Optimization Through Perfect Plant Design

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Agenda

- What is Optimization?
- Ideal Chilled Water Plant Design
- Relational Controls vs PID Controls
- Total System Energy Examples
- Q & A

What is Optimization?

Approach to System Optimization

Design

- System Infrastructure
- Selection of Components

Operate

- Plant Automation
- Component Application
- Networked Optimization Software

Maintain

- Enhanced Visibility
- Measurement & Verification
- Persistent Maintenance

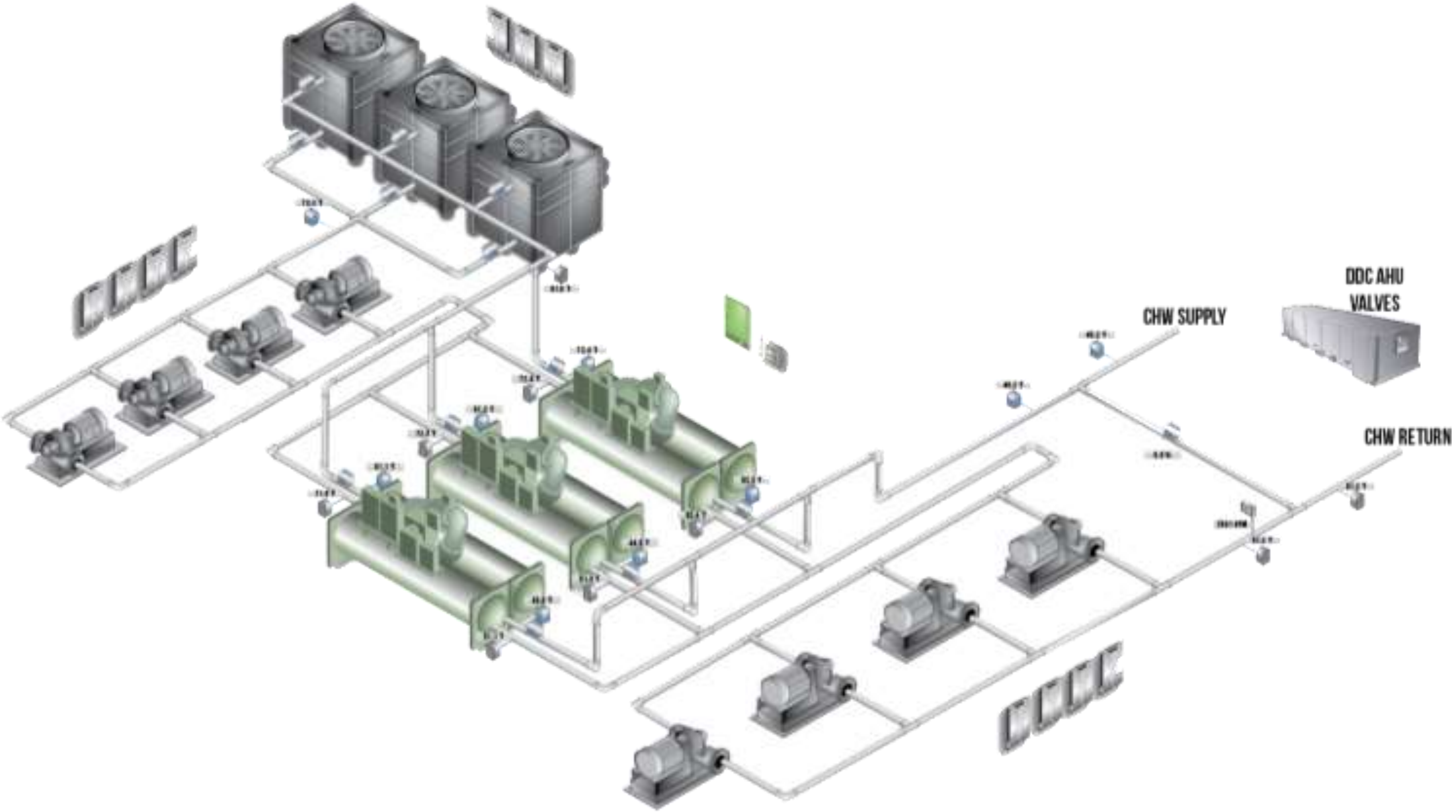
Chiller Plant Efficiency Scale

Just like miles per gallon, the kW/ton figure reflects the efficiency of the chiller plant regardless of the amount of cooling produced

Average annual chilled water plant efficiency in kW/ton.
Input includes: chillers, tower fans, condenser pumps, and chilled water pumping.

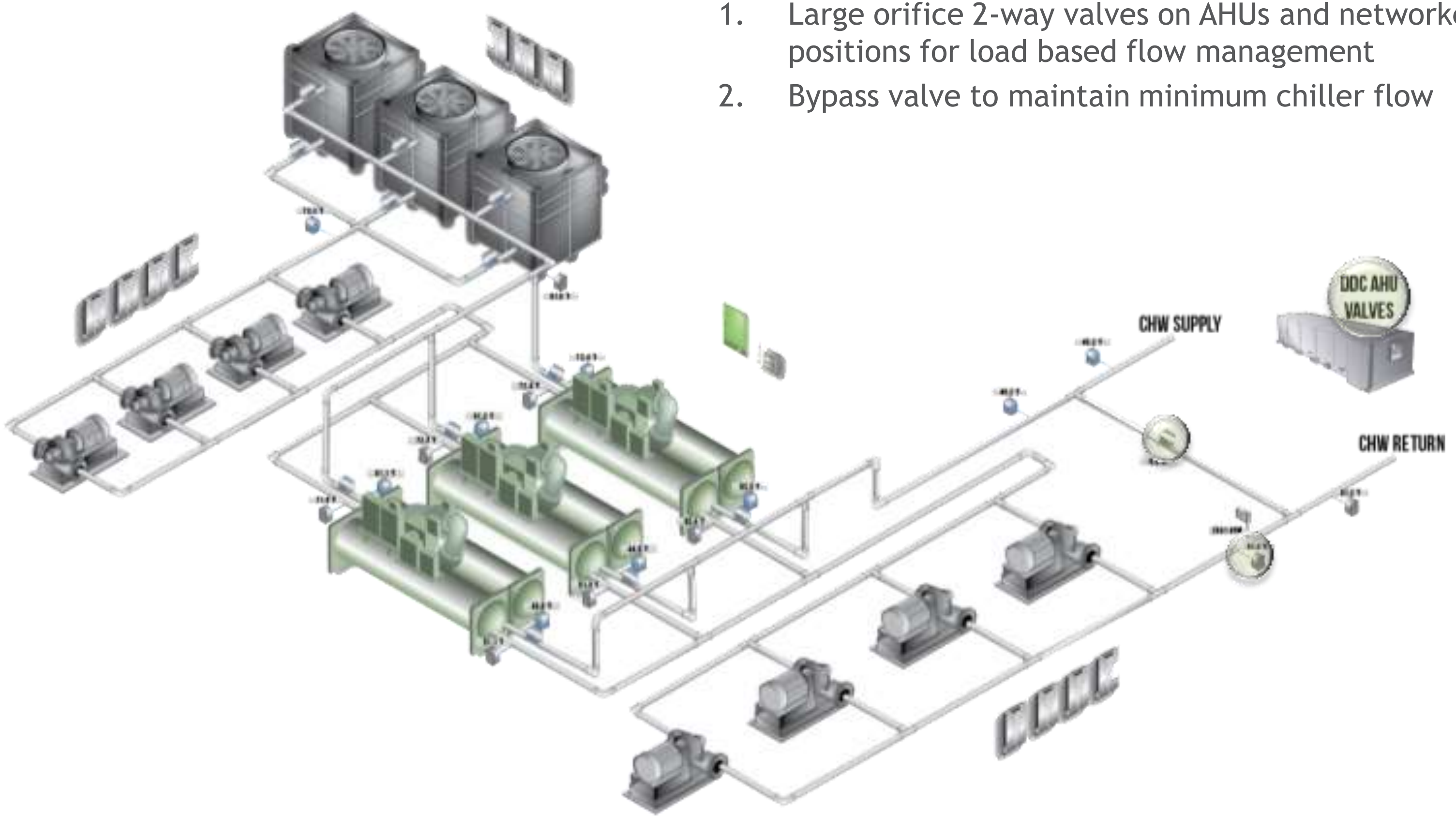
Annual average kW per ton

All-Variable Speed Chiller Plant with Relational Control



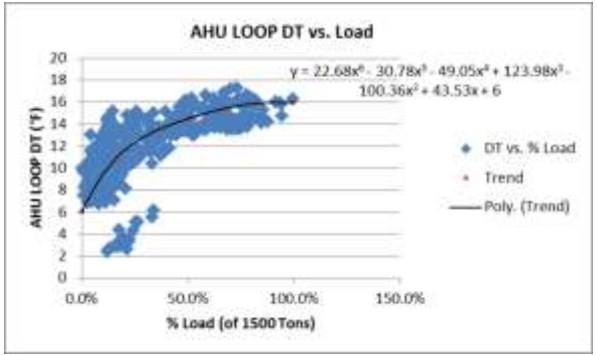
Variable Primary Flow Chilled Water Pumping

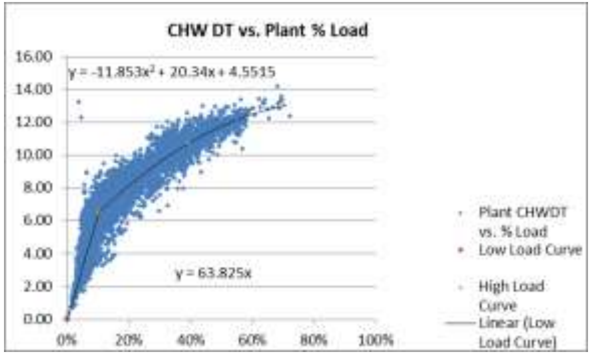
1. Large orifice 2-way valves on AHUs and networked valve positions for load based flow management
2. Bypass valve to maintain minimum chiller flow

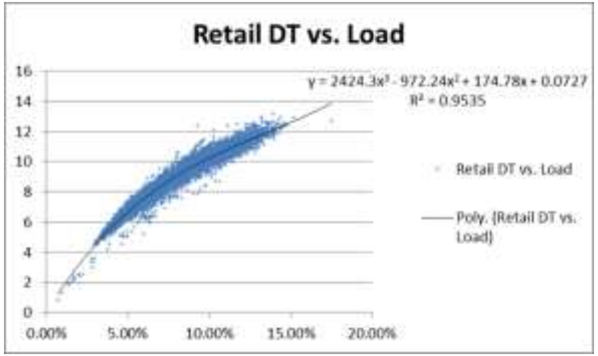


CHW System Design Best Practices

- Design AHU Loads for high DT (Higher the better within budget)
- Design Plant for Lowest DT to meet one chiller at full load!
- Design chillers with Low Pressure Drops (15 Ft or less)



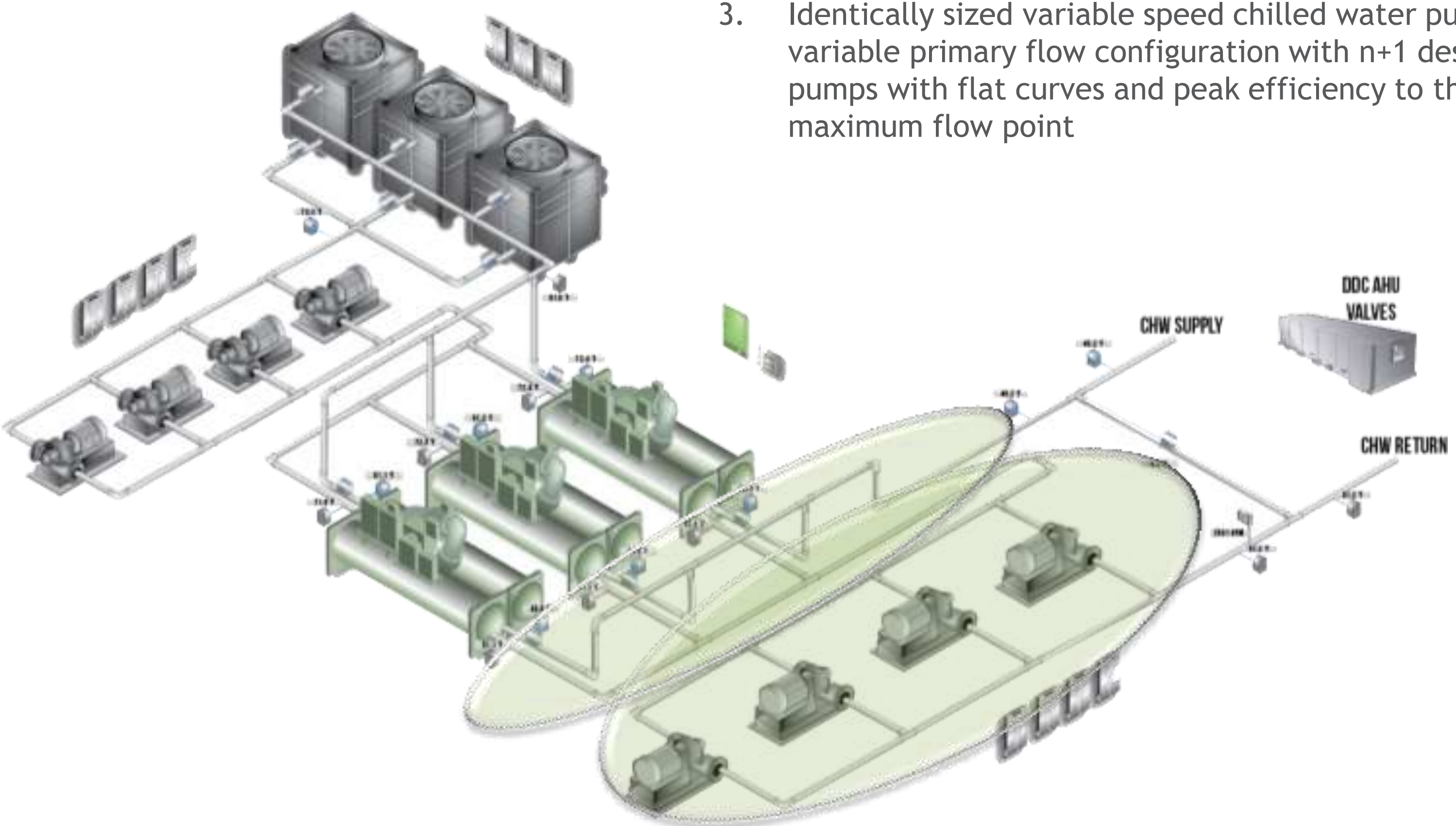




- Eliminate Decouplers (Throughout entire system!)
  - Exception: Process loads at higher temperatures; check valve from return to supply only
- Don’t undersize piping
- Don’t plan for 3-way valve at end of loop. This is never necessary!

Variable Primary Flow Chilled Water Pumping

3. Identically sized variable speed chilled water pumps in variable primary flow configuration with n+1 design. Select pumps with flat curves and peak efficiency to the right of the maximum flow point

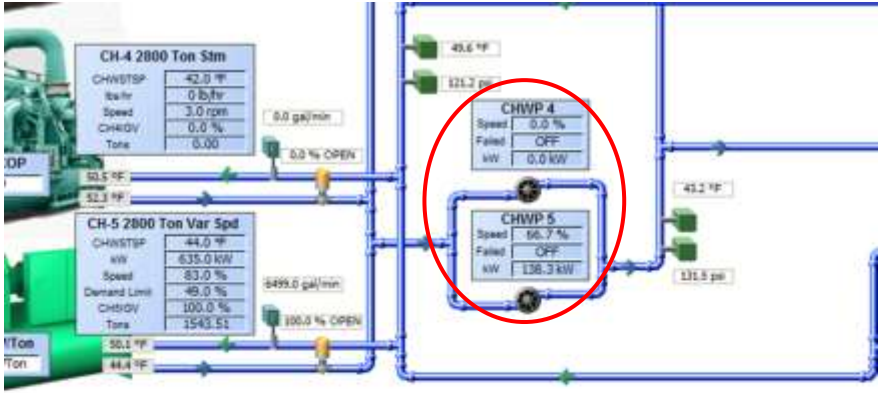


Pump Redundancy Used for Efficiency

CHWP Energy Snap Shot

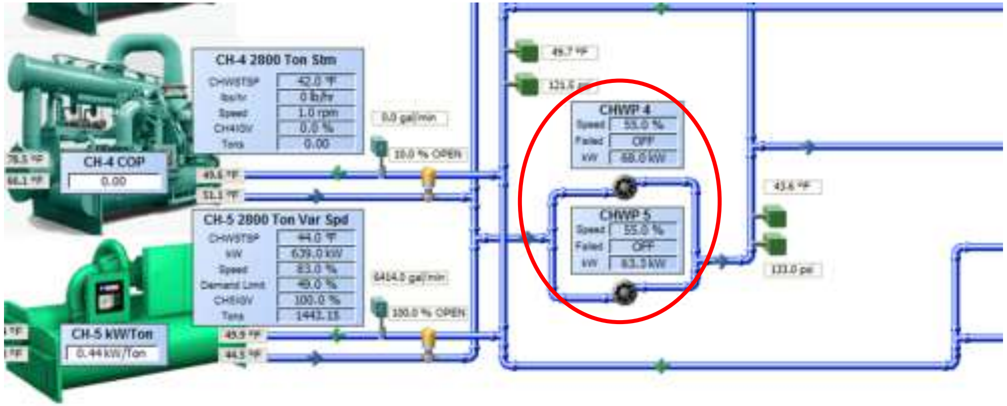
One CHWP Operating

- ~6700 GPM @ 250FT(Design)
    - 100% Spd (~450 kW)
- 6499 GPM @ ~60 Ft (Spot)
    - 66.7% Speed (138.3 kW)



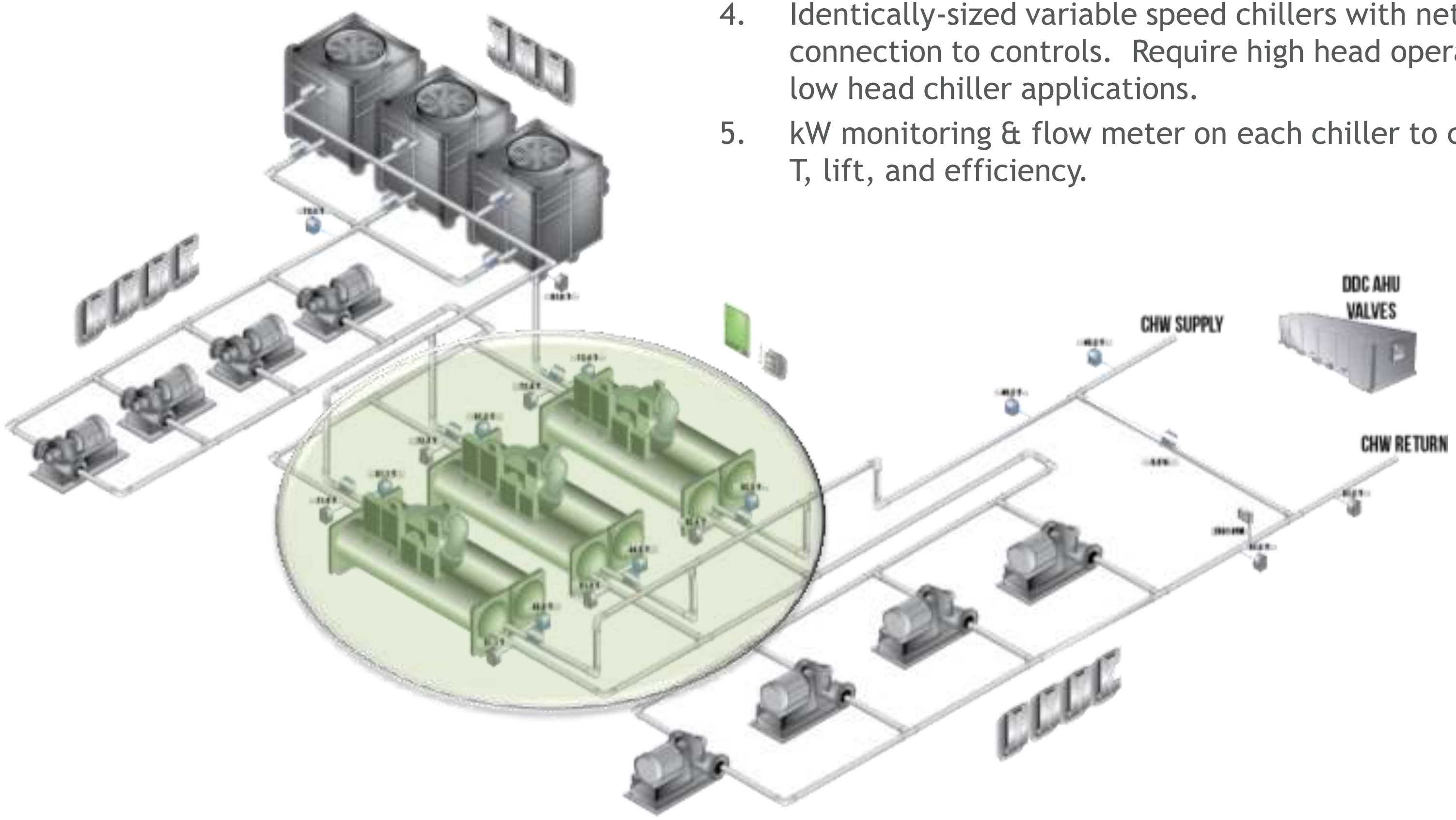
Two CHWPs Operating

- 6414 GPM @ ~60 Ft (Spot)
    - 55% Speed
    - (2) ~65 kW each (~130 kW Total)



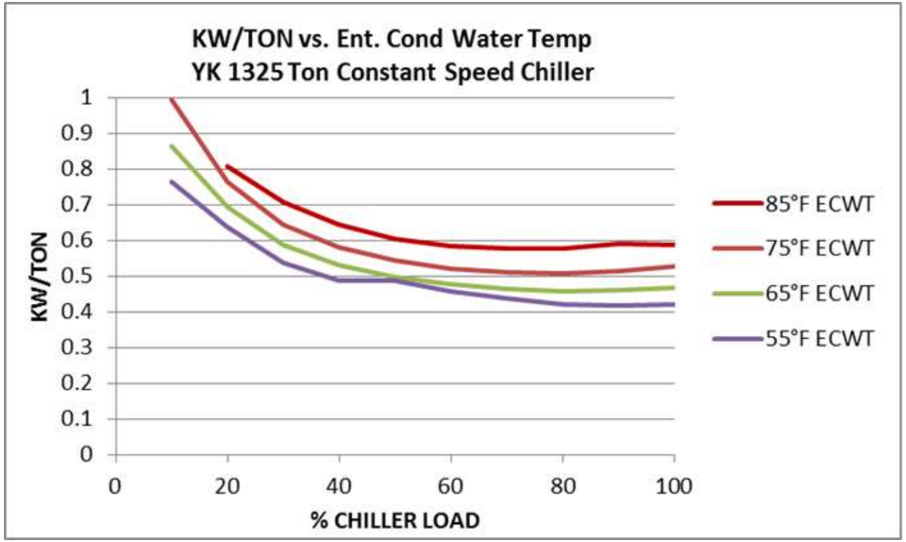
Variable Speed, Flow, and Temperature Chillers

4. Identically-sized variable speed chillers with network connection to controls. Require high head operating point for low head chiller applications.
5. kW monitoring & flow meter on each chiller to calculate delta T, lift, and efficiency.

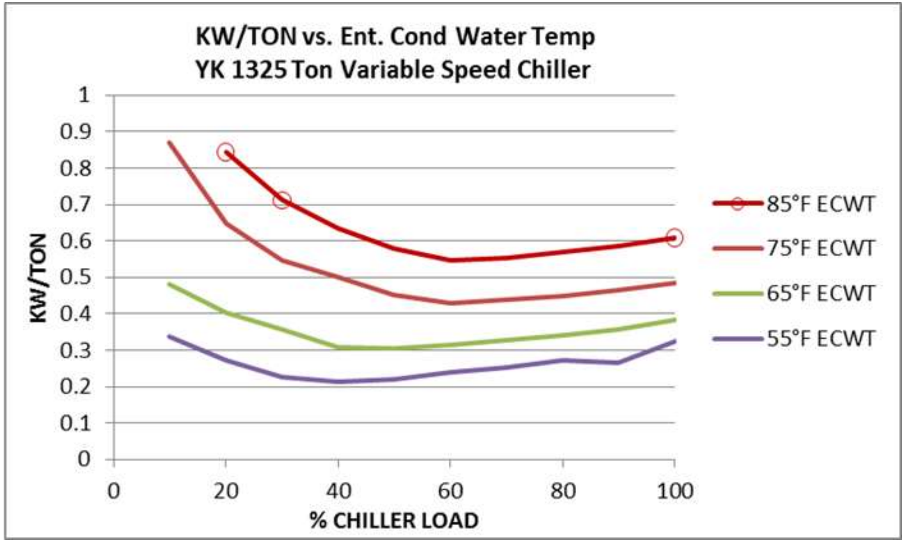


Constant Speed vs. Variable Speed Chillers

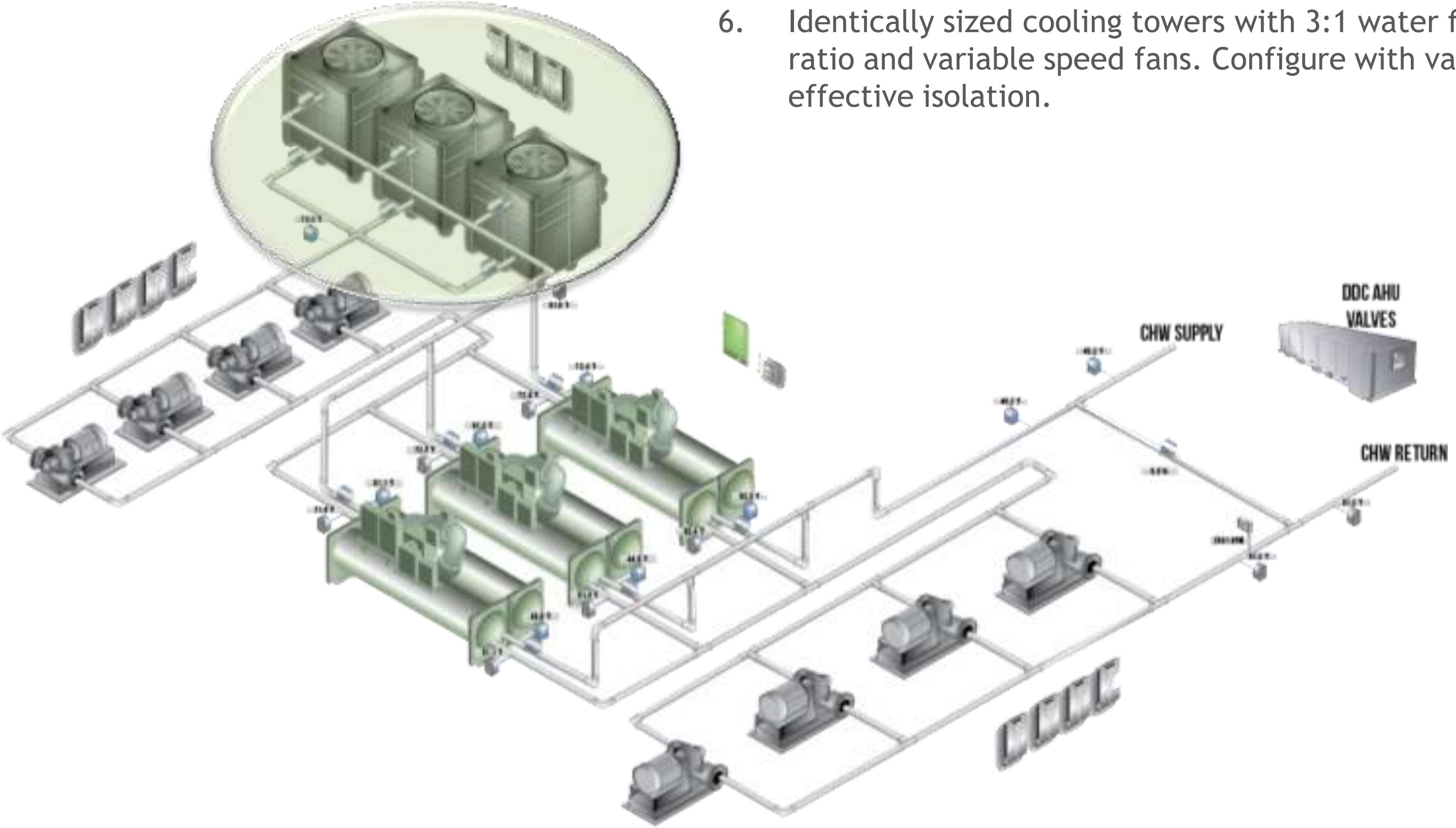
CS Chiller



VS Chiller



Variable Flow, Variable Temperature Condenser Water System



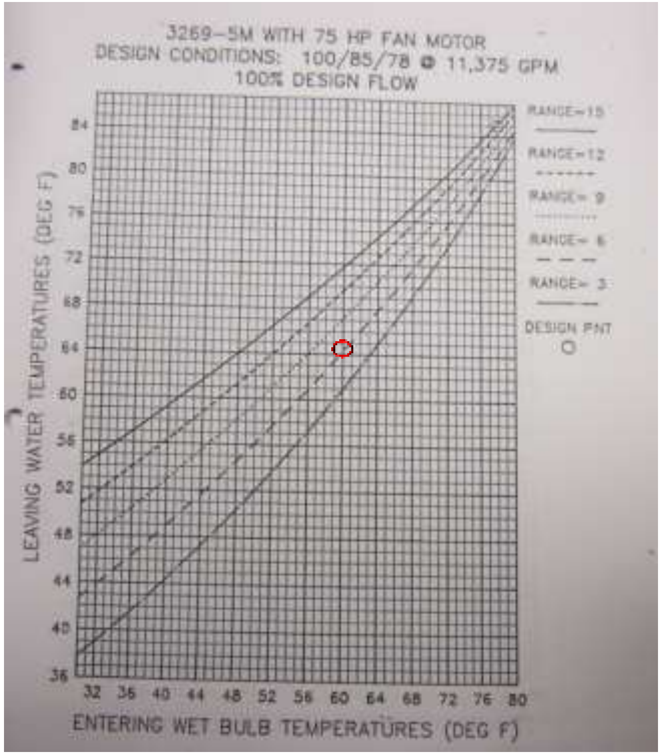
6. Identically sized cooling towers with 3:1 water flow turndown ratio and variable speed fans. Configure with valves for effective isolation.

Affects of Variable Condenser Water Flow

Cooling Tower Performance

- Cooling Tower (Full Flow)
  - 2843 Tons (11,375 GPM)
  - 60 deg F Wet Bulb Temp
  - 70.5 deg F Entering Tower Water Temp
  - 64.5 def F Leaving Tower Water Temp

4.5 deg F Approach



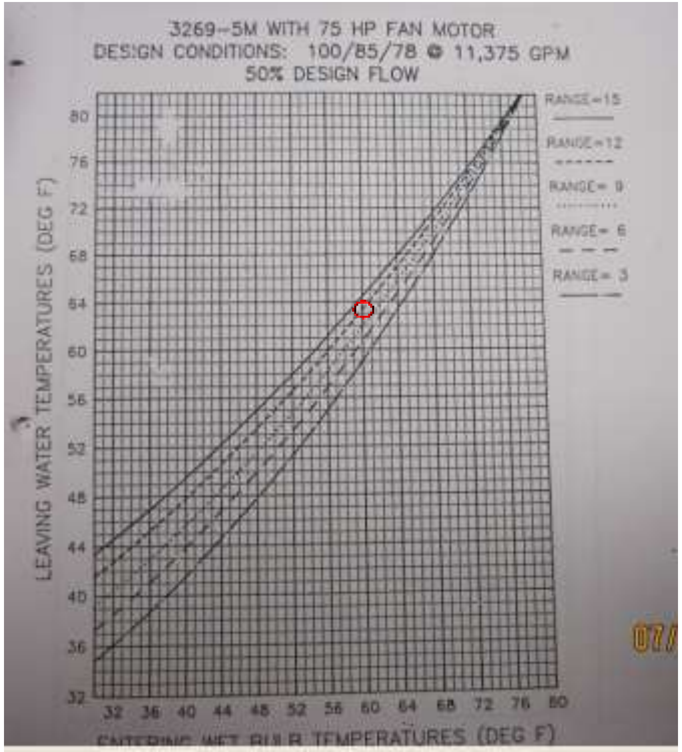
Affects of Variable Condenser Water Flow

Cooling Tower Performance

- Cooling Tower (Full Flow)
  - 2843 Tons (***5,687*** GPM)
  - 60 deg F Wet Bulb Temp
  - ***75.5*** deg F Entering Tower Water Temp
  - ***63.5*** def F Leaving Tower Water Temp

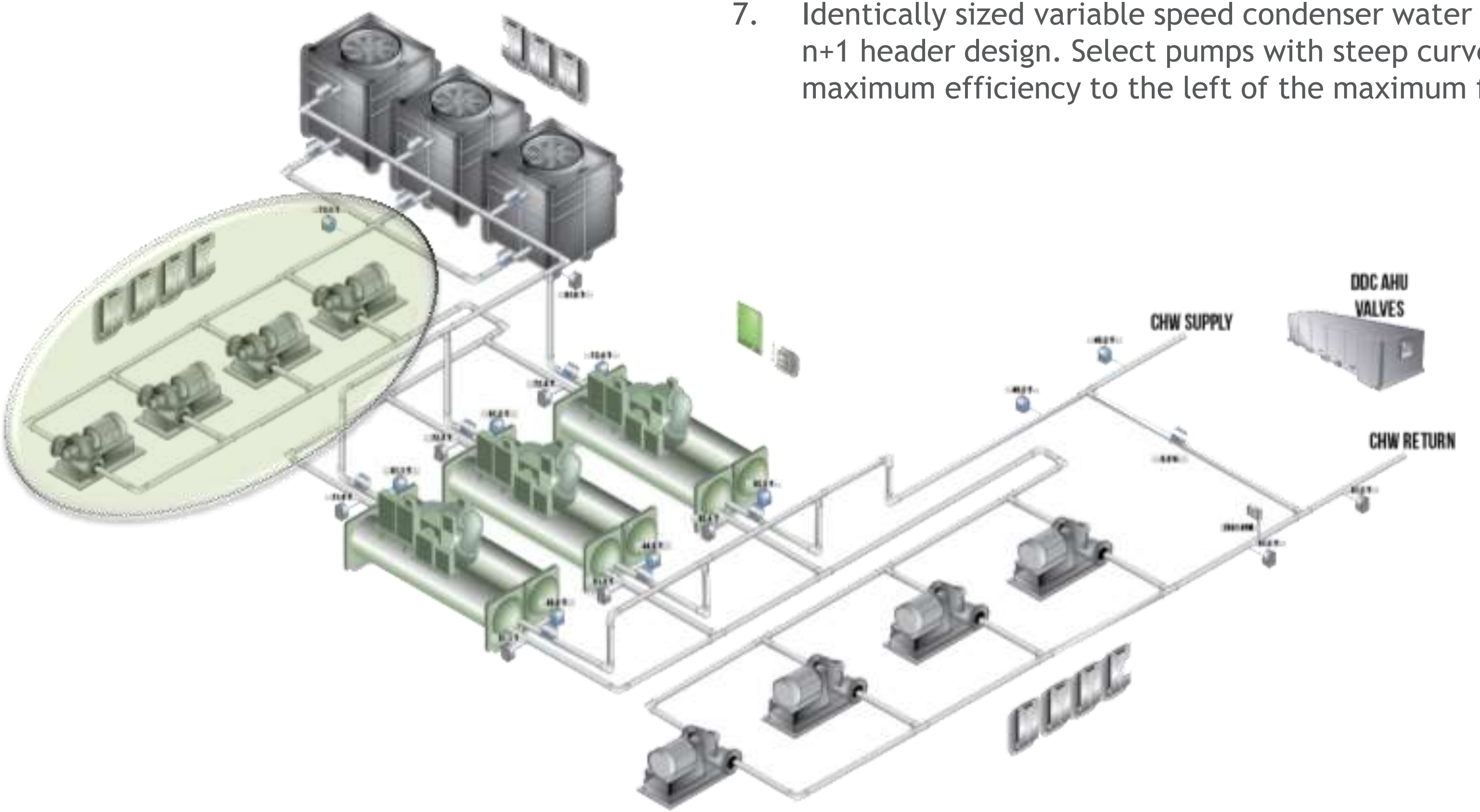
3.5 deg F Approach

Turndown is critical for Tower Performance



Variable Flow, Variable Temperature Condenser Water System

7. Identically sized variable speed condenser water pumps with n+1 header design. Select pumps with steep curves and maximum efficiency to the left of the maximum flow point.



Affects of Variable Condenser Water Flow

The Mis-Conception: “There is no benefit.”

- Slowing Down Condenser Water Pump Will Never Save Overall Plant Energy Use
- Reduced Flow Degrades Chiller Performance
- The Chiller Energy Always Outweighs the Condenser Pump Energy
- Reduced Flow Degrades Tower Performance
- Chillers Are Not Capable of Variable Condenser Water Flow

Affects of Variable Condenser Water Flow

Self Balancing – Savings Even on Perfectly Designed Systems!

Example Design Conditions:

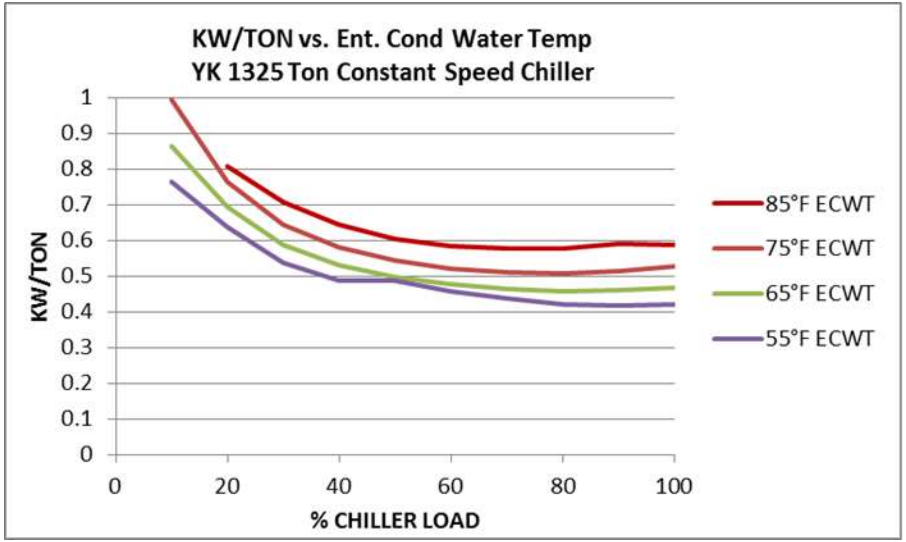
- 4 CDWPs & 4 Chillers
- Chiller Piping and Barrel PD = 20 ft
- CT Piping and Static Head = 15 ft
- Pipe & Fitting losses = 65 ft
- Total Flow 12,000 GPM @ 100 ft

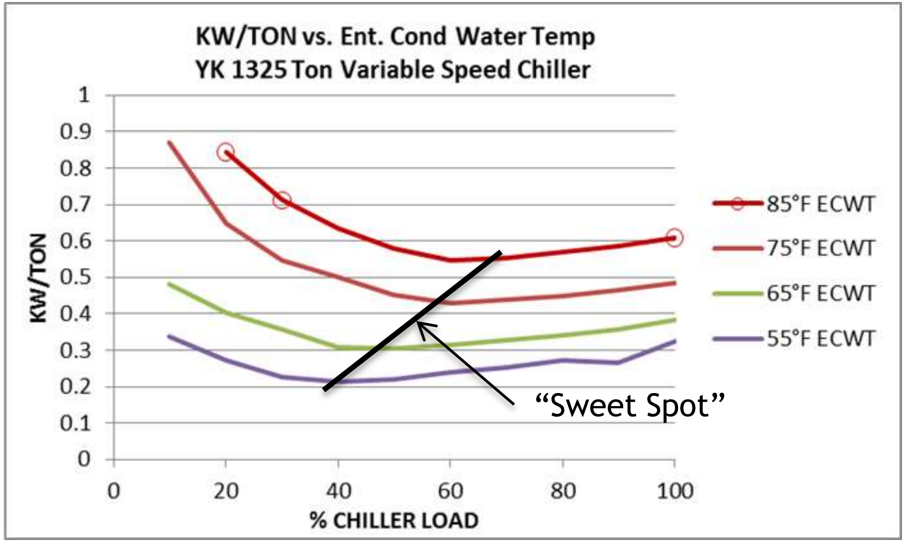
Part Load Example:

- 1 CDWP & 1 Chiller
- Chiller Piping and Barrel PD = 20 ft
- CT Piping and Static Head = 15 ft
- Pipe & Fitting losses ~ 5 ft
- Total Flow 3,000 GPM **@ 40 ft**

Affects of Variable Condenser Water Flow

Chiller Staging



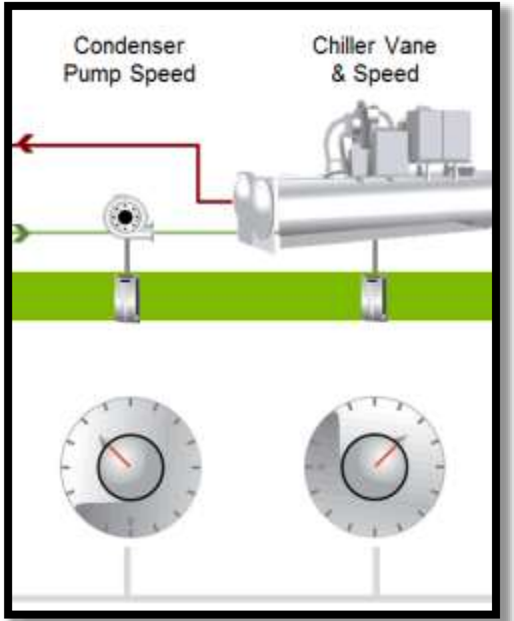


Affects of Variable Condenser Water Flow

Chiller Energy vs. Condenser Pump Energy

Example:

- 100 HP CDW Pump (~75 kW)
  - 3000 GPM @ 100 Ft HD.
- 1000 Ton Chiller @ 50% Load
- Options:
  - 100% (3000 GPM) Flow – 5 ºF Delta T (Chiller)
  - 50% (1500 GPM) Flow – 10 ºF Delta T (Chiller)



Question:

- Does The Pump Energy offset Chiller Energy?

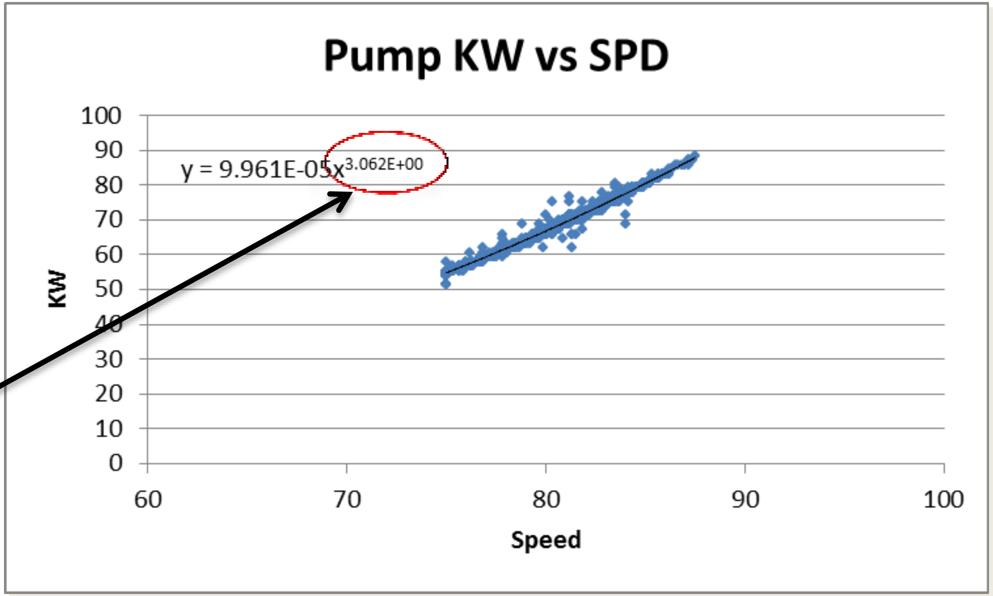
Affects of Variable Condenser Water Flow

Condenser Water Pump

- CDWP Energy (75 kW peak)
- 50% CDW Flow ~ 60% Pump Speed
- 60% Pump Speed = 21.6% Power (16.2 kW)
- 75 kW – 16.2 kW = 58.8 kW Saved

- Pump Affinity Law:

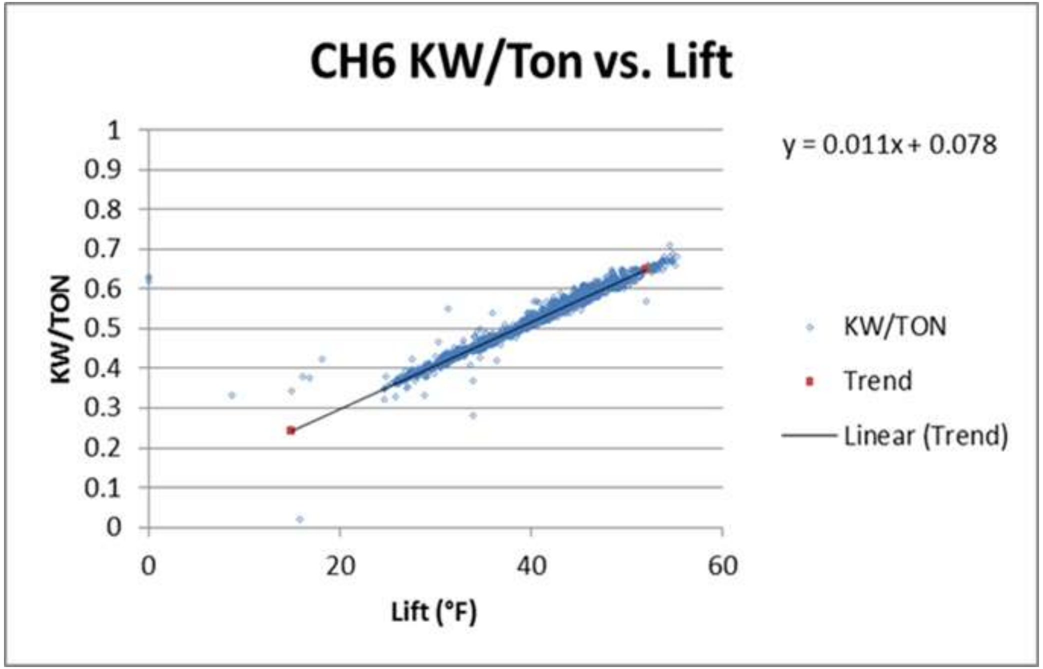
KW ~ Spd^3



Affects of Variable Condenser Water Flow

Chiller

- Chiller Energy (600 kW peak)
- 50% CDW Flow = 5.0 ºF Lift Increase
- 0.011 X 5.0 ºF = 0.055 kW/Ton Increase
- 0.055 kW/Ton X 500 Tons = 27 kW Lost



Results

- CDWP: 58.8 kW Saved
- CH: 27 kW Lost

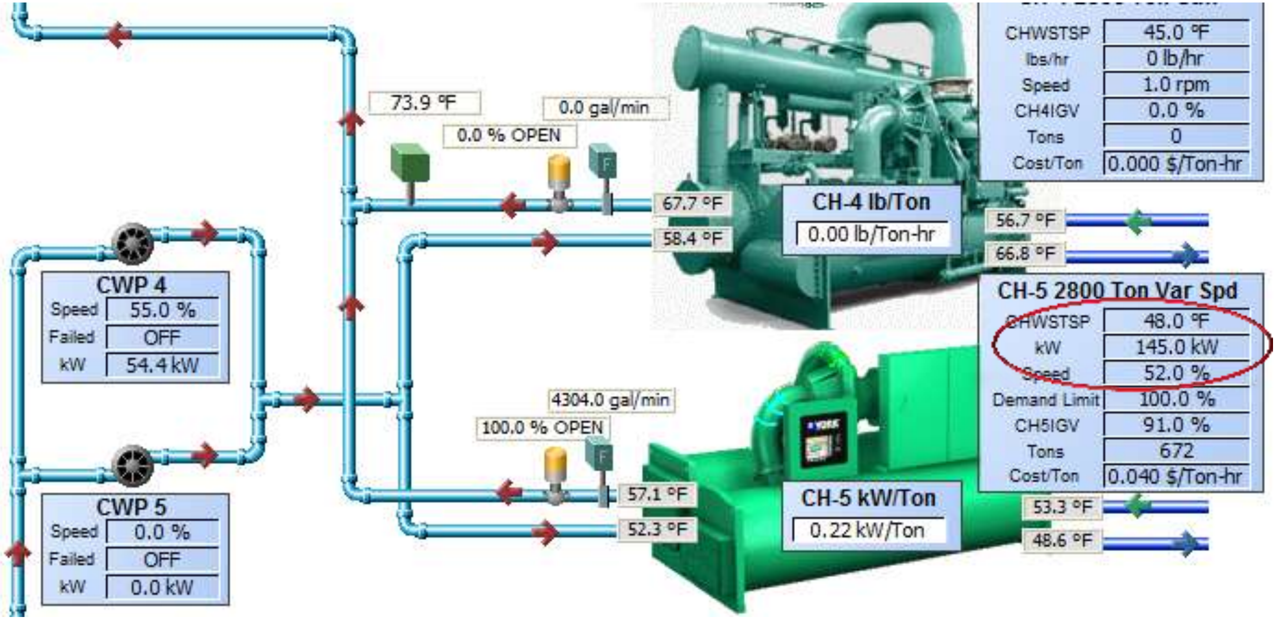
- Net: 31.3 kW Saved

Variable Condenser Water Flow – Real World Application

In winter operation there's no advantage to higher condenser water flow because the chiller is at minimum lift conditions!

<u>CDWP Energy Snap Shot</u>

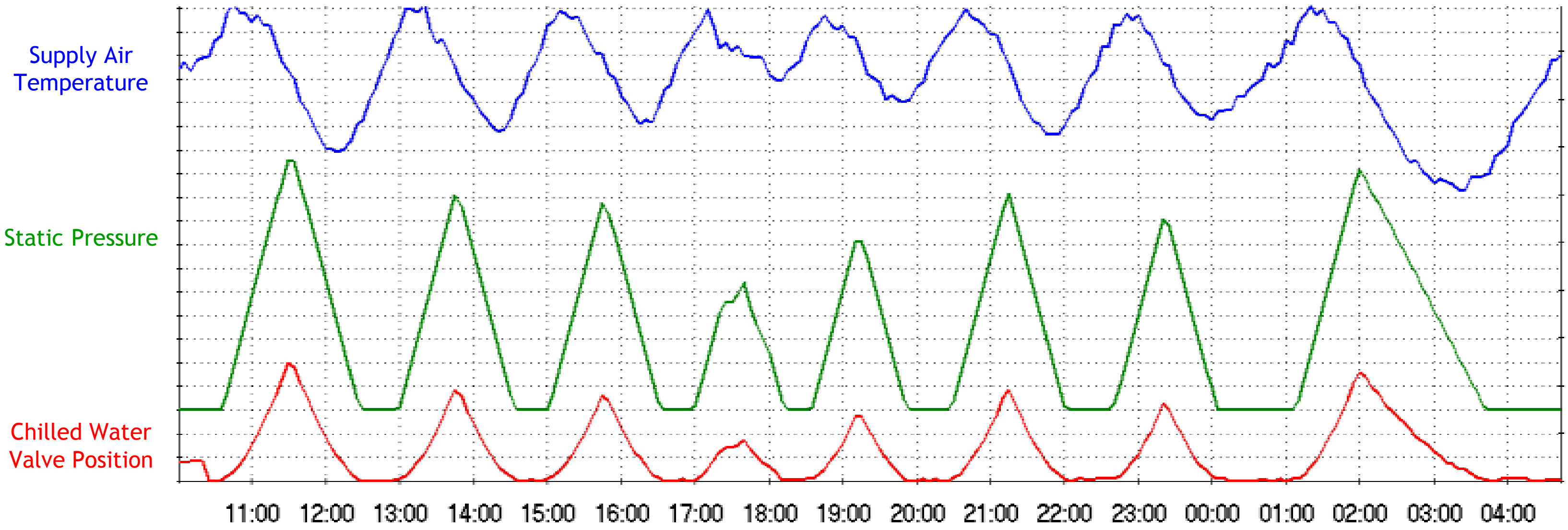
- 4304 GPM (~50% Flow)
- 55% Speed
- 54.4 kW (295 kW Design)
- **240 kW Saved vs. Design**
- *<u>Chiller Only Using 145 kW</u>*



Conventional PID Control

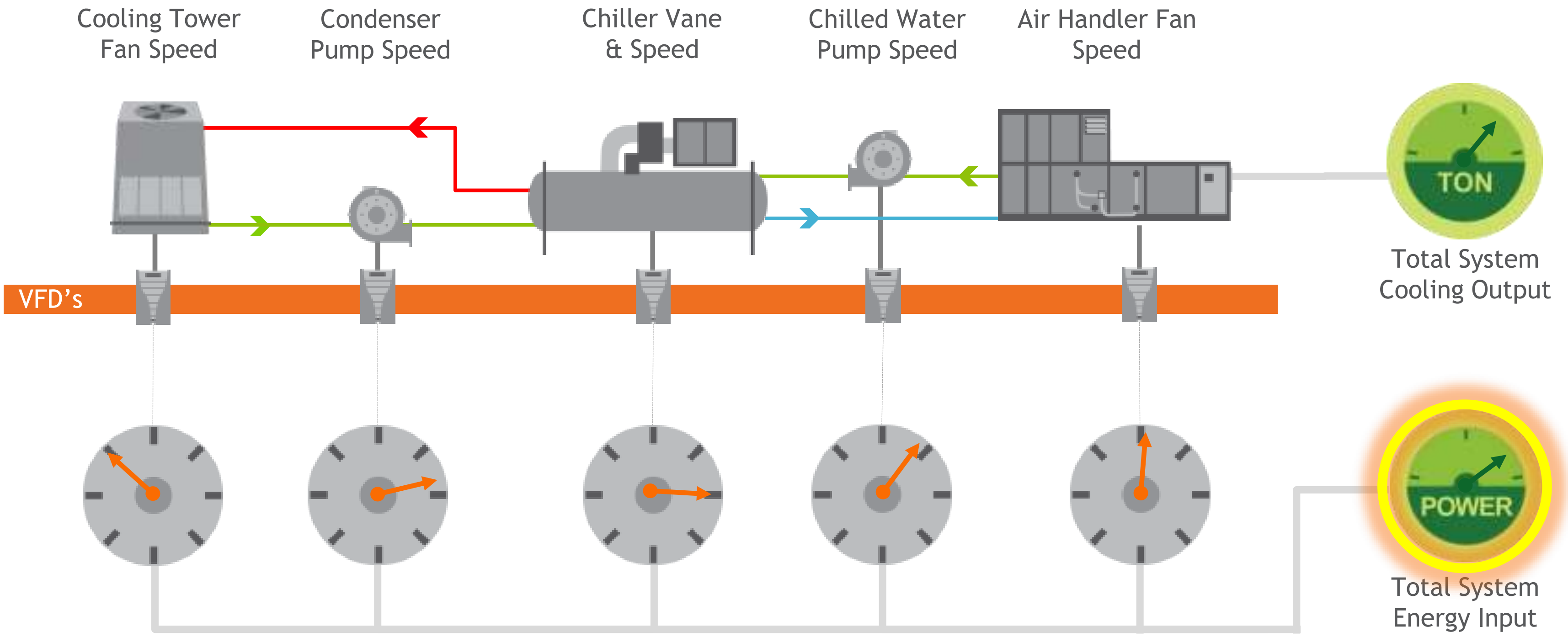
The biggest threat to effective optimization is lack of system transparency and instability

- Common approach: hunt and reset
- Hunting creates instability and loss of savings



All-Variable Speed System with Relational Control

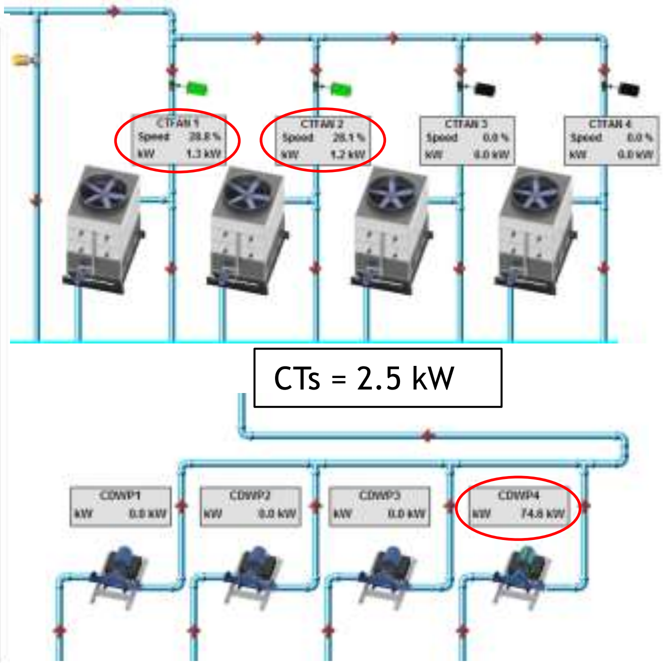
Eliminating hunting with relational control



Total System Schematic

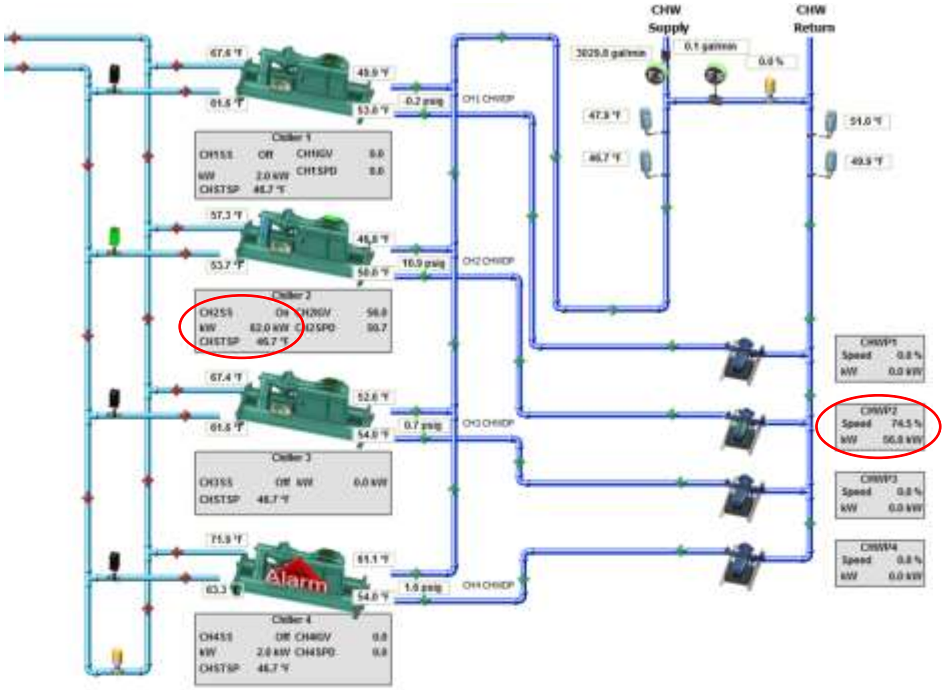
Total System Energy – Mostly Variable Speed, PID Control

Plant Tons
380.0 Tons
kW/Ton
0.57 kW/Ton
Chiller kW/Ton
0.21 kW/Ton
Plant kW
215.9 kW
OAT
42.2 °F
OATWB
39.3 °F
CHW DP Local
32.2 psi
CHW DP Remote
14.4 psig



CTs = 2.5 kW

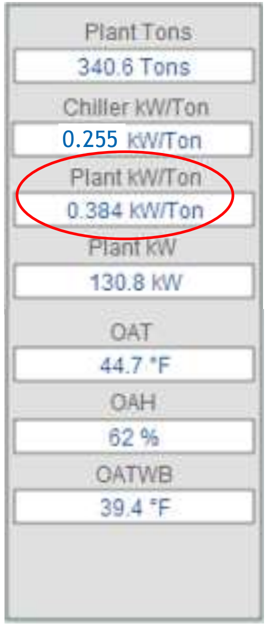
CDWPs = 74.6 kW

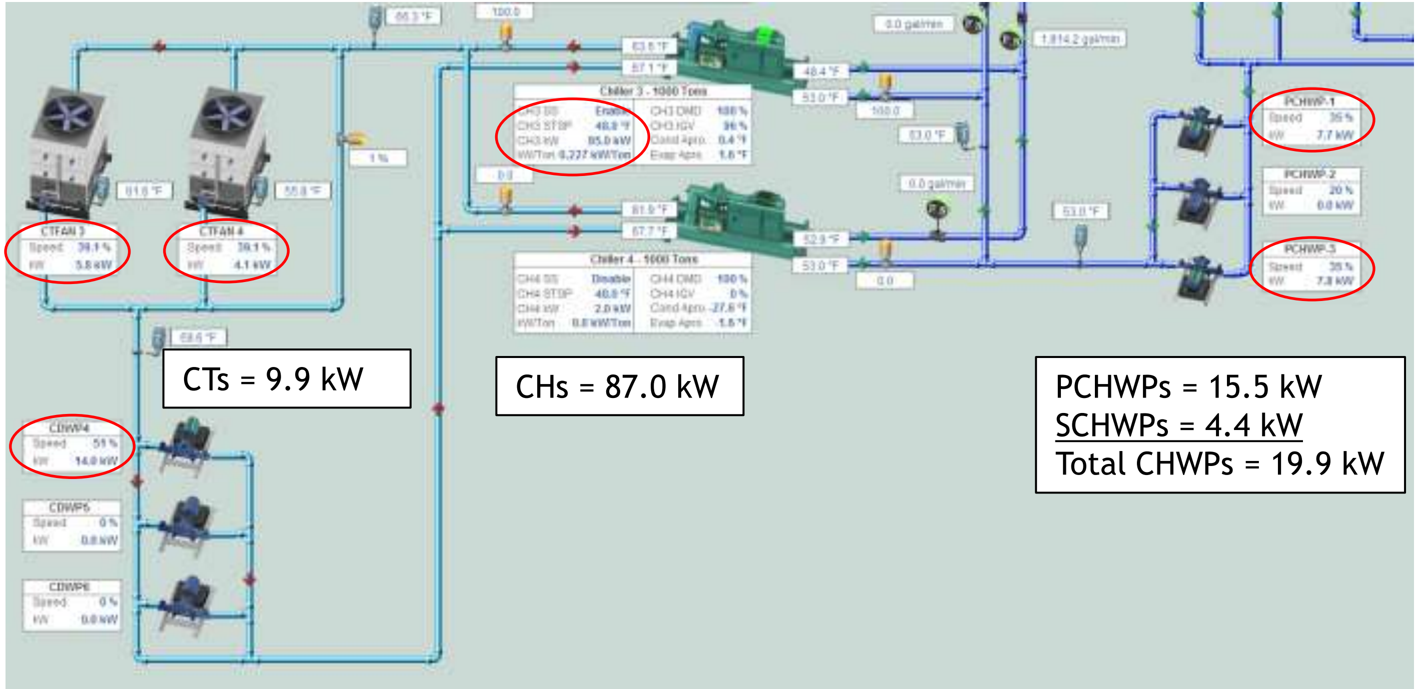


CHs = 82.0 kW

CHWPs = 56.8 kW

Total System Energy – All Variable Speed, Relational Control





CTs = 9.9 kW

CHs = 87.0 kW

PCHWPs = 15.5 kW
SCHWPs = 4.4 kW
Total CHWPs = 19.9 kW

CDWPs = 14.0 kW

Total System Energy Comparison

Mostly Variable Speed System		All Variable Speed Headered System
System = 215.9 kW		System = 130.8 kW
System = 380 Tons		System = 340 Tons
OAWB Temp = 39.3 ºF		OAWB Temp = 39.4 ºF
CTs - 0.007 kW/Ton	<	CTs - 0.029 kW/Ton
CDWPs - 0.196 kW/Ton	>	**CDWPs - 0.041 kW/Ton**
CHWPs - 0.149 kW/Ton	>	**CHWPs - 0.058 kW/Ton**
CHs - 0.211 kW/Ton	<	CHs - 0.255 kW/Ton
Total System – 0.563 kW/Ton		Total System – 0.384 kW/Ton

31.8% Improvement

Summary

- Optimization is a complete approach that begins with sound design, followed by intelligent controls, and ongoing upkeep
- All variable speed chillers, CHW pumps, CDW pumps, and cooling towers
- Reduce system design pressure drop as much as possible
- Eliminate mixing!!! (primary-only, no decoupled pumping)
- Plan for low delta T at part load conditions
- Optimization software using relational control, not PID control
- Continuous Measurement, Verification, and Monitoring; Persistent maintenance

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Thank you.

Engineered. Deployed. Proven.