Optimizing Central Chilled Water Systems

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Learning Objectives

1. Gain a better understanding of the operational dynamics of various load and equipment components in chilled water systems
2. Understand opportunities to provide both functional and energy efficient operation of chilled water systems
3. Develop a logical approach to the performance optimization of chilled water systems

Presentation Outline

- Foundation of CHW Plant Operation
- Hydronic System Design
- Chiller Fundamentals
- Optimizing Plant Performance
- Building Interfaces

Sustainability Opportunities

- Optimize energy use
- Protect and conserve water
- Effective use of natural resources

Foundation of Operation

Deliver CHW to all loads under various load conditions as efficiently as possible

- Why look "outside the plant"?
  - Understand how distribution system will operate
  - Understand how CHW ΔT will be effected by dynamics of the systems connected

Understanding Loads & Their Impact on Design

- Overall plant capacity is determined by peak design load
- Cooling load profile describes how the load varies over time is needed to design the plant to stage efficiently
- Cooling load "diversity"

Chilled Water Plant Efficiency

- Operating kW/ton achievable in today's plants (includes chillers, cooling towers and pumps)

0.4 - 0.7	Excellent
0.7 - 0.85	Good
>1.0	Needs Improvement

- We should design plants to measure and provide performance metrics

Discussion on Hydronics

Purpose of Pumping Systems

Move enough water through the piping system
at the minimum differential pressure
that will satisfy all connected loads

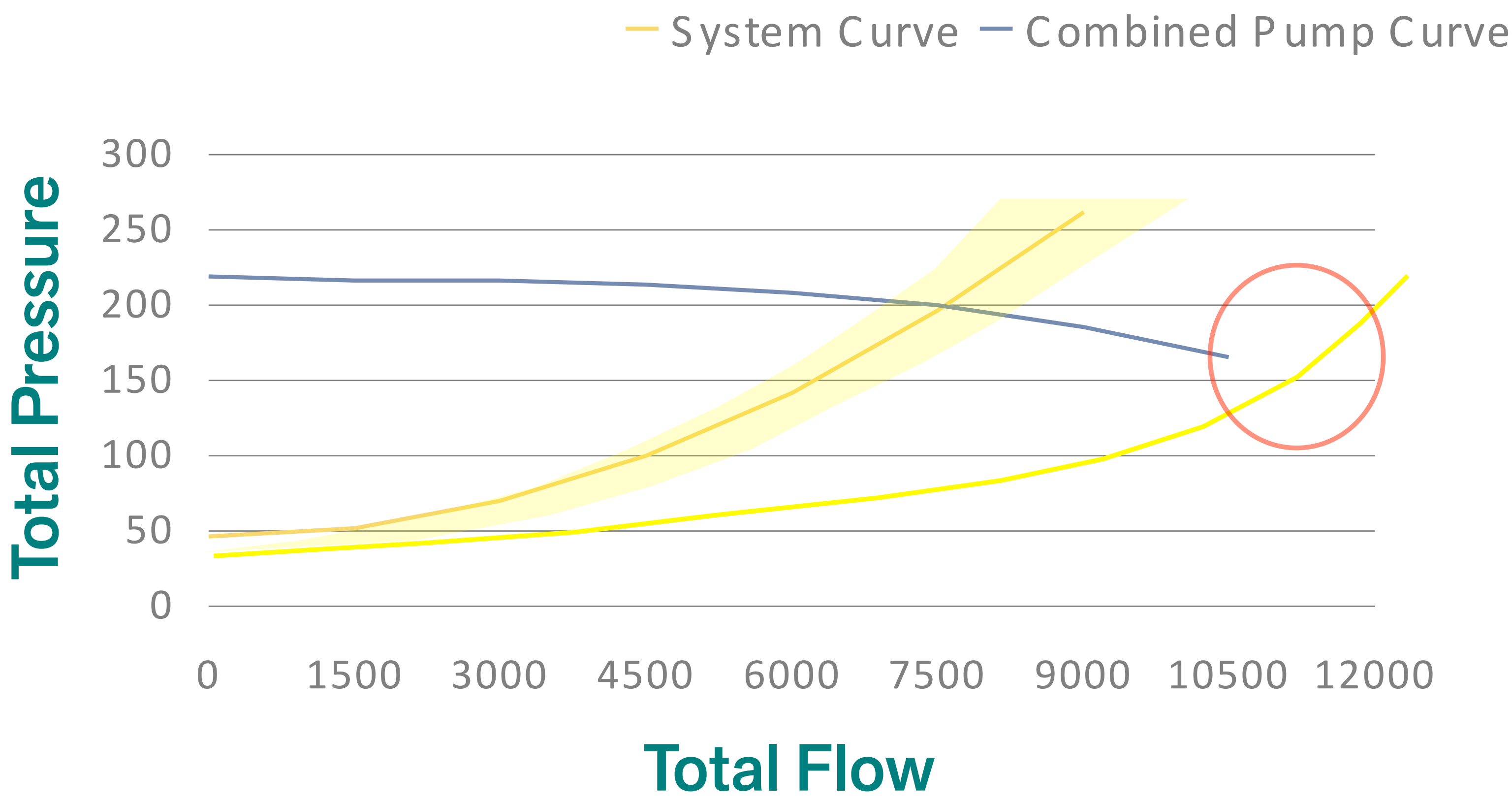
Understanding Hydronics

- The pumping system will be required to operate under various load conditions
- Variable flow system differential pressures throughout the system will be dynamic
- Hydronic systems should be hydraulically modeled to design or troubleshoot complex systems

Caution

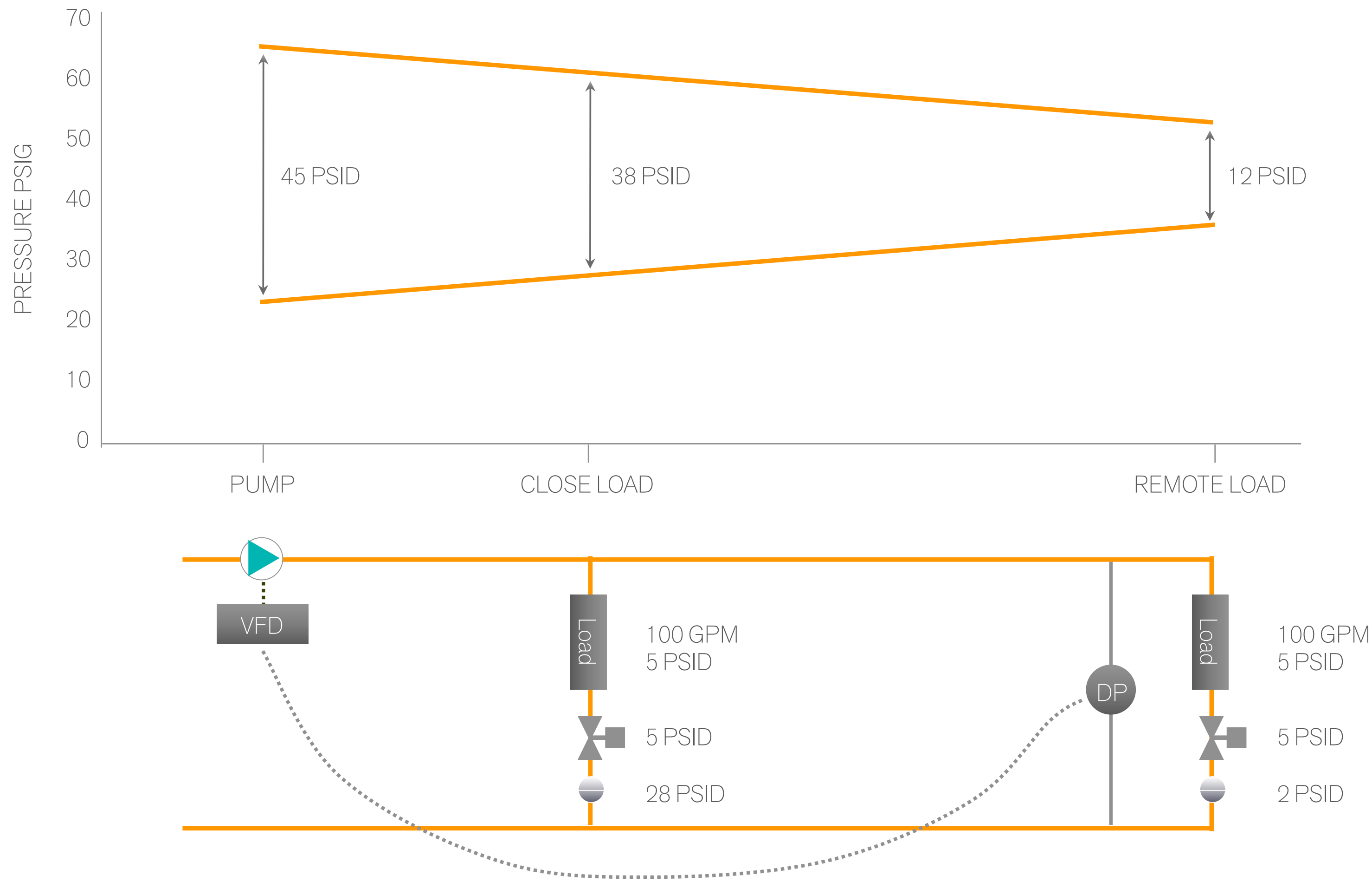
- Excessive pump head can cause systems to not function as designed and waste considerable energy
- Pump Selection

System & Pump Curves



Hydronic Fundamentals

Variable Flow System Dynamics



Hydronic Fundamentals

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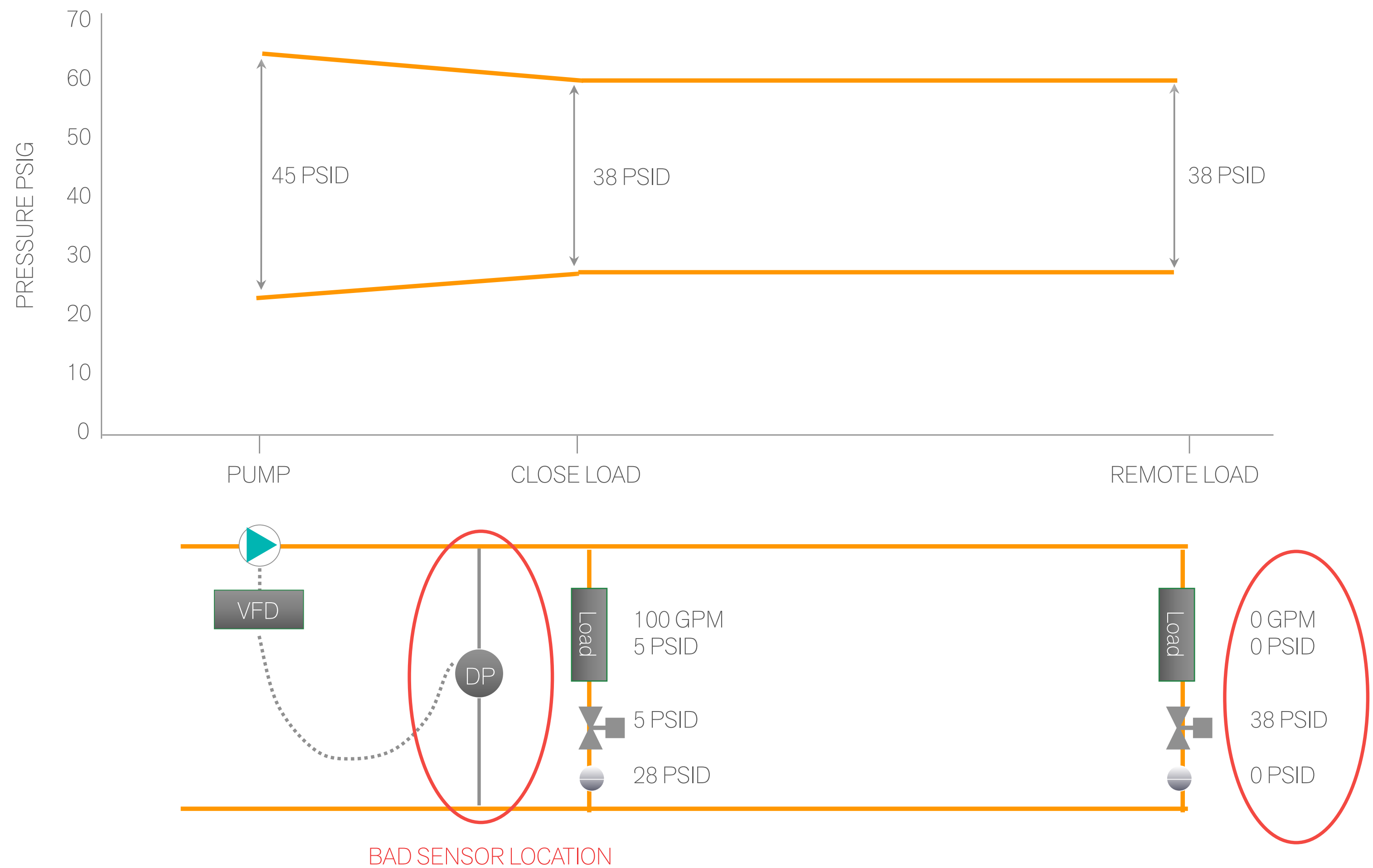

Hydronic Fundamentals

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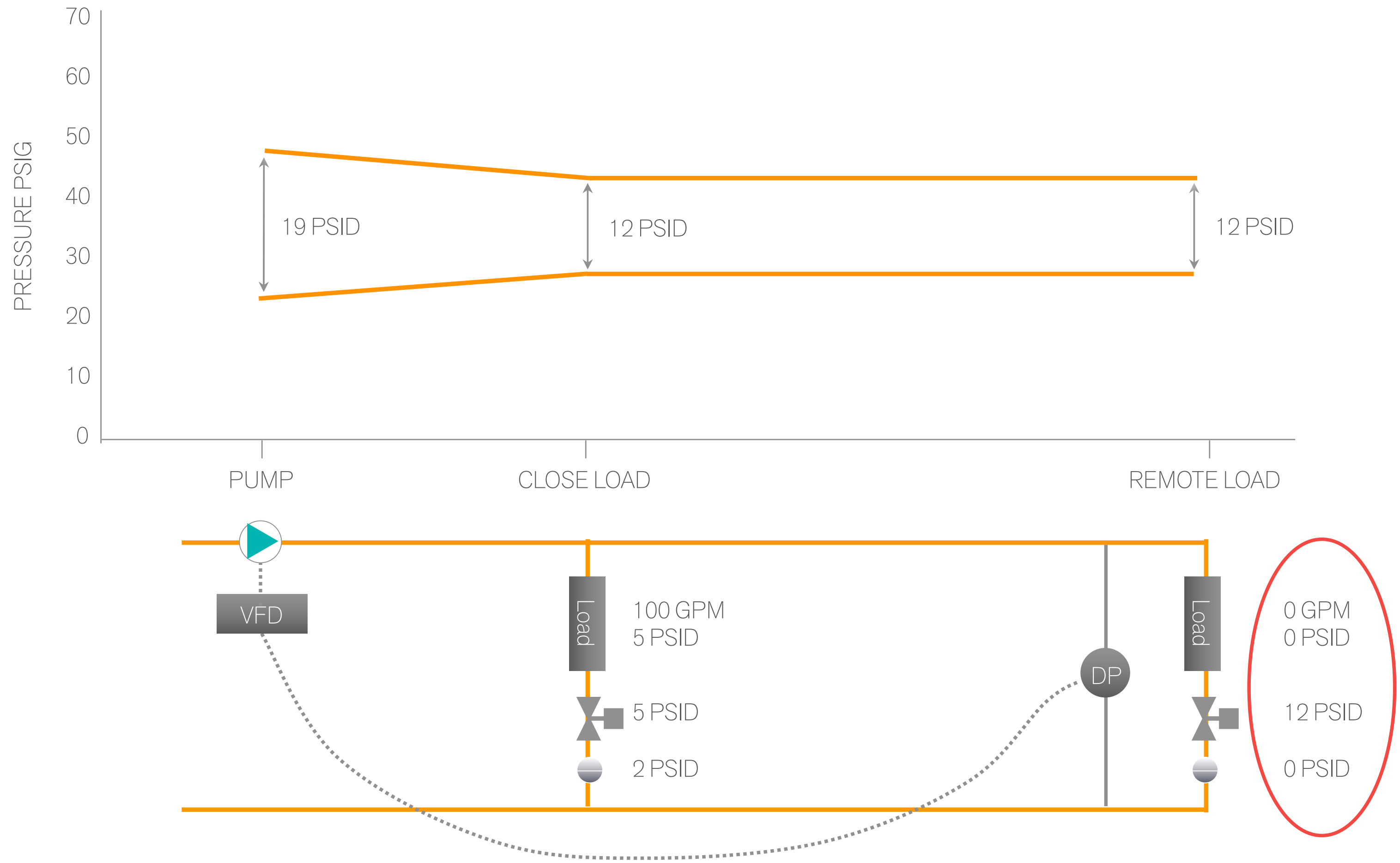


Hydronic Fundamentals

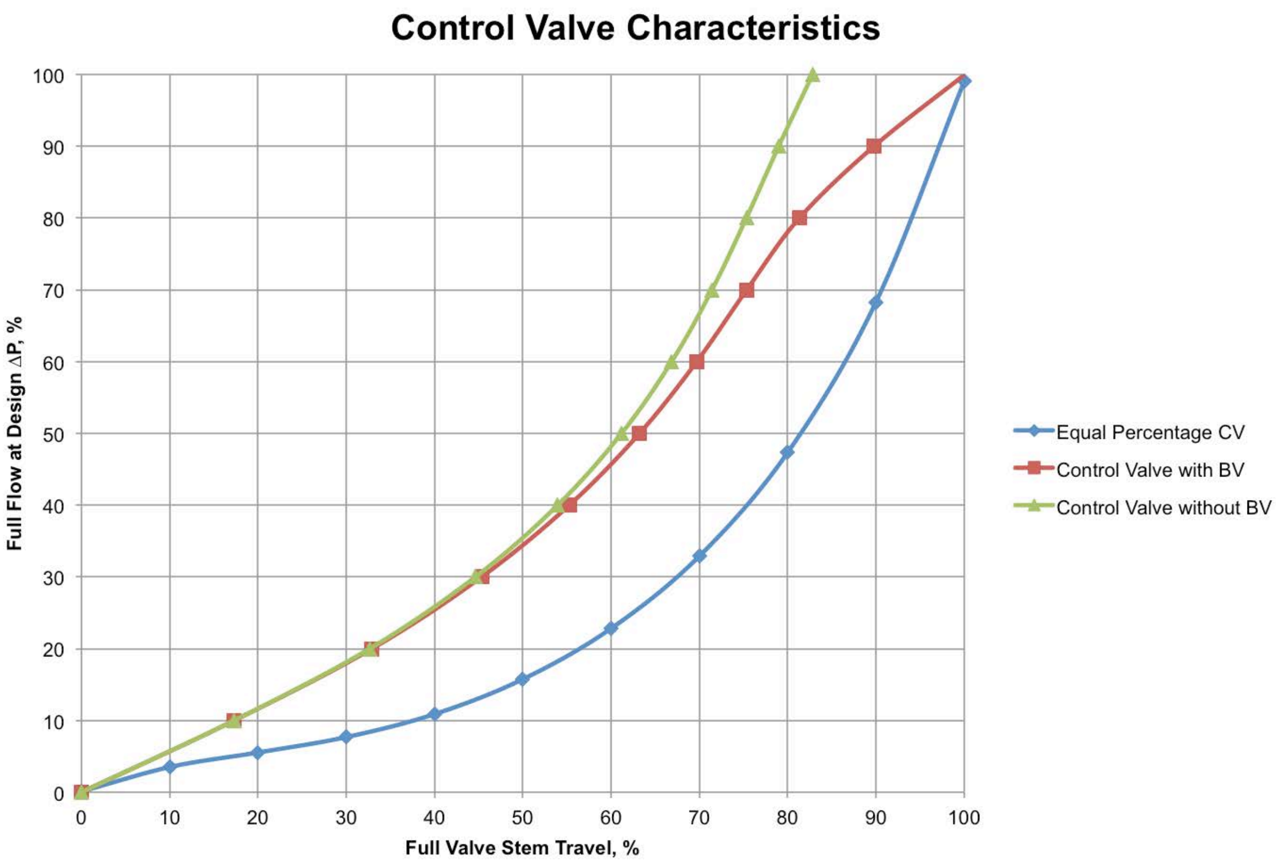
Variable Flow System Dynamics

CONTROL VALVE ΔP AT VARIOUS LOAD CONDITIONS

	Case 1 Full Flow	Case 2 75% Flow	Case 3 50% Flow	Case 4 25% Flow	Case 5 10% Flow
Branch Flow (gpm)	100	75	50	25	10
Branch ΔP	38	38	38	38	38
Coil ΔP	5.0	2.8	1.3	0.3	0.1
Balancing Valve ΔP	28.0	15.8	7.0	1.8	0.3
Control Valve ΔP	**5.0**	**19.4**	**29.8**	**35.9**	**37.7**

Hydronic Fundamentals

Variable Flow System Dynamics



Impact of Balancing Valve

Control Valve ΔP = 3.0 psig
Coil ΔP = 5.0 psig
Excess ΔP = 7.4 psig

Size BV for Excess ΔP

Balancing Considerations

Variable Flow Systems

- *Too large a balancing valve pressure drop affects the performance and flow characteristic of the control valve. Too small a pressure drop affects its flow measurement accuracy as it is closed to balance the system.*
  - ASHRAE 2011 Applications Handbook, page 38.8

Hydronic Pumping Conclusions

- Coil heat transfer is easier to control in low head (< 50 ft) branches
- Remote, high head loads can be served more efficiently with variable speed series booster pumping

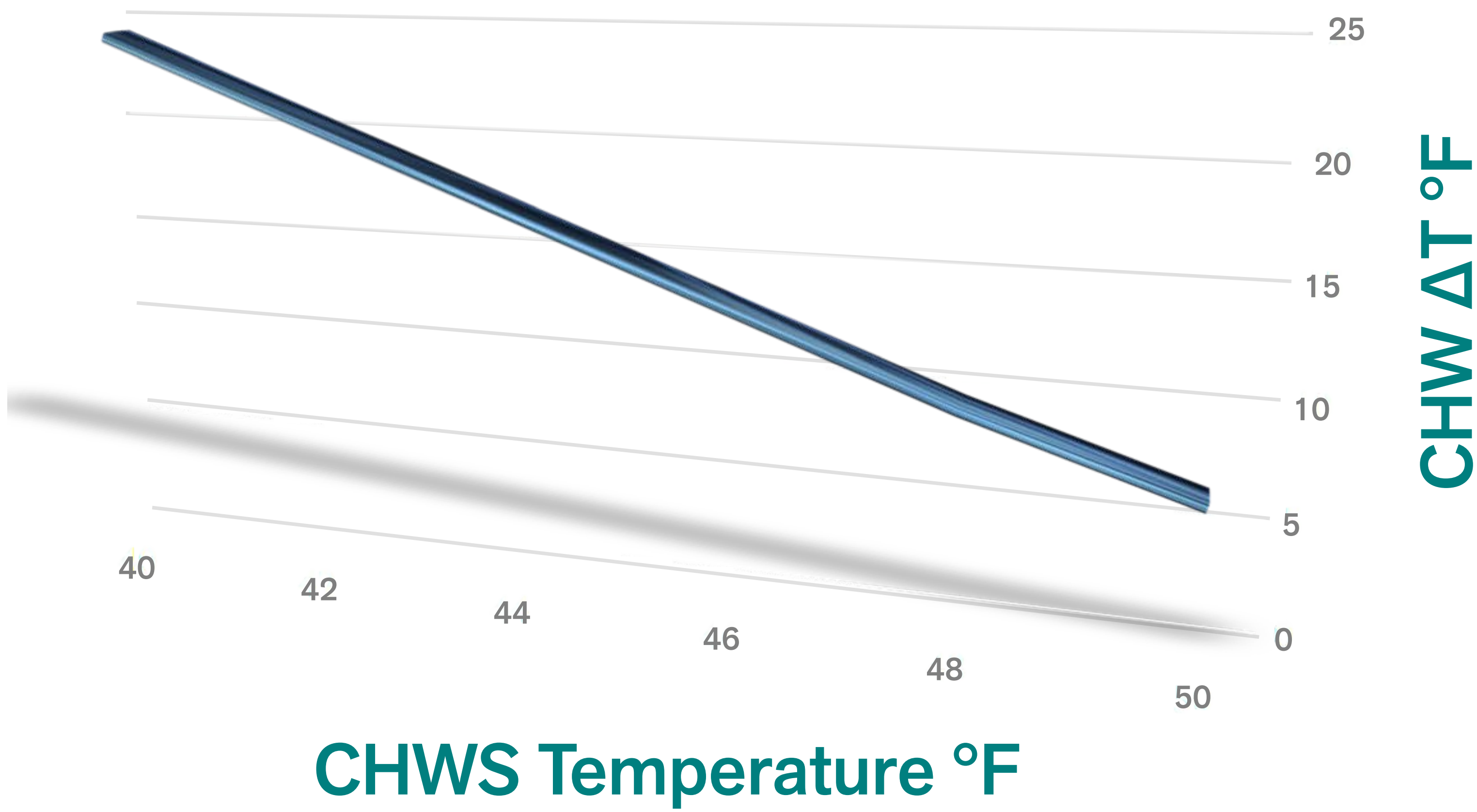
What You Must Know About CHW ΔT

CHW Temperature Differential

- Poor CHW ΔT is the largest contributor to poor CHW plant performance
- To predict ΔT, you must know:
  - Characteristics of connected loads
  - Control valve requirements and limitations
  - Control valve control algorithms and set points
  - Heat exchanger characteristics

Chilled Water Coil Characteristics

Assumes Constant Load on a Given Coil



Factors that Degrade ΔT

Assuming Coils are Selected for Desired ΔT

- Higher CHWS temperature
- Lower entering air temperature (economizer)
- Control valve issues
  - 3-way control valves
  - 2-position valves on fan coil units
  - Valves exposed to high ΔP and can't shutoff
- Controls not controlling
  - Setpoint cannot be achieved
  - Valves not interlocked to close if unit turns off

ΔT Conclusions

- Design, construction and operation errors that cause low ΔT can be avoided
- Other causes for low ΔT can never be eliminated
- *Therefore, system design must accommodate the level of degradation anticipated*

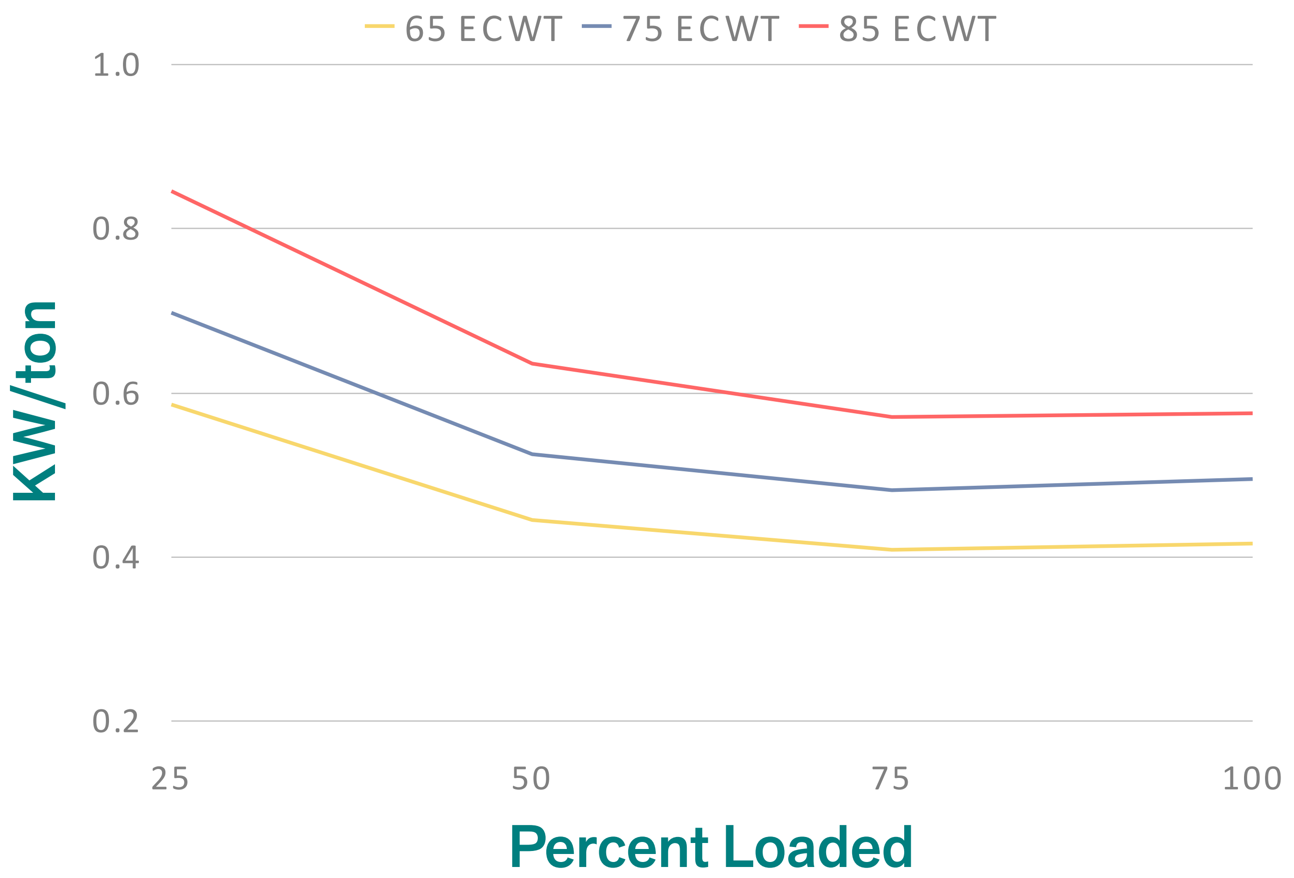
Chiller Fundamentals

Understanding Compressor Lift

- Temperature Lift = SCT - SST
  - Saturated Condensing Temperature (SCT) is dependent upon LEAVING condenser water temperature
  - Saturated Suction Temperature (SST) is based off of LEAVING chilled water temperature

Centrifugal Chiller without VFD

1200T Low Pressure



Centrifugal Chiller with VFD

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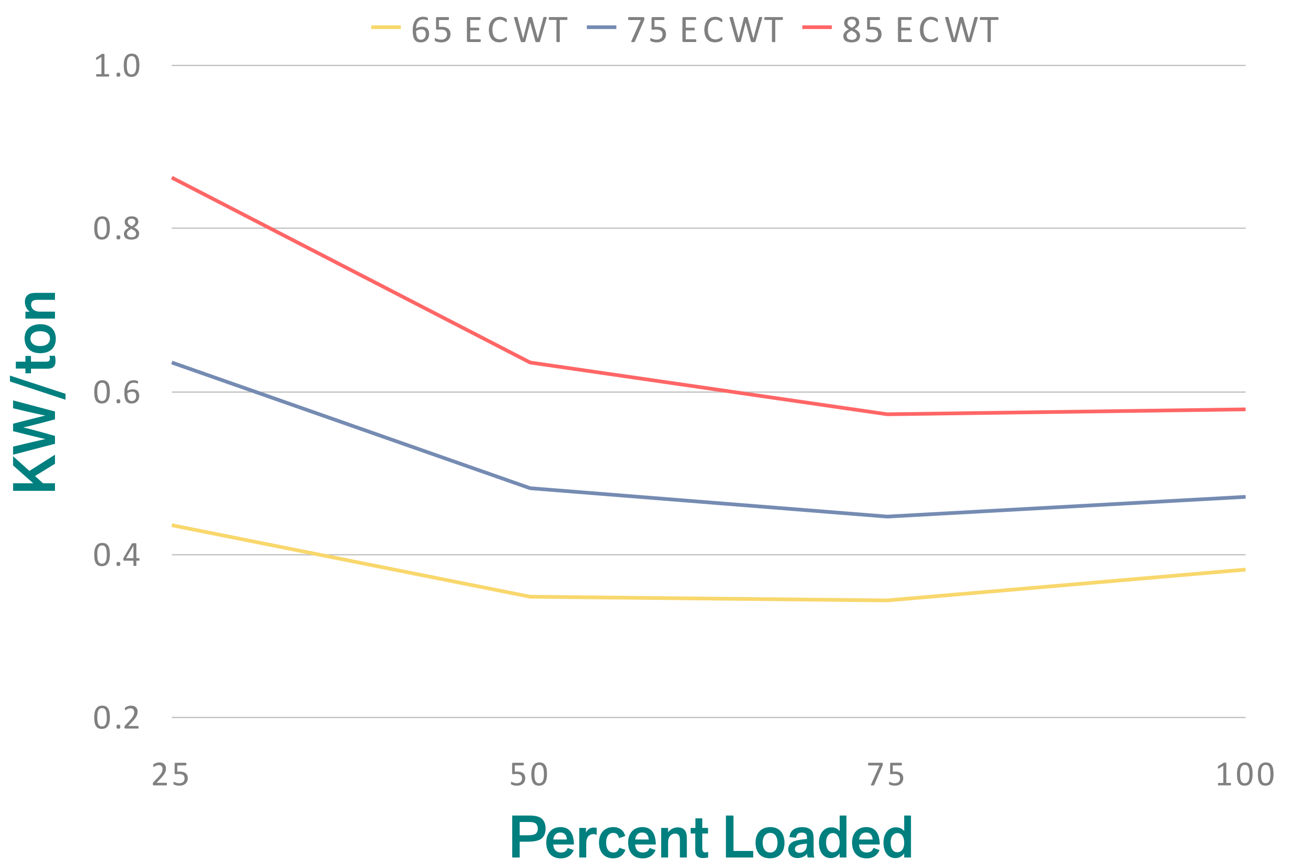

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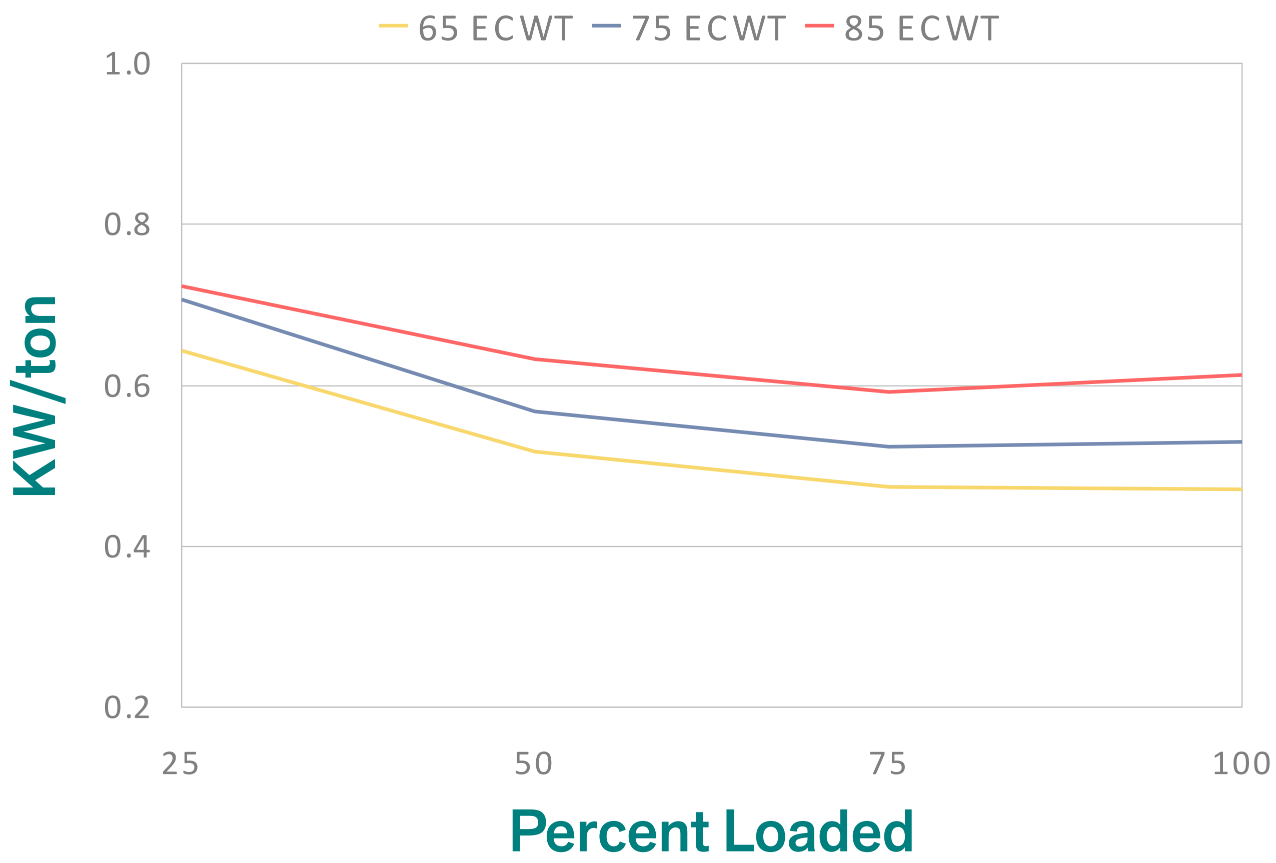

Centrifugal Chiller with VFD

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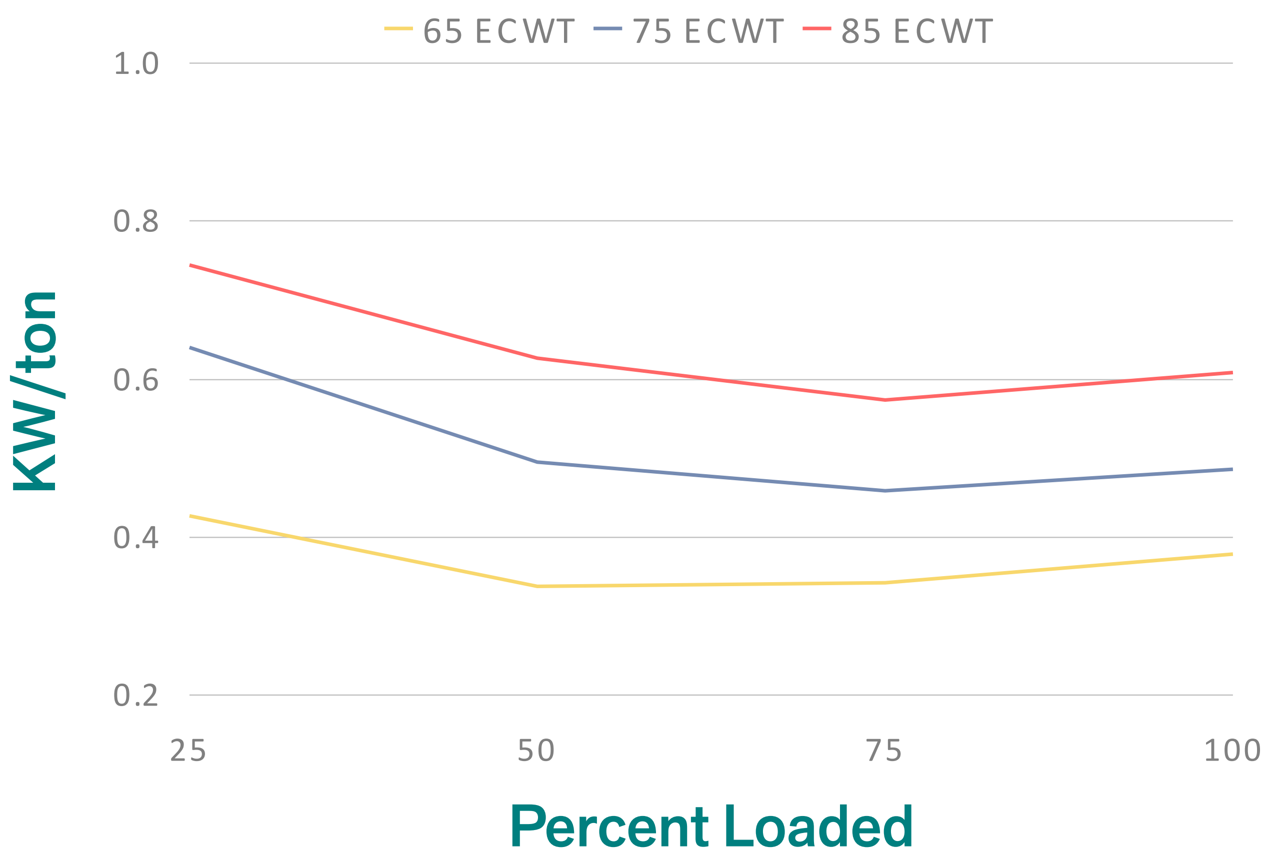
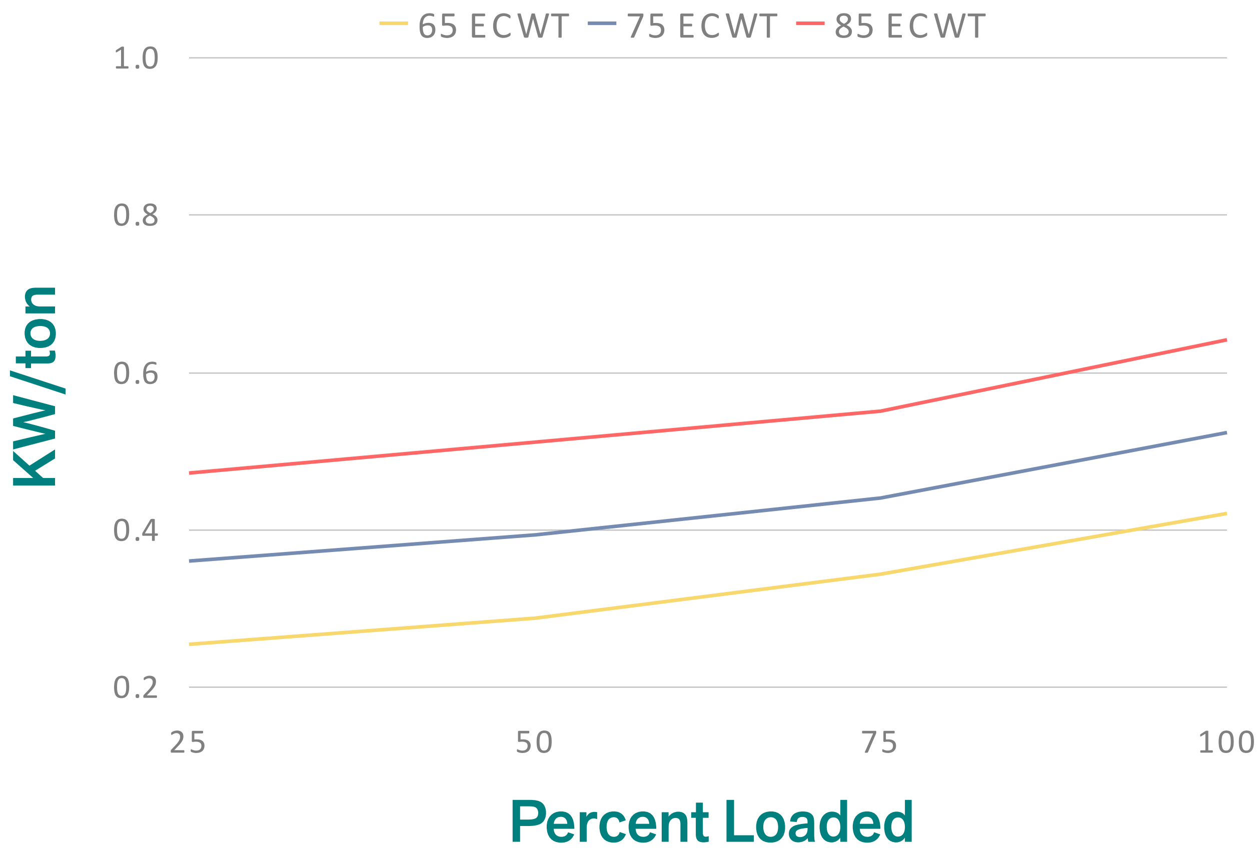


Centrifugal Chiller Comparison

Centrifugal Chiller with VFD

1000T High Pressure, Multiple Oil-Free Compressors



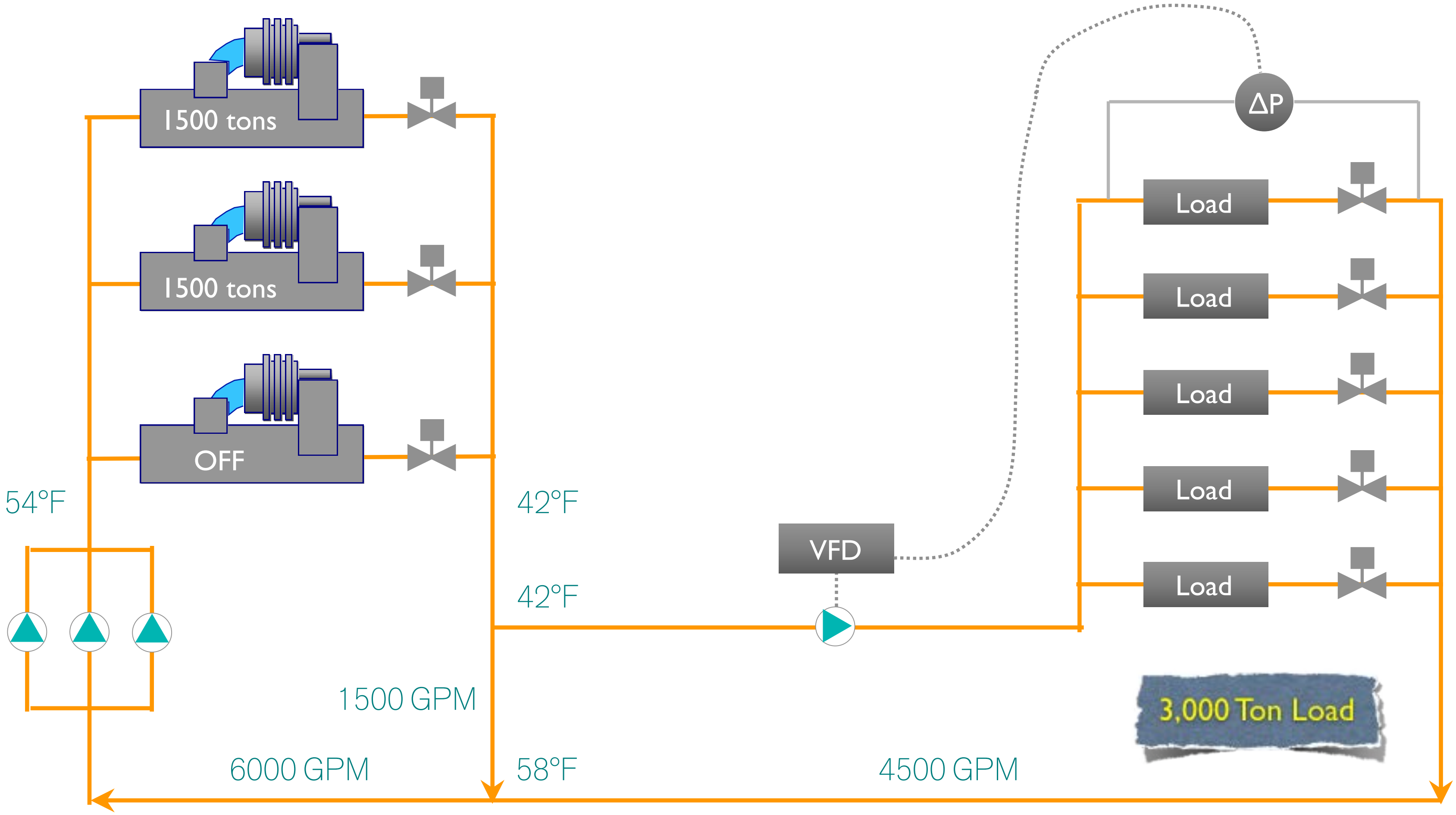
Optimizing Plant Performance

Primary-Secondary vs Variable Primary Flow

- Variable primary flow plants can provide advantages over traditional primary-secondary configurations
- Less plant space required for VPF
- VPF is not conducive to CHW Thermal Energy Storage

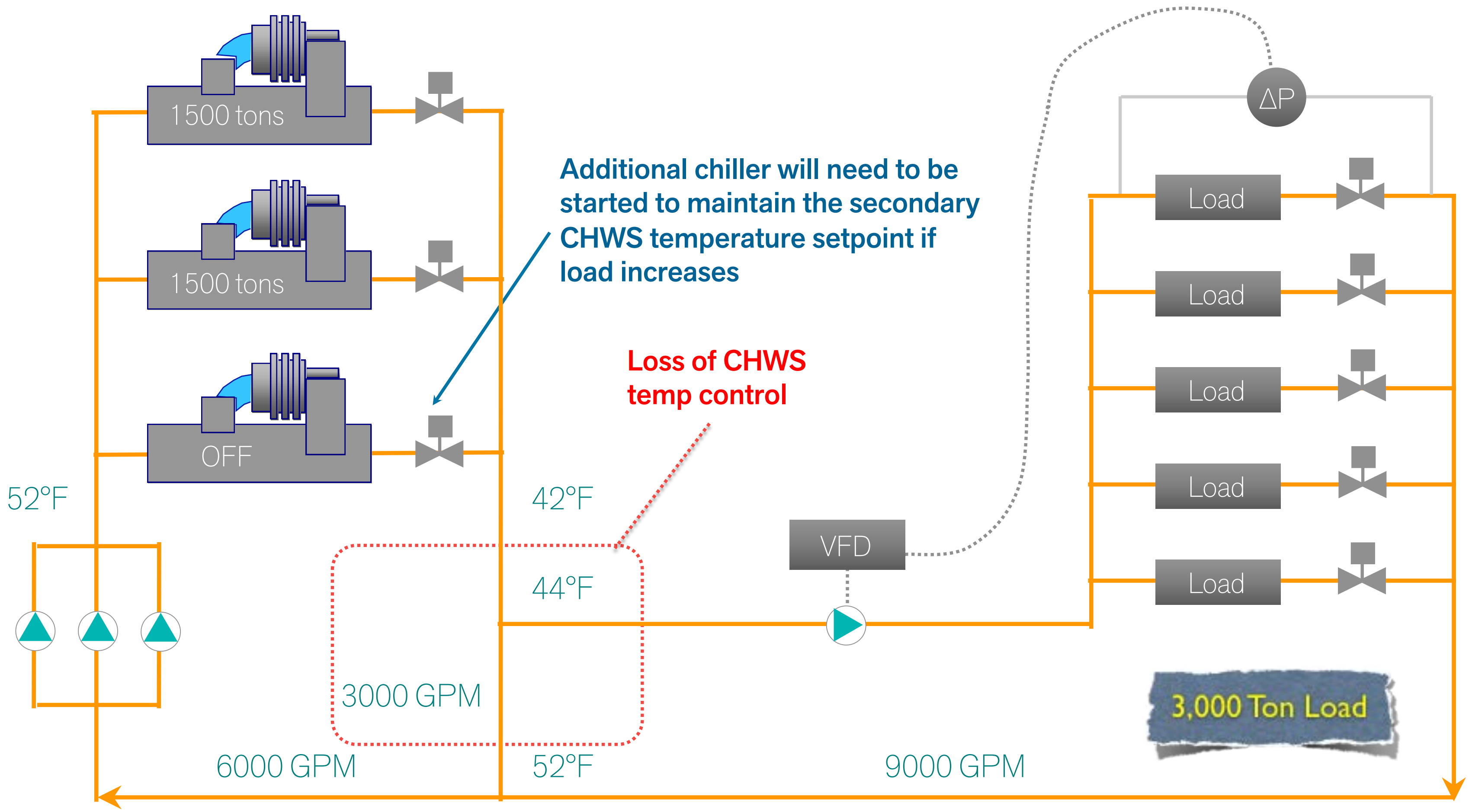
Primary-Secondary Variable Flow

Part Load Operation - 4500 Ton Plant



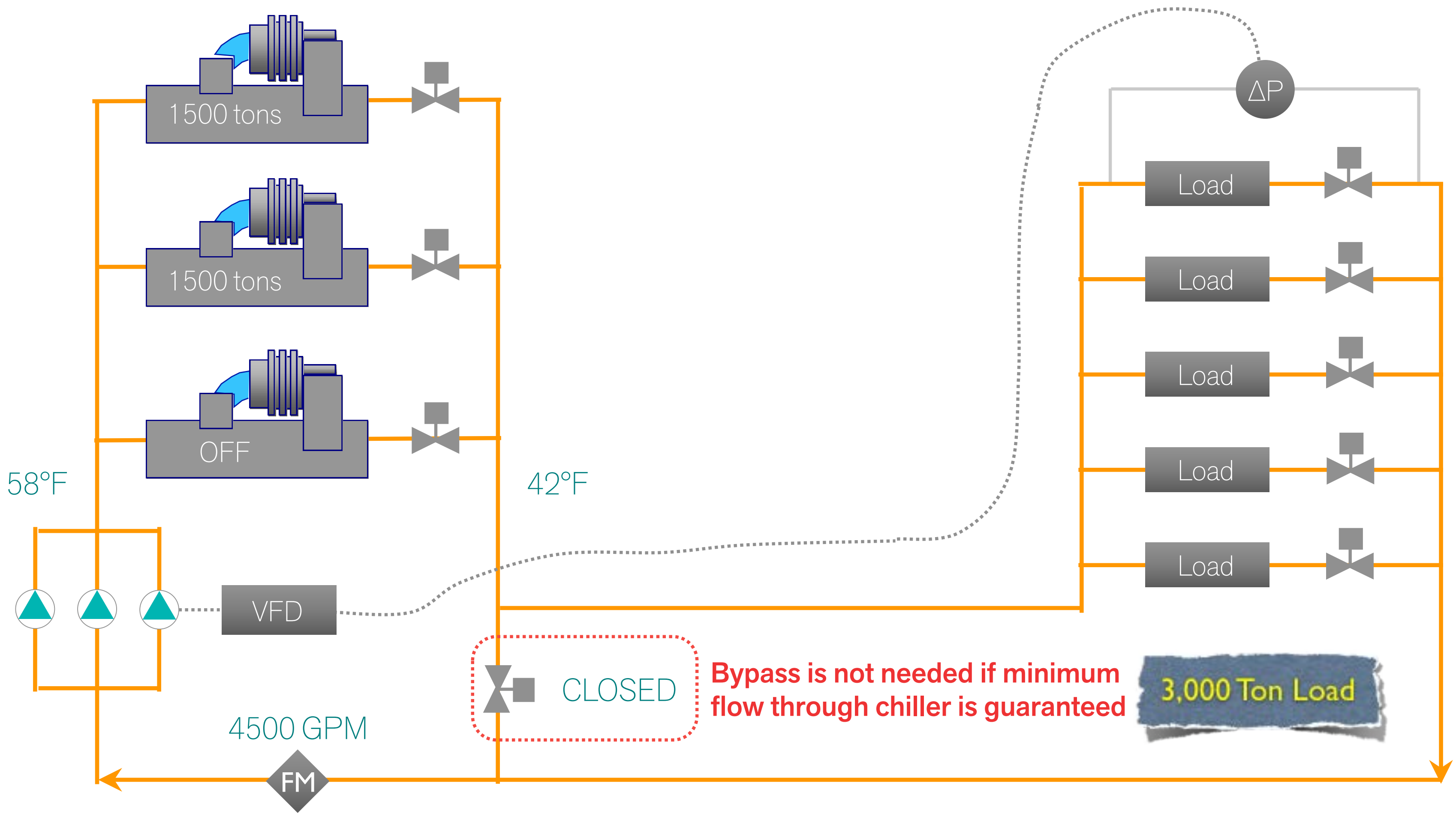
Primary-Secondary Variable Flow

Effect of Low CHWR Temperature
Low ΔT Syndrome



Variable Primary Flow

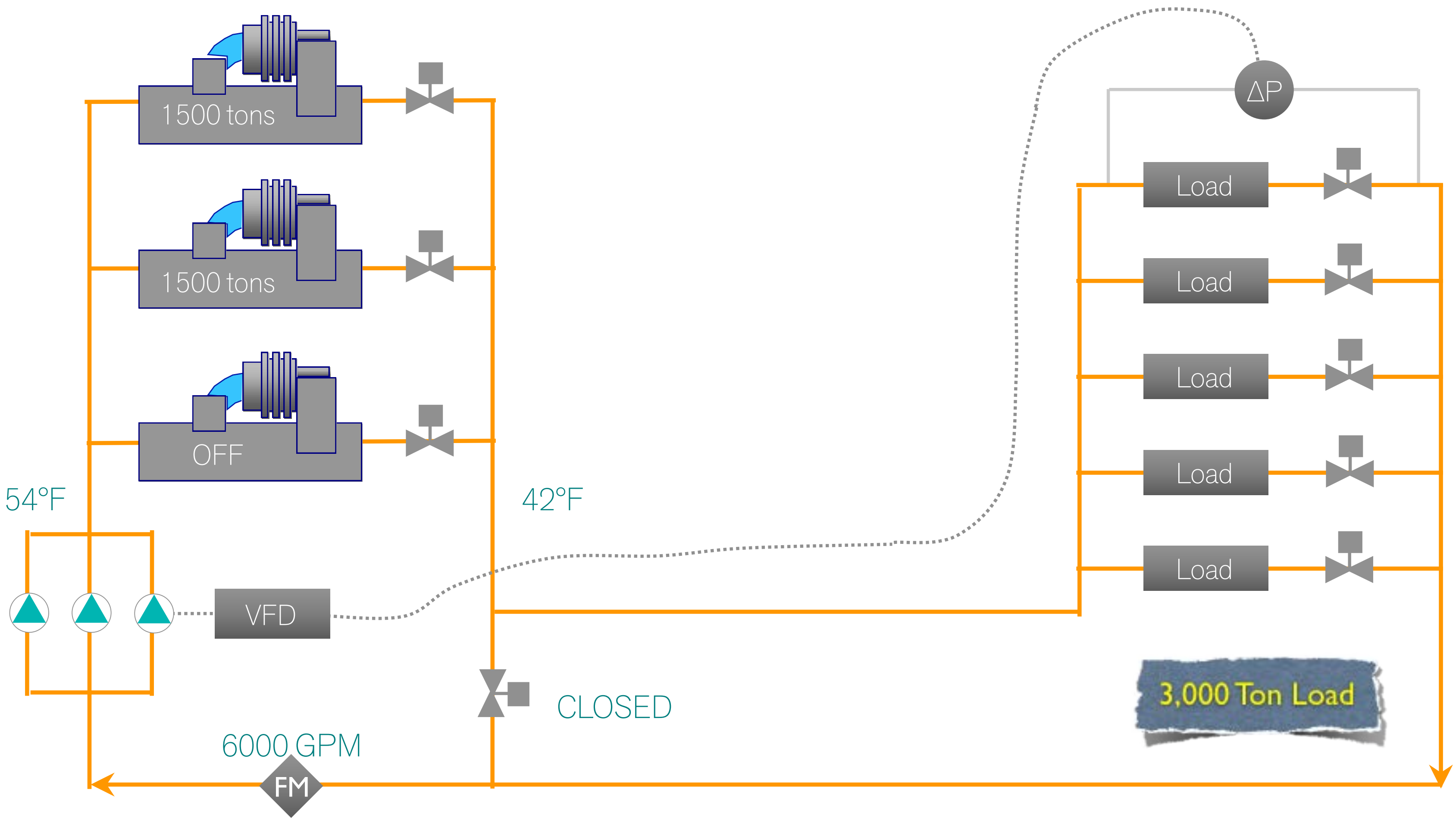
Part Load Operation - 4500 Ton Plant



Bypass is not needed if minimum flow through chiller is guaranteed

Variable Primary Flow

Effect of Low CHWR Temperature

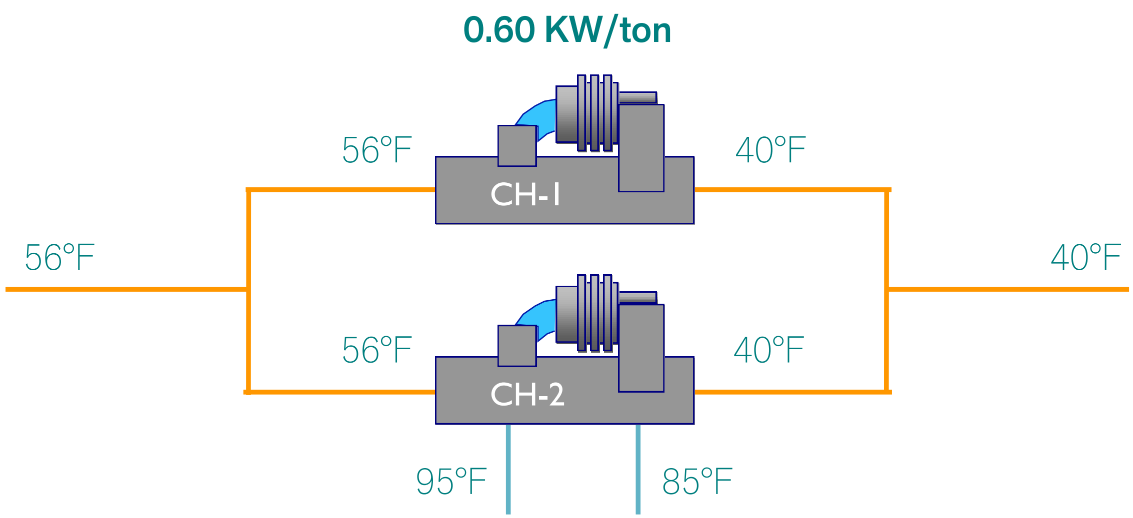


Series Arrangement

- In applications with high lift, a series evaporator arrangement can improve overall plant performance

Series versus Parallel

With High Lift Requirement

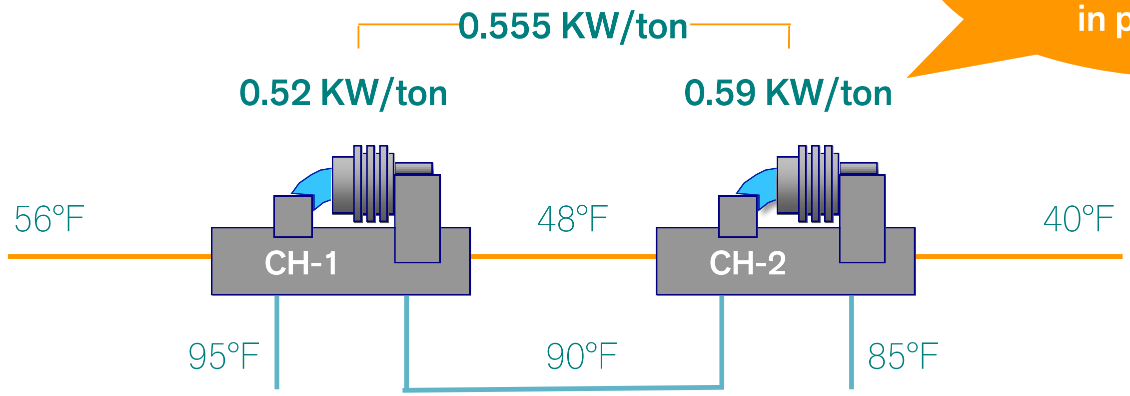


Parallel-Parallel Arrangement

Series versus Parallel

With High Lift Requirement

30 feet head increase on condenser water would result in 230 KW increase in pump power



Series-Counterflow Arrangement

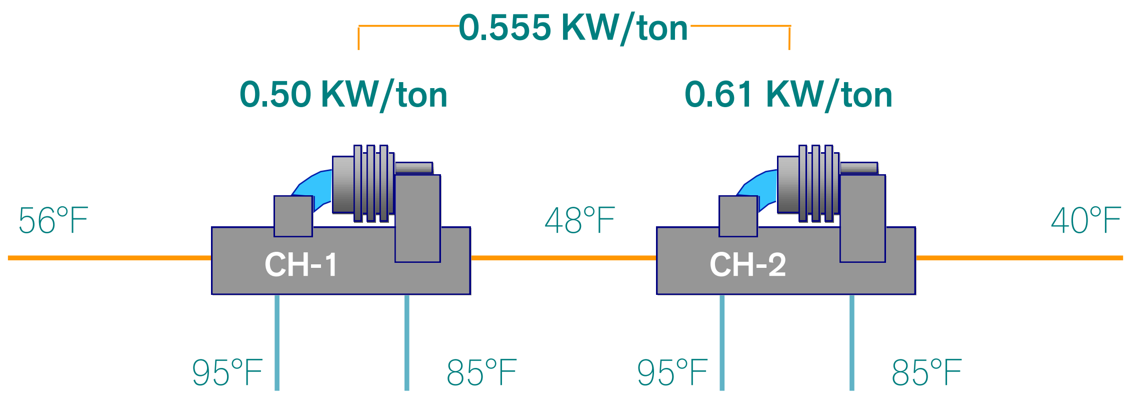
7% KW Reduction on Chillers

or

~~450~~ 220 *KW Reduction on 10,000 ton Plant*

Series versus Parallel

With High Lift Requirement



Series-Parallel Arrangement

7% KW Reduction
or

450 KW Reduction on 10,000 ton Plant

Optimize Heat Rejection

- Oversized cooling towers can decrease approach to lower chiller lift requirements and improve plant KW/ton
- Approximately 1.5% chiller KW reduction per °F lift reduction

Lowering CWS by from 95°F to 93°F
3% Chiller KW Reduction
or

180 KW Reduction on 10,000 ton Plant

CHW ΔT

Increased chiller lift would result in 167 KW increase in chiller power

	Option 1	Option 2
CHWS Temp	40°F	38°F
CHWR Temp	56°F	58°F
CHW ΔT	16°F	20°F
Plant Size	10,000 tons	10,000 tons
CHW Flow	15,000 gpm	12,000 gpm
Head	200 feet head	146 feet head
Pump KW	667	413

38% Pump KW Reduction

or

87

~~254~~ KW Reduction on 10,000 ton Plant

Thermal Energy Storage

- Chilled water thermal storage is a viable means of reducing peak electrical demand and increasing plant efficiency
- Less chiller and cooling tower capacity required
- You may qualify for a Permanent Load Shift incentive
- Keep it simple!

Building Interface Considerations

Building Interface Considerations

Energy Transfer Stations Using Heat Exchangers

- Heat exchangers designed with lower approaches will typically yield higher CHW ΔT
- Always focus on supplying load with proper CHWS temperature

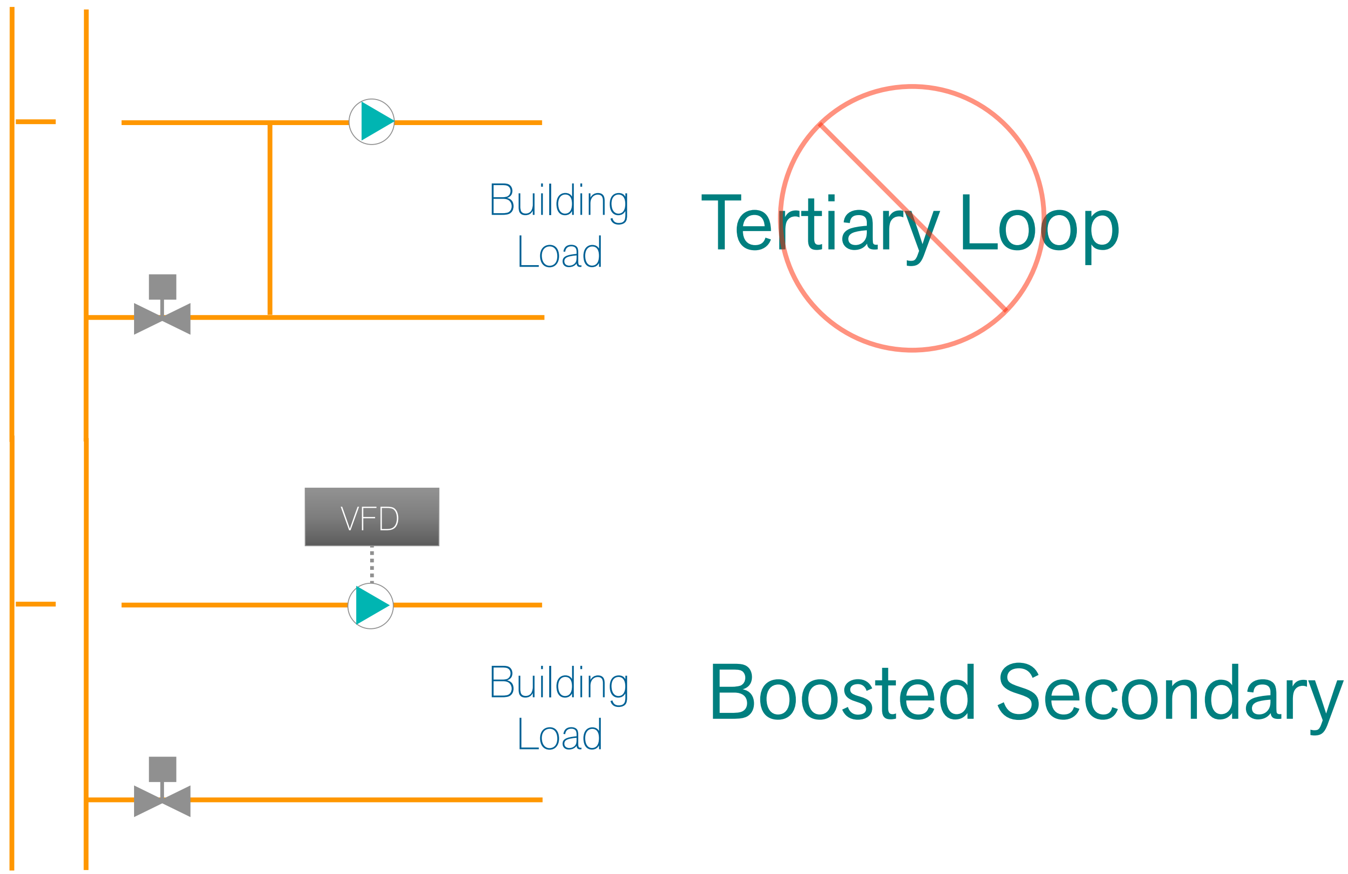
Building Interface Considerations

without Heat Exchangers

- Avoid chilled water tertiary loops
  - Remember cooling coil fundamentals
- A variable speed booster pump should be used to boost differential pressure when needed

Building Interface Considerations

without Heat Exchangers



A Case for Metering

- Most efficiently designed systems are horribly inefficient after several years of operation
- How can we improve operation if we don't evaluate the efficiency?
- Calibrate regularly

A Case for Commissioning

- Commissioning is a systematic process of assuring that systems perform in accordance with the design intent and owner's operational needs
- Retro-commissioning

Control Design Issues

- Control strategies should consider impact on complete system
- Aim to continually optimize energy efficiency for entire system
  - Demand control
  - Relational control
- Aim for reliability and "simplicity"

Summary

- Understand parameters that affect chiller plant and overall system performance
- Optimize operation through equipment selection and control sequences to deliver CHW to all loads as efficiently as possible throughout the year
- Commission and monitor plant performance

If you are not prepared to be wrong, you won't come up with anything original

For More Information

- ASHRAE Self Directed Learning Course
  "Fundamentals of Water System Design"
- ASHRAE District Cooling Guide, 2013
- ASHRAE Journal series *"Optimizing Chilled Water Plants"*
- *Hydronic System Design & Operation* by E.G. Hansen

Thank You