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Trane Engineers Newsletter Live

Chilled-Water System Design Trends

Presenters: Susanna Hanson, Mike Patterson and Jeanne Harshaw (host)

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Agenda

Trane *Engineers Newsletter Live* Series

Chilled-Water System Design Trends

Abstract

Improved technology and controls for chilled-water systems over the past several years enable these types of systems to do more and save more. This ENL will review recent advancements in technology and trends due to these developments, system strategies that can take advantage of the latest technology and when various system strategies should be used. Consideration will be given to: variable primary, primary secondary, constant flow, series chillers, chilled water reset, pump pressure optimization, flow rates and turndown, heat exchanger types, and the components of air- and water-cooled systems.

Presenters:

Susanna Hanson, Trane Applications Engineer and Mike Patterson, Centrifugal Chiller Product Manager

After viewing attendees will be able to:

1. Summarize how the latest chiller, controls and refrigerant changes will affect chilled-water plant performance
2. Identify chiller plant configurations, and the benefits as well as common "gotchas" of each
3. Compare competing design and control strategies to reduce system energy use and lower energy costs
4. Summarize the opportunities various design and optimization strategies offer systems
5. Explain how and why variable flow systems have become more common – and the risks of misapplying them

Agenda

1) Why is there still anything to learn about design and control of chiller plants?
   a) New technology
   b) New refrigerants
   c) Advancements in controls
   d) Prevalence of variable speed compressors
2) Chilled water side configurations and optimizations
   a) Variable-Primary vs Primary-Secondary vs Constant flow
   b) Series chillers
   c) Chilled water reset versus pump pressure reset
   d) Variably low flow versus constantly low flow condenser pump
   e) Special considerations for variable speed chillers
   f) Special considerations for smaller chillers
3) Condenser side system configurations and controls
   a) Chiller-tower optimization
   b) Chiller-tower-condenser pump optimization
   c) Low flow condenser designs
   d) Air-cooled chiller component optimization
4) Technical Summary
   a) Chiller trends
   b) Chilled water controls
   c) Condenser water controls
   d) Air cooled controls

Ingersoll Rand

Presenter biographies

Susanna Hanson | applications engineer | Trane
Susanna is an applications engineer at Trane with over 15 years of experience with chilled-water systems and HVAC building load and energy analysis. Her primary responsibility is to aid system design engineers and Trane personnel in the proper design and application of HVAC systems. Her main areas of expertise include chilled-water systems and ASHRAE Standard 90.1. She is also a Certified Energy Manager.

She has authored several articles on chilled-water plant design, and is a member of ASHRAE SSPC 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. Susanna earned a bachelor's degree in industrial and systems engineering from the University of Florida, where she focused on building energy management and simulation.

Mike Patterson, LEED AP BD+C | product manager, centrifugal chillers | Trane

Mike is the product manager for Trane centrifugal chillers. Prior to joining the chiller group he developed expertise in the areas of energy modeling and ASHRAE Standard 90.1 in his role as a Marketing Engineer with Customer Direct Service (C.D.S.), the group responsible for the development of and training for HVAC design and analysis software. As an instructor with the Trane Graduate Training Program he was responsible for training Trane engineers and customers on energy fundamentals and energy modeling programs.

Prior to joining Trane, Mike spent 10 years as a pilot in the United States Air Force with over 2,300 hours in the KC-135 and T-37. Mike earned his bachelor's degree in Engineering Mechanics from the United States Air Force Academy. He also holds a Master's in Business Administration from Regis University.

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Learning objectives

- Summarize
- Identify
- Understand
- Summarize

Trane Chilled-Water Programs 2005-2015

- 2015 Variable Speed Drives on Compressors
- 2015 Coil Selection and Optimization
- 2014 Chilled Water Terminal Systems
- 2013 All Variable Speed Chilled Water Plants
- 2011 Upgrading Existing Chilled Water Systems
- 2010 Central Geothermal Systems
- 2009 Ice Storage Systems
- 2008 Small Chilled Water Systems (Part 2)
- 2007 Waterside Heat Recovery
- 2006 VSDs on System Components
- 2005 Cooling Towers and Condenser Water Systems
- 2004 Small Chilled Water Systems (Part 1)


AGENDA
• Trends in Chiller and Plant Design
• System Configurations
• Chilled-water side
• Condenser-water side
• Air-cooled condensers


Today's Presenters
Mike Patterson
Product Manager,
Centrifugal Chillers
Susanna Hanson
Applications
Engineer

Trends in Chiller Design

Why is there still anything to learn about design and control of chiller plants?

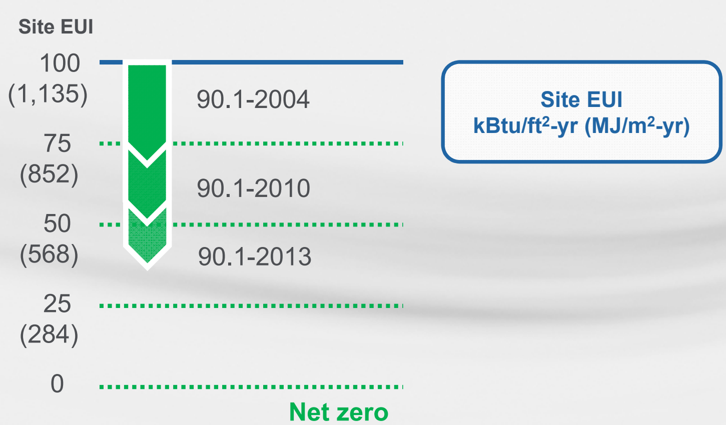
- Equipment design trends
- Control trends

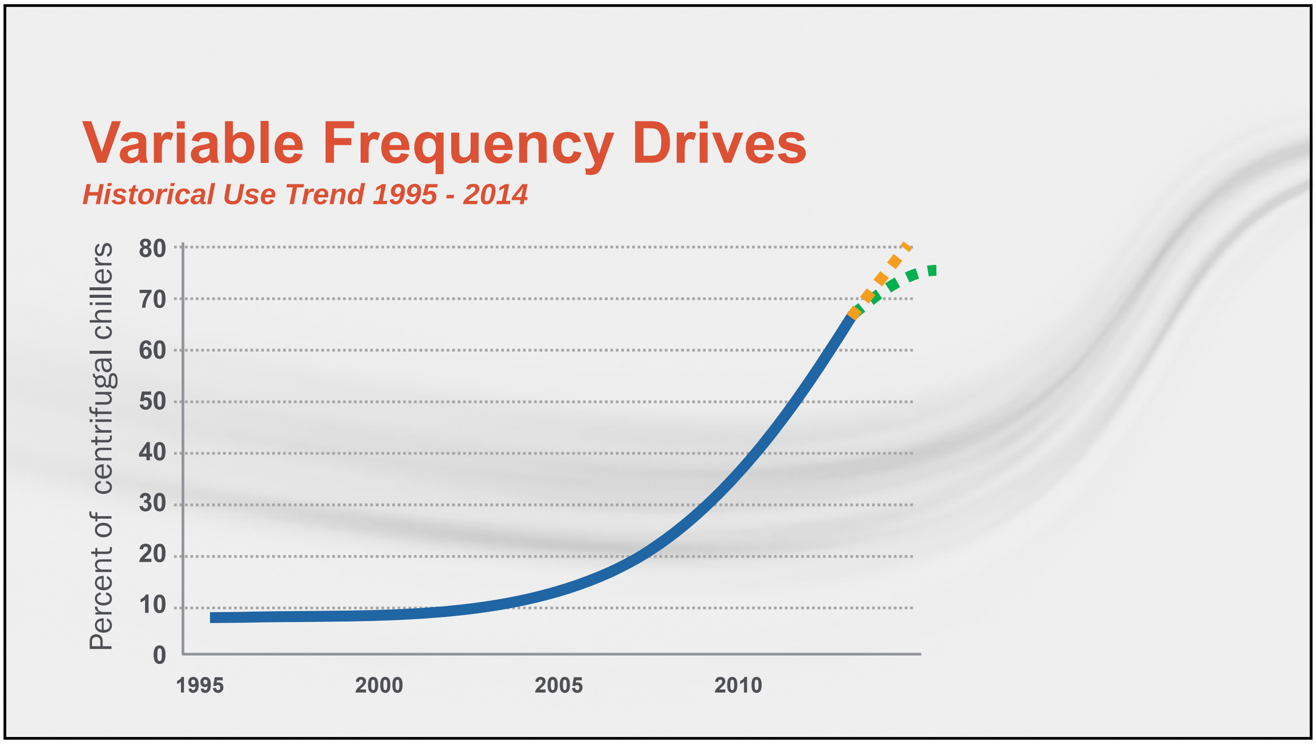
Equipment Design Trends

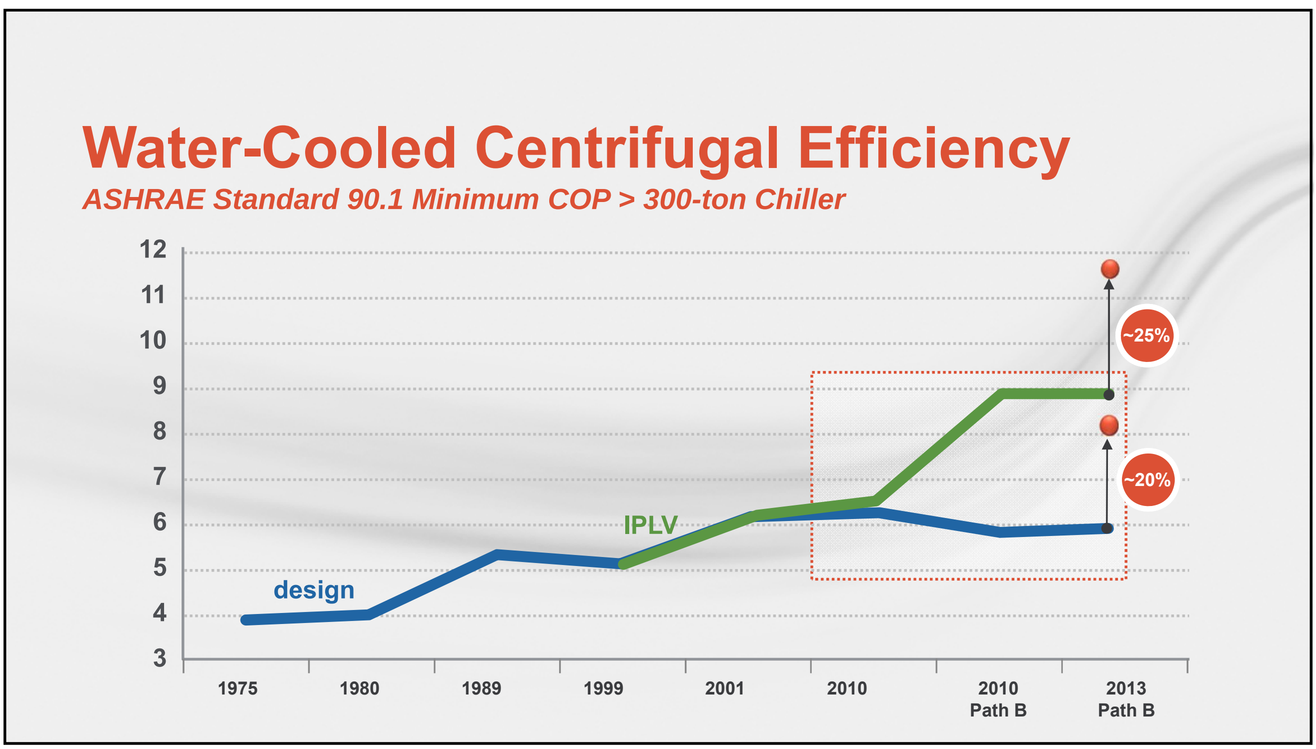
- Continued march towards greater efficiency
- Variable frequency drives
- Compressor design
- Application-driven enhancements
- Regulatory environment for refrigerants

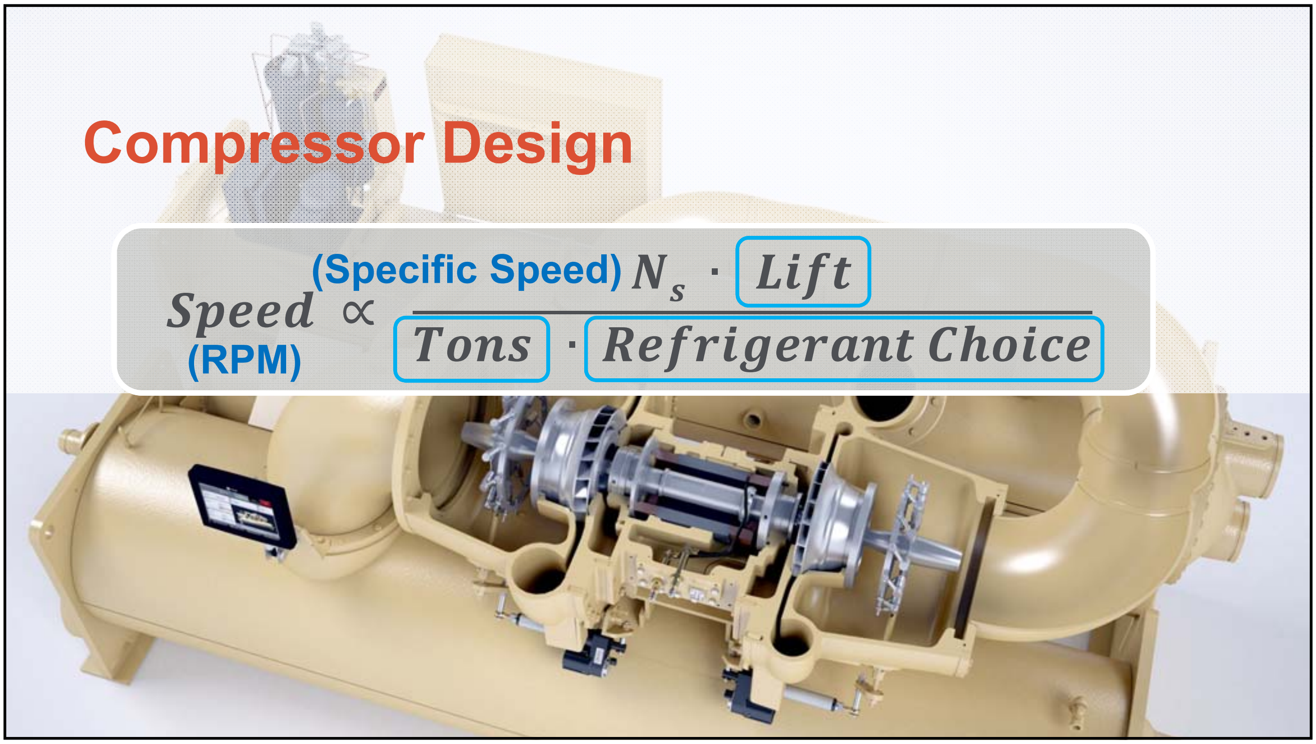
Continued March to Greater Efficiency

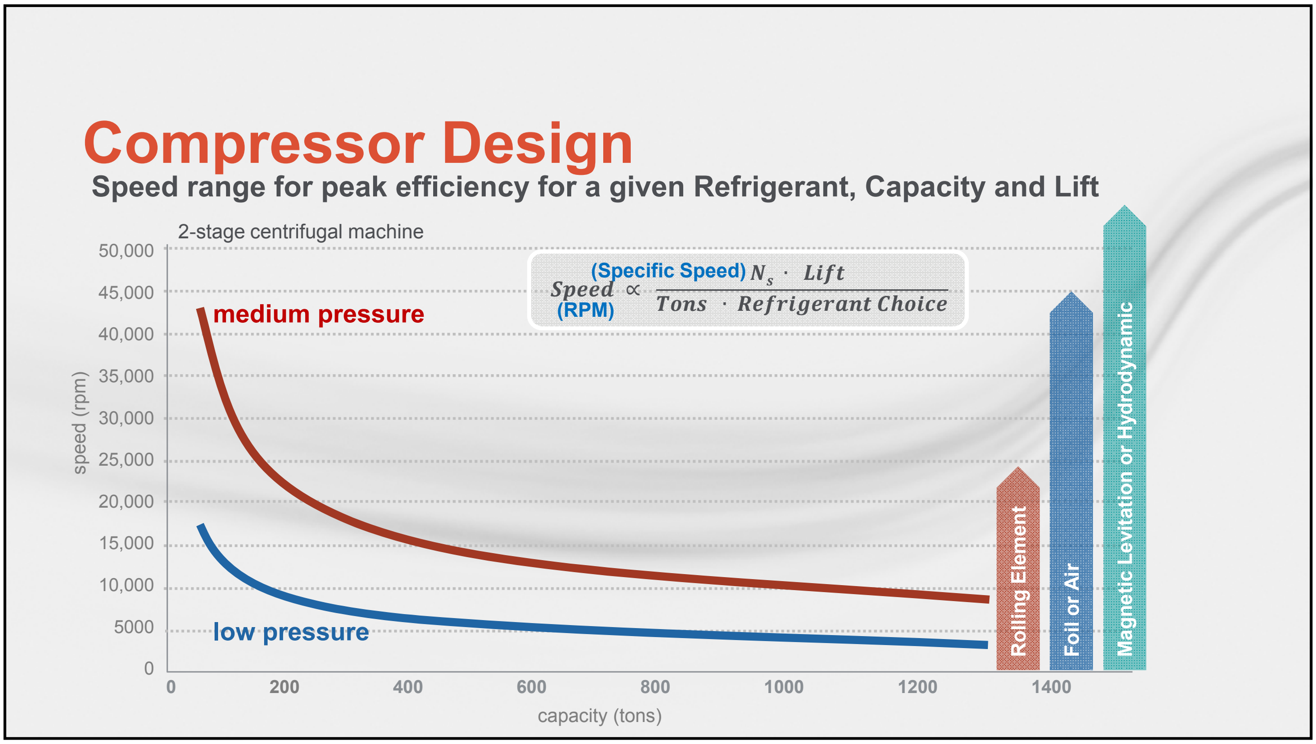
Commercial Buildings



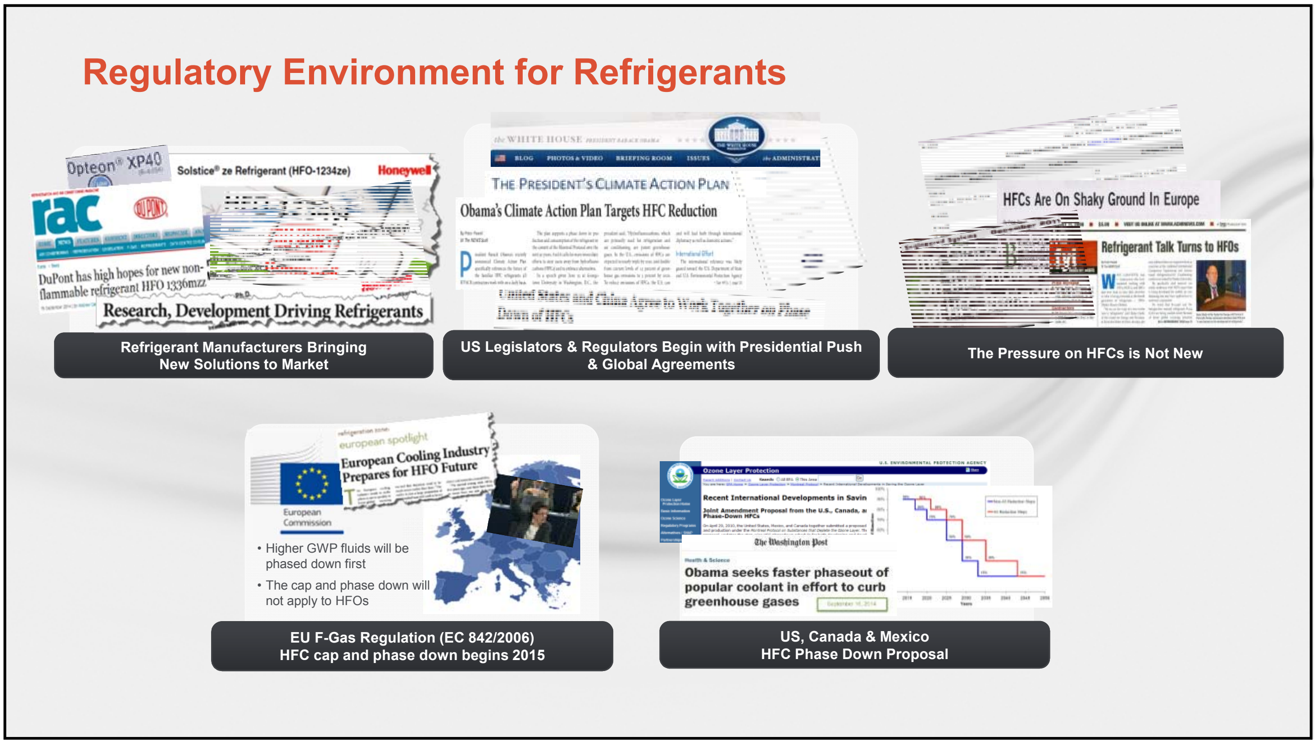

Variable Frequency Drives
Historical Use Trend 1995 - 2014
Percent of centrifugal chillers
80
70
60
50
40
30
20
10
0
1995
2000
2005
2010


Water-Cooled Centrifugal Efficiency
ASHRAE Standard 90.1 Minimum COP > 300-ton Chiller
12
11
10
9
8
7
6
5
4
3
design
IPLV
~25%
~20%
1975
1980
1989
1999
2001
2010
2010 Path B
2013 Path B


Compressor Design
(Specific Speed) N_s · Lift
Speed ∝ Tons · Refrigerant Choice
(RPM)


Compressor Design
Speed range for peak efficiency for a given Refrigerant, Capacity and Lift
2-stage centrifugal machine
(Specific Speed) N_s · Lift
Speed ∝ Tons · Refrigerant Choice
(RPM)
medium pressure
low pressure
speed (rpm)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5000
0
0
200
400
600
800
1000
1200
1400
capacity (tons)
Rolling Element
Foil or Air
Magnetic Levitation or Hydrodynamic


Application Driven
• Required 10ºF & 115ºF
• Easy maintenance
• Highly efficient
Result
• Packaged screw chiller (250 ton)
• Dry-cooler


Regulatory Environment for Refrigerants
Research, Development Driving Refrigerants
DuPont has high hopes for new non-flammable refrigerant HFO 1336mzz
Refrigerant Manufacturers Bringing New Solutions to Market
The President's Climate Action Plan
Obama's Climate Action Plan Targets HFC Reduction
United States and China Agree to Work Together on Phase Down of HFCs
US Legislators & Regulators Begin with Presidential Push & Global Agreements
HFCs Are On Shaky Ground In Europe
Refrigerant Talk Turns to HFOs
The Pressure on HFCs is Not New
European Cooling Industry Prepares for HFO Future
Higher GWP fluids will be phased down first
The cap and phase down will not apply to HFOs
EU F-Gas Regulation (EC 842/2006) HFC cap and phase down begins 2015
Obama seeks faster phaseout of popular coolant in effort to curb greenhouse gases
US, Canada & Mexico HFC Phase Down Proposal


Controls Trends
Open Protocols
Connectivity
Diagnostics
Cancel
My building
Edit
Username
Trane
Password
Remember Login
ON
Connect

Open Protocols

Total Building Automation Systems Market: Percent of Revenue by Protocol, North America, 2011

Protocol	Share (%)
BACnet	38.0 to 40.0
LonWorks	22.0 to 25.0
Proprietary	25.0 to 28.0
Others*	10.0 to 15.0

*Others include ModBus, TCP/IP, OPC, Web services, and wireless.
Source: Frost & Sullivan analysis.

BACnet International

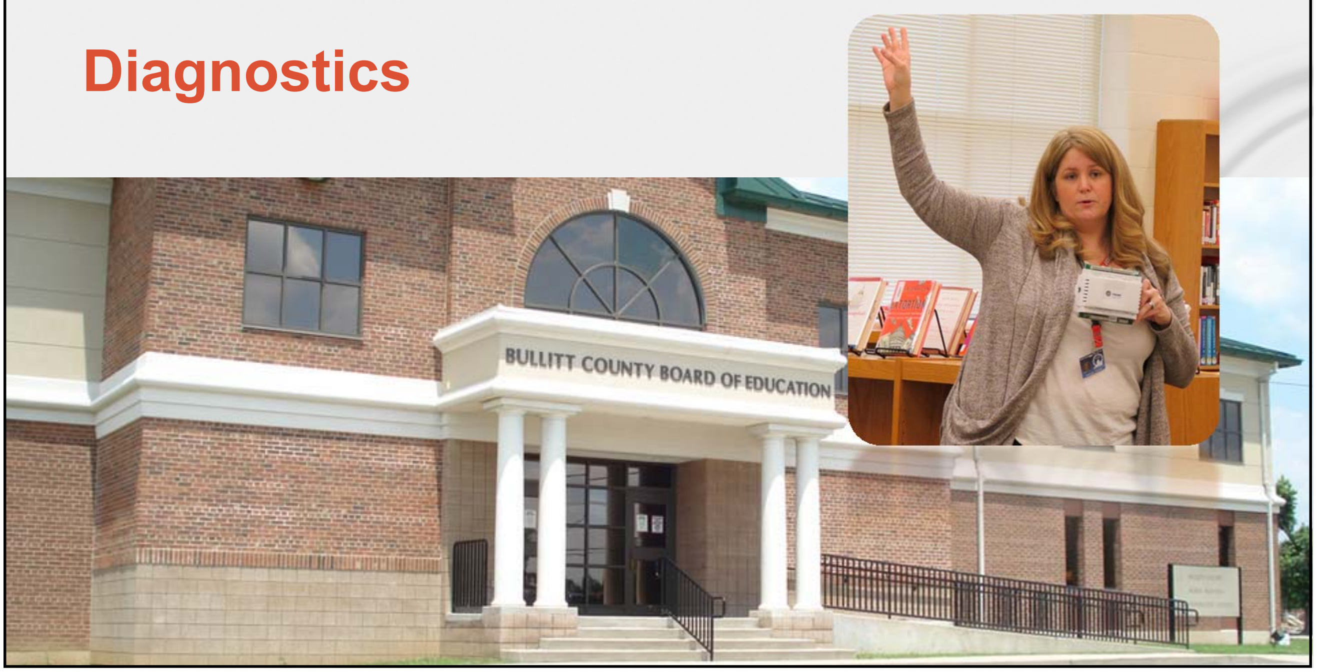
LonMark

Modbus

Connectivity

Diagnostics

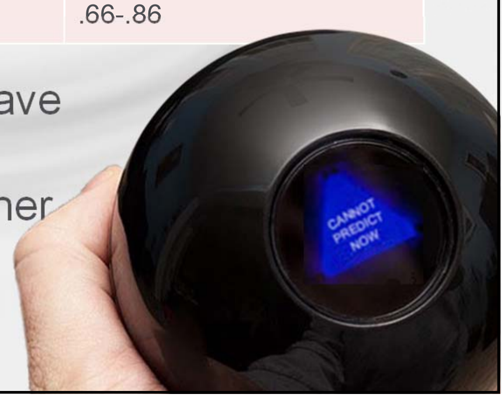
Diagnostics



Minimally-Compliant Chiller Plant

Conventional assumption for code range		0.75-0.90 kW/ton (annual)
90.1-2010	Chillers + towers + CW pumps	.68-.88
90.1-2013	Chillers + towers + CW pumps	.66-.86

It's easy to operate in what would have been deemed "excellent," just by meeting code – depending on weather and load profile.



AGENDA

- Trends in Chiller and Plant Design
- **System Configurations**
  - **Chilled-water side**
  - Condenser-water side
  - Air-cooled condensers

System Configurations

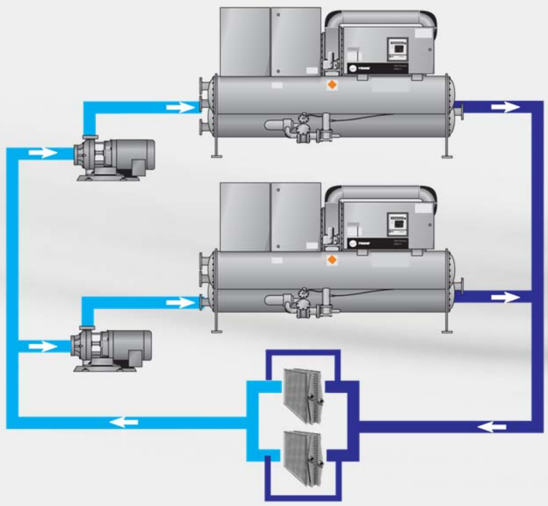
equipment capabilities, advantages, considerations

- Chilled-water side
- Condenser side

Chilled-Water Side

- Constant flow
- Primary-Secondary flow
- Variable-Primary flow
- Variable-primary, Variable-secondary

Constant Flow

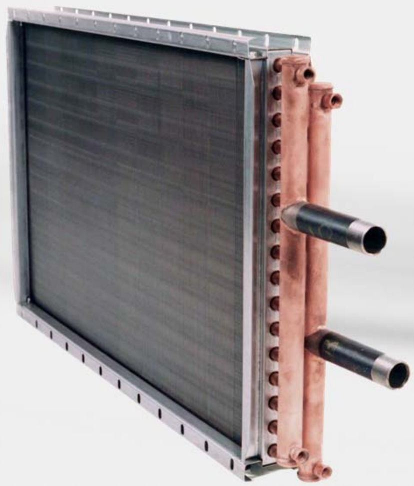


- Three-way valves
- Fan speed control
- ASHRAE Standard 90.1 allows
  - if total chilled water pump energy is ≤ 10 horsepower, or
  - if there are three or fewer control valves or
  - if designed at chiller minimum flow
- Apply VFD on pump instead of starter
  - don’t trim the pump impeller
  - eliminate temptation for triple duty valves

Constant Flow Design and Operation

- Proper coil selection
- Lower flow rates save pump energy, eliminate buffer tank
- Low loads CHW temp reset saves chiller energy

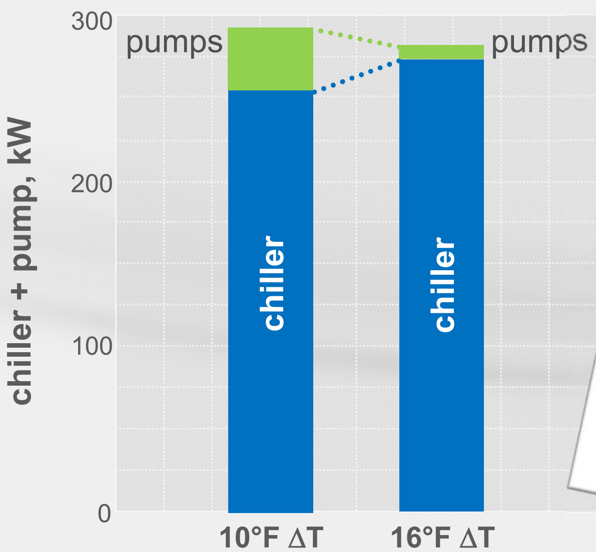
Coil Selections

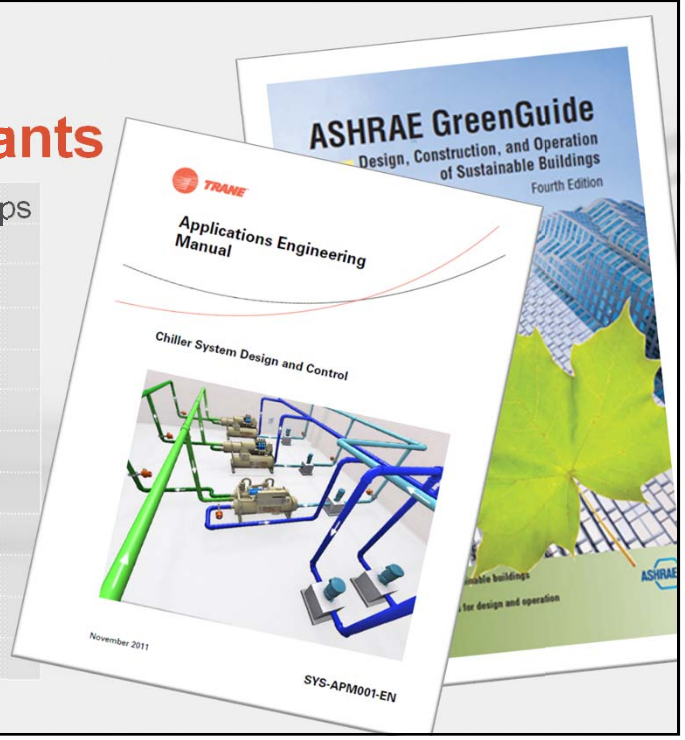


Select coils for

- Large delta T
- Moisture carryover avoidance
- Cost—footprint of the unit
- Size—casing and installation limitations
- Air pressure drop—fan energy and clean-ability indicator
- Split dehumidification—separating latent and sensible loads

Low-Flow Chiller Plants





Minimum Loop Time

- Gallons/gpm
- Varies by manufacturer
- Varies by chiller type
- Typically 1 to 5 minutes

Nominal Pipe Size (in)	Water Content per foot of pipe Volume (US Gal)
1/4	0.003
3/8	0.006
1/2	0.010
3/4	0.023
1	0.041
1 1/4	0.064
1 1/2	0.092
2	0.163
2 1/2	0.255
3	0.367
4	0.653
5	1.02
6	1.47
8	2.61
10	4.08
12	5.88
15	9.18

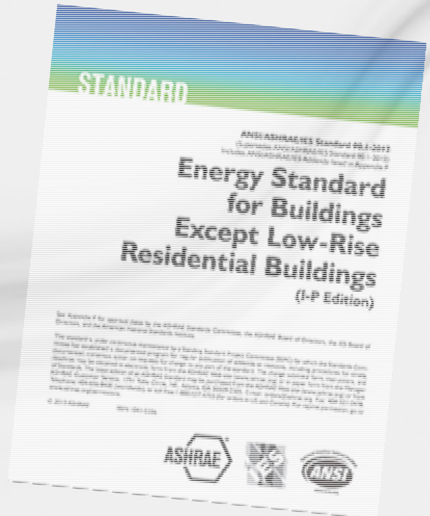
Loop Time: Volume/Flow Rate

1-chiller system, 54 tons

chilled water DT	pump power	pumping cost/ton	buffer tank size
10°F	2.3 hp	$10.56	105 gal
18°F	0.7 hp	$ 3.40	not required

Constant Flow Chiller Energy Reduction

- Chilled-water reset
  - Can save 1–2% of chiller energy per 1°F of reset
  - Based on temperature
    - Return chilled water
    - Outdoor air
    - Zone
- Required in 90.1-2013 addendum (published 2015)
  - or do pump pressure reset, based on critical valve (N/A for constant flow)



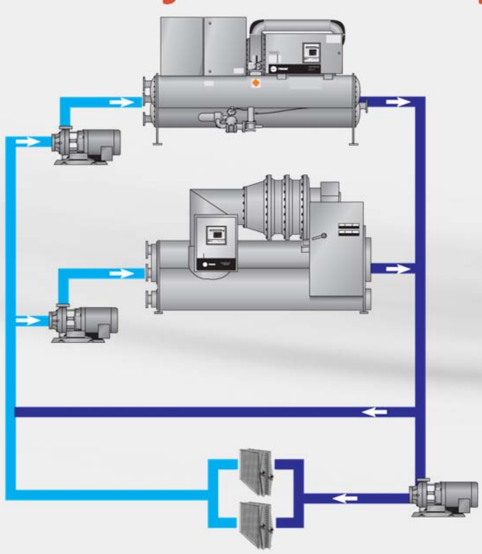
Going Too Far With CHW Reset

- Chilled water reset should be dynamic – look at zones, valves
- Worsens low delta T syndrome
- Reset downward as valves go nearly wide open
- Revert to design temperature to restore missing/lost system cooling capacity

Constant Flow Concerns

- Energy waste – pumped cooling that's not used
  - Go to chiller minimum flow at design and there is less pump energy waste, but still has chiller waste
- Starved coils when chillers in parallel
  - If you want/need full redundancy in chillers, only run the second chiller when the other is off
- Low delta T without low load shrinks chiller capacity

Primary-Secondary Flow (Decoupled)

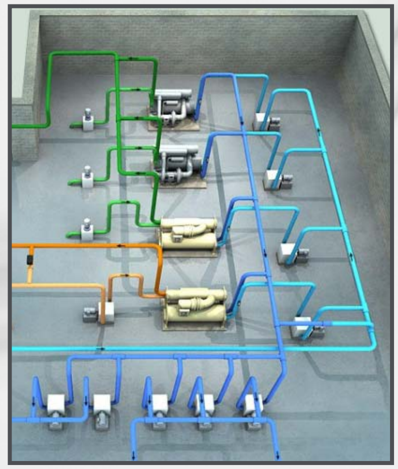


Subtract a chiller if decoupler flow > 1.2 times its flow

Add a chiller when bypass flow goes deficit: $Flow_{secondary} > Flow_{primary}$

Primary- Secondary Appeal

- Chillers of different vintages, sizes, expansion easy
- Simple, forgiving system control
- Less pumping energy than constant flow
- Better multiple chiller staging at part load than constant flow



Primary-Secondary Concerns

- More pumps, valves, pipes
- Low chiller delta T from bypassed water
- No method for overcoming system low delta T inside the chiller plant
- Flow control rather than chiller capacity control

Primary-Secondary Hiccups

- Bypass line is too short
- Chiller capacity waste

P-S Bypass Line Too Short

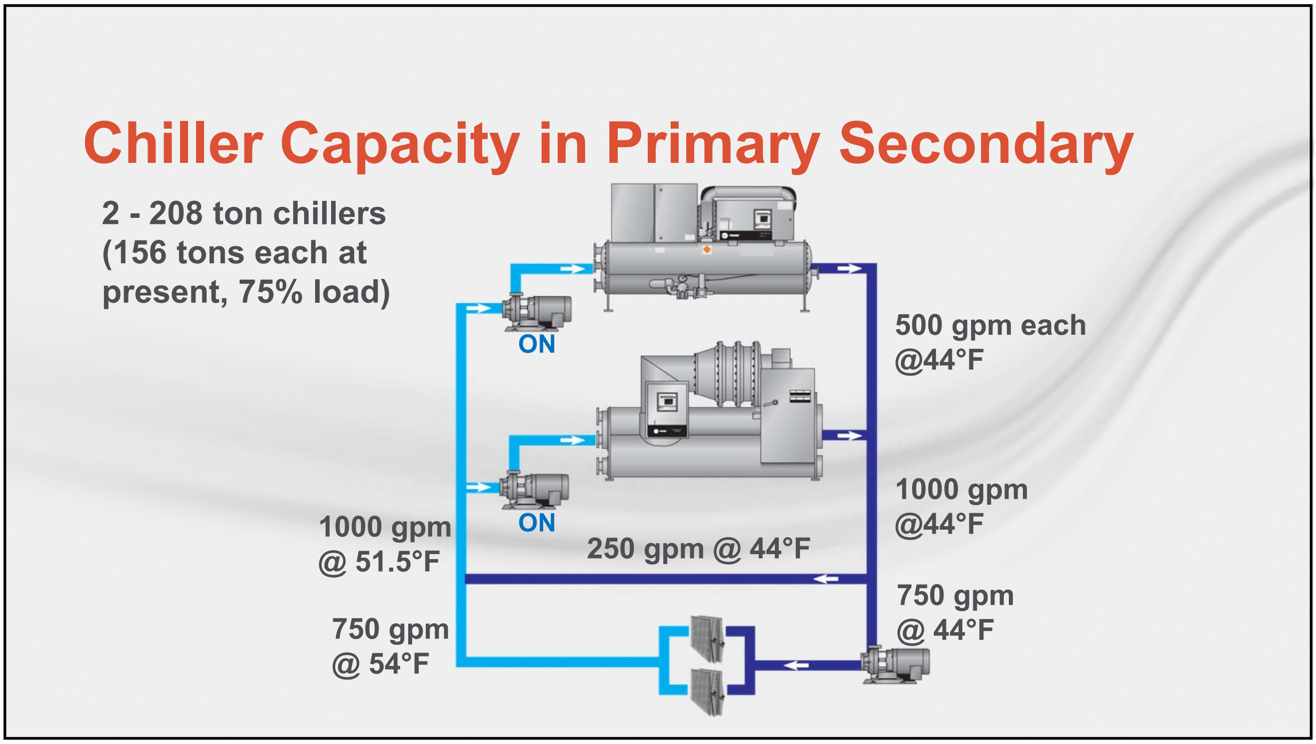
- Direction of flow in bypass is unstable
  - Can't be used to sequence chillers on
  - Lose control of supply water temperature as flow recirculates
- Surplus flow calculation is incorrect
  - Can't be used to sequence off a chiller

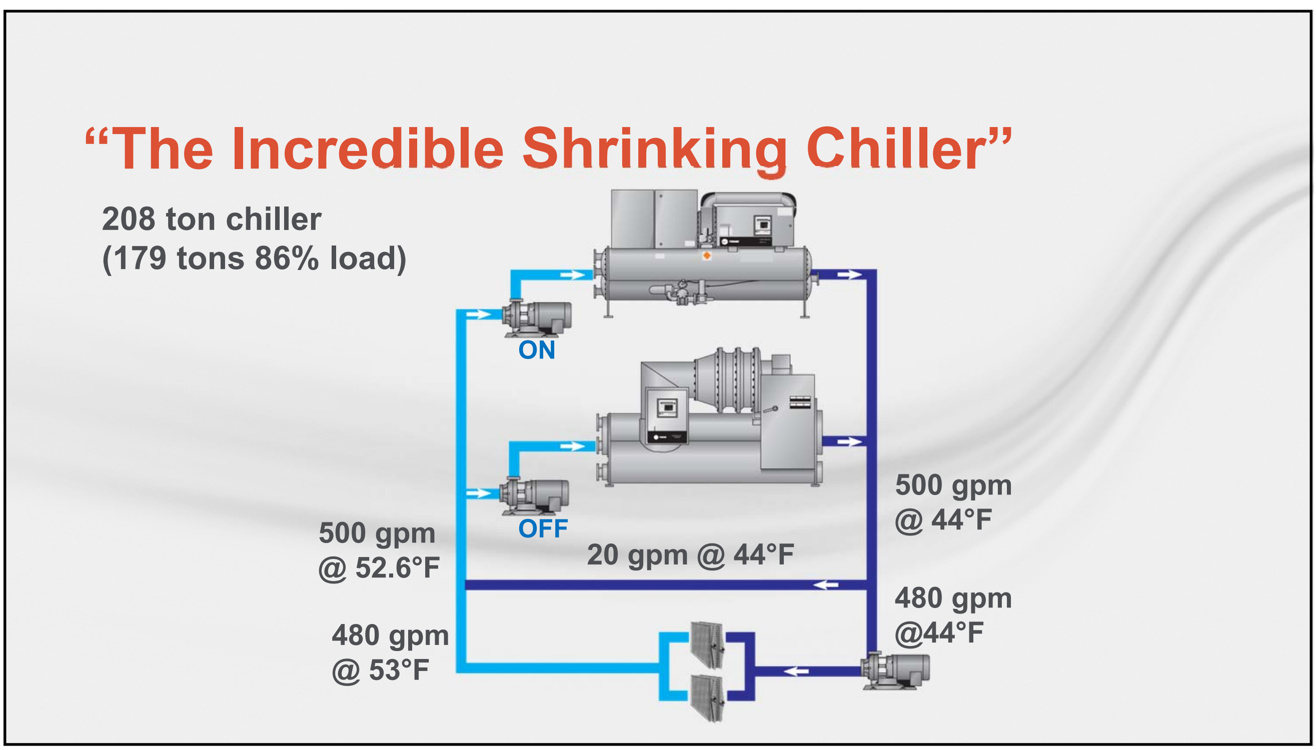
Correcting for Poor Bypass Line

- Aim for 10 pipe diameters
- Add elbows to straight pipe
- Add a tank
- Add a check valve?

Primary-Secondary Hiccups

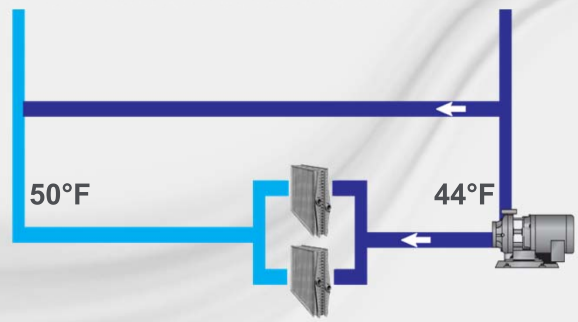
- Bypass line is too short
- Chiller capacity waste


Chiller Capacity in Primary Secondary
2 - 208 ton chillers
(156 tons each at
present, 75% load)
ON
500 gpm each
@44°F
1000 gpm
@44°F
1000 gpm
@ 51.5°F
ON
250 gpm @ 44°F
750 gpm
@ 44°F
750 gpm
@ 54°F


“The Incredible Shrinking Chiller”
208 ton chiller
(179 tons 86% load)
ON
500 gpm
@ 44°F
500 gpm
@ 52.6°F
OFF
20 gpm @ 44°F
480 gpm
@44°F
480 gpm
@ 53°F

Causes of Low Delta T

- Coil bypass
- Three way valves
- Valve leakage
- Temperature sensor calibration
- Inaccurate control or overrides
- Excess pressure
- Chilled-water reset



Minimizing the Effects of Low Delta T

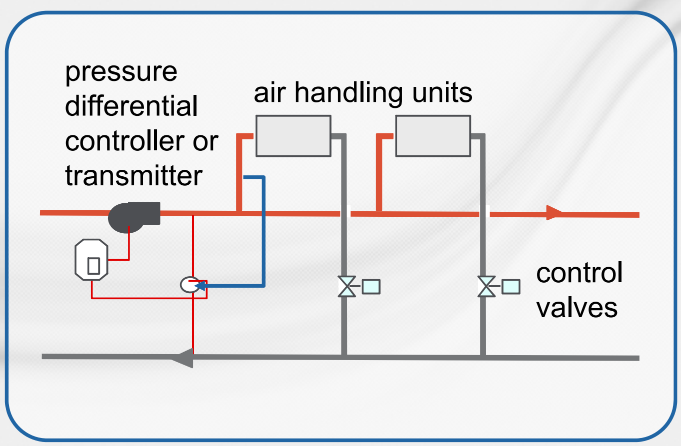
- Reduce surplus flow
  - Swing chiller or asymmetry in chiller sizes
  - More, smaller chillers
- Unequally load chillers
  - Move the decoupler to preferentially load one or more chillers
- Load based add sequence
  - Forces deficit flow – not advised
- Convert to variable primary flow
  - Increase chiller flow to meet the load
- Reset chilled water setpoint downwards
  - Release chilled water reset before adding chillers

Optimizing Primary-Secondary

- Pump pressure reset
- Chilled water reset

Pump Pressure Reset

- Remote DP or
- Critical valve based
  - Monitor critical AHU valve position
  - Reset distribution static pressure setpoint
  - Any valve > 90 percent open increase setpoint
  - All valves < 80 percent open decrease setpoint



Optimizing Primary-Secondary

- Pump pressure reset versus chilled water reset

% Load	Chiller plus pump power at 44	Chiller plus pump power at 48	VS Chiller plus pump power at 44	VS Chiller plus pump power at 48
75%	Flow too high at 48		Flow too high at 48	
50% at 65F ECWT	82.7 kW	89.9 kW **9% worse**	50.8 kW	48.6 kW **4% better**
25% at 65F ECWT	51.8 kW	51.6 kW **0.3% better**	30.2 kW	27.2 kW **10% better**
50% at 75F ECWT	89.3 kW	95.9 kW **7% worse**	66.6 kW	63.4 kW **5% better**
25% at 75F ECWT	56.5 kW	56.1 kW **0.7% better**	41.8 kW	38.1 kW **9% better**

Constant Speed Chillers — Variable Speed Chillers

Consider Resetting Chilled-Water Temp

- Flow is constant
- Healthy delta T
  - 15-20°F design delta T systems
- Variable speed chillers, at low load conditions (< 50% system load)
- Minimum flow has already been reached – variable primary
- Waterside free cooling is taking place

Optimizing Primary-Secondary

- Pump pressure reset versus chilled water reset

% Load	Chiller plus pump power at 44	Chiller plus pump power at 48	VS Chiller plus pump power at 44	VS Chiller plus pump power at 48
75%	Flow too high at 48		Flow too high at 48	
50% at 65F ECWT	82.7 kW	89.9 kW **9% worse**	50.8 kW	48.6 kW **4% better**
25% at 65F ECWT	51.8 kW	51.6 kW **0.3% better**	30.2 kW	27.2 kW **10% better**
50% at 75F ECWT	89.3 kW	95.9 kW **7% worse**	66.6 kW	63.4 kW **5% better**
25% at 75F ECWT	56.5 kW	56.1 kW **0.7% better**	41.8 kW	38.1 kW **9% better**

Constant Speed Chillers Variable Speed Chillers

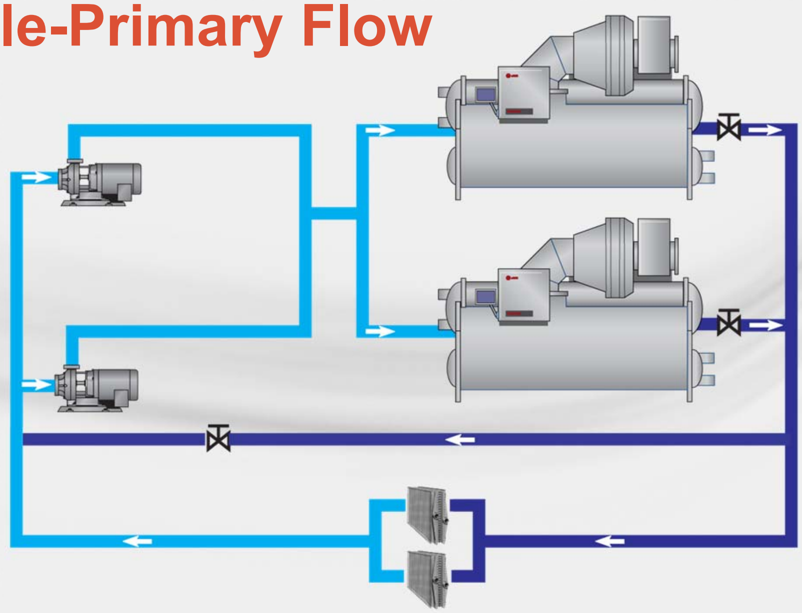
Caveats on Resetting Chilled Water Temp

- Beware of permanent overrides – watch valve positions and/or fan speed
- Beware of rogue zones defeating the logic if using critical valves

Special Considerations for VSD Chillers

- Sequencing may be different
  - Bring an additional chiller on sooner
  - Achieve balance within the chiller plant
  - Proper component sequencing
- Proper component capacity control
  - Minimum load may be higher
  - Watch for worse turndown in chillers with oversized compressors
- Backup power gen sizing implications
  - Generators get larger not smaller when you have a VSD instead of a starter
  - Active front end on VSD required, else 50% larger GenSet needed

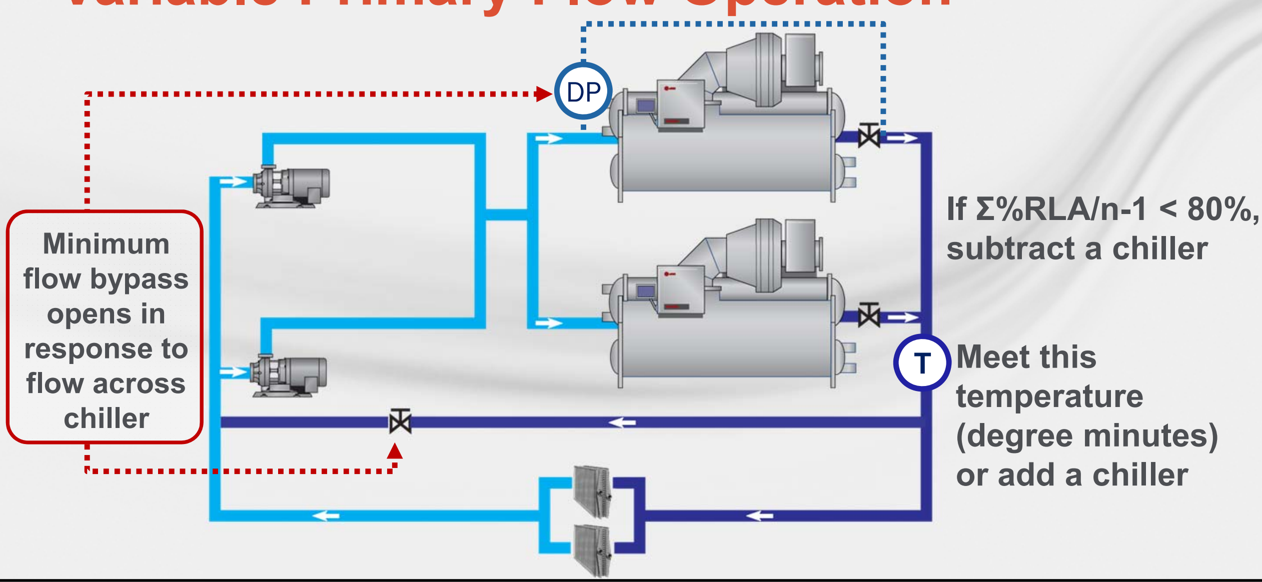
Variable-Primary Flow



Variable-Primary Flow

- Mid-1990s – present
- Benefits
  - Least energy use
  - Delta T remains high at most load conditions
  - Fewer chillers operating
  - Less or no flow in decoupler/bypass
- Disadvantages
  - More complex system controls
  - Chiller capabilities must be good enough
  - Asymmetry in chiller vintage and size difficult to accommodate

Variable Primary Flow Operation



Variable-Primary Flow Hiccups

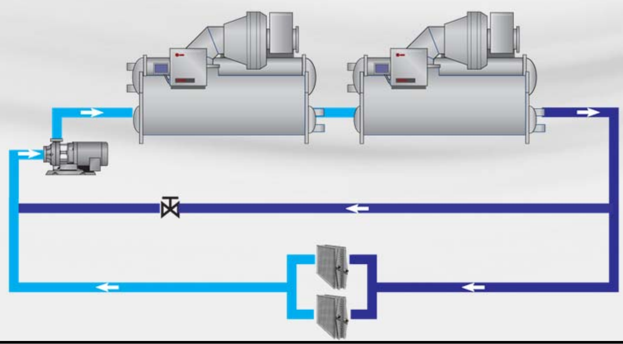
- More complex system controls
- Chiller capabilities must be good enough
- Asymmetry in chiller vintage and size difficult to accommodate
- Manual control is not good enough

Special Considerations for Small Systems

- If it has a buffer tank and only one chiller
  - Not much loop volume means not much pump energy
  - Design to lowest, constant flow and operate there
- Small systems usually use small chiller(s)
  - Plate heat exchanger limitations
  - Chiller flow turndown – more bypass needed in VPF
  - Often limited to 14 - 16°F delta T

Chillers in Series in VPF

- Double digit savings percentages on chiller energy
- Simplifies plant control in VPF
- Increase flow to load chillers in VPF systems
- Pressure drop increase in VPF reduced at most load points



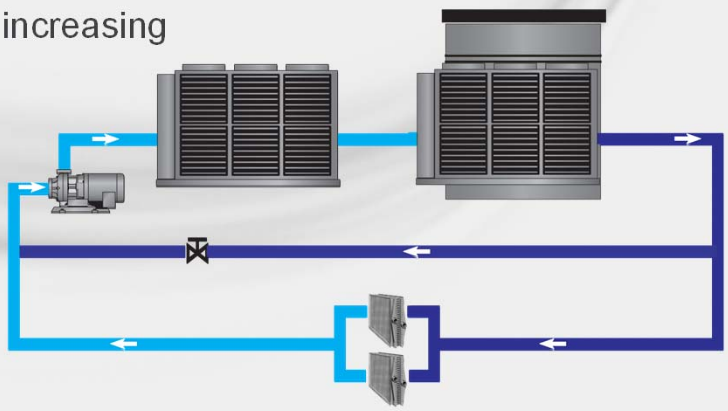
Pump Horsepower Comparison

110T parallel			
Load	Pump Flow	Sys PD	HP
100	310	70.0	5.5
90	279	60.5	4.3
80	262	52.4	3.5
70	262	45.6	3.0
60	262	39.7	2.6
50	155	36.0	1.4
40	132	30.6	1.0
30	132	27.5	0.9
20	132	25.2	0.8
10	132	23.8	0.8

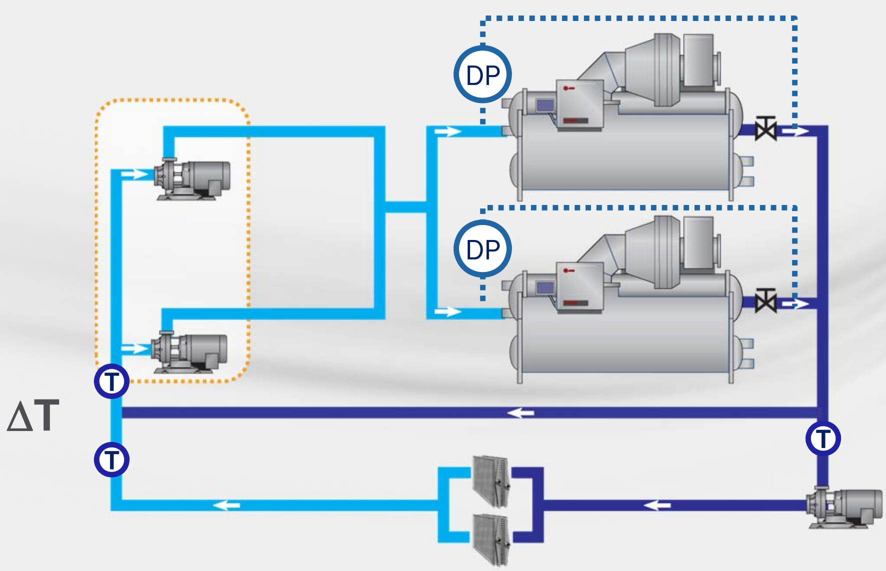
100T series			
Pump Flow	Sys PD	w/ CV opt.	HP w/opt
310	88.4	88.4	7.0
279	75.4	74.4	5.3
248	63.8	61.4	3.9
217	53.5	50.5	2.8
186	44.6	40.6	1.9
155	37.1	32.1	1.3
124	30.9	24.9	0.8
120	27.6	20.6	0.6
120	25.3	17.3	0.5
120	24.0	15.0	0.4

Special Considerations for Small Chillers

- Staged compression
  - Chillers in series fight each other
  - Consider ice storage for increasing plant delta T instead
- Preferentially loading downstream or equal loading requires math
- Thermal storage has ultimate flow turndown



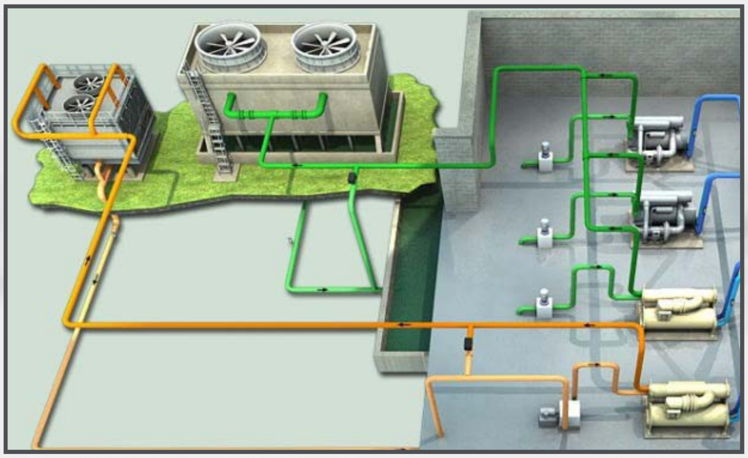
Variable Primary–Variable Secondary



Condenser Side

- Water-cooled condensing
- Air-cooled condensing

Water-Cooled Systems



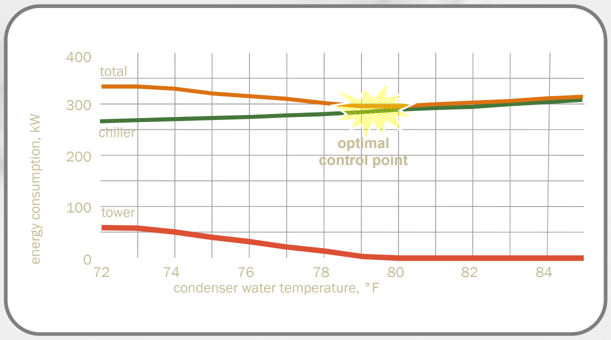
Water-Cooled Condensing Tips

- Objective: Colder water at a lower energy input
- Tower selection: 80 gpm/hp or better
- Tower selection: 12-15 degree range (2-2.5 gpm/ton)
  - Centrifugal chiller selection impact
- Tower selection: 5-10 degree approach, depending on load profile
- Tower flow turndown - run more towers at a time at low speed
  - 50-66% turndown (down to 1/3 flow if possible)
  - May not need control valves on the water flow per cell

2011 ENL: Upgrading Existing Plants

VSDs in Chilled Water Systems

- Chillers
  - VSDs may provide benefits for "low-lift" operation
  - For replacements compare "same price" VSD and premium efficiency chillers
- Tower fans
  - VSDs great for retrofits
  - Chiller-tower optimization



2013 ENL: All-Variable-Speed Chilled-Water Plants

Variable Condenser Water Flow

- Determine what savings, if any, are possible
  - Are pumps already low power?
  - Can reducing tower-fan speed achieve most of the savings?
- If you decide to reduce flow dynamically:
  - Find minimum condenser-water flow rate
  - Examine system at various loads and wet-bulbs, as well as chiller/tower combinations
    - Keep chiller out of surge
  - Document the sequence of operation
  - Help commission the system

Base System Assumptions

- Chicago office building with economizer
- ChW conditions – 56°F-42°F (1.7 gpm/ton)
- CW conditions – 85°F-94.4°F (3 gpm/ton)
  - Condenser pipes sized for 3 gpm/ton
- Cooling tower cell and pump per chiller
- 1, 2, or 3 constant speed chillers (0.567 kW/ton)
- Fixed tower setpoint (85°F)

System Alternatives

- Components
  - Tower fan VFD
  - Chillers VFDs – (0.585 kW/ton)
  - Condenser water pump VFD
- Design
  - 2 gpm/ton condenser water flow rate
- Controls
  - Near-optimal tower control
  - Near-optimal tower and condenser water pump control

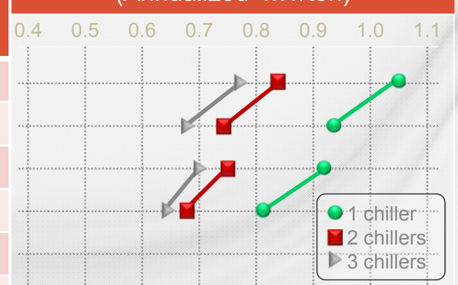
Annual Analysis – What Metric?

- Annual performance metric
  - kWh/ton-hour
  - Referred to as “annualized kW/ton”

Variable-Speed Tower Fan Optimized Control

Annualized System Performance

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	System Performance (Annualized kW/ton)
CS	1 Spd	3	CF	85°F	
CS	1 Spd	3	CF	Opt	
CS	VS	3	CF	85°F	
CS	VS	3	CF	**Opt**	

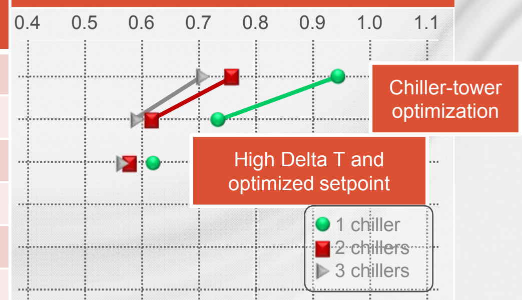


- Multiple chillers improve system efficiency
- Optimal tower fan control saves significant energy
- Variable speed tower fans save energy (fan laws)
- Tower fan control is absolutely critical to save energy when variable speed chillers are installed

2 gpm/ton Condenser Flow
Annualized System Performance

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
VS	VS	3	CF	85°F
VS	VS	3	CF	Opt
VS	VS	2	CF	Opt

System Performance (Annualized kW/ton)

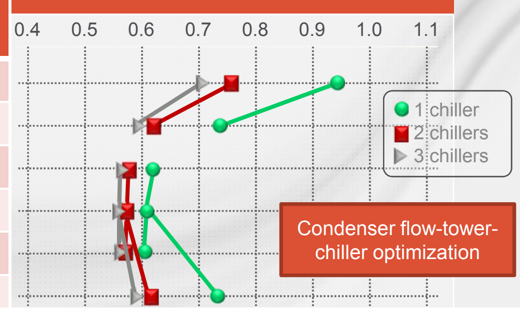


- Optimal tower setpoint control is very important.
- Condenser water design flow rate is important - and more important with fewer chillers.
- Condenser water "…life cycle costs were minimized at the largest of the three ΔTs analyzed, about 15ºF. This was true for office buildings and datacenters and for both single-stage centrifugal chillers and two-stage centrifugal chillers." Taylor (ASHRAE Journal December 2011)

Variable Condenser Flow
Annualized System Performance

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
VS	VS	3	CF	85°F
VS	VS	3	CF	Opt
VS	VS	2	CF	Opt
VS	VS	3	VF	Opt
VS	VS	2	VF	Opt
VS	VS	3	VF-disabled	Opt

System Performance (Annualized kW/ton)

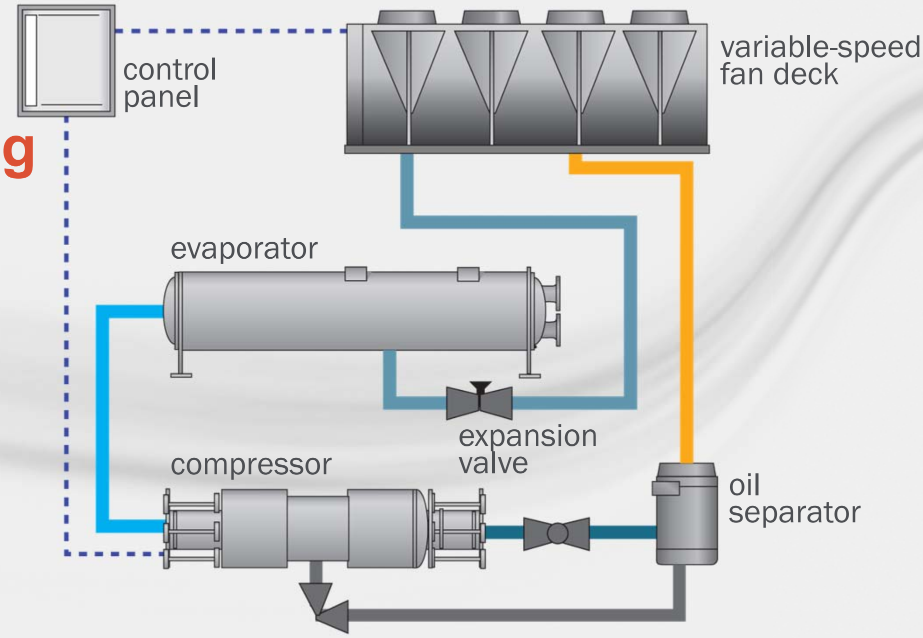


- Reduced, low flow all the time, at design – eliminates most of the energy waste.
- Variable, lower flow some of the time, does a little better with single chiller plants.
- A sub-optimal condenser water flow design **requires** optimized control and regresses to perform worse than low-flow, high delta-T constant flow if optimizations are disrupted.

Summary

- Operating multiple chillers improves system efficiency
- Optimal variable speed tower fan control saves significant energy
  - and critical for systems with variable speed drive chillers
- Proper (less than 3.0 gpm/ton) condenser water flow rate is very important
- Variable condenser water flow can save energy
  - Perhaps not in a hot, humid climate
  - Requires controls to remain active and properly operated

Air-Cooled Condensing

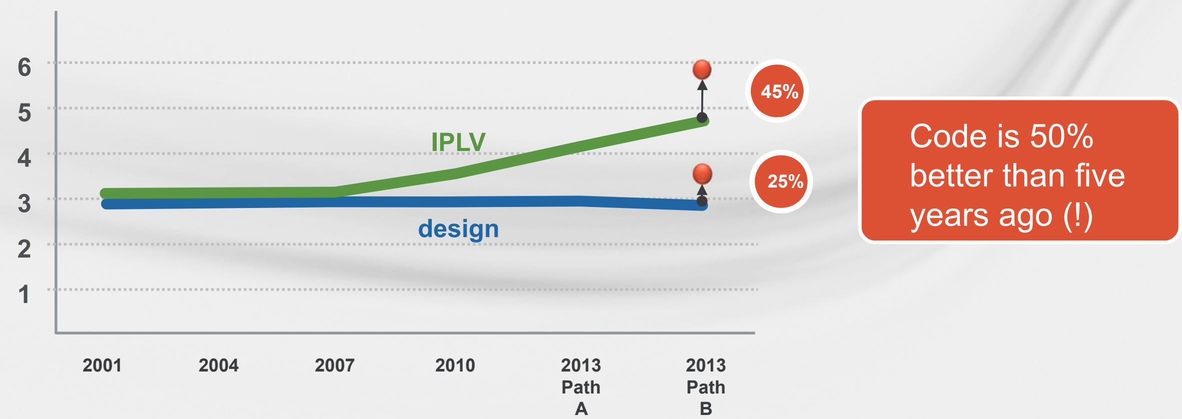


Air-Cooled Condensing Trends

- Water is not a trivial resource
- Easier to maintain
- More efficient than it used to be

Air-Cooled Chiller Efficiency

ASHRAE Standard 90.1 Minimum COP > 300-ton Chiller

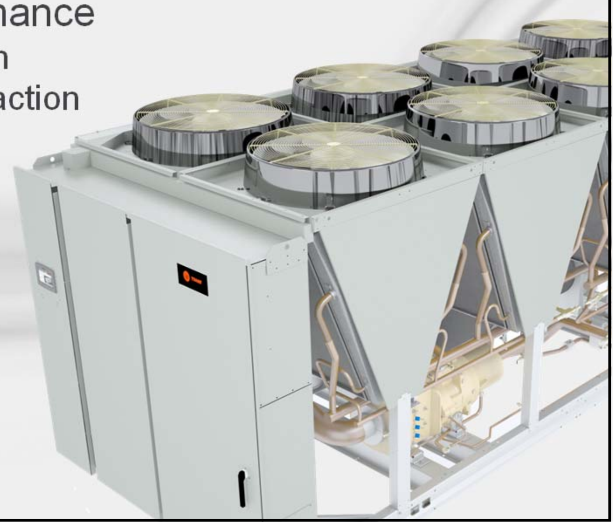


Air-Cooled Condensing Trends

- Water is not a trivial resource
- Easier to maintain
- More efficient than it used to be
- Optimizations built into air cooled chiller packages
  - All variable speed chilled water plants

Air-Cooled Chiller Trends

- Improved heat exchanger performance
  - Reduced refrigerant charge per ton
  - Less corrosion from galvanic interaction
- Variable speed condenser fans
  - Improved efficiency and sound
- Variable speed compressors
  - Improved efficiency and sound
- Chillers as heaters
  - Desuperheating due to refrigerant
  - Heat pump (reversible chillers)



Air-Cooled Chiller Optimizations

- Fan speed and compressor discharge pressure optimization
  - Essentially same as chiller-tower optimization without the pesky condenser water pump
  - It’s in there…part load performance tables show the benefits of having variable speed on fans and compressors
- Ice storage
  - Takes advantage of additional reduction in OAT at night
  - Air-cooled chiller plant energy performance equals optimized water-cooled performance

200 ton myPLV – Air Cooled

Miami, FL

Conditions	Base	Option 1
EER @ 25% load, ODDB = 74.7° F	14.5	18.9
EER @ 50% load, ODDB = 78.6° F	14.1	16.2
EER @ 75% load, ODDB = 84.0° F	12.0	13.0
EER @ 94% load, ODDB = 87.8° F	10.9	11.3
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	13.3	15.3
Annual kW-hrs	487,746	428,929
Annual Consumption Charge	$ 48,775	$ 42,893
Annual Demand Charge (Est)	$ 20,768	$ 20,360
Total Annual Energy Charge	$ 69,542	$ 63,253
Simple Payback (years)		1.3 Years

Montgomery, AL

Conditions	Base	Option 1
EER @ 25% load, ODDB = 71.2° F	15.0	19.5
EER @ 50% load, ODDB = 80.9° F	13.7	15.8
EER @ 75% load, ODDB = 86.8° F	11.6	12.5
EER @ 94% load, ODDB = 90.9° F	10.4	10.8
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	13.3	15.7
Annual kW-hrs	255,374	221,404
Annual Consumption Charge	$ 25,537	$ 22,140
Annual Demand Charge (Est)	$ 16,840	$ 16,509
Total Annual Energy Charge	$ 42,377	$ 38,650
Simple Payback (years)		2.1 Years

Montreal, Quebec

Conditions	Base	Option 1
EER @ 25% load, ODDB = 66.2° F	15.9	20.7
EER @ 50% load, ODDB = 74.6° F	14.8	17.0
EER @ 75% load, ODDB = 80.7° F	12.6	13.6
EER @ 94% load, ODDB = 86.8° F	11.0	11.4
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	14.7	17.7
Annual kW-hrs	118,496	100,440
Annual Consumption Charge	$ 11,850	$ 10,044
Annual Demand Charge (Est)	$ 17,098	$ 16,763
Total Annual Energy Charge	$ 28,948	$ 26,807
Simple Payback (years)		3.7 Years

Philadelphia, PA

Conditions	Base	Option 1
EER @ 25% load, ODDB = 71.7° F	15.0	19.5
EER @ 50% load, ODDB = 79.2° F	14.0	16.1
EER @ 75% load, ODDB = 85.9° F	11.7	12.6
EER @ 94% load, ODDB = 90.7° F	10.4	10.8
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	13.3	15.5
Annual kW-hrs	368,498	323,018
Annual Consumption Charge	$ 36,850	$ 32,302
Annual Demand Charge (Est)	$ 18,627	$ 18,262
Total Annual Energy Charge	$ 55,477	$ 50,564
Simple Payback (years)		1.6 Years

Phoenix, AZ

Conditions	Base	Option 1
EER @ 25% load, ODDB = 77.2° F	14.1	18.3
EER @ 50% load, ODDB = 89.3° F	12.4	14.3
EER @ 75% load, ODDB = 98.9° F	10.3	11.1
EER @ 94% load, ODDB = 105.3° F	9.8	10.2
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	12.4	14.9
Annual kW-hrs	363,435	311,351
Annual Consumption Charge	$ 36,343	$ 31,135
Annual Demand Charge (Est)	$ 17,299	$ 16,960
Total Annual Energy Charge	$ 53,643	$ 48,095
Simple Payback (years)		1.4 Years

Seattle, WA

Conditions	Base	Option 1
EER @ 25% load, ODDB = 67.4° F	15.6	20.3
EER @ 50% load, ODDB = 77.0° F	14.4	16.6
EER @ 75% load, ODDB = 83.4° F	12.1	13.1
EER @ 94% load, ODDB = 90.1° F	10.5	10.9
EER @ 100% load, ODDB = 95.0° F	9.6	9.8
Price	[illegible]	[illegible]
myPLV™ (EER)	14.5	17.7
Annual kW-hrs	99,179	83,078
Annual Consumption Charge	$ 9,918	$ 8,308
Annual Demand Charge (Est)	$ 16,382	$ 16,061
Total Annual Energy Charge	$ 26,300	$ 24,368
Simple Payback (years)		4.1 Years

Variable Speed Air-Cooled Payback Years

City	Simple Payback (years)
Akron/Canton, OH	3.3
Denver, CO	3.1
Dallas, TX	2.1
Greensboro, NC	2.8
Kansas City, KS	2.8
Los Angeles, CA	2.0
Miami, FL	1.3
Montgomery, AL	2.1
Montreal, Quebec	3.7
Philadelphia, PA	1.6
Phoenix, AZ	1.4
Seattle, WA	4.1

Takeaways – Chiller Trends

- Expect chillers to continue to improve
  - We are not at max tech!
- Lift, tonnage, & refrigerant drive compressor design
- Refrigerant is changing (again!)
- Open controls are here: BACnet is leading the way
- Data and analytics are key to realizing the expected long-term energy savings

Takeaways – Chilled Water Side

- Low flow all the time is (still) a great idea
- Chilled water reset is great for constant flow
- Be careful when applying it to variable flow systems (including decoupled systems)
  - Consider chilled water reset first if the chillers are variable speed
  - Do pump pressure reset first for constant speed chillers
  - Watch for rogue zones that are never satisfied

Takeaways – Condenser Water Side

- Chiller-tower optimization always makes sense
- Low flow all the time is a great idea
- Dynamically varying condenser flow can be done, if necessary
- Air-cooled systems are simpler, efficient and quiet today

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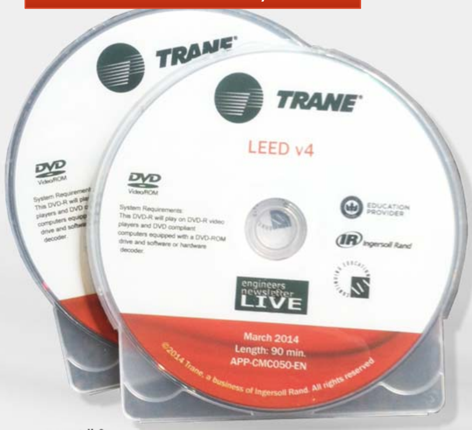

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Chilled Water System Design Trends

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Industry Resources

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *ANSI/ASHRAE/IESNA Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings*. Available from www.ashrae.org/bookstore

Industry Articles

ASHRAE. 2006. ASHRAE GreenGuide: The Design, Construction, and Operation of Sustainable Buildings. 2nd ed.

Bahnfleth and Peyer, Comparative analysis of variable and constant primary flow chilled-water-plant performance," HPAC Engineering, 41-50, April 2001

Baker, M., D. Roe, M. Schwedler. 2006. "Prescription for chiller plants." ASHRAE Journal 48(6):H4 – H10.

Braun, J.E., G.T. Diderrich. 1990. "Near optimal control of cooling towers for chilled water systems." ASHRAE Transactions 96(2) pp. 806–813.

Crowther, H., and J. Furlong., "Optimizing Chillers & Towers," ASHRAE Journal 46(7), July 2004, pp 34-40.

Frost & Sullivan. *Analysis of the North American Building Automation Systems Market Full-building Integration and Energy Savings are Shaping the Market*. September 2012

Kreutzmann , J. "Campus Cooling: Retrofitting Systems," HPAC Engineering, July 2002

Lindhorst, P. 1998. "Motor and drive compatibility: A Must." Electrical Construction & Maintenance. http://ecmweb.com/mag/ electric_motor_drive_compatibility/

LBNL Study 56637, 2004. The Cost-Effectiveness of Commercial Buildings Commissioning, Lawrence Berkeley National Laboratory, Portland Energy Conservation Inc., Energy Systems Laboratory, Texas A&M University, sponsored by the U.S. Department of Energy: http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html

Schwedler, M. 1998. "Take it to the Limit…Or Just Halfway?" ASHRAE Journal 40(7) pp. 32–39.
Cascia, M. 2000. "Implementation of a near-optimal global set point control method in a DDC controller." ASHRAE Transactions 106(1), pp. 249–263.

Schwedler, M., and B. Bradley. 2001. "Uncover the hidden assets in your condenser water system." HPAC Engineering:68–75.

Schwedler, M., 2009. "Upgrading Existing Chilled-Water Systems," ASHRAE Journal 51(11), pp. 16-32.

Taylor, S., 2009. "Primary-Only vs. Primary-Secondary Variable Flow Systems," ASHRAE Journal 44(2), pp. 25-29

Taylor, S. "Optimizing Design & Control Of Chilled Water Plants." ASHRAE Journal (December 2011): 22-34. Available at www.ashrae.org

Waltz, J., "Don't Ignore Variable Flow," Contracting Business, July 1997

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Trane *Engineers Newsletters*

Available to download from <www.trane.com/engineersnewsletter>

Guckelberger, D., "ASHRAE Standard 15 applied to Packaged, Split and VRF Systems." *Engineers Newsletter* 37-1 (2008).

Guckelberger, D., "The tortuous path from industry standard to local code." *Engineers Newsletter* 28-2 (1999).

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"ASHRAE Standard 90.1-2010," Engi**neers Newsletter Live program,** APP-CMC040-EN (DVD), Trane, 2010.

"VSDs and Their Effect On System Components," Engineers Newsletter Live program, APP-CMC025-EN (DVD), Trane, 2006.

"Ice Storage Design and Application," Engineers Newsletter Live program, APP-CMC036-EN (DVD/on-demand), Trane, 2009.

"Central Geothermal Systems Design and Application," Engineers Newsletter Live program, APP-CMC039-EN (DVD/on-demand), Trane, 2010.

"Upgrading Existing Chilled-Water Systems," Engineers Newsletter Live broadcast, APP-CMC041-EN (DVD/on-demand), Trane, 2011.

"All-Variable-Speed Chilled-Water Plants," Engineers Newsletter Live program, APP-CMC049-EN (DVD/on-demand), Trane, 2013.

"Chilled-Water Terminal Systems," Engineers Newsletter Live program, APP-CMC052-EN (DVD/on-demand), Trane, 2014.

"Variable-Speed Drives On Compressors," Engineers Newsletter Live program, APP-CMC053-EN (DVD/on-demand), Trane, 2015.

"Coil Selection and Optimization," Engineers Newsletter Live program, APP-CMC054-EN (DVD/on-demand), Trane, 2015.

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Trane Publications

Available to purchase from www.trane.com/bookstore

Hanson, S., M. Schwedler."Chiller System Design and Control," SYS-APM001-EN, Trane, 2009 http://www.trane.com/COMMERCIAL/DNA/View.aspx?i=468

Available to purchase from trane.com/engineersnewsletter

Hanson, S. "ASHRAE Standard 90.1-2010: Updates to Mechanical Systems" Engineers Newsletter 39-3, Trane, 2010.

Schwedler, M. and B. Bradley. 2002. "Variable-Primary-Flow Systems Revisited." Engineers Newsletter 30(4). Trane.

Schwedler, M. and B. Bradley. 1995. "Tower water temperature—control it how???" Engineers Newsletter 24(1). Trane.

Analysis Software

Trane Air-Conditioning and Economics (TRACE™ 700). Available at www.trane.com/TRACE

TRACE 700 Trane Chiller Plant Analyzer. Available at www.trane.com/ChillerPlantAnalyzer

Trane myPLV™, Chiller economic comparison tool.
Available at www.trane.com/myPLV

TRACE™ 700 User's Manual, Trane, CDS-PRM001-EN, 2008.

CoolTools™ Chilled Water Plant Design, Hydeman, M., K. Gillespie, and R. Kammerud. 2000. PG&E's CoolTools program is a toolkit to improve evaluation and operation of chilled-water plants. Available at http://www.pge.com/mybusiness/edusafety/training/pec/toolbox/hvac/

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Chilled-Water System Design Trends

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Rate the length of the program.	Appropriate	Too long	Too short
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Are there any other events/topics you would like Trane to offer to provide additional knowledge of their products and services?

Additional questions or comments:

Trane *Engineers Newsletter LIVE: Chilled-Water System Design Trends*
APP-CMC056-EN QUIZ

1. The minimum code for chillers today is at "Max Tech" – there is no more room for improvement with known, available technologies.

   True
   False

2. Low, constant flow systems at or near minimum chiller flow can be an cost- and energy-efficient way to design a small system with one chiller operating at a time, series chillers, or with a chiller in series with thermal storage.

   True.
   False.

3. Three methods of raising chiller delta T in a primary-secondary system are:
   a. Discovering and correcting problems in valve operation
   b. Reducing the amount of surplus flow in the decoupler bypass
   c. Lowering the chiller leaving water temperature (releasing chilled water reset)
   d. Installing a control valve in the decoupler pipe

4. Variable-primary is a good conversion for existing chiller plants with primary-secondary configuration because it reduces installed costs.

   True
   False

5. Air-cooled systems are lagging further and further behind water-cooled systems in efficiency.

   True
   False