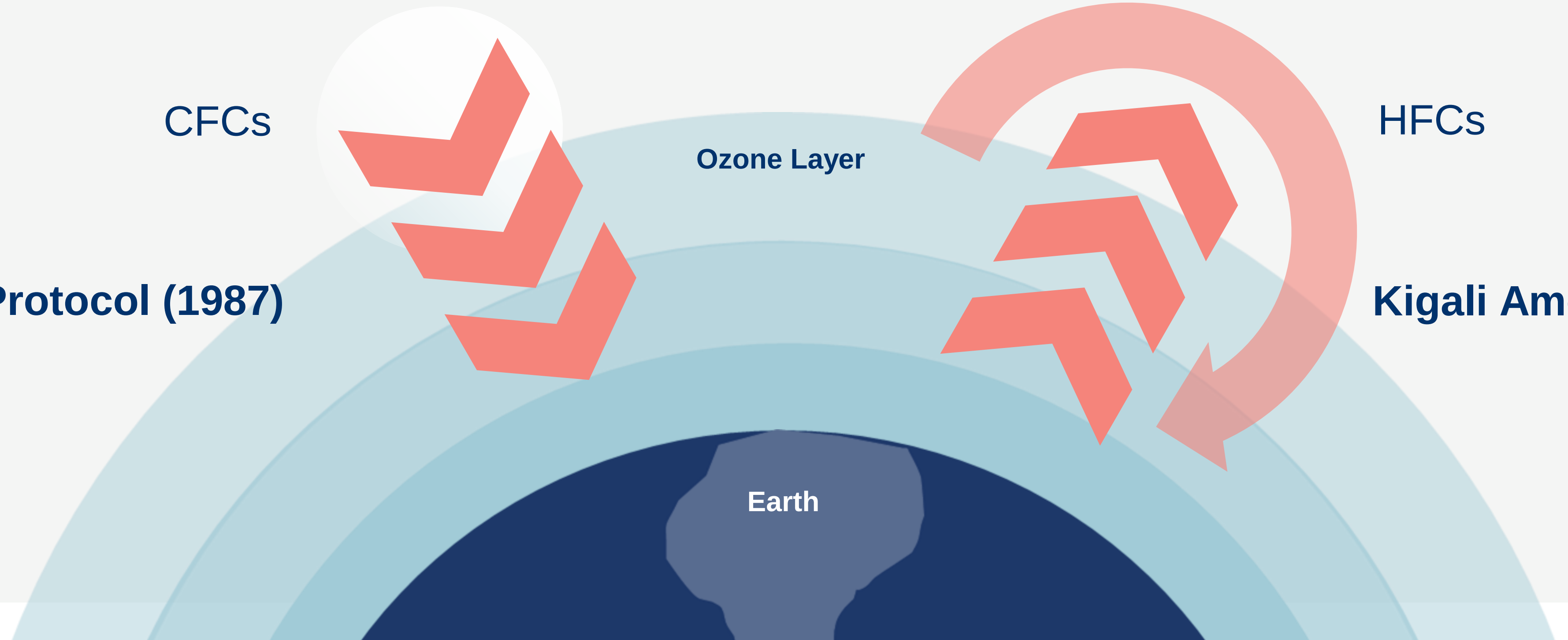
Potential of a substance to **reduce the amount of ozone** in the atmosphere which blocks harmful radiation

GWP
Global Warming Potential - *Current Concern*

Potential for a gas to **trap heat** in the atmosphere - contributing to climate change

CFCs

Montreal Protocol (1987)



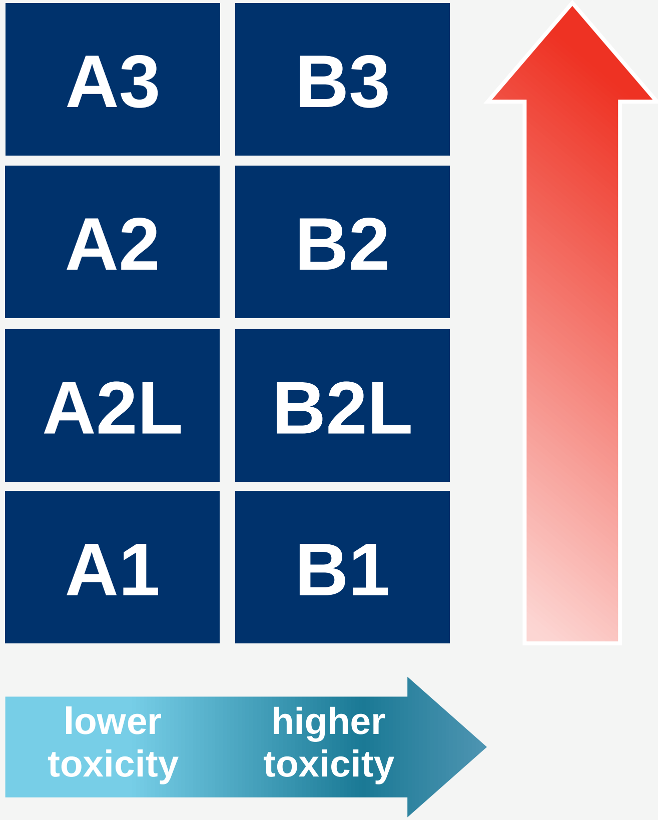
HFCs

Kigali Amendment (2016)

Next-Generation Refrigerants

Safety

- ASHRAE® Standard 34: Designation and Safety Classification of Refrigerants
- Toxicity: Occupational exposure limit (ppm in a workday)
- Flammability: Ignition and burn velocity
- New refrigerants A2L: **R-32 and R-454B**
  - Low toxicity (A)
  - Hard to ignite (needs an open flame)
  - Low burning velocity



CLASS 3
Higher flammability explosive, like propane (R290), Isobutane (R600a)

CLASS 2
Flammable, R152a

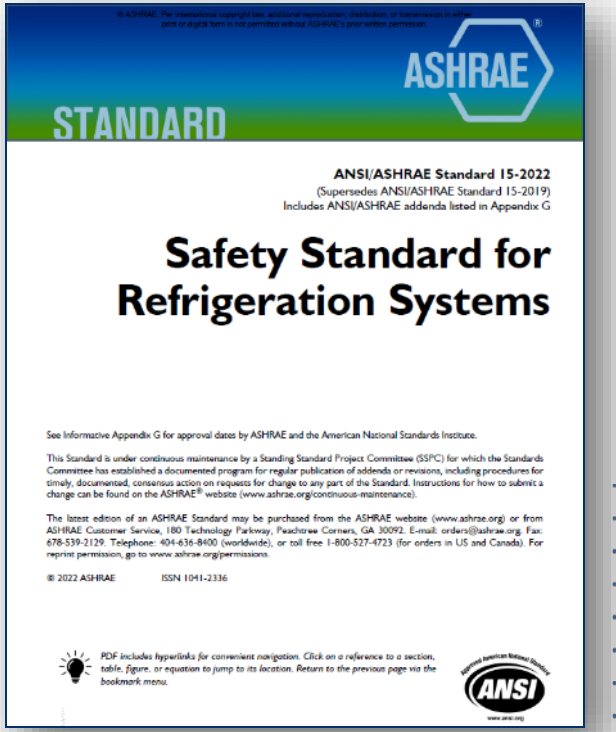
CLASS 2L
Lower flammability <10 cm/sec burning velocity, R32, R1234yf, R454b

CLASS 1
No-flame propagation R123, R134a, R404A, R410A, etc., called nonflammable

ASHRAE® Standard 15-2022

ASHRAE® Standard 15: Safety Standard for Refrigeration Systems

- Design, construction, installation and operation of refrigeration systems
- New systems, replacements, alterations and conversions.



STANDARD

ASHRAE

ANSI/ASHRAE Standard 15-2022
(Supersedes ANSI/ASHRAE Standard 15-2019)
Includes ANSI/ASHRAE addenda listed in Appendix G

Safety Standard for Refrigeration Systems

See Informative Appendix G for approval dates by ASHRAE and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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Approved American National Standard
ANSI
www.ansi.org

Determine safety requirements

- ✓ Lookup safety group classification of the refrigerant (Std 34)
- ✓ Determine occupancy classification of the building (S. 4)
- ✓ Determine “system probability” classification

Reference links for “Engineering Newsletter” on ASHRAE 15 on the last slide.

Where to Learn More on ASHRAE® Standard 15

→ **Trane Engineers Newsletter LIVE: ASHRAE® Standard 15 2022**

→ **Trane Engineers Newsletter: A2L Refrigerants and ASHRAE® Standard 15**

→ **Applications Engineering Manuals and Guides**

Common Refrigerant Types

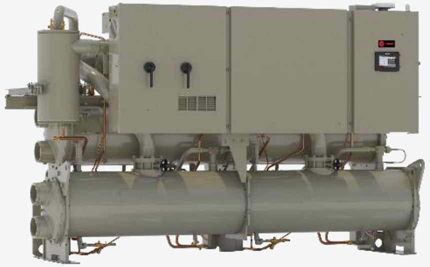
Pressure	Refrigerant	GWP	Class
Low	R-123	77	B1
	R-514A	1.7	B1
	R-1233zd(E)	1	A1
Medium	R-134a	1430	A1
	R-513A	630	A1
	R-515B	298	A1
	R-1234yf	6	A2L
	R-1234ze(E)	4	A2L
High	R-410A	2088	A1
	R-454B	467	A2L
	R-32	675	A2L

Chiller Applications – What’s Changing?

Chiller Applications

Wide Range of Compressor and Chiller Lift Requirements



Application	Data Center	Water Cooled Chiller	Air Cooled Chiller	Low Temp Process	Heat Recovery	High Temp Heat Recov.
Evaporator (F)	60	40	40	20	40	40
Condenser (F)	90	90	110	110	140	180
“Lift” (F)	**30**	**50**	**70**	**90**	**100**	**140**

Heat Pumps are driving new technology for high lift compressors

Data Centers are driving new technology for low lift chillers

Chiller Technology for Low Lift

Example Centrifugal Air Cooled Chiller

Example Ratings for Centrifugal AC Chiller

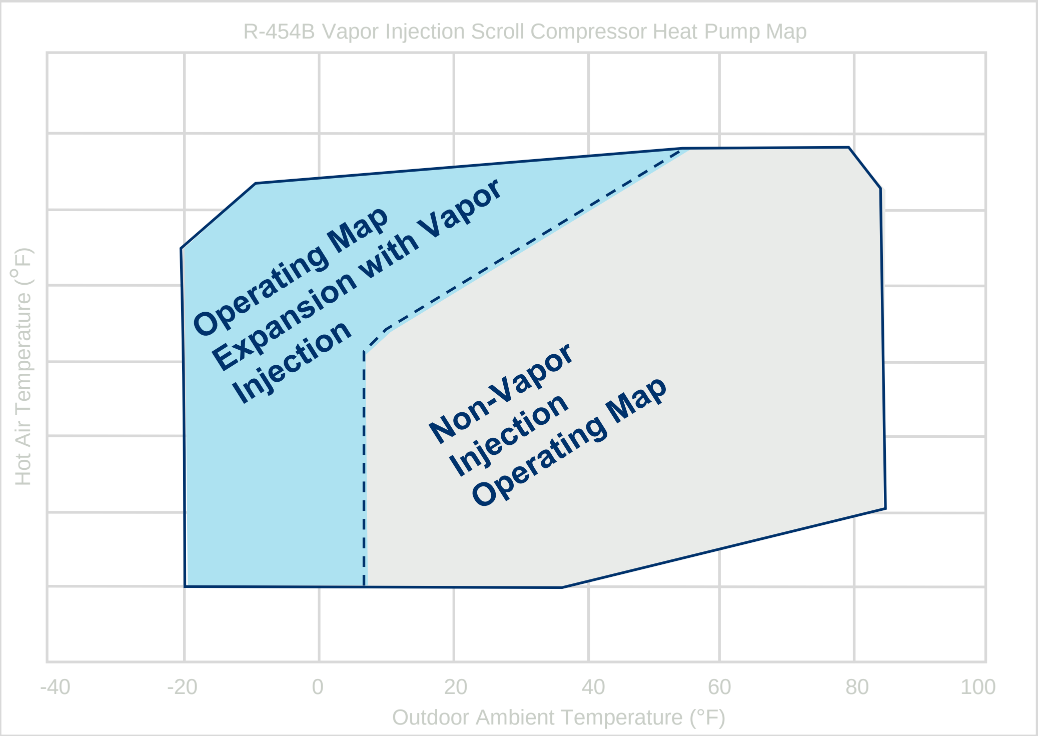
- Chilled water: 38-86F
- Ambient Temp: 0-122F

Compressor Technology

- High Speed Centrifugal Compressors
- Magnetic Bearings

Compressor Technology for Higher Lift

- **Vapor Injection Compressors**
  - Interstage inlet port extends operating map
- **Alternate Refrigerants**
- **Multi-stage Compressors**
  - Discharge of one stage feeds the next
- **Cascaded Compressors**
  - Discharge of one compressor feeds the next
- **Cascaded Chillers**
  - Condenser of one chiller hooked up to the evaporator of next.



Vapor injected scroll compressor 110-130F lift

Compressor Technology for Higher Lift

Example screw compressor
R513A: ~100F lift
R515B: ~125F lift

Vapor Injection Compressors

- Interstage inlet port extends operating map

✓ **Alternate Refrigerants**

Multi-stage Compressors

- Discharge of one stage feeds the next

Cascaded Compressors

- Discharge of one compressor feeds the next

Cascaded Chillers

- Condenser of one chiller hooked up to the evaporator of next.

Compressor Technology for Higher Lift

Vapor Injection Compressors

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Alternate Refrigerants

✓ **Multi-stage Compressors**

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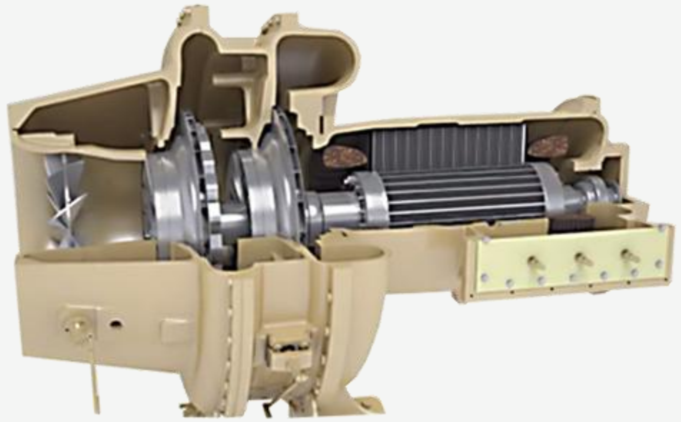

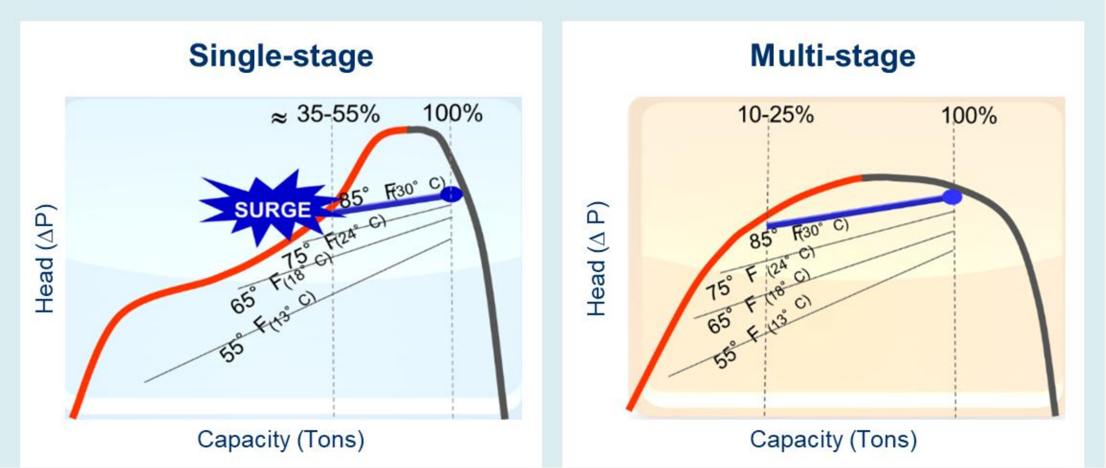

Compressor Technology for Higher Lift

Vapor Injection Compressors

- Interstage inlet port extends operating map

Alternate Refrigerants

Multi-stage Compressors

- Discharge of one stage feeds the next

✓ **Cascaded Compressors**

- Discharge of one compressor feeds the next

Cascaded Chillers

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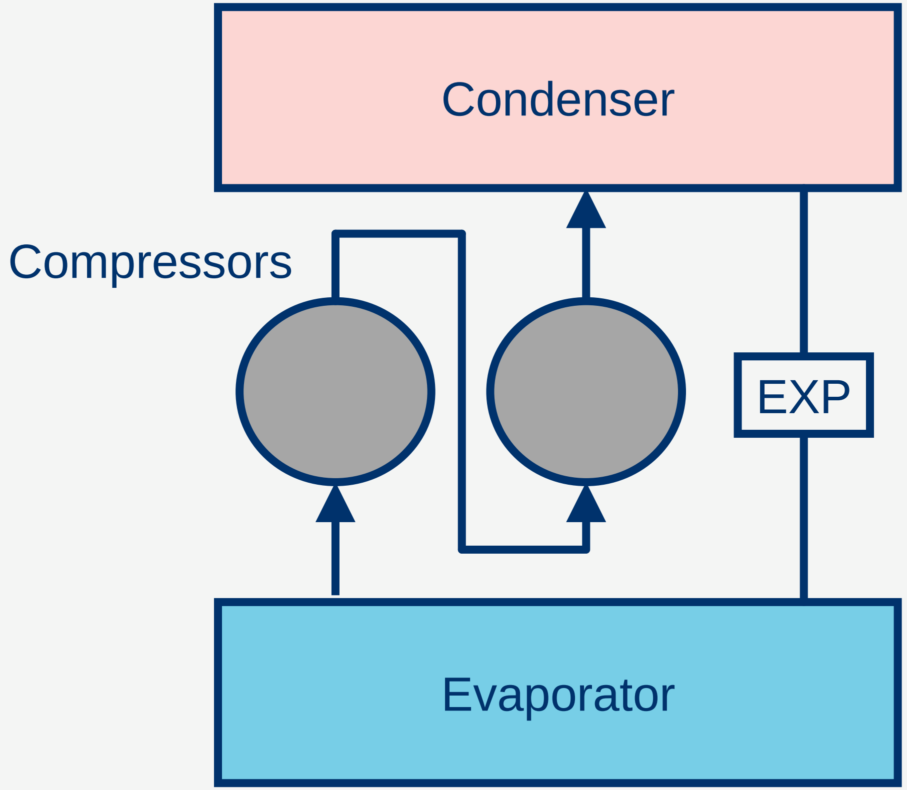


Cascaded Centrifugal Compressors ~130F lift

Compressor Technology for Higher Lift

Vapor Injection Compressors

- Interstage inlet port extends operating map

Alternate Refrigerants

Multi-stage Compressors

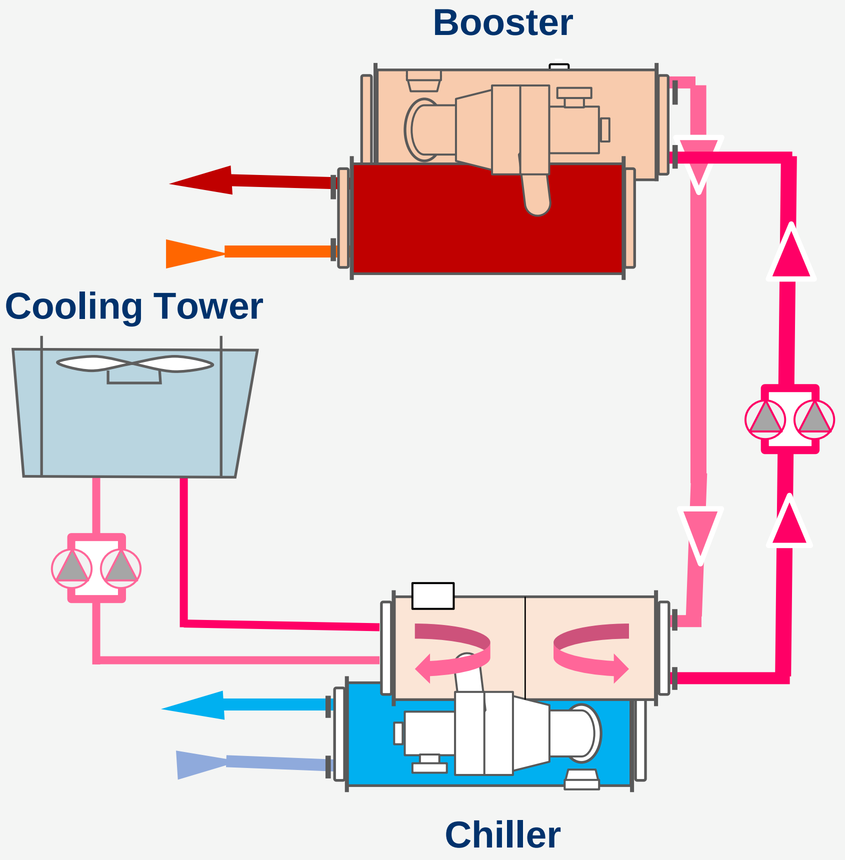
- Discharge of one stage feeds the next

Cascaded Compressors

- Discharge of one compressor feeds the next

✓ **Cascaded Chillers**

- Condenser of one chiller hooked up to the evaporator of next.

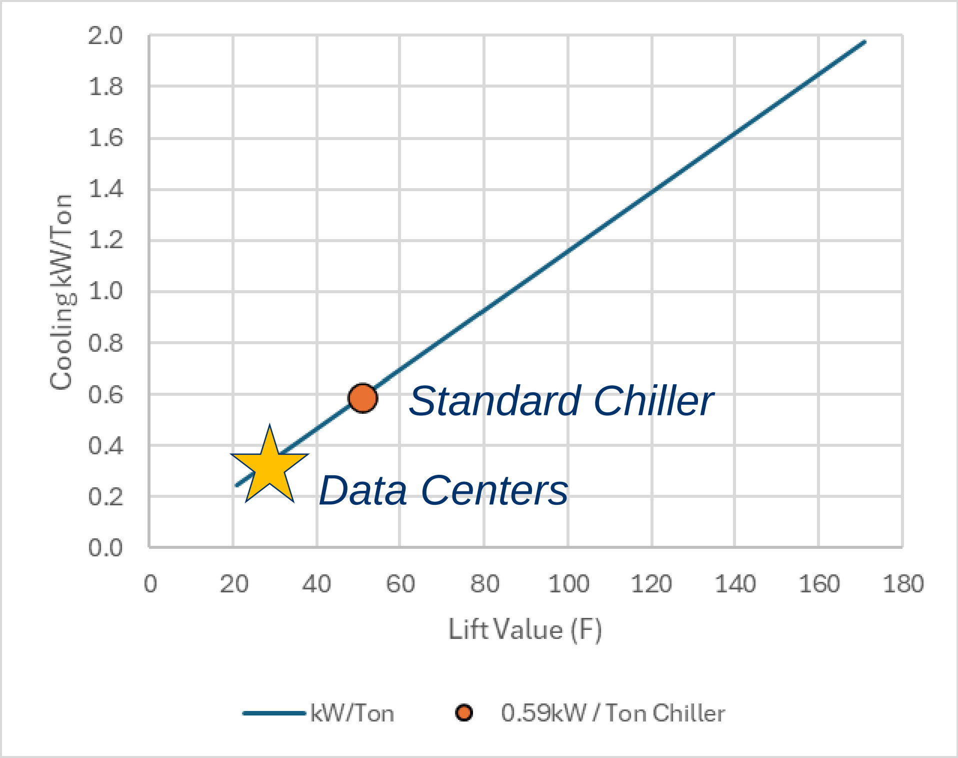


Cascaded Centrifugal Chillers ~140F lift
Centrifugal Chiller + Screw Booster ~170F lift

Efficiency Impact of High Lift

Chiller Efficiency

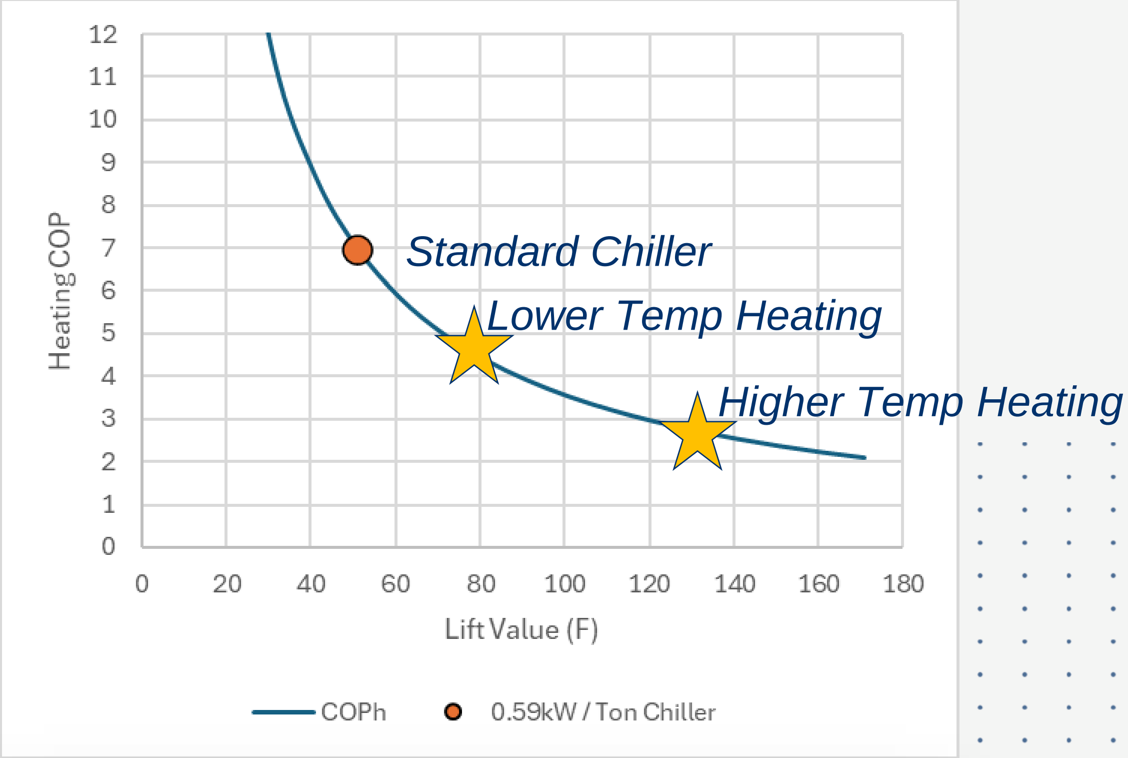
- Compressor Power is proportional to lift
  "Carnot Efficiency"
- High lift = higher power = lower efficiency
- $$\frac{kW}{Ton} = \frac{Electrical\ kW\ input}{Cooling\ Tons\ output}$$



Efficiency Impact of High Lift

Heating Efficiency

- Compressor Power is proportional to lift
  "Carnot Efficiency"
- High lift = higher power = lower efficiency
- $$COP = \frac{Heating\ kW\ output}{electrical\ kW\ input}$$
- COP = "Coefficient of Performance"



Thumb rule: 1% efficiency penalty per 1F over 105F

Efficiency Impact of High Lift

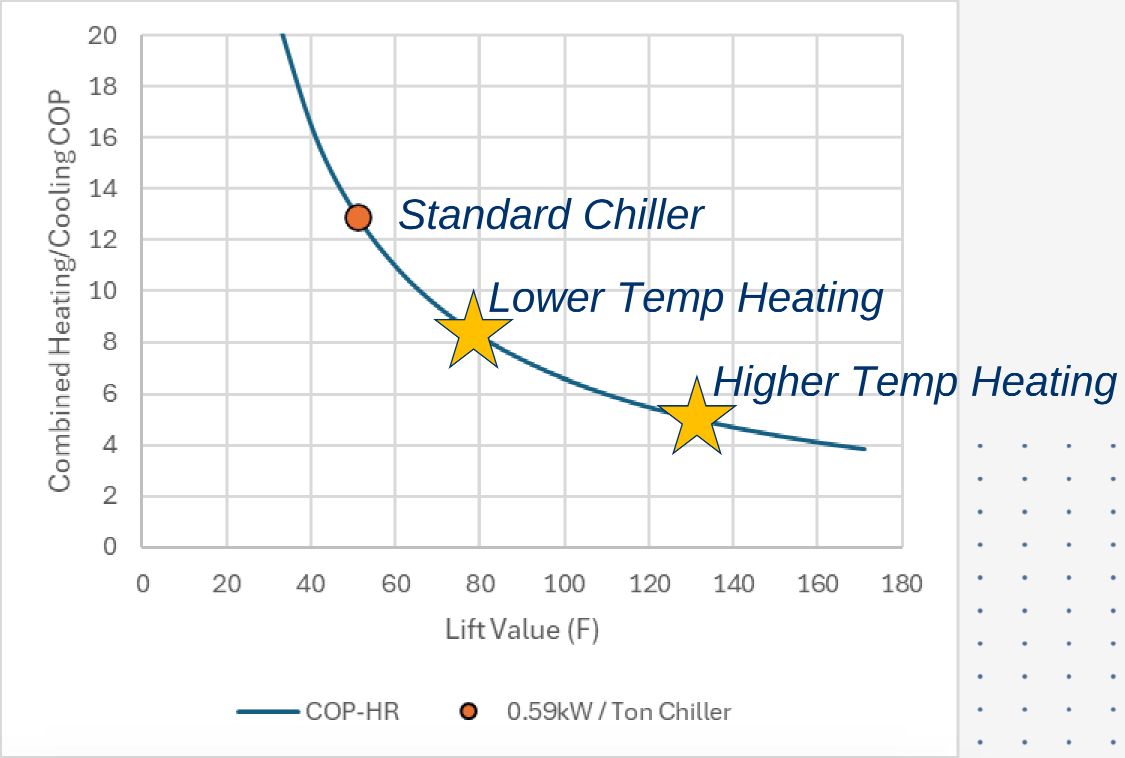
Heat Recovery Efficiency - Include Heating AND Cooling output

- Compressor Power is proportional to lift
  "Carnot Efficiency"

- High lift = higher power = lower efficiency

- $$COP = \frac{Heating\ kW + Cooling\ KW}{electrical\ kW\ input}$$

References:
ASHRAE® "A Guide for Applying Heat Pumps and Beyond".
Engineering Newsletter "Heating with Lower-Temperature Hot Water".



Thumb rule: 1% efficiency penalty per 1F over 105F

Summary

- **New refrigerant types for lower Global Warming Potential (GWP)**
  - ASHRAE® 15
- **New compressor technologies for high and low lift applications**
  - Vapor injection
  - Refrigerant types
  - Multistage
  - Cascaded compressors or chillers
- **Tradeoffs between compressor lift and efficiency**
  - Low lift = high efficiency
  - High lift = reduced efficiency

Thank You!

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Water-Cooled vs. Air-Cooled Chillers Efficiency and Applications

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