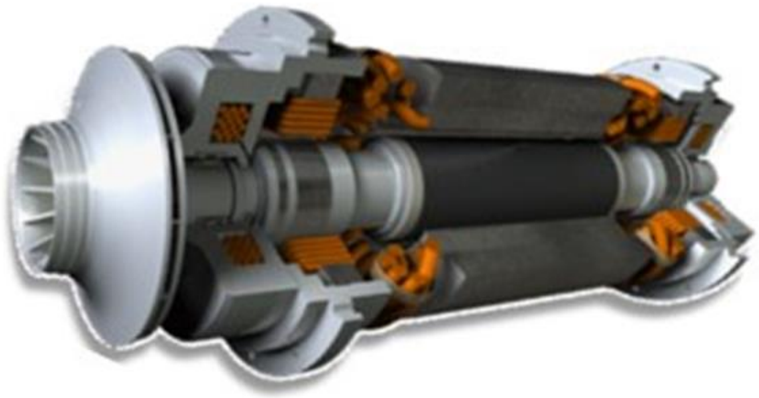
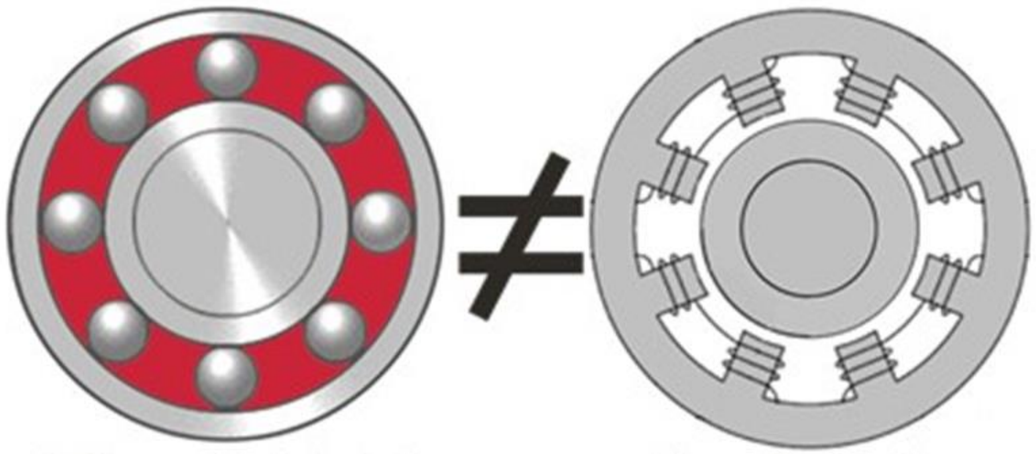
INTERNATIONAL DISTRICT ENERGY ASSOCIATION

Welcome to the IDEA Webinar Series

- The webinar will **start promptly at 2:00pm EST (Boston time) and is scheduled to last one (1) hour; including time for questions.**
- Please **mute your phone** during the webinar. All lines are muted.
- If you are having problems with video or audio, please send a note via the Chat Box function on the right side. Click the Chat box and choose – **"Chat privately to Cheryl Jacques (host)". Or call to IDEA at +1-508-366-9339.**
- **Questions to Presenters**: Please enter your **Questions** in the **Q&A** box at the lower right of the screen. These questions will be moderated and addressed as time allows. We plan to handle Q&A at the conclusion of the presentation.
- **Survey**: Please complete the brief on-line survey following the webinar.
- **Webinar Download or Streaming**: Webinar will be recorded and available via download or streaming. Slides will be made available in pdf format. Please visit **www.districtenergy.org.**





Refrigerant Lubricated
Ceramic Ball Bearings

Magnetic Bearings

WHY ALL OIL-FREE CHILLERS ARE NOT CREATED EQUAL

January 2017

YORK®

Johnson Controls

Agenda

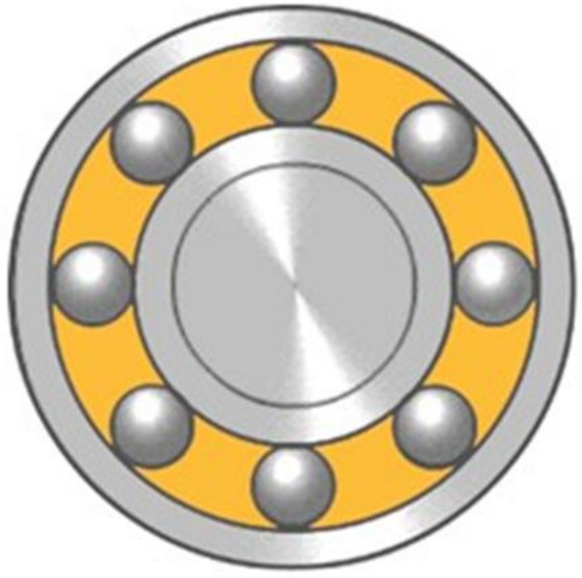
- Review Centrifugal Chiller Bearing Options
  - Oil-lubricated Ball Bearings
  - Fluid Film Oil Bearings
  - Refrigerant-lubricated Ball Bearings
  - Magnetic Bearings
- Deeper Dive into Oil-Free Options
- Why YORK Magnetic Bearings - The YORK YMC^2 Chiller
- Case Study Example

“You Can’t Open a Window”

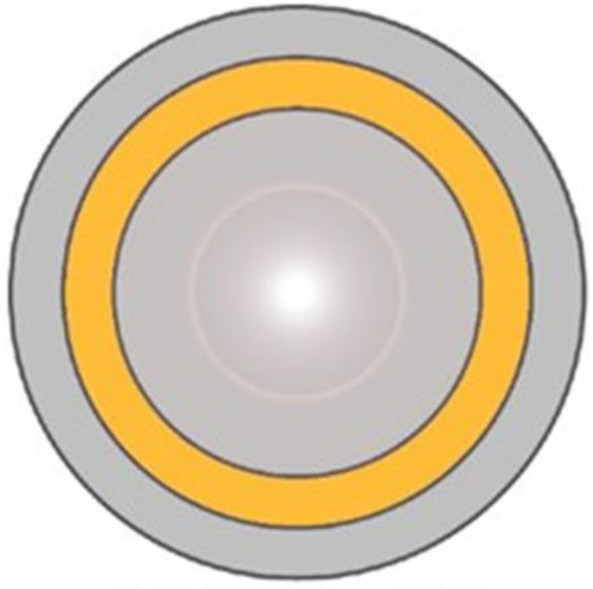
- YORK Navy Systems introduced magnetic-bearing technology in 1998
  - Used for over 125 mission critical naval applications

Bearing Options

Oil-lubricated Systems

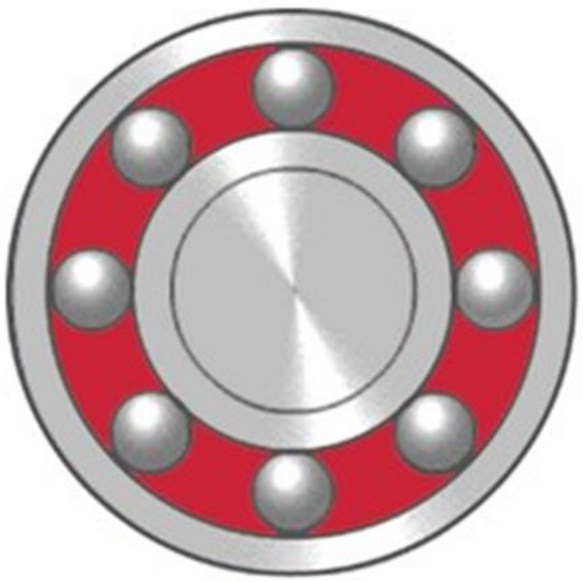


Oil-lubricated Ball Bearings

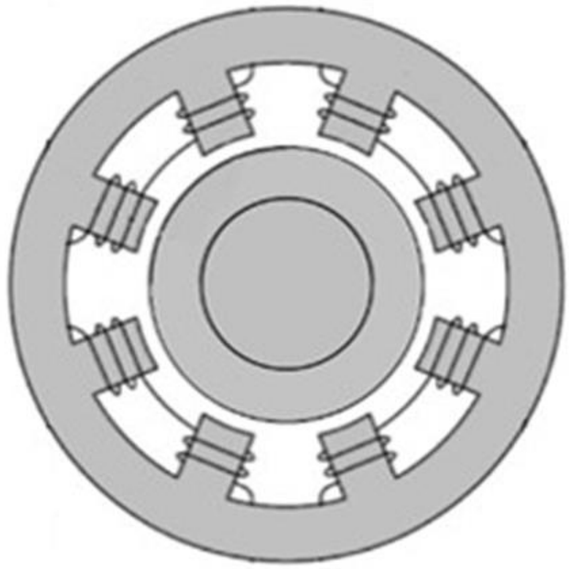


Fluid Film Oil Bearings

Oil-free Systems



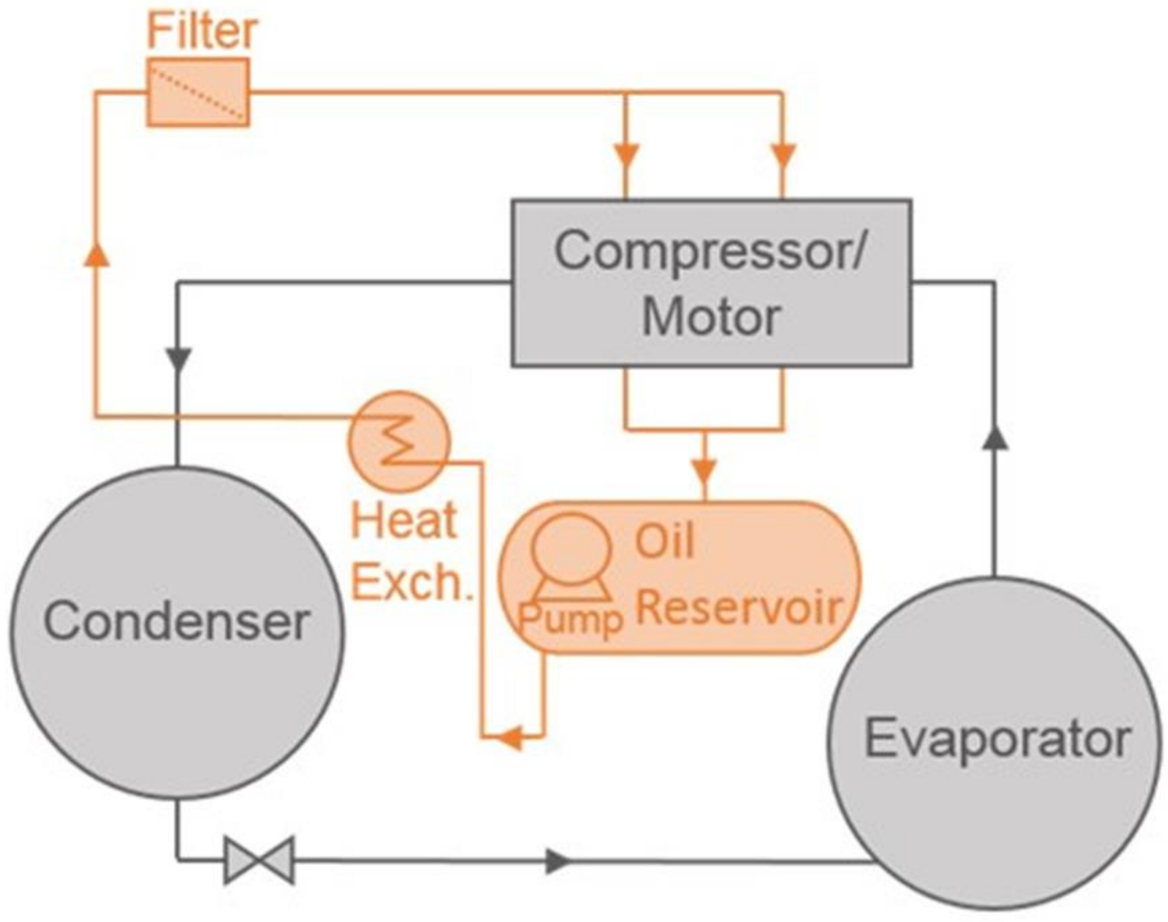
Refrigerant-lubricated Ball Bearings



Magnetic Bearings

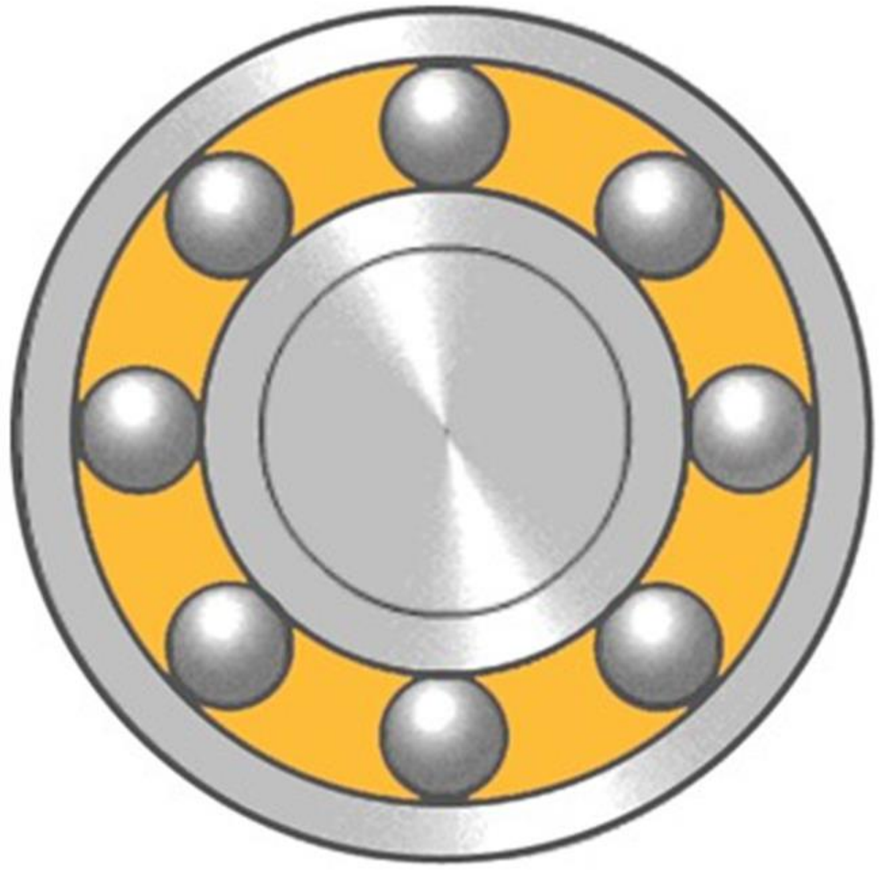
Oil-lubricated Ball Bearings

- Oil system
  - Oil management and disposal
- Rolling element ball bearings
  - Reduced mechanical friction losses
- Regular maintenance
  - Regular check of oil level
  - Filter inspection/replacement



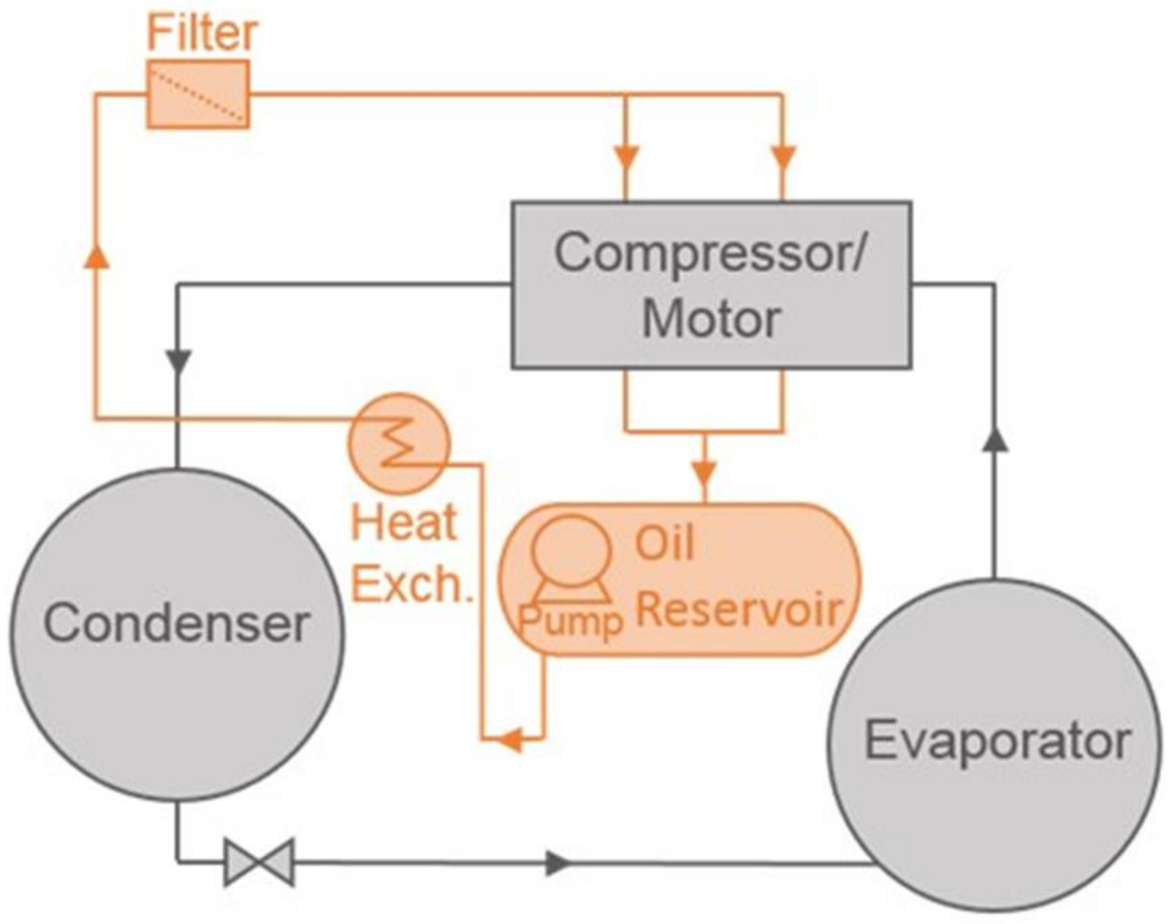
Oil-lubricated Ball Bearings

- Bearing life based on fatigue – L10
  - Contamination can significantly shorten bearing life
  - Failure occurs with little or no warning
- Bearing failure can be catastrophic to motor
  - Replacement requires:
    - Bearing housing removal
    - Equipment uncoupling
    - Motor removal/replacement



Fluid Film Oil Bearings

- Oil system
  - Oil management and disposal
  - Traditional system used in YORK YK chillers
- Sleeve bearing design
  - No contact between bearing and shaft
- Regular maintenance
  - Regular check of oil level
  - Filter inspection/replacements



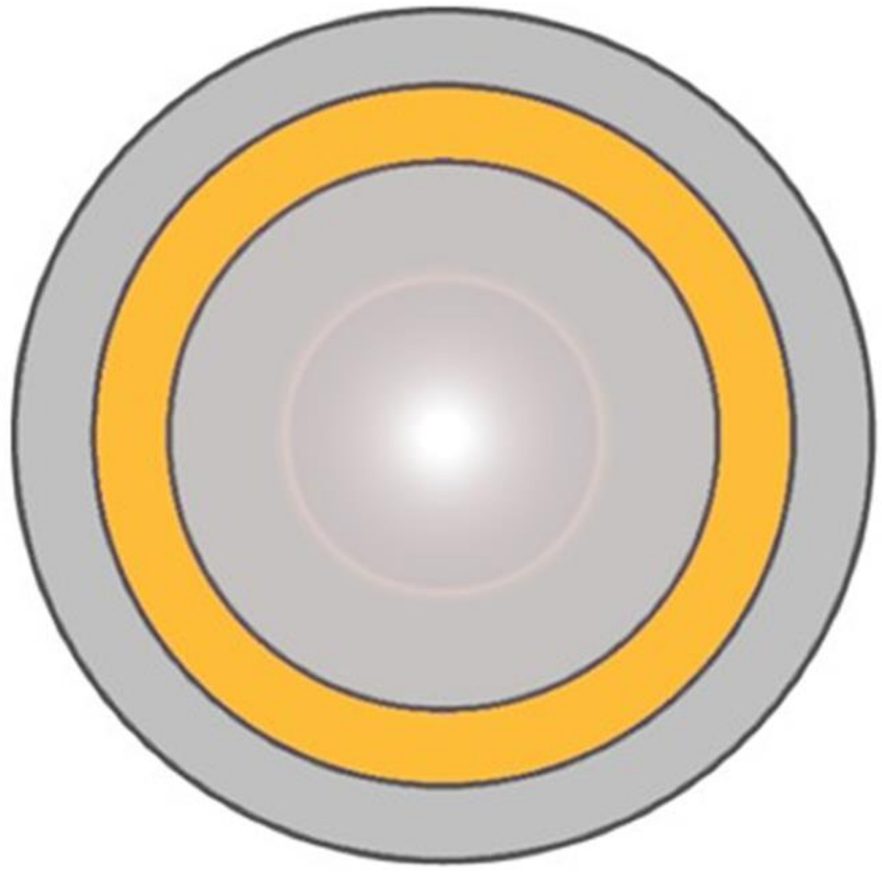
→ Primary Refrigerant Circuit

→ Bearing Lubrication Oil Circuit*

**Connection locations may vary*

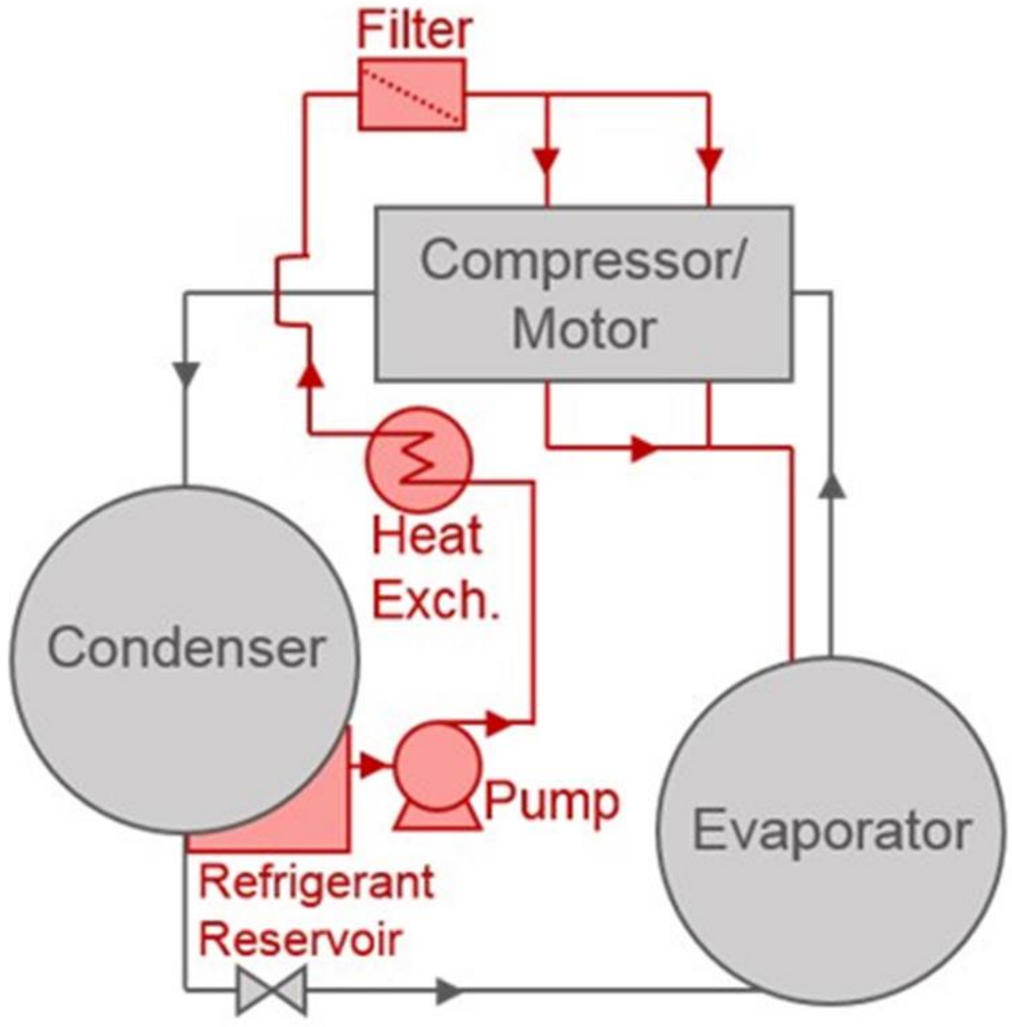
Fluid Film Oil Bearings

- Use principle of hydrodynamic lubrication
  - Creates wedge of oil between shaft and bearing
  - Minimum oil film thickness requirement
- No metal to metal contact
  - Theoretical infinite lifespan
- Temperature sensors can give warning before failure
  - Replacement requires - Upper bearing housing removal



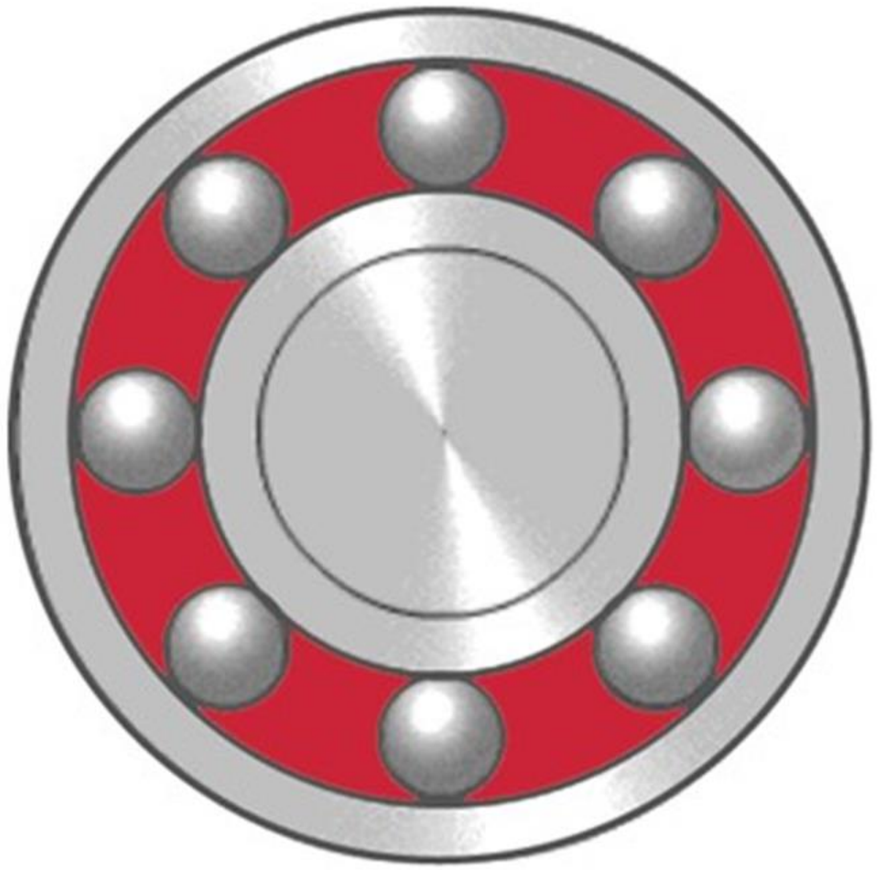
Refrigerant-lubricated Ball Bearings

- Oil-free operation
  - Reduces CO_2 emissions
- Hybrid ceramic ball bearings
  - Reduced mechanical friction losses
- Regular maintenance
  - Refrigerant level monitoring
  - Additive level monitoring (if applicable)
  - Filter inspection/replacement
- Limited operating range
  - Refrigerant lubrication limits compressor speeds



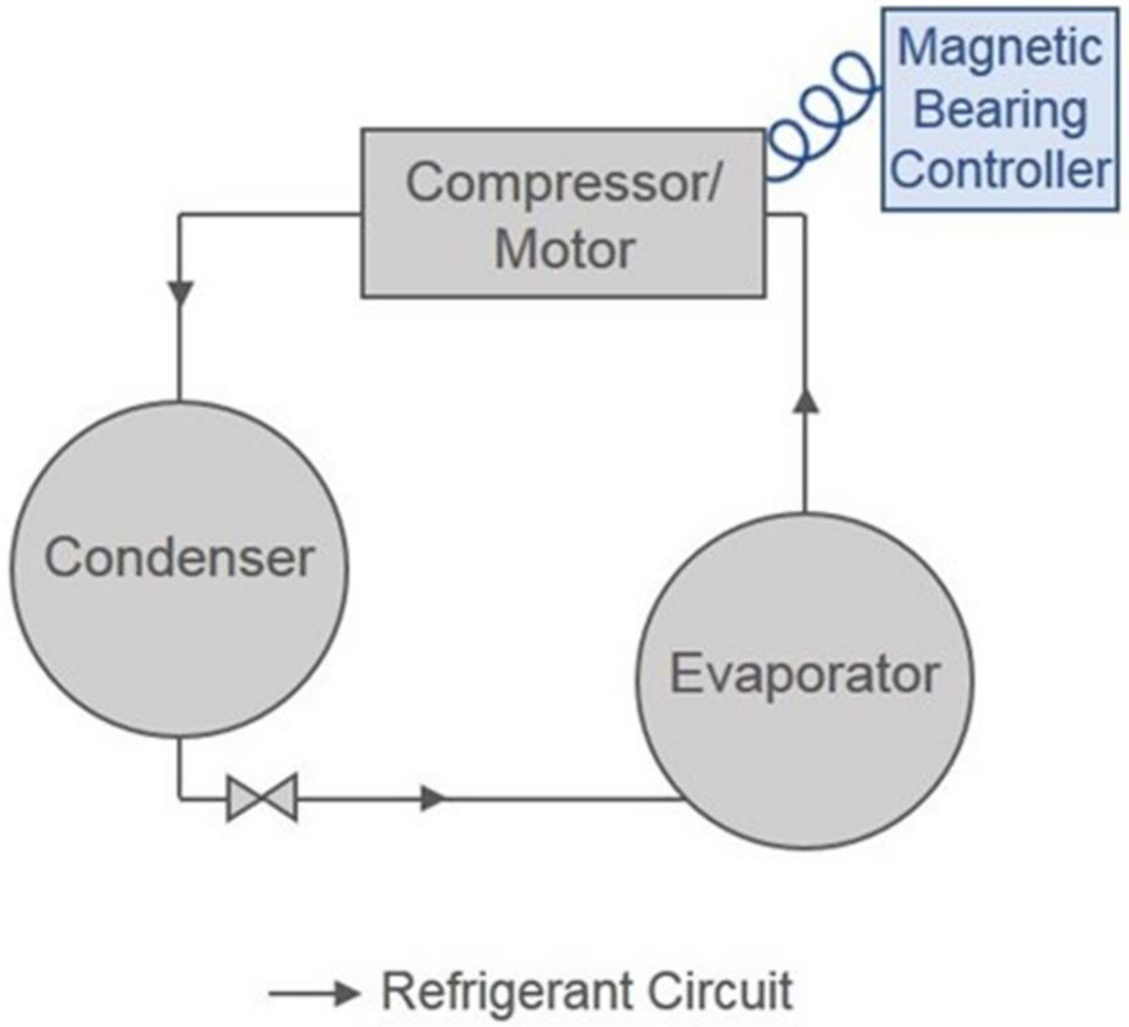
Refrigerant-lubricated Ball Bearings

- Bearing life based on fatigue – L10
  - Contamination can significantly shorten bearing life
  - Failure occurs with little or no warning
  - Difficult to predict with refrigerant as lubricant
- Refrigerants show poor lubricity & sensitivity to temperature changes
  - Typically, refrigerants and oil are mixed to lubricate bearings
  - Refrigerant as a lubricant must be sub-cooled to avoid flashing in the bearings
- Relatively new and experimental



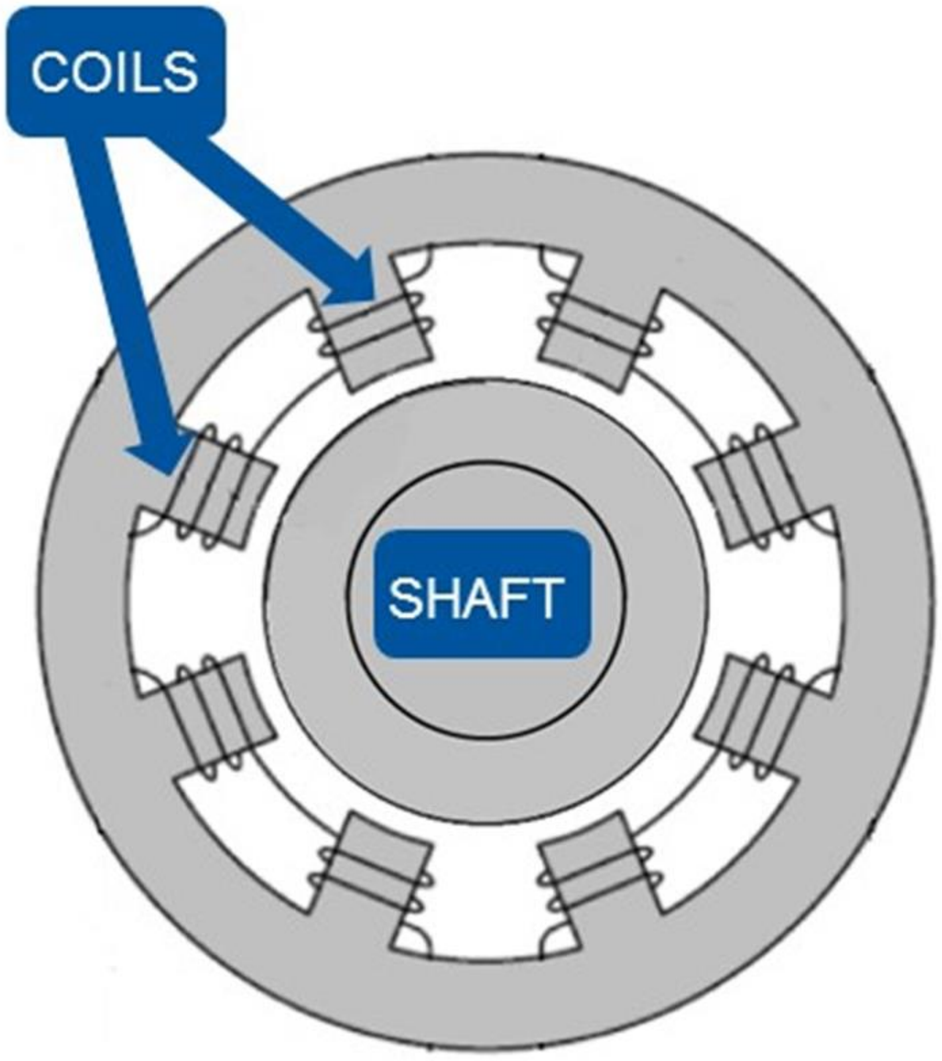
Magnetic Bearings

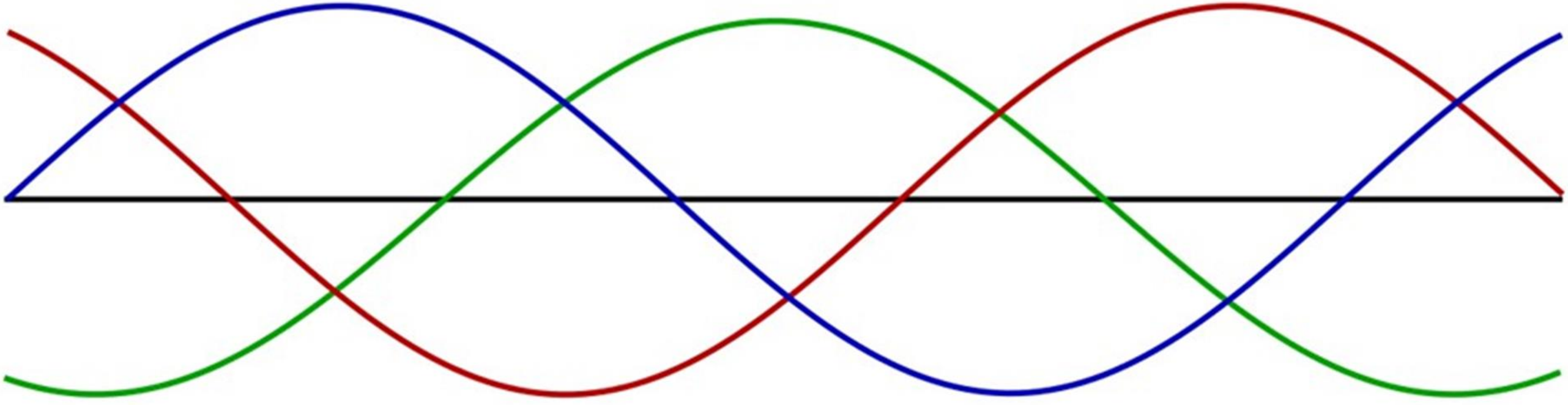
- Lubrication-free
  - Increases durability
- Non-contact design
  - Eliminates mechanical friction losses
  - Theoretical infinite lifespan
- Simple design for low maintenance
  - Bearings last the life of the chiller
  - Less components to service and maintain



Magnetic Bearings

- Magnetic bearings support load using magnetic levitation
- Proven technology in critical applications
  - First patents came during WWII
  - 1974 – CR Meeks published "Magnetic-Bearings – Optimum Design and Application"
    - Proposed the basic magnetic-bearing design used today

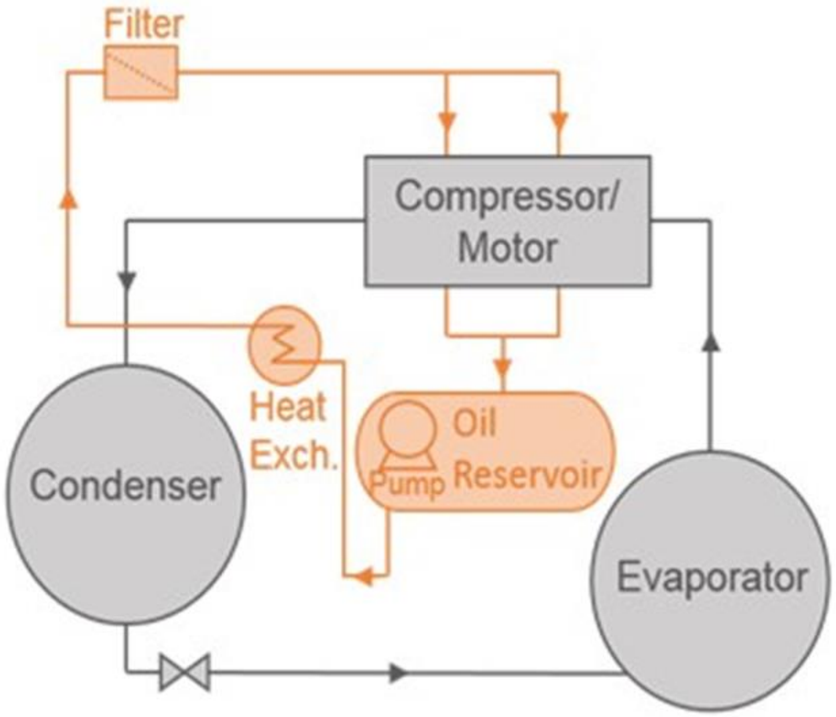




Rotating 3-phase magnetic field

Simplicity is Key

Oil-Lubricated Bearings

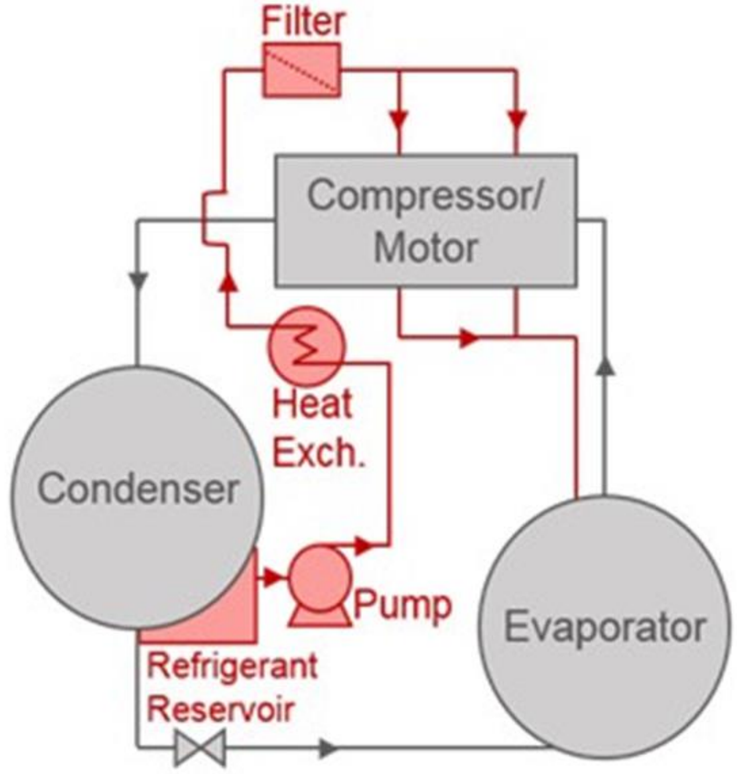


→ Primary Refrigerant Circuit

→ Bearing Lubrication Oil Circuit*

**Connection locations may vary*

Refrigerant-Lubricated Ball Bearings

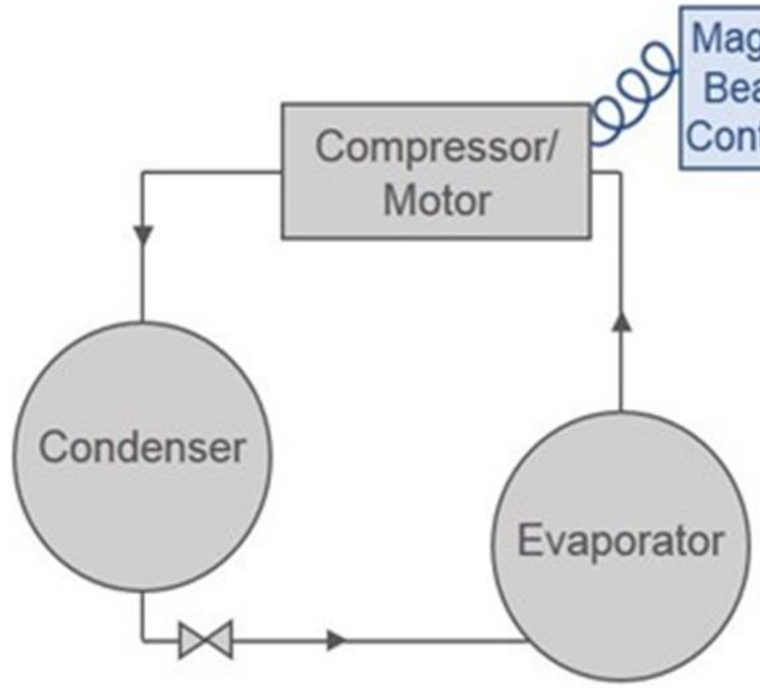


→ Primary Refrigerant Circuit

→ Bearing Lubrication Refrigerant Circuit*

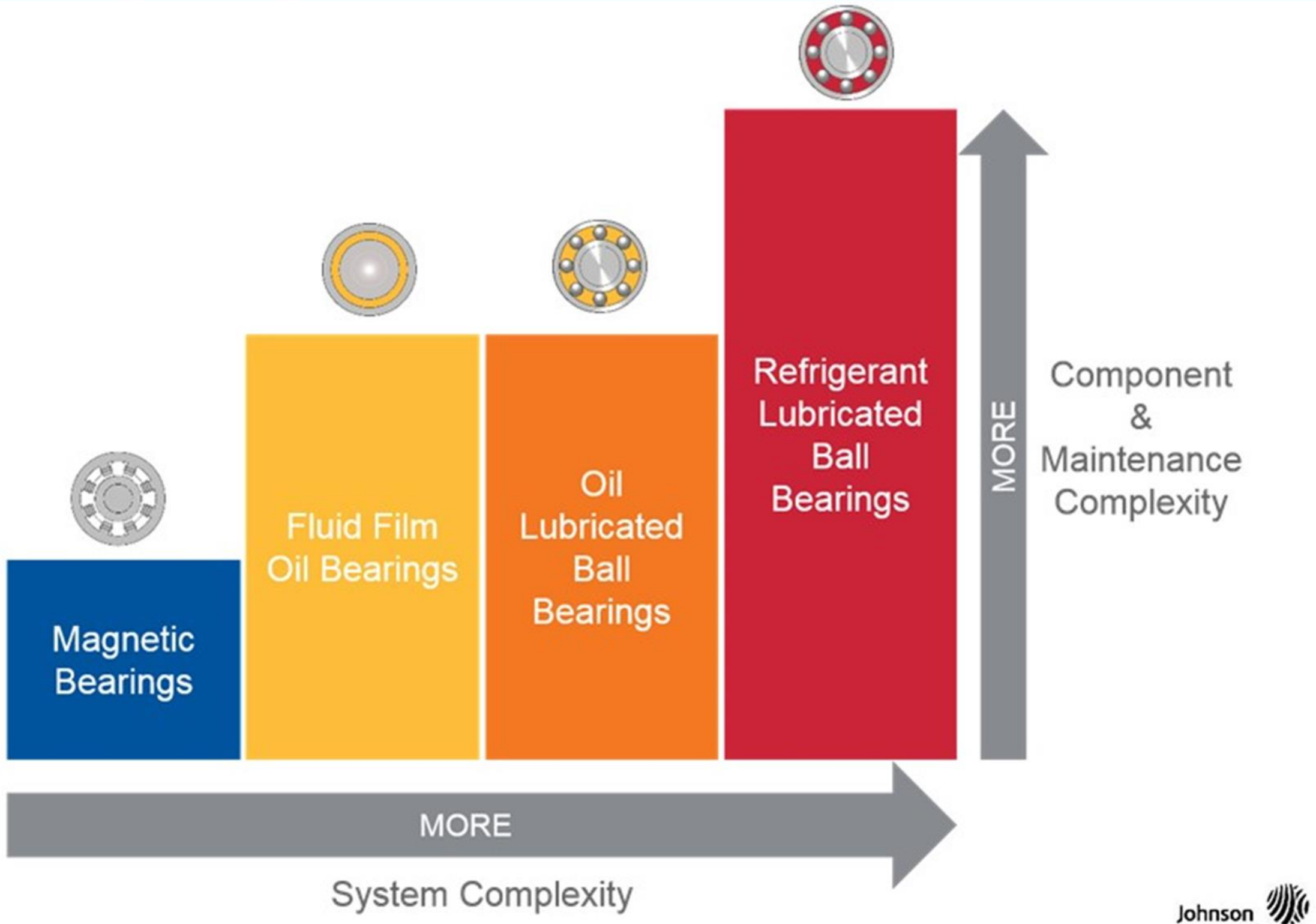
**Connection locations may vary*

Magnetic Bearings

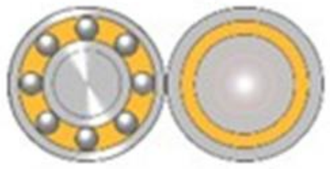


→ Refrigerant Circuit

Simplicity is Key

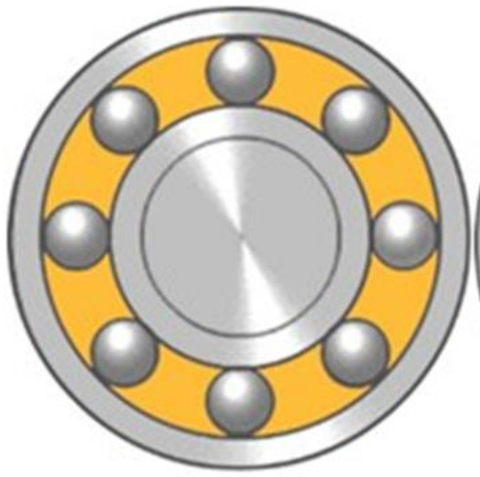


Cost Comparison

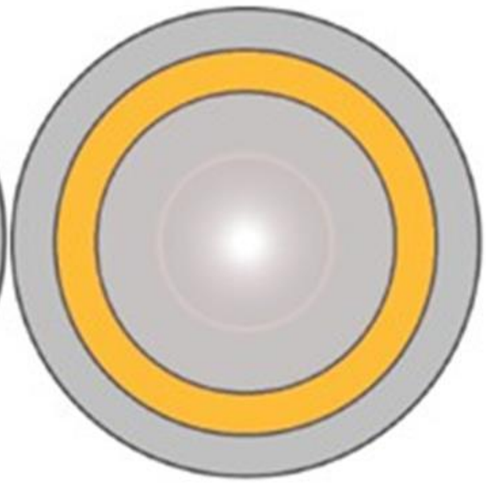


Bearing Type	Oil-lubricated Ball Bearings	Refrigerant-lubricated Ball Bearings	Magnetic Bearings
First Cost: Bearings	$	$	$$
Filter	$	$	-
Pump	$	$	-
Heat Exchanger	$	$	-
Additives	-	$	-
Bearing Replacement & Labor	$$	$$	-
Down Time	$$	$$	-

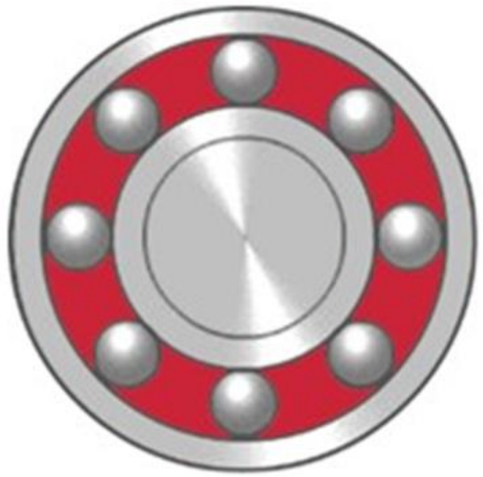
Advancing Technology



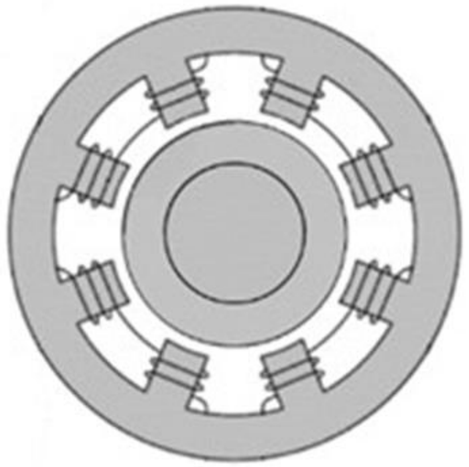
Oil-lubricated Ball Bearings



Fluid Film Oil Bearings



Refrigerant-lubricated Ball Bearings



Magnetic Bearings

The YORK YMC² Chiller

Highly Efficient

Sustainable

Versatile

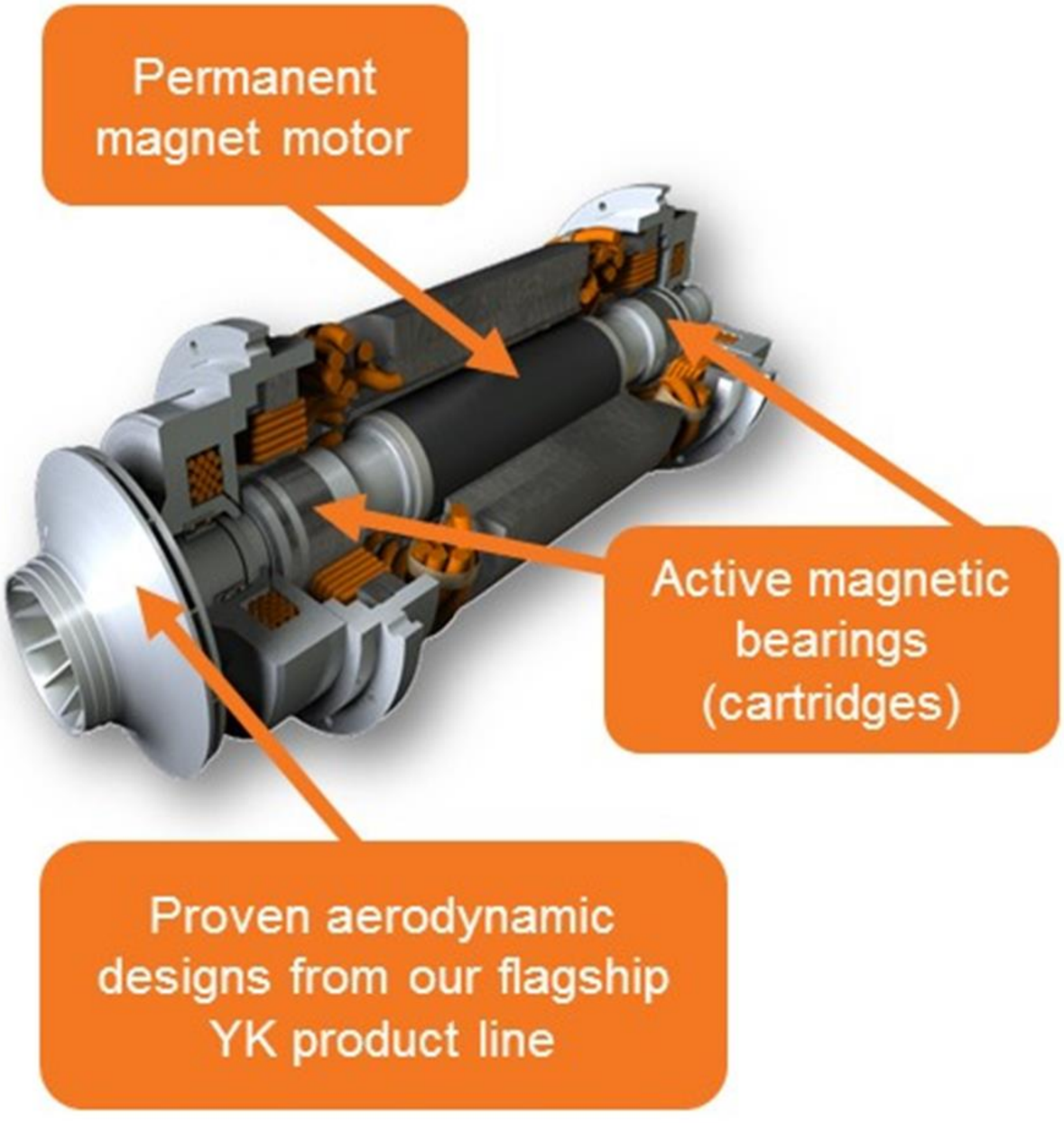
Strongly Dependable

Smart Investment

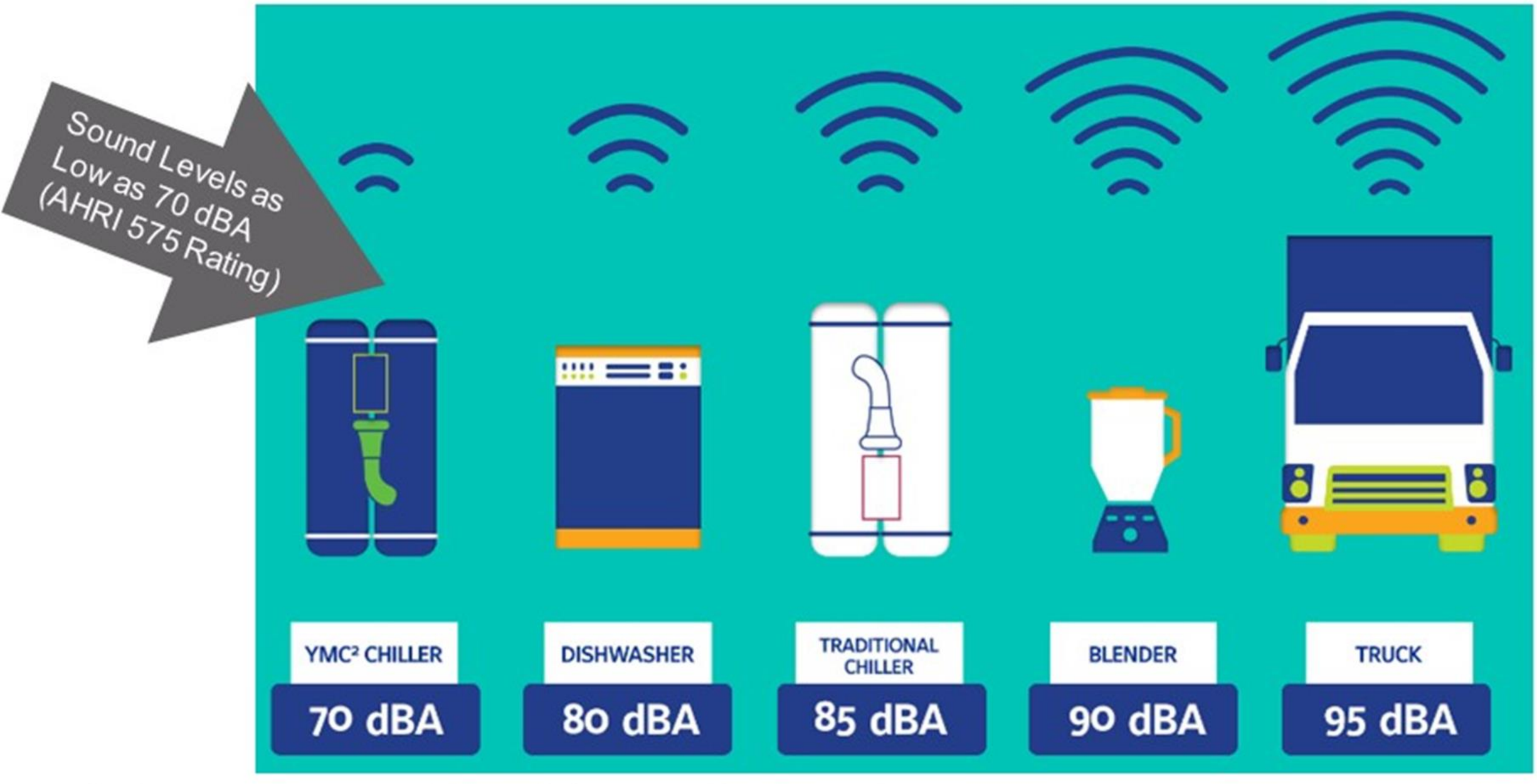
Lowest Sound Levels on the Market

The Premier Magnetic Bearing Chiller

- Widest operating range to maximize efficiency
  - Magnetic bearings do not limit operating range of the compressor
- Fastest start-up time
  - No lubrication system delay sequence
- Environmentally responsible
  - Reduced greenhouse gas emissions
- Reliable
  - Technology is used in mission-critical military applications

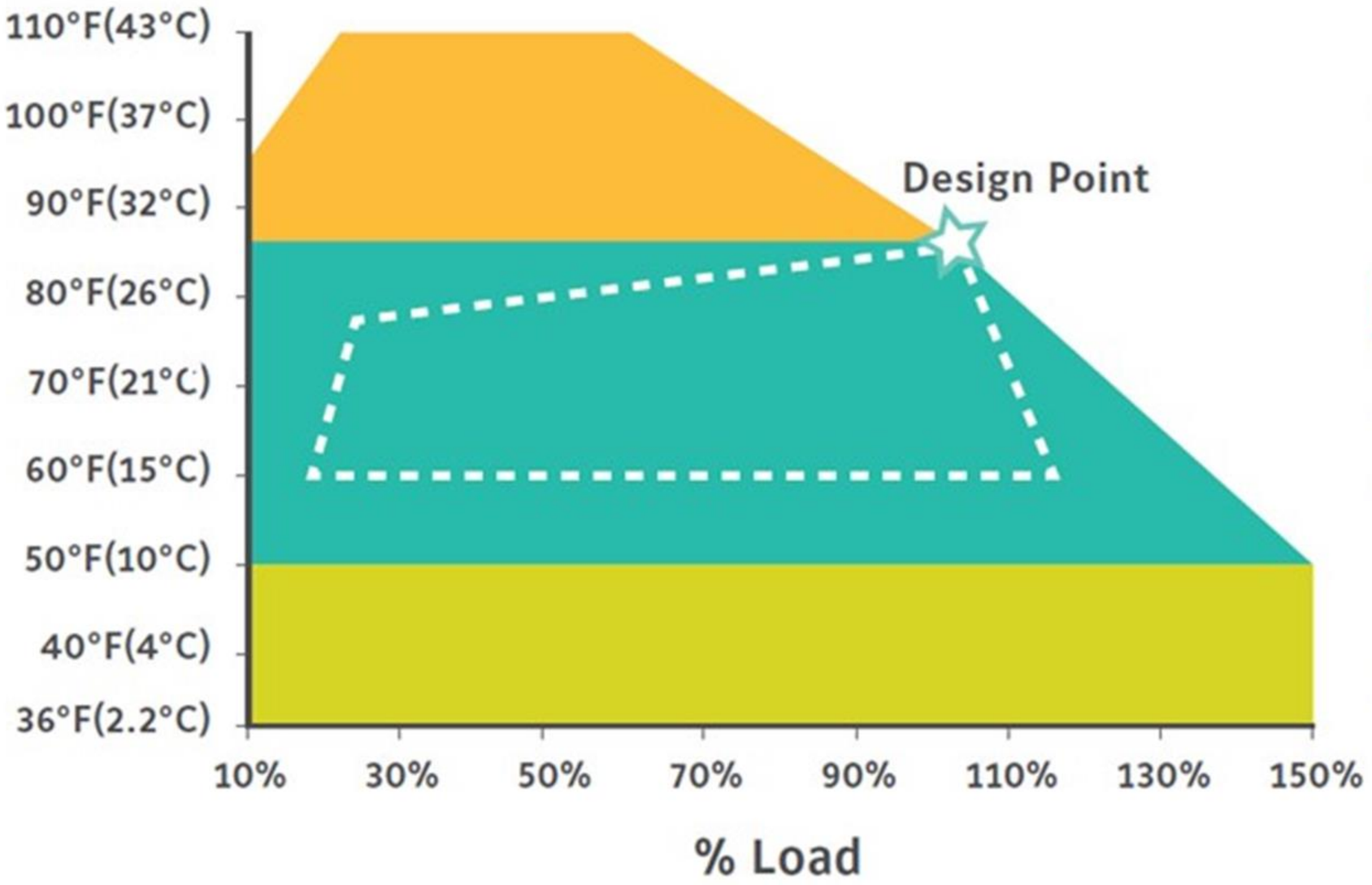


Impressive Sound Levels



- Sound Levels Achieved through the use of:
  - Permanent magnet motor with active magnetic bearings
  - OptiSound™ Control

Widest Operating Envelope



Higher ECWT
Stable Operation

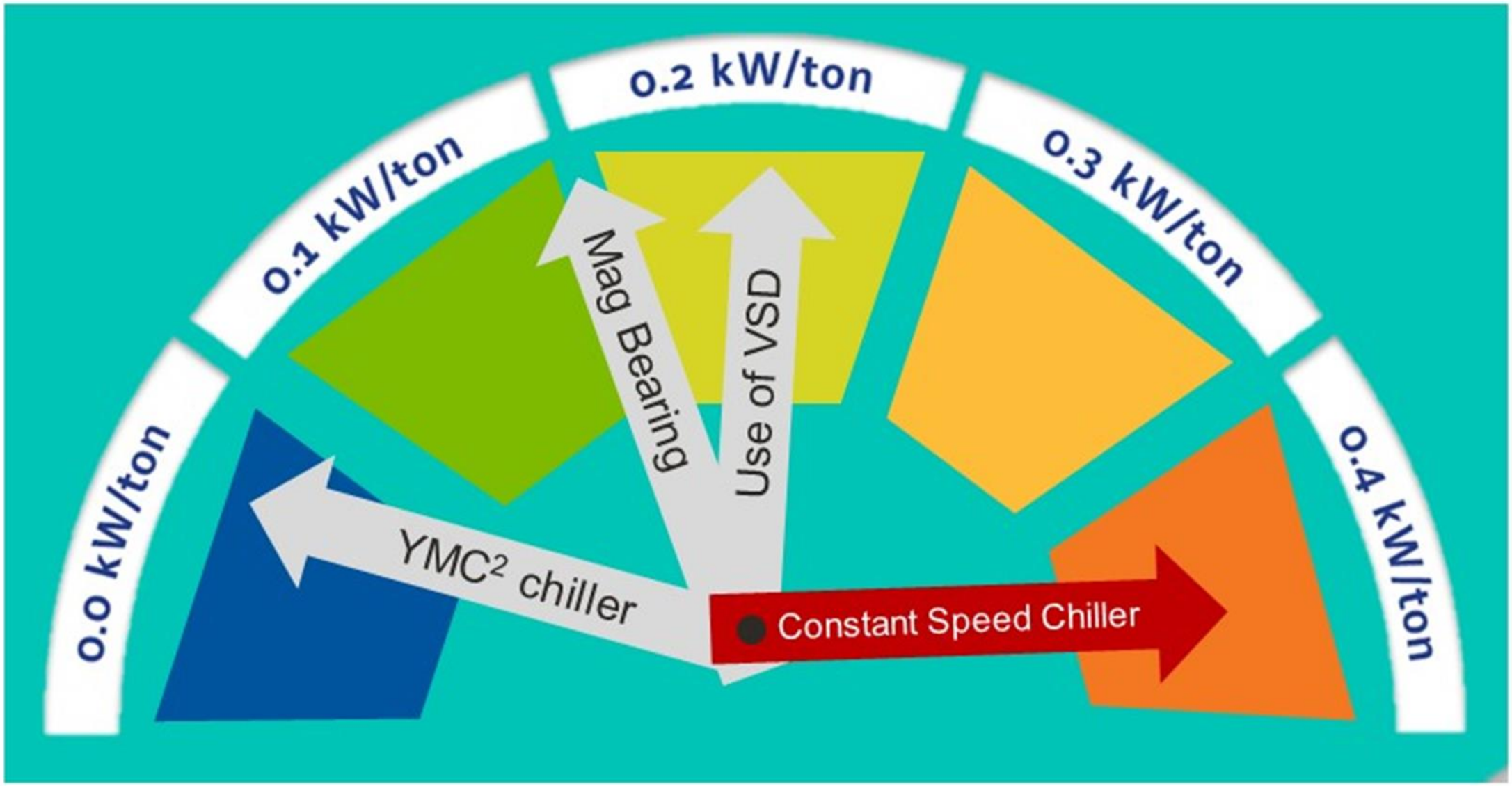
Other Magnetic Bearing Chiller Operation Range

Lower ECWT
Real-World Operation

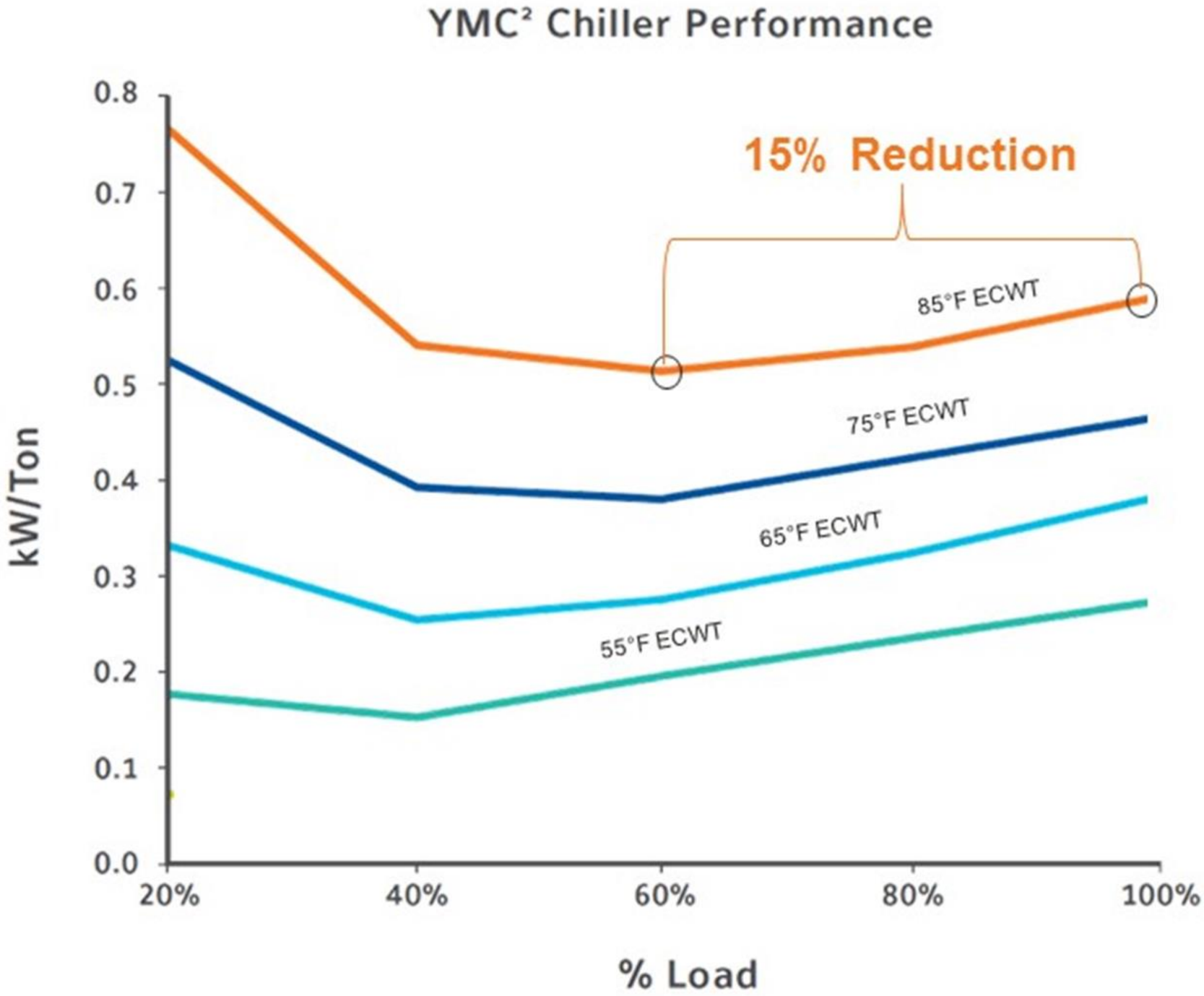
Extra-Low ECWT
Out-of-This-World Operation

ECWT – Entering Condenser Water Temperature

Part Load Efficiency – Then and Now

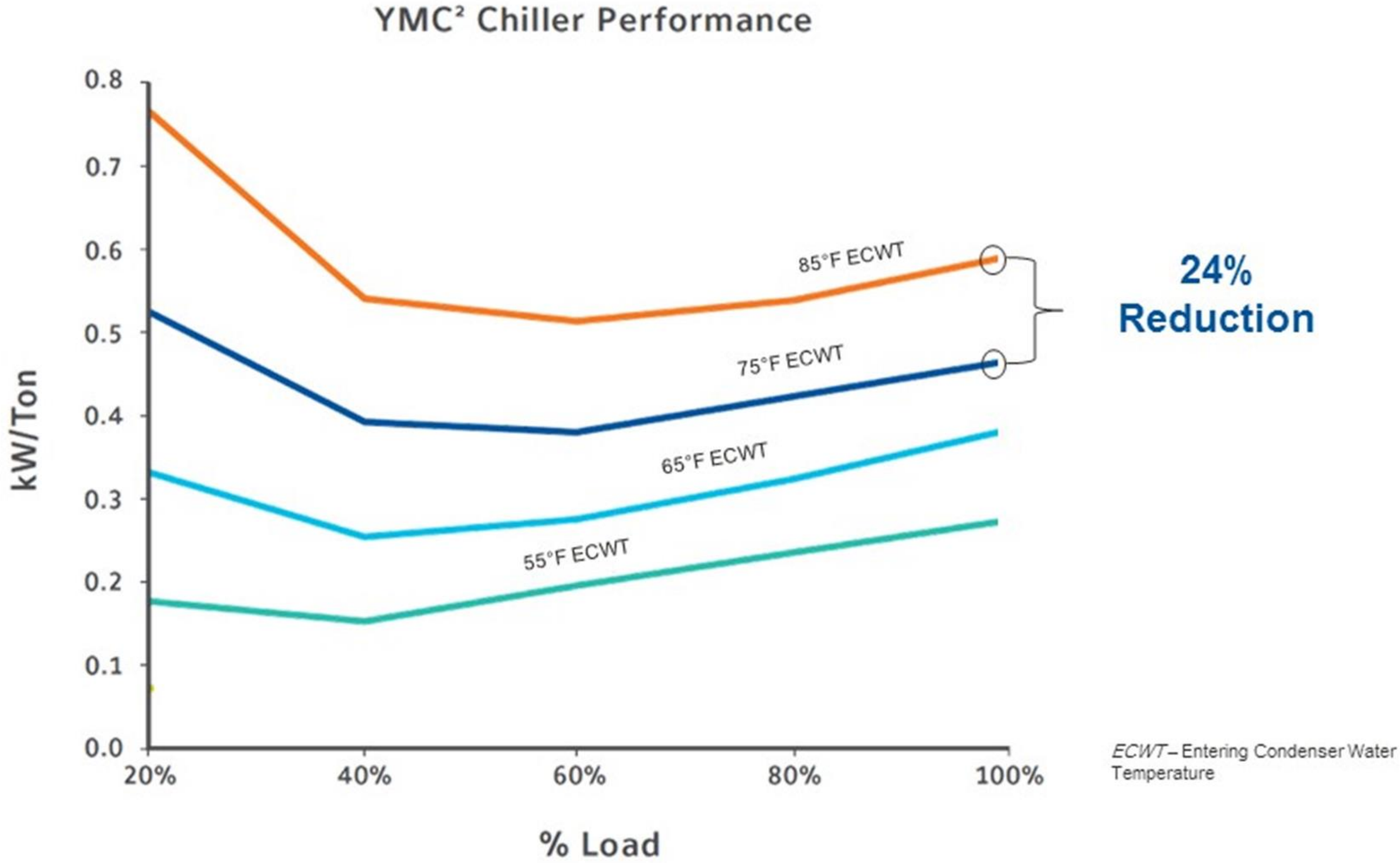


Real World Efficiency – Lift vs Load



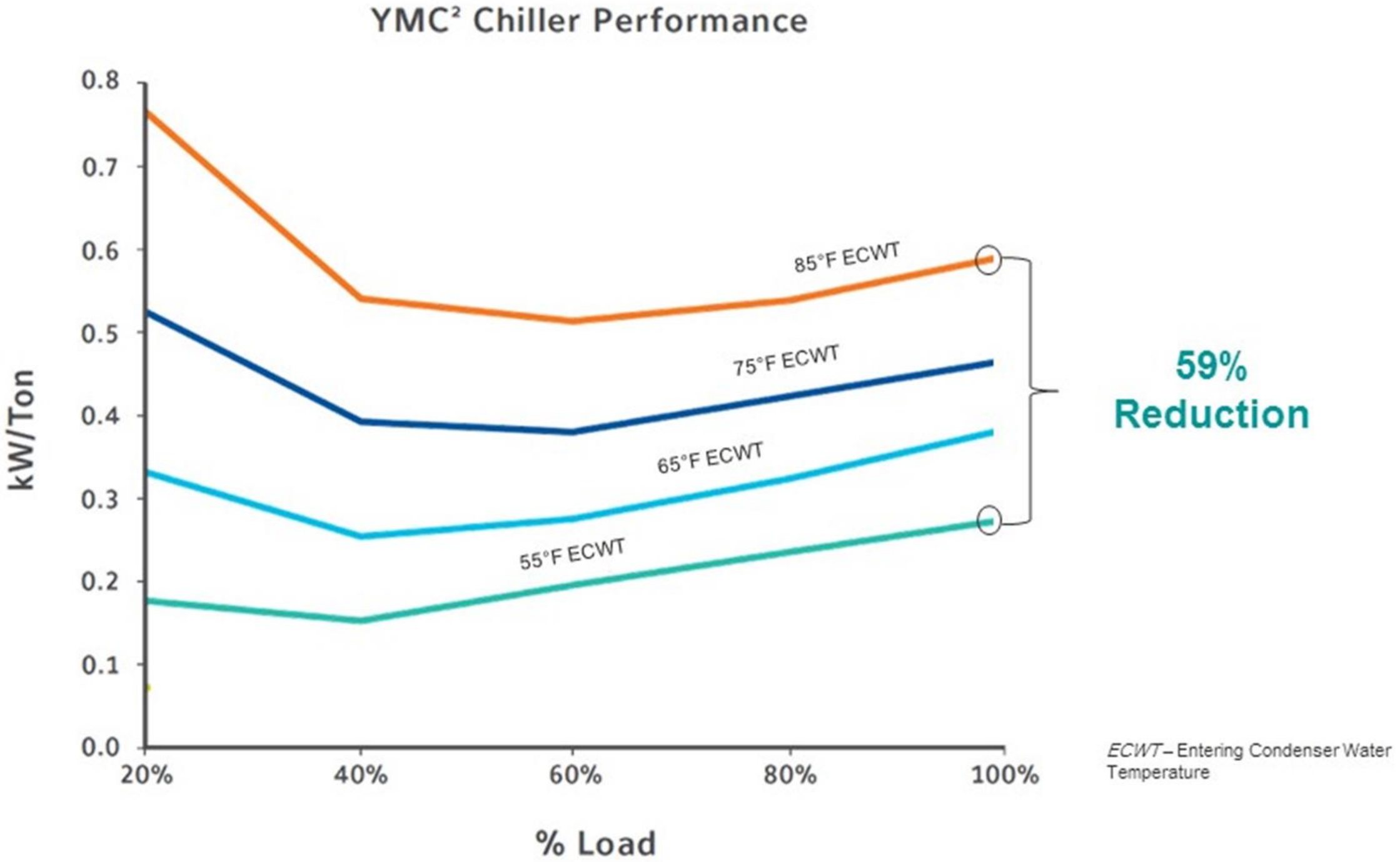
ECWT – Entering Condenser Water Temperature

Real World Efficiency – Lift vs Load



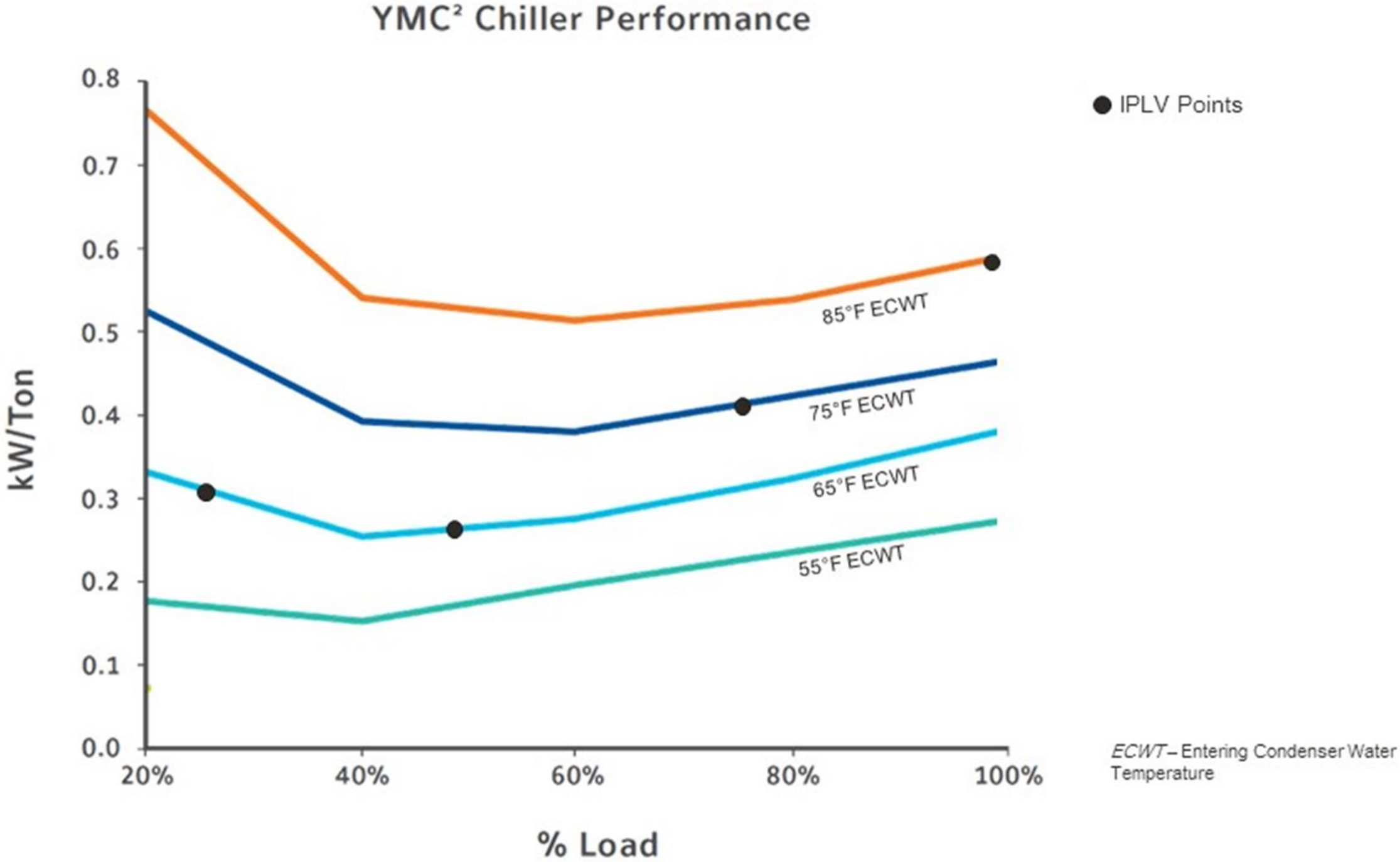
ECWT – Entering Condenser Water Temperature

Real World Efficiency – Lift vs Load



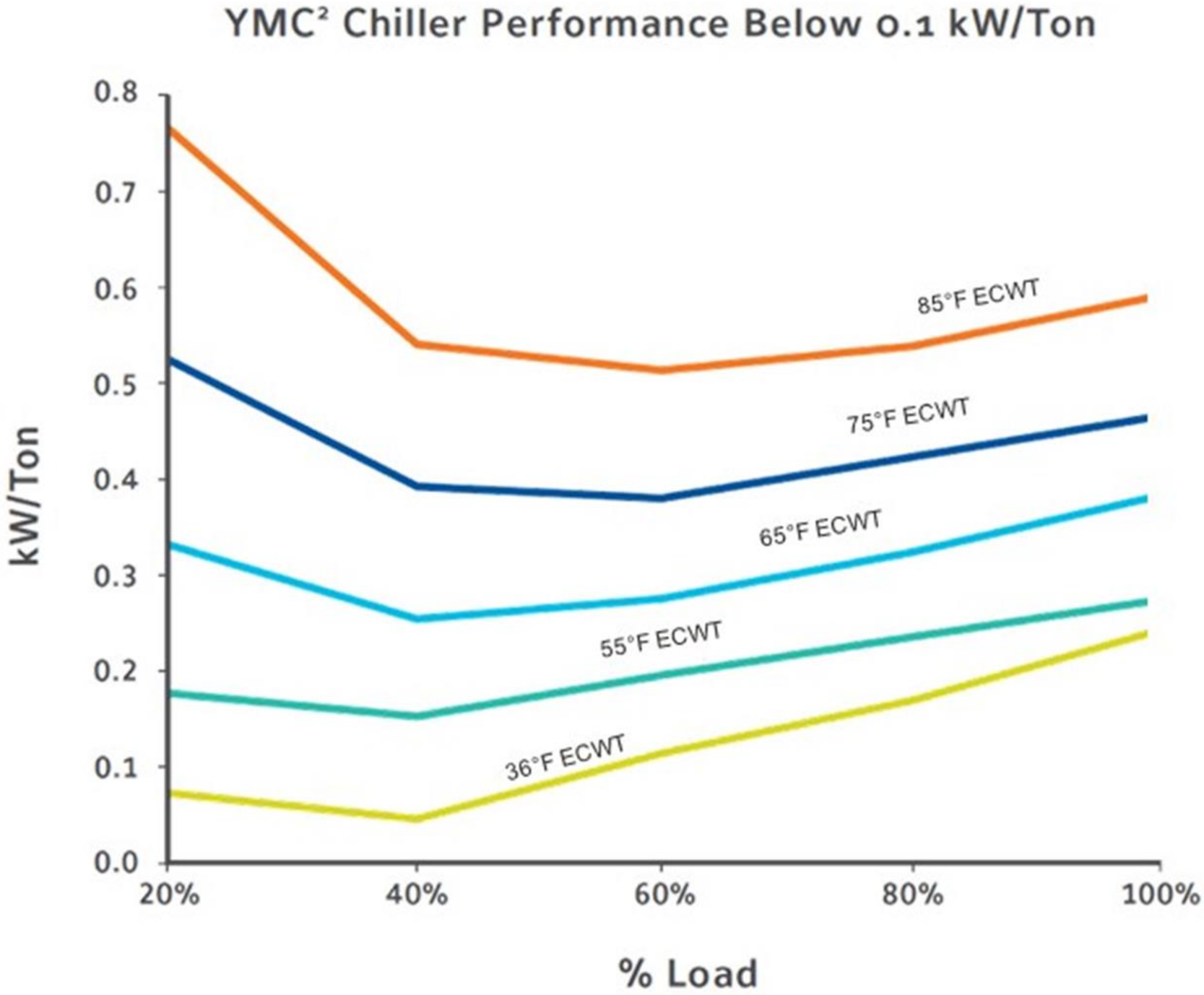
ECWT – Entering Condenser Water Temperature

Real World Efficiency – YMC² @ AHRI



ECWT – Entering Condenser Water Temperature

Real World Efficiency – YMC² @ 36°F ECWT



ECWT – Entering Condenser Water Temperature

Efficiency – YMC² Min ECWT Report

Model	YMC2-S1758AB
Specified Net Capacity (Tons)	500.0
Rated Net Capacity (Tons)	500.0
Full Load (kW/Ton.R)	0.5287
IPLV.IP (kW/Ton.R)	0.3068
Input Power (kW)	264.4
Starter Type	HYP0612XHC***-46A
Compressor	M2C-246FAC
Evaporator	EB3314-371-CS*-2***
Condenser	CB3314-260-ES*-2***

Project:
Unit Tag:
Engineer:
Customer:

Rating Program: LTS 1.0.6005
Software Version: YW 16.03b
Date: 08/22/2016 08:05:51

Partload Data (Minimum Condenser Water Temperature)

CEFT (°F)	% LOAD									
	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
85.00°	0.5287	0.5142	0.5000	0.4930	0.4965	0.5096	0.5386	0.5960	0.7973	-
80.00°	0.4737	0.4554	0.4427	0.4348	0.4322	0.4386	0.4578	0.5068	0.6508	1.303
75.00°	0.4202	0.4015	0.3882	0.3796	0.3712	0.3767	0.3925	0.4221	0.5351	1.068
70.00°	0.3707	0.3516	0.3368	0.3253	0.3174	0.3147	0.3250	0.3495	0.4032	0.8147
65.00°	0.3277	0.3062	0.2894	0.2760	0.2663	0.2589	0.2623	0.2807	0.3197	0.6510
60.00°	0.2885	0.2654	0.2457	0.2299	0.2181	0.2097	0.2066	0.2181	0.2470	0.3751
55.00°	0.2526	0.2281	0.2062	0.1880	0.1739	0.1642	0.1577	0.1616	0.1804	0.2564
50.00°	0.2229	0.1948	0.1708	0.1510	0.1347	0.1209	0.1125	0.1088	0.1181	0.1600
45.00°	0.2054	0.1749	0.1472	0.1271	0.1040	0.08943	0.07931	0.08274	0.1253	0.2173
40.00°	0.2008	0.1737	0.1487	0.1259	0.09605	0.08181	0.07299	0.08996	0.1443	0.2232
39.00°	0.2007	0.1739	0.1489	0.1267	0.09634	0.08219	0.07118	0.08874	0.1430	0.2228
38.00°	0.2009	0.1742	0.1492	0.1272	0.09691	0.08300	0.07124	0.08753	0.1414	0.2224
37.00°	0.2014	0.1747	0.1496	0.1278	0.09816	0.08435	0.07236	0.08634	0.1398	0.2220
36.00°	0.2021	0.1754	0.1502	0.1284	0.1012	0.08573	0.07350	0.08517	0.1381	0.2216

**Values are in kW/Ton.R*

Efficiency – YMC² Min ECWT Report

250 Ton Efficiency = 0.089kW/ton

	60%	50%	40%	30%	20%	10%
50.00°	0.15[illegible]7	0.1209	0.1125	0.1088	0.1181	0.1600
45.00°	0.1040	0.08943	0.07931	0.08274	0.1253	0.2173
40.00°	0.09605	0.08181	0.07299	0.08996	0.1443	0.2232
39.00°	0.09634	0.08219	0.07118	0.08874	0.1430	0.2228
38.00°	0.09691	0.08300	0.07124	0.08753	0.1414	0.2224
37.00°	0.09816	0.08435	0.07236	0.08634	0.1398	0.2220
36.00°	0.1012	0.08573	0.07350	0.08517	0.1381	0.2216

That's 22 kW!!

Efficiency – YMC² Min ECWT Report

Traditional "constant speed" chiller efficiency = 0.4563 kW/ton

@50% load and 65°F ECWT

250 Ton Efficiency = 0.089kW/ton

	60%	50%	40%	30%	20%	10%
50.00°	0.13[illegible]7	0.1209	0.1125	0.1088	0.1181	0.1600
45.00°	0.1040	0.08943	0.07931	0.08274	0.1253	0.2173
40.00°	0.09605	0.08181	0.07299	0.08996	0.1443	0.2232
39.00°	0.09634	0.08219	0.07118	0.08874	0.1430	0.2228
38.00°	0.09691	0.08300	0.07124	0.08753	0.1414	0.2224
37.00°	0.09816	0.08435	0.07236	0.08634	0.1398	0.2220
36.00°	0.1012	0.08573	0.07350	0.08517	0.1381	0.2216

80.5% Efficiency Improvement!!

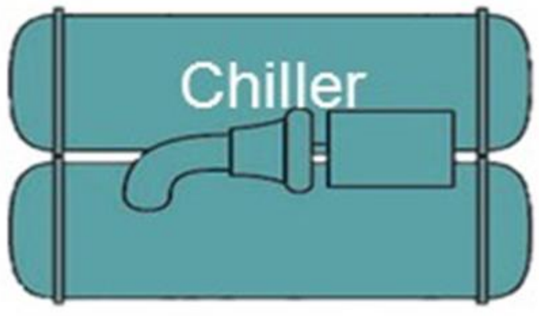
YORK®

CASE STUDY

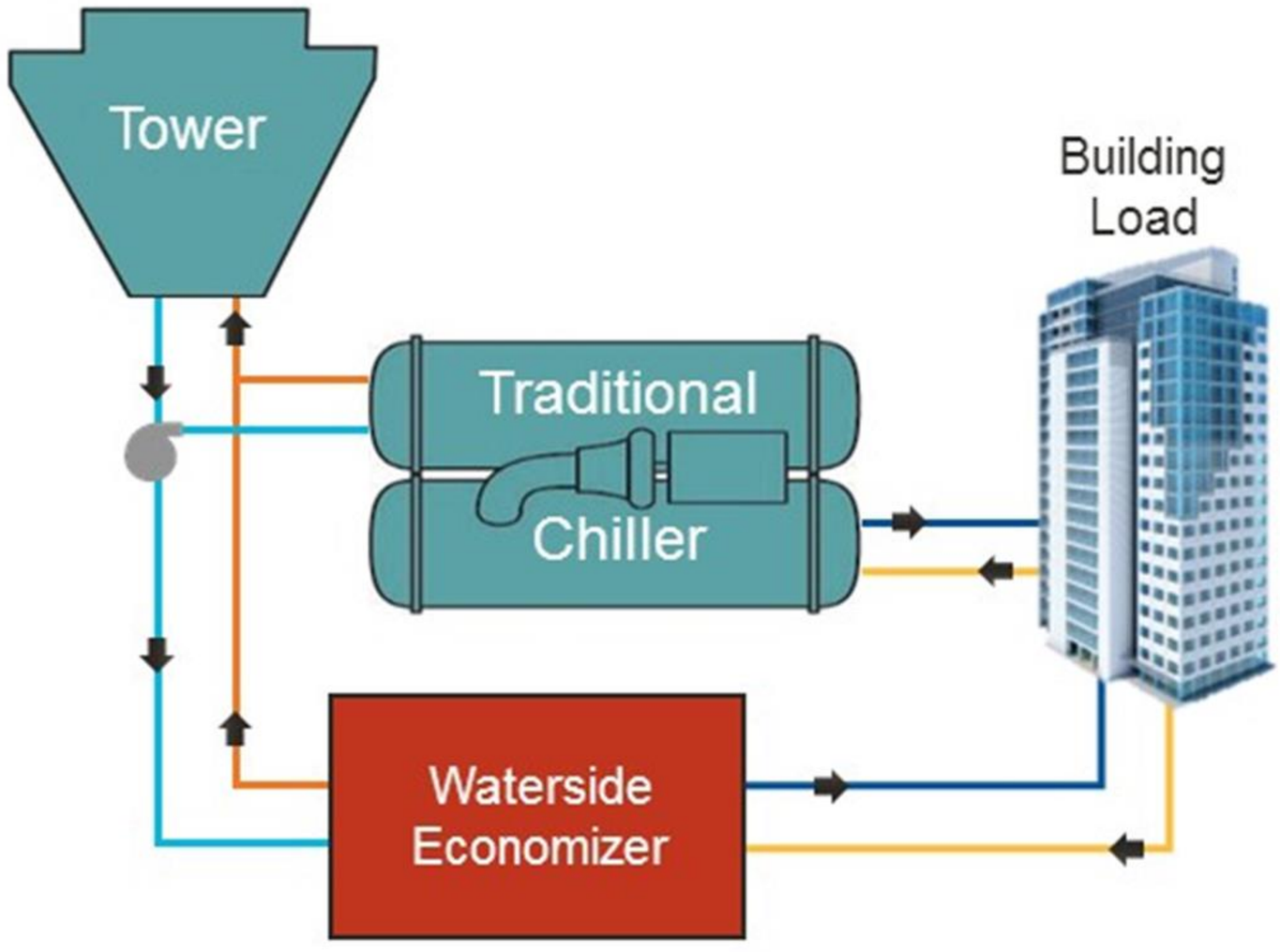
Johnson Controls

Traditional Design

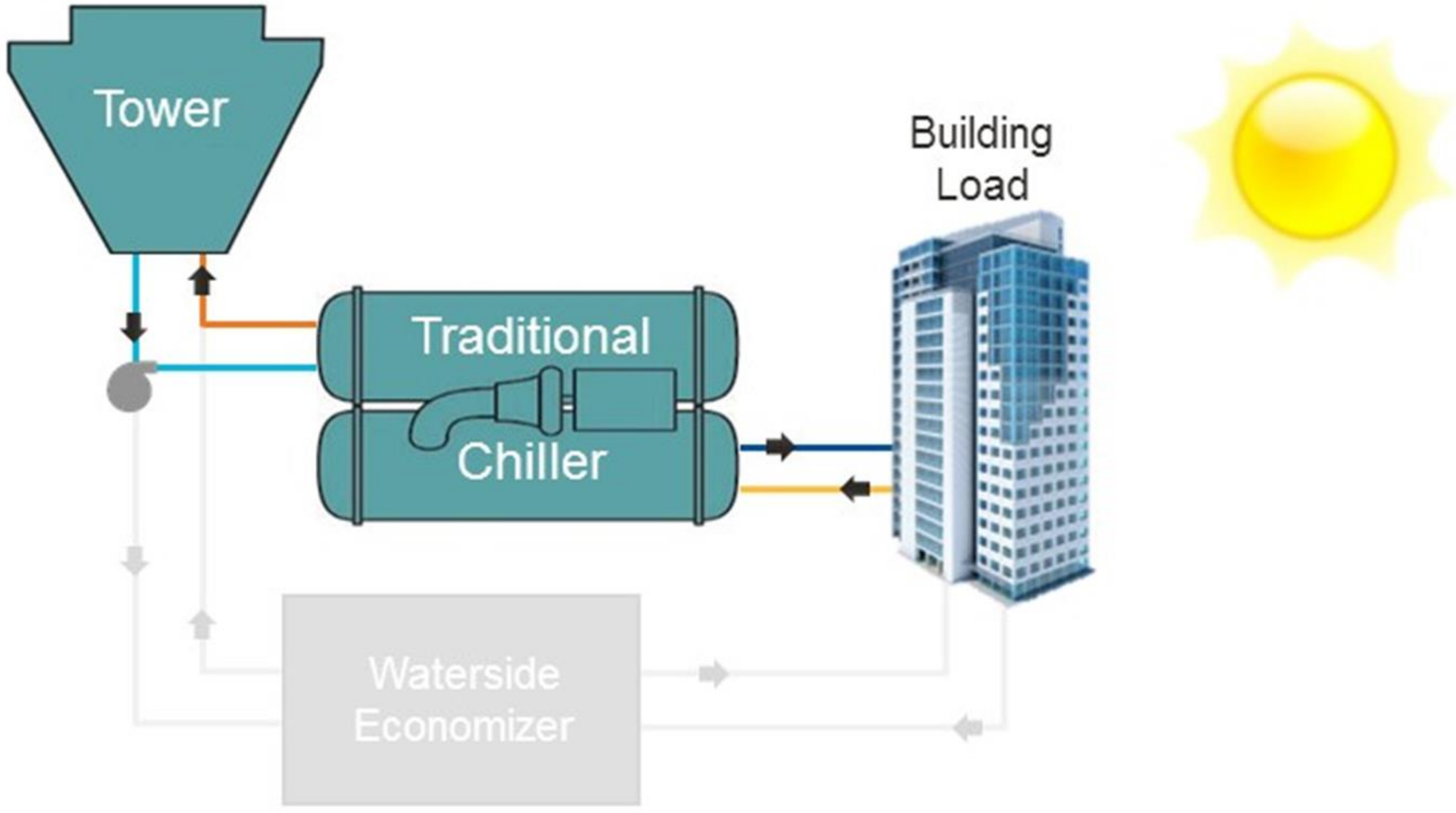
Base Chiller	Waterside Economizer
▪ ASHRAE 90.1 Path B (≥400TR) ▪ (variable speed drive chiller) ▪ FL = 0.585 kW/ton ▪ IPLV = 0.380 kW/ton	▪ Other possible term used: ▪ Free Cooling Heat Exchanger or Plate and Frame



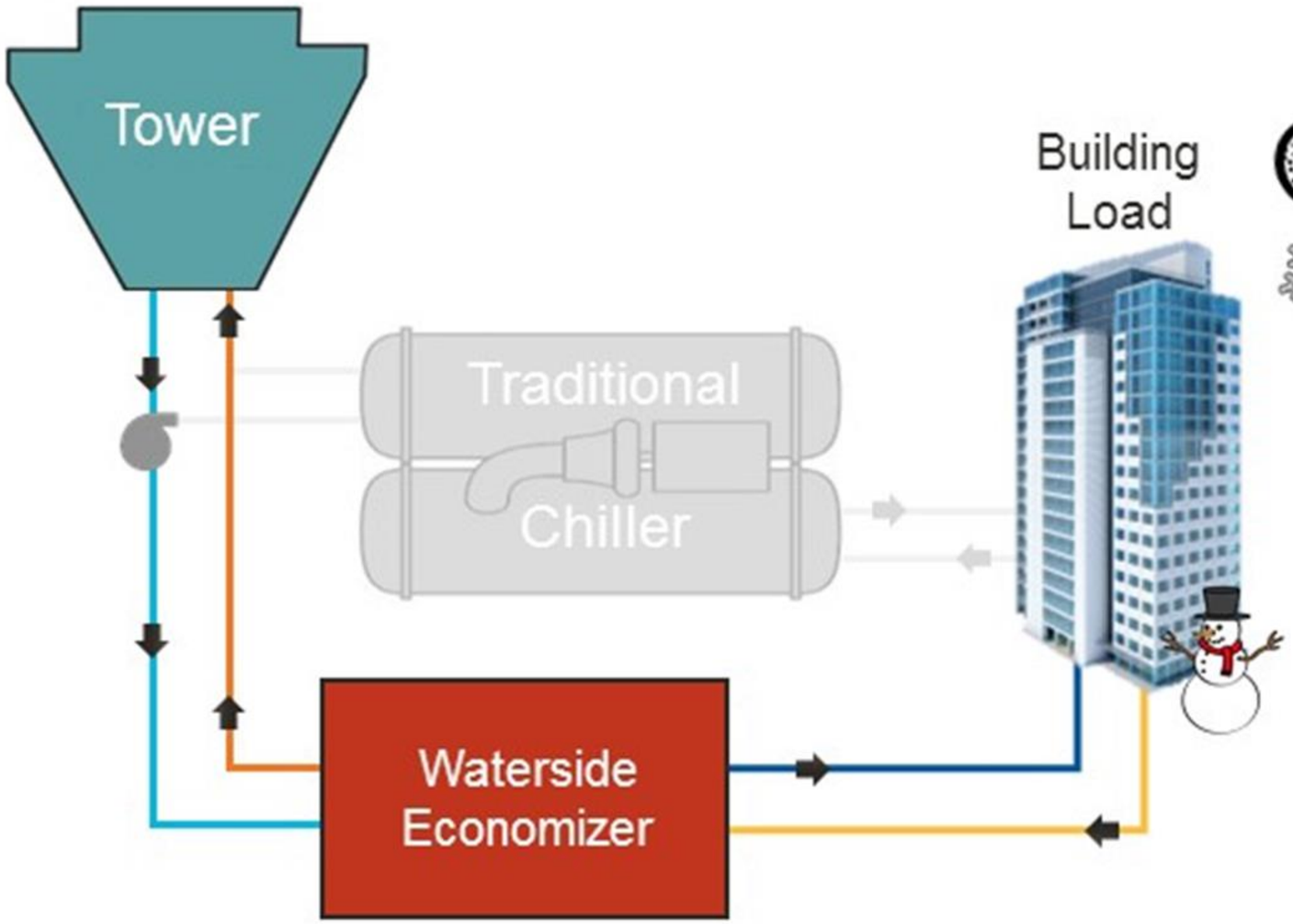
Traditional Operation



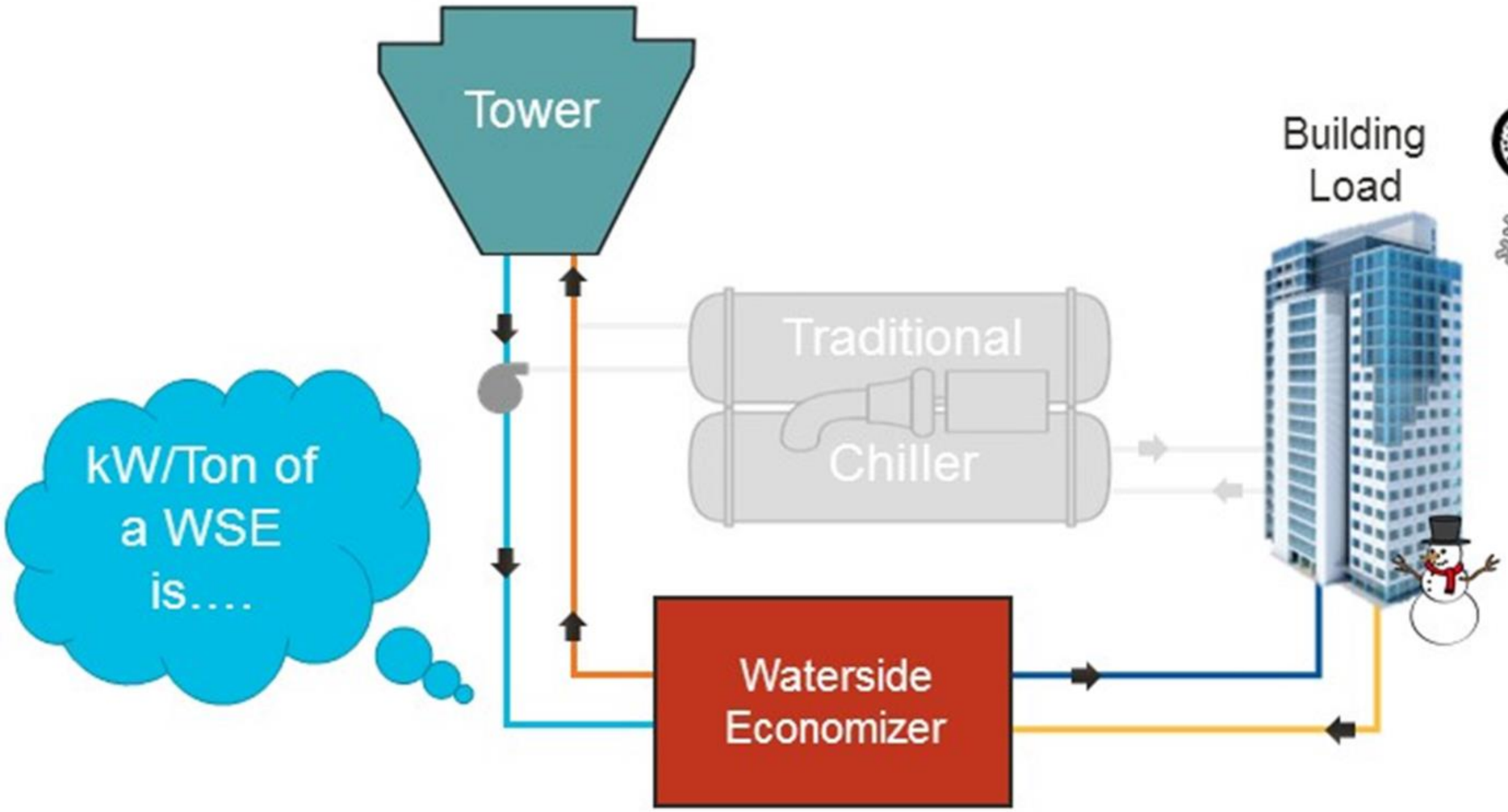
Traditional Operation – Mechanical Cooling Mode - Chiller



Traditional Operation – Free Cooling Mode - Water Side Economizer



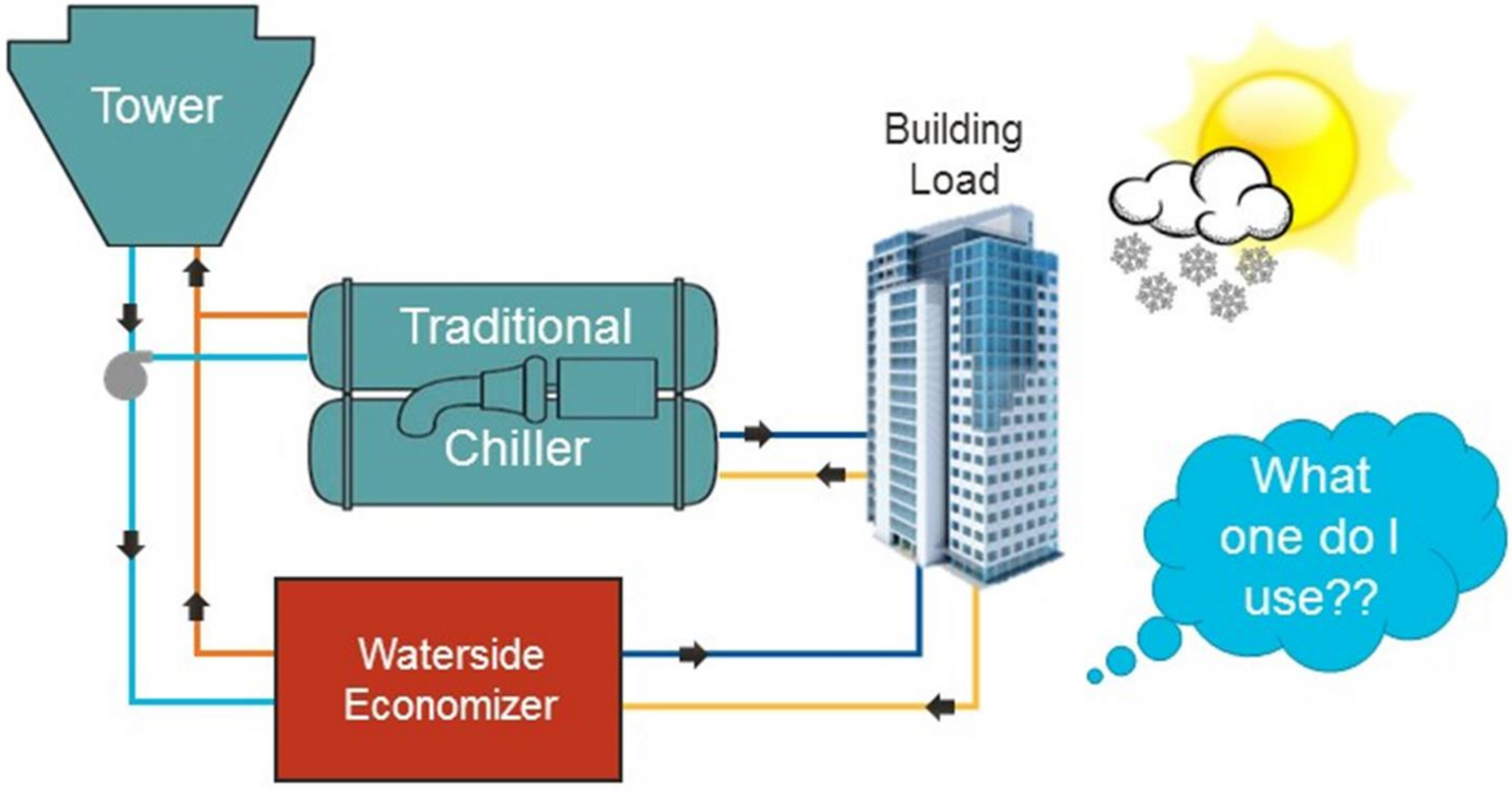
Traditional Operation – Free Cooling Mode - Water Side Economizer



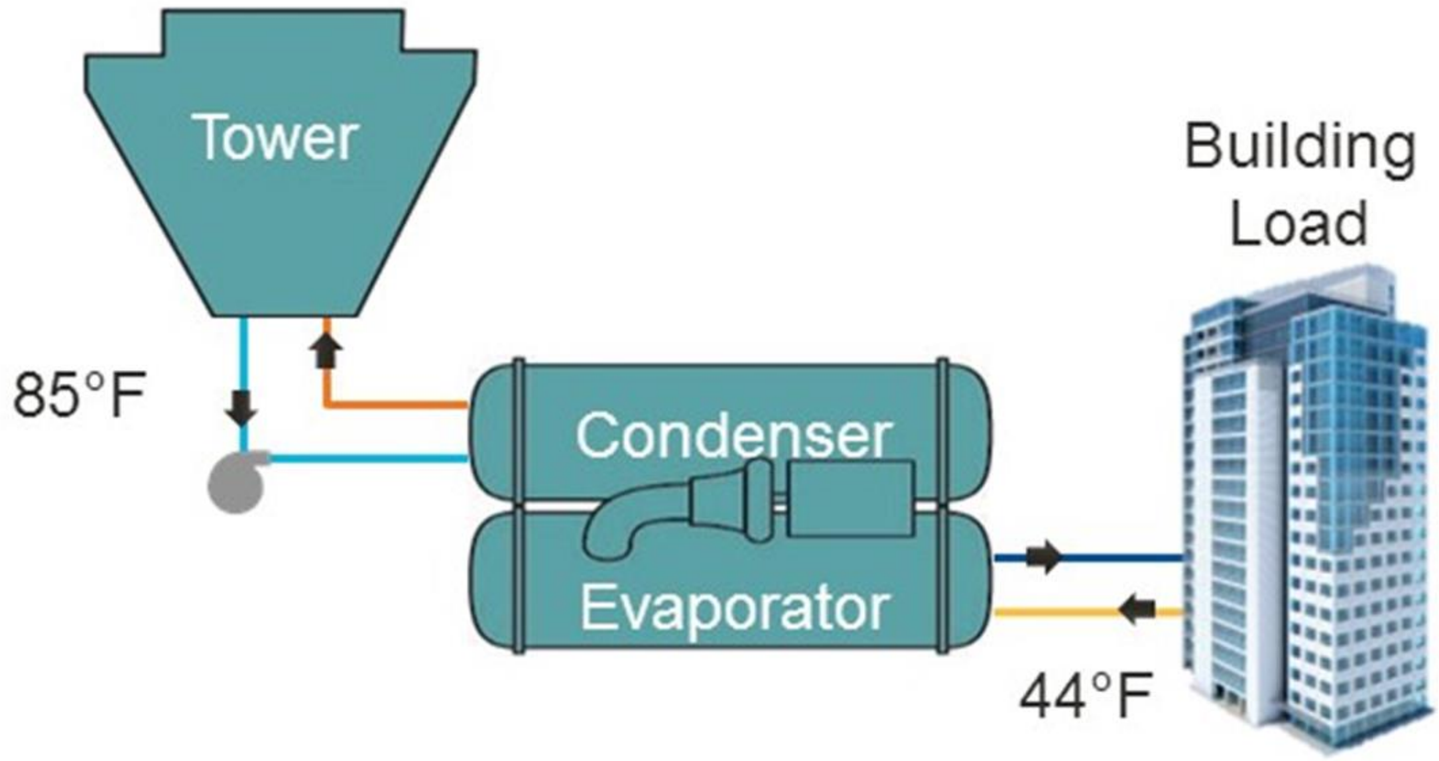
Traditional "constant speed" chiller efficiency = 0.4563 kW/ton

@50% load and 65ºF ECWT

Traditional Operation – Shoulder Months



AHRI Conditions – Traditional System Operation

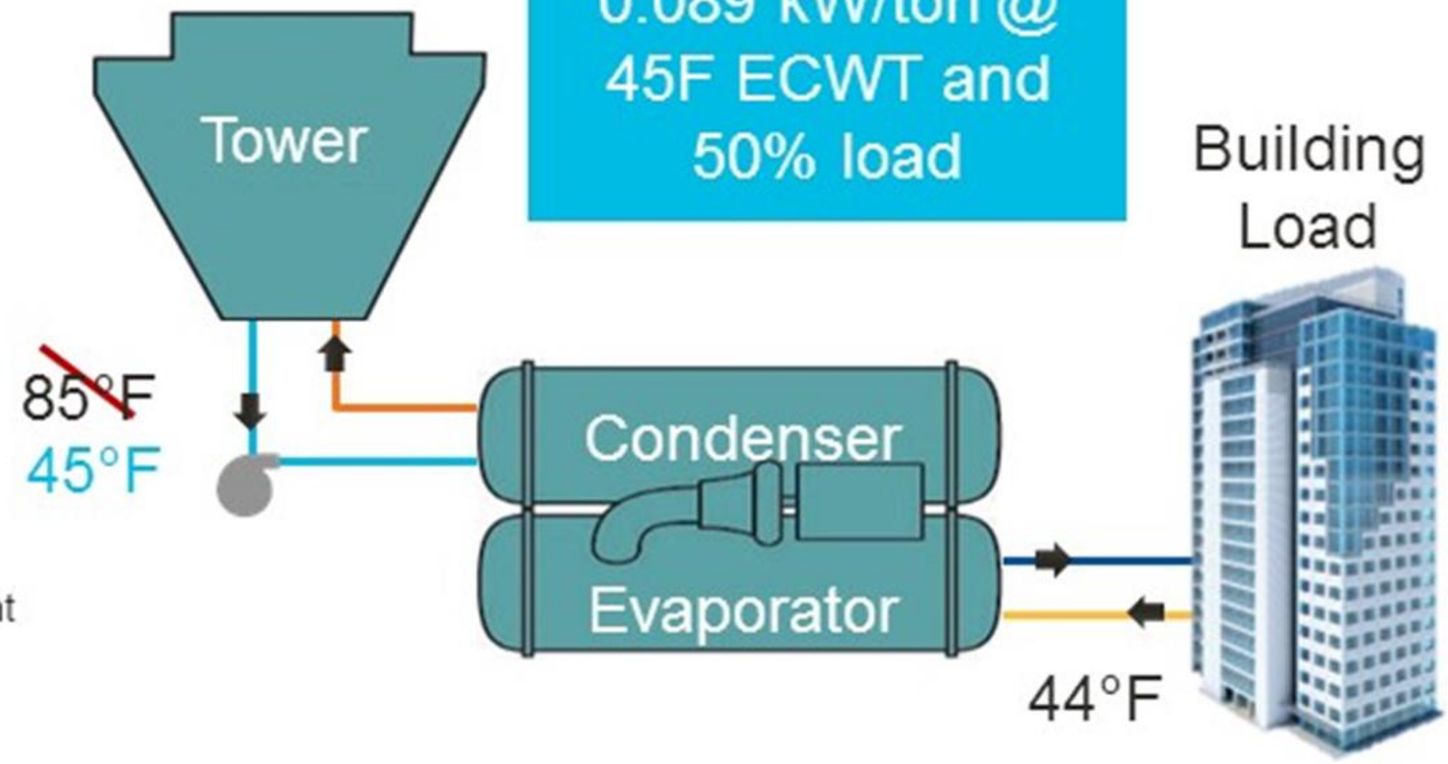


AHRI Conditions: Flow Rate

- Evaporator Flow Rate: 2.4 gpm/ton (0.043 lps/kW)
- Condenser Flow Rate: 3.0 gpm/ton (0.054 lps/kW)

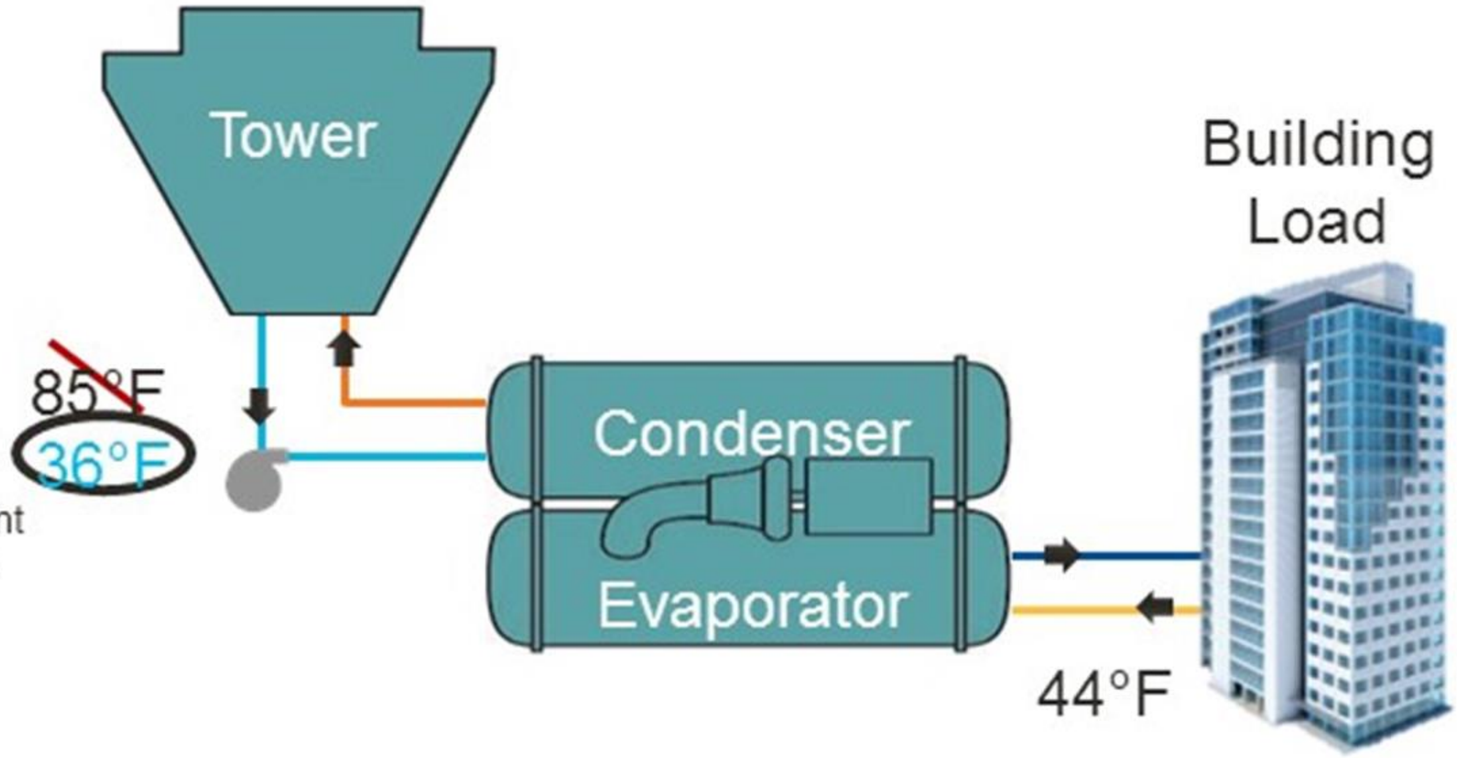
YMC² Chiller Low Lift

YMC² efficiency is 0.089 kW/ton @ 45F ECWT and 50% load



*Flow Rate is Constant Per Design Condition

YMC² Chiller Inverted Duty



*Flow Rate is Constant
Per Design Condition

- YMC² is the **FIRST** chiller in the world to continuously operate in inverted duty
  - **Inverted Duty**: entering condenser water is lower than the leaving chilled water temperature

How can the YMC² Operate in Inverted Duty?

Oil-Free Operation

Eliminates concerns about oil or refrigerant return to the bearings

Permanent Magnetic Motor & Active Magnetic Bearing

Chiller can adjust speed to operate in a wide range of conditions

Motor Speed
Traditional: 2:1 ratio
YMC²: 4:1 ratio

Variable Orifice

Ensures adequate refrigerant flow from the condenser to the evaporator to avoid starving the evaporator

Background on the Engineering Study

- Completed by outside 3rd party Consulting Engineering Firm
- Various load profiles completed
- This case study will focus on:
  - 1000 Ton (3510 kW) new office building (2x 500 ton chillers)
    - 200 Ton (700 kW) – internal base load
  - Variable primary flow chilled water
  - Constant speed condenser pump
  - Optimized (VSD) tower control

Energy Cost Savings

Location	Electricity Rate ($/kWh)
Chicago	$0.089
Dallas	$0.078
San Francisco Bay Area	$0.156

Modeling Assumptions

- ASHRAE 90.1-2013
  - The chilled water plants are modeled according to the Appendix G baseline with variable speed chillers and primary-only, variable flow chilled water loops
- eQUEST simulation program utilized to obtain hourly chilled water load profiles
- Theoretical Optimal Plant Performance approach in obtaining the chilled water plant performance
- Flat electricity rates are assumed based on the Energy Information Administration average price database

Energy Cost Savings

Location	Electricity Rate ($/kWh)	Plant Annual Energy Cost		Energy Cost Savings
		Base Chiller and Waterside Economizer	The YORK YMC² Chiller	
Chicago	$0.089	$70,900	$69,700	$1,200
Dallas	$0.078	$98,000	$87,400	$10,600
San Francisco Bay Area	$0.156	$125,900	$112,300	$13,600

Modeling Assumptions

- ASHRAE 90.1-2013
  - The chilled water plants are modeled according to the Appendix G baseline with variable speed chillers and primary-only, variable flow chilled water loops
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Cost of Waterside Economizer System - San Francisco Consultant Plant Costs Example

Plate and Frame Heat Exchanger	Installation, Piping, and Accessories	Controls
▪ $23,811	▪ $142,475	▪ $32,975

Don’t Forget About the Routine Maintenance Costs

Upfront Cost Savings

Location	Cost Associated with Waterside Economizer	Annual Energy Cost Savings of the YMC²	Payback on WSE
Chicago	$149,752	$1,200	NEVER
Dallas	$211,507	$10,600	NEVER
San Francisco Bay Area	$199,261	$13,600	NEVER

Modeling Assumptions

- Costs Estimates are based on data provided by contractors and suppliers for the plant configurations
- Total installed costs are adjusted based on city cost indexes from the RS Means Mechanical Cost Data

More Advantages

Mechanical Plant Footprint Savings

- Space can be used for business investment

Fewer Water Leak Points

- Less pipe
- Fewer bypass/isolation valves

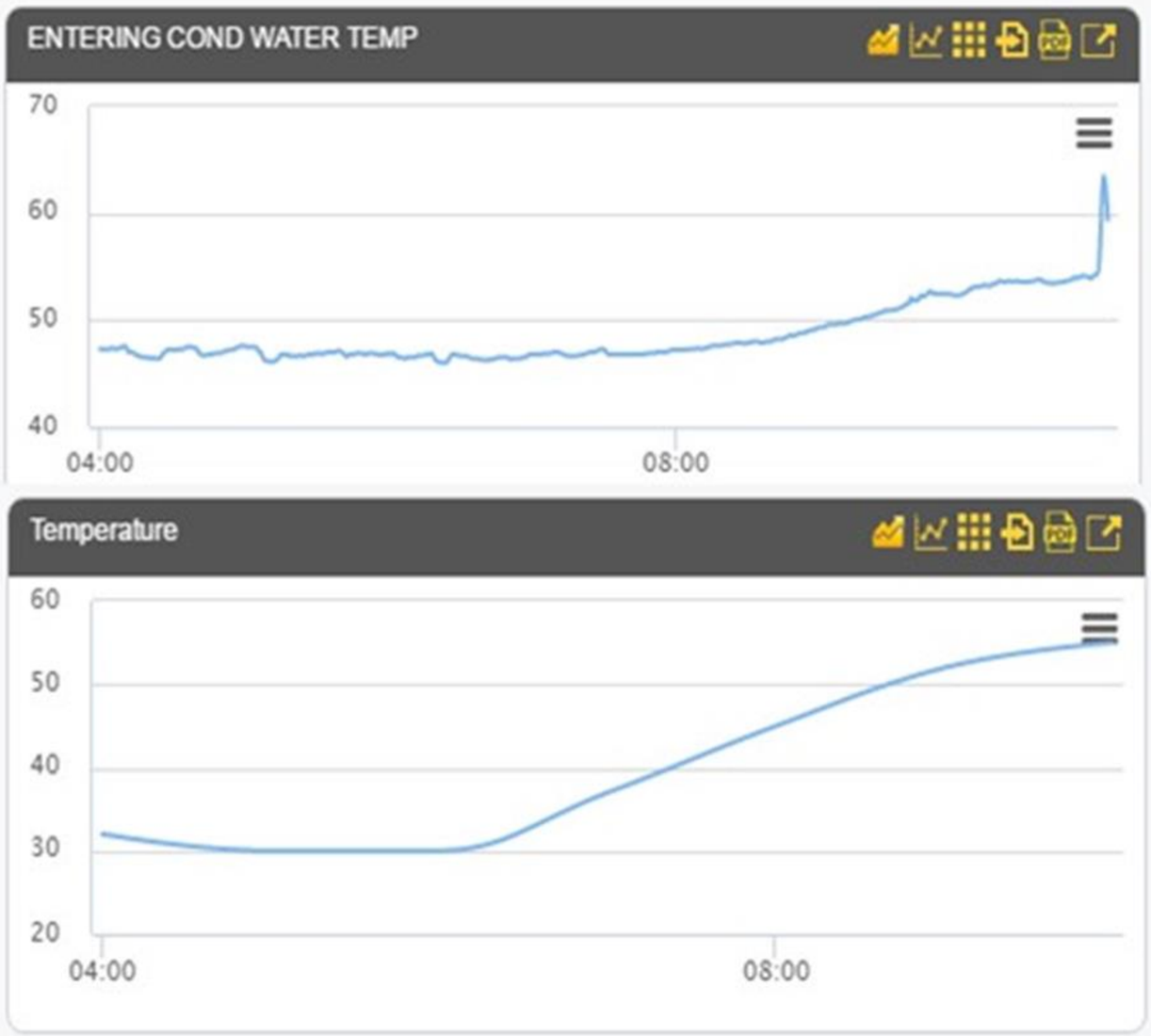
Save on Routine Maintenance

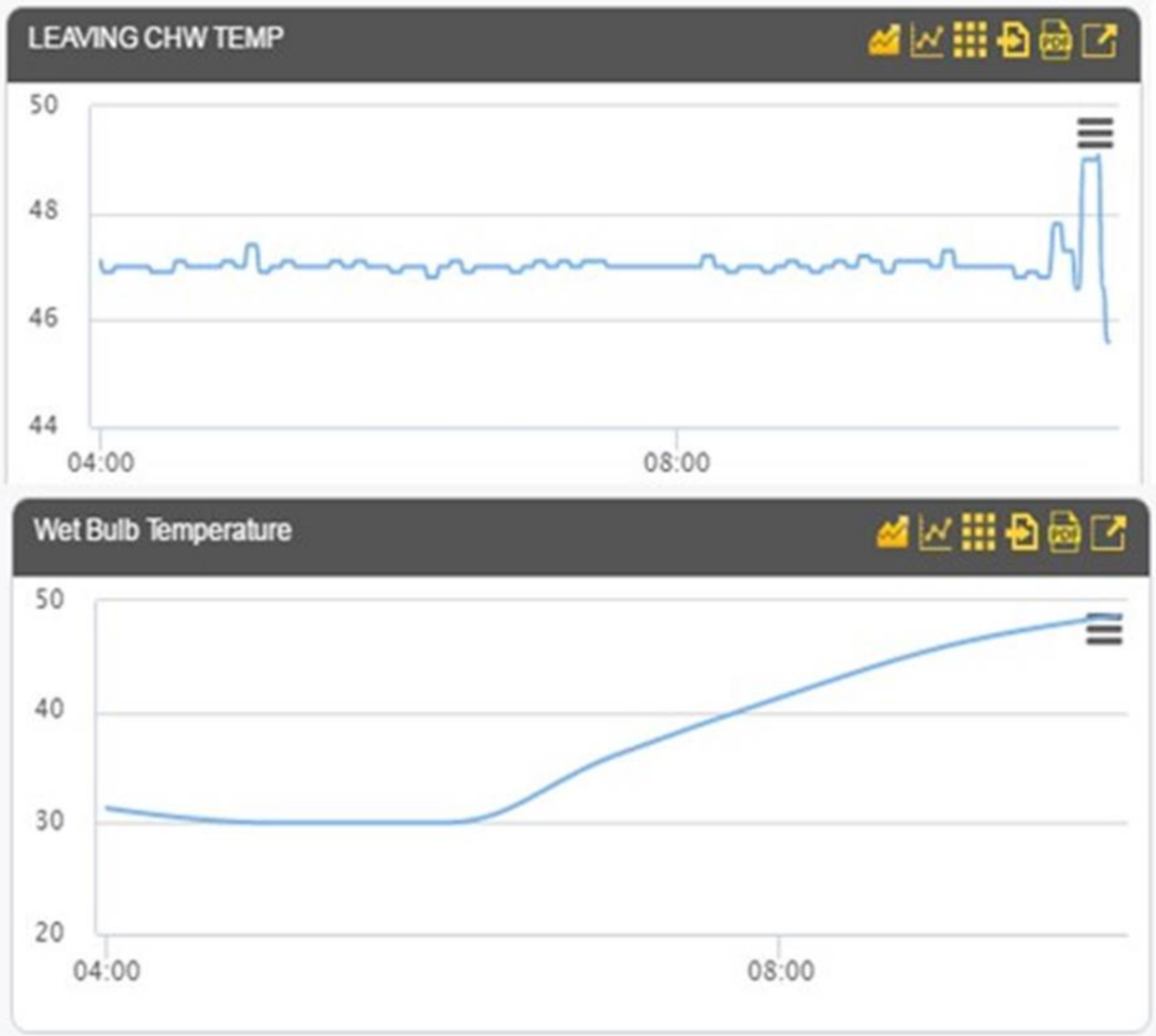
- Cleaning of plate and frame heat exchanger
- Sensor calibration

Accommodate for Increased Building Load

- Investment for the future

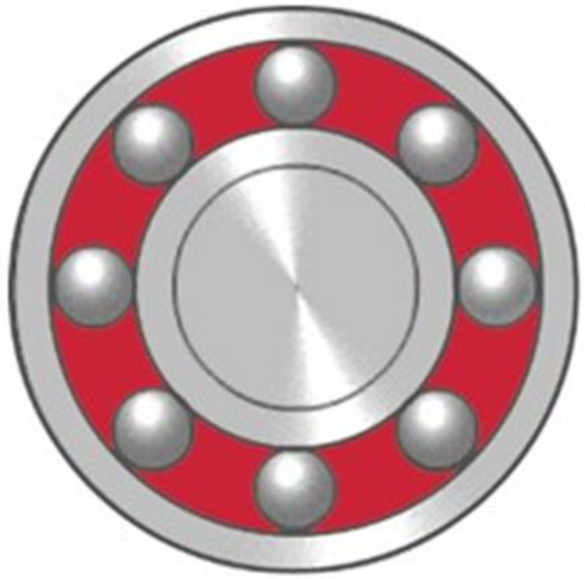
This is actually happening!!



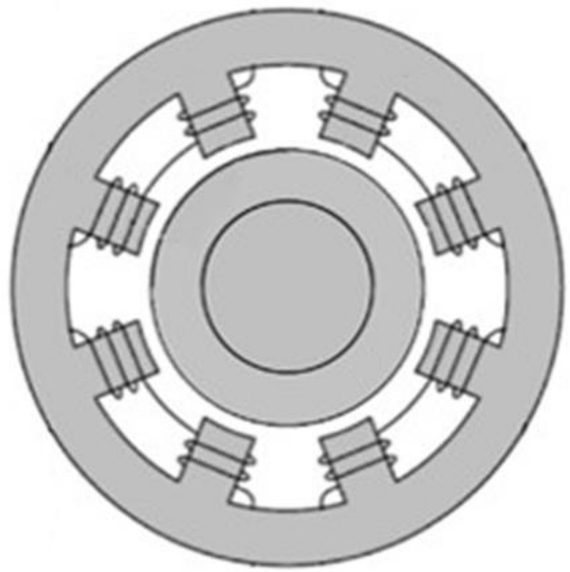


Summary

- Four key bearing options for centrifugal chillers
- Oil and oil-free options all have unique advantages
- Two options for oil-free bearings



- There is only one lubricant-free bearing option



More Information

- Visit Johnson Controls
  - Booth at the AHR Expo – C3124
  - Exhibit #34 at IDEA Campus Energy Conference, Miami

- Visit www.york.com/mars for more information about the YORK YMC^2 chillers

- Search “york.com magnetic bearings” in google to access additional information

Questions?