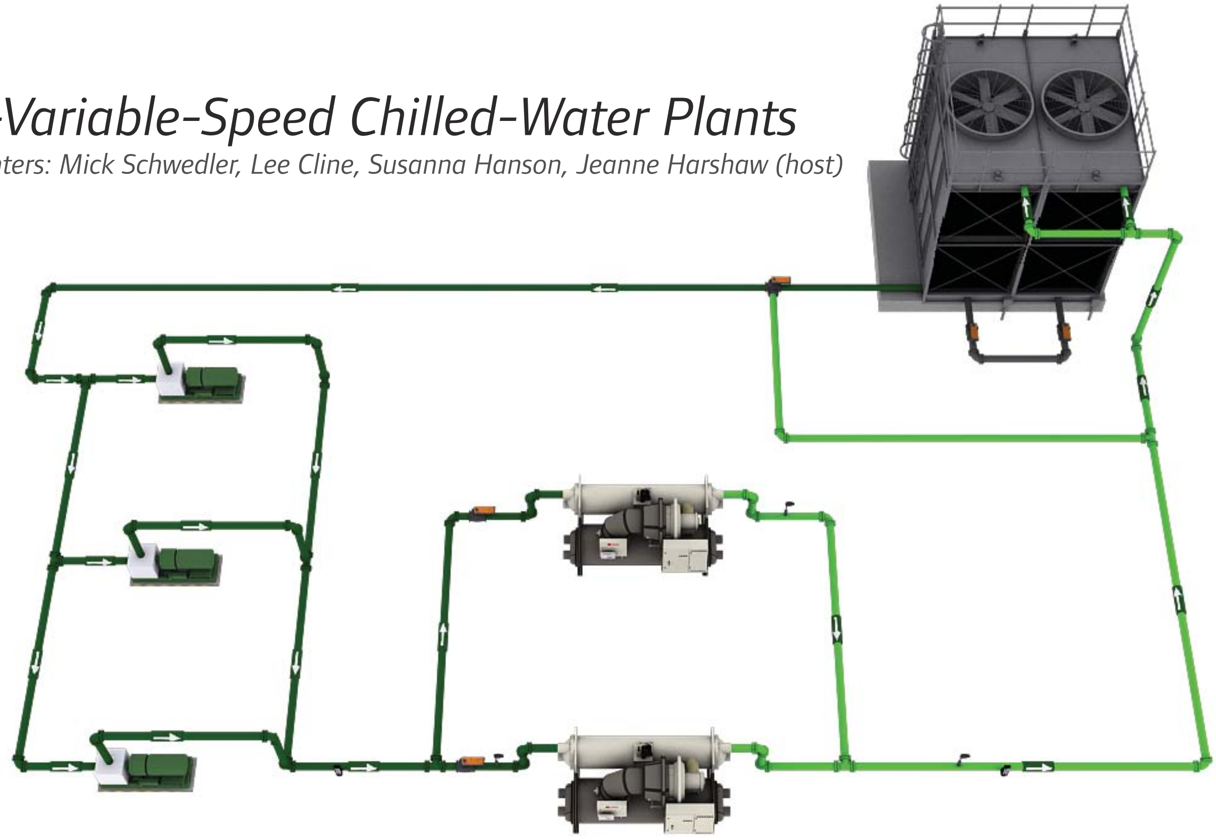
TRANE

Trane Engineers Newsletter Live

All-Variable-Speed Chilled-Water Plants

Presenters: Mick Schwedler, Lee Cline, Susanna Hanson, Jeanne Harshaw (host)



Ingersoll Rand

TRANE

Agenda

Trane Engineers Newsletter Live Series

All-Variable-Speed Chilled-Water Plants

Abstract

Variable frequency drives (VFDs) are being used on all chilled-water system components (fans, pumps, and chillers), and for good reason. When systems are properly designed and controlled, they offer the opportunity for significant energy savings as well as improved operation. With these new opportunities come new complexities. This ENL discusses all variable-speed chilled-water system design and control. Discussion will include individual component and system performance as well as system design options and control.

Presenters: Trane applications engineers Lee Cline, Susanna Hanson and Mick Schwedler.

After attending you will be able to:

- Build the case for variable speed to be used in the context of broader chiller plant design objectives – understanding that it's not a one size fits all.
- Identify energy saving opportunities in various chilled water plants
- Summarize control options and their energy and complexity impact, regardless of the planned chiller plant design
- Summarize the impact of operating on the edges of the safe operating envelope.
- Summarize limit protection mode considerations and the importance of incorporating into the control system.

Agenda

History of VSD use in chiller plant operation

a) Potential efficiency of chiller plants (various configurations)

b) VSDs impact on HVAC components

c) Existing system review

System configuration examples - what's the payoff?

All variable-speed chiller plant operation

a) Understanding of control options and their energy and complexity impact, regardless of the planned chiller plant design

b) Importance of incorporating limit mode into the control system

User interaction

Application to existing systems

Resources

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.

Mick Schwedler | manager, applications engineering | Trane
Mick has been involved in the development, training, and support of mechanical systems for Trane since 1982. With expertise in system optimization and control (in which he holds patents), and in chilled-water system design, Mick's primary responsibility is to help designers properly apply Trane products and systems. To do so, he provides one-on-one support, writes technical publications, and presents seminars.

A recipient of ASHRAE's Distinguished Service and Standards Achievement Awards, Mick is past Chair of SSPC 90.1. He also contributed to the ASHRAE GreenGuide and is a member of the USGBC Education Events Committee. Mick earned his mechanical engineering degree from Northwestern University and holds a master's degree from the University of Wisconsin Solar Energy Laboratory.

Lee Cline | applications engineer | Trane
Lee is a staff engineer in the Systems Engineering Department with over 30 years of experience at Trane. His career at Trane started as a factory service engineer for heavy refrigeration, helping to introduce the CVHE centrifugal chiller with electronic controls to the industry. Following that Lee was a member of the team that kicked off the microelectronic building automation and Integrated Comfort Systems controls – ICS - offering at Trane.
He continues to push new unit and system control and optimization concepts into the industry, many of which are integrated in Trane EarthWise™ Systems. As a Systems Engineer Lee also has the opportunity to discuss HVAC system application and control with owners, engineers and contractors on a daily basis.

Lee earned his Bachelors degree in Mechanical Engineering from Michigan Technological University. He is a member of ASHRAE and a Registered Professional Engineer in the State of Wisconsin.

TRANE

All-Variable-Speed Chilled-Water Plants

engineers newsletter LIVE

Ingersoll Rand

Ingersoll Rand

is a USGBC Education Provider committed to enhancing the professional development of the building industry and LEED Professionals through high-quality continuing education programs.

As a USGBC Education Provider, we have agreed to abide by USGBC-established operational and educational criteria, and are subject to course reviews and audits for quality assurance.

U.S. GREEN BUILDING COUNCIL USGBC EDUCATION PROVIDER

GBCI CMP

All-Variable-Speed Chilled-Water Plants (Course ID: 0090010398)

Approved for 1.5 GBCI hours for LEED professionals

"Trane" is a Registered Provider with The American Institute of Architects Continuing Education System. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Visit the Registered Continuing Education Programs (RCEP) Website for individual state continuing education requirements for Professional Engineers.

www.RCEP.net

Copyrighted Materials

learning objectives

After today's program you will be able to:

- Build the case for variable speed to be used in the context of broader chiller plant design objectives –understanding that it's not a "one size fits all"
- Identify energy saving opportunities in various chilled water plants
- Summarize control options and their energy and complexity impact, regardless of the planned chiller plant design
- Summarize the impact of operating on the edges of the safe operating envelope
- Summarize limit protection mode considerations and the importance of incorporating into the control system

Today's Presenters

Lee Cline
Applications Engineer

Susanna Hanson
Applications Engineer

Mick Schwedler
Applications Engineer

7

Agenda

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

8

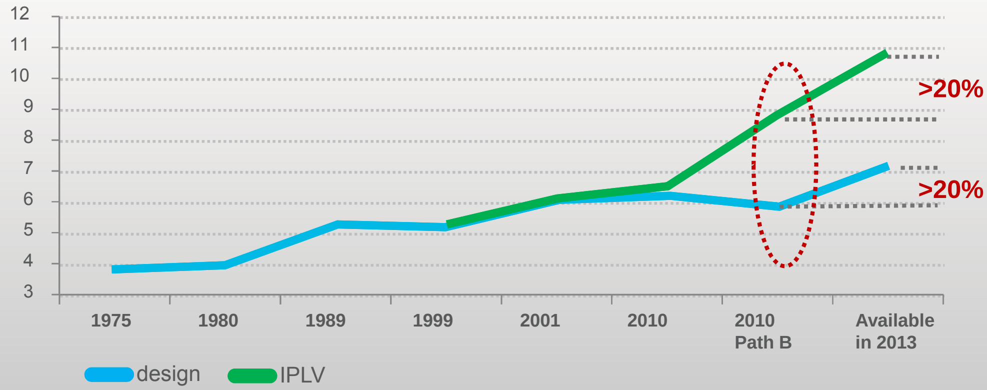
Agenda

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

Why are you here today?

- Efficiency rising
  - Full load and lift
  - Part load and lift
- VSDs being applied to all pieces of the system
- Operation is often out-sourced
  - Want to understand the system opportunity
  - Want to understand how the system works

ASHRAE Standard 90.1 Minimum COP > 300-ton Chiller



11 |

Variable Speed Drives are Being Applied

- Chilled water pumps (1989)
  - Variable primary flow becoming more prevalent
- Cooling towers (1999)
- Chillers (2010 – Path B)
- Condenser water pumps (2013)

12 |

Chilled-Water Pumping: 90.1-1989 (sort of)

- **9.5.5.3 Variable Flow.** Pumping systems that serve control valves designed to modulate or step open and closed as a function of load shall be designed for variable fluid flow. The system shall be capable of reducing system flow to 50% of design flow or less. Flow may be varied by one of several methods, **including but not limited to variable-speed-driven** pumps, staged multiple pumps, or pumps riding their characteristic performance curves

13

Evolution of Chilled-Water (ChW) Pump Requirements

- ≤30% of design wattage at 50% design flow;
- controls (such as variable speed control) to achieve…(performance)
  - 90.1-1999, -2001, -2004, 2007:
    - Pump head exceeds 100 feet and power exceeds 50 hp
  - 90.1-2010
    - Motors exceed 5 hp

14

Pump Requirements

$$hp = \frac{tons \times gpm/ton \times \Delta P}{3960 \times Pump\ efficiency}$$

- Assumptions
  - 75% pump efficiency
  - 12°F chilled water ΔT (2.0 gpm/ton)

Pump Head (ft H20)	Pump Power (hp)	Chiller Capacity (tons)
100	>50	>740
50	>5	>150
100	>5	>75

15

Evolution of Cooling Tower VSD Requirement – 90.1-1999

- **6.5.3.2** (Heat rejection) **Fan Speed Control**. Each fan powered by a motor of 7.5 hp or larger shall have the capability to operate that fan at two-thirds of speed or less and shall have controls that automatically change the fan speed to contain the leaving fluid temperature or condensing temperature/pressure of the heat rejection device…

16

Chiller
Table 6.8.1C - Excerpt

90.1-2007 Addendum M

		Path A	Path B
Air cooled < 150 tons		9.562 EER 12.5 IPLV	
Air cooled 150+ tons		9.562 EER 12.75 IPLV	
Water cool. pos. displ.	>75 tons	0.780 kW/ton 0.630 IPLV	0.800 kW/ton 0.600 IPLV
	75 - less than 150 tons	0.775 kW/ton 0.615 IPLV	0.790 kW/ton 0.586 IPLV
	150 - less than 300 tons	0.680 kW/ton 0.580 IPLV	0.639 kW/ton 0.490IPLV
	300+ tons	0.620 kW/ton 0.540 IPLV	0.718 kW/ton 0.540 IPLV
Centrifugals	< 300 tons	0.634 kW/ton 0.596 IPLV	0.639 kW/ton 0.450 IPLV
	300 – less than 600 tons	0.576 kW/ton 0.549 IPLV	0.600 kW/ton 0.400 IPLV
	600+ tons	0.570 kW/ton 0.539 IPLV	0.590 kW/ton 0.400 IPLV

17 |

Evolution of VSDs on Condenser Water (CW) Pumps

- VSD used as a replacement for a starter
- VSD used to balance the flow rate (instead of balancing valve) – energy savings
- Use the VSD to vary condenser water flow rate?
- Not required by 90.1 on systems with three or fewer control valves
  - Most condenser systems have isolation, not control, valves

18 |

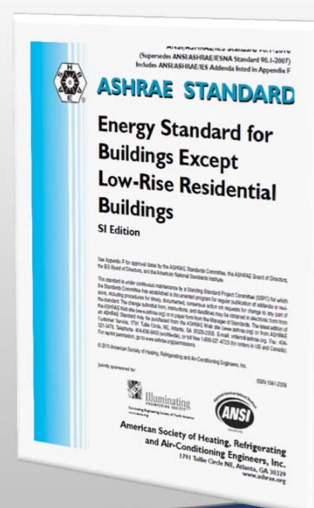
Agenda

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

19 |

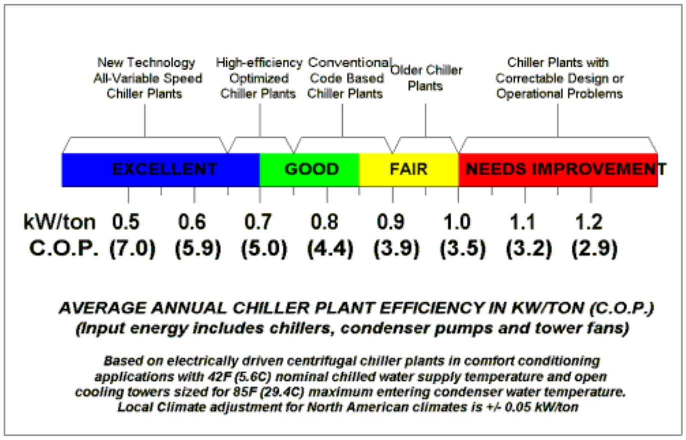
Potential Efficiency of Chiller Plants

- Report card of existing plants
- Annualized kW/ton or COP
- 90.1-2013 preview



20 |

Chiller Plant Report Card

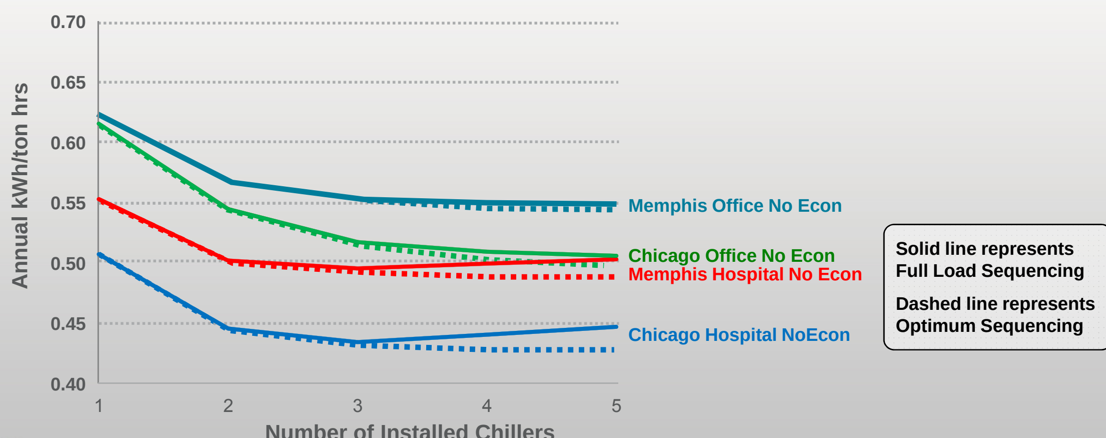


For centrifugal chillers

"Add 0.05 to 0.10 for screw or scroll chillers"

Sliding Scale Report Card

Annualized kW/ton for chiller plants with varying number of installed chillers (Power includes the chillers, condenser pumps, tower fans)



Conventional Code-Based Chiller Plants

- 6.1 General
- 6.2 Compliance Paths
- 6.3 Simplified Approach Option for HVAC Systems
- 6.4 Mandatory Provisions
- 6.5 Prescriptive Path

ASHRAE Standard 90.1-2013

- Mandatory requirements
  - Chiller efficiency
  - Tower efficiency
  - Load and pump head calculations
  - Piping insulation (unless chilled fluid is between 60-105°F)
- Prescriptive hydronic requirements
  - Pump speed or chilled water reset
  - Variable flow
  - Hot gas bypass limitation

Addendum CH

Mandatory: Chiller Efficiency as of 2015

Chiller type/size	Path A	Path B
Air cooled < 150 tons	10.1 EER and 13.7 IPLV	9.7 EER and 15.9 IPLV
Air cooled >= 150 tons	10.1 EER and 14.0 IPLV	9.7 EER and 16.1 IPLV
WC pos. disp. < 75 tons	0.750 kW/ton & 0.600 IPLV	0.780 kW/ton & 0.500 IPLV
WC pos. disp. 75 < 150 tons	0.720 kW/ton & 0.560 IPLV	0.750 kW/ton & 0.490 IPLV
WC pos. disp. 150 < 300 tons	0.660 kW/ton & 0.540 IPLV	0.680 kW/ton & 0.440 IPLV
WC pos. disp. 300 < 600 tons	0.610 kW/ton & 0.520 IPLV	0.625 kW/ton & 0.410 IPLV
WC pos. disp. >= 600 tons	0.560 kW/ton & 0.500 IPLV	0.585 kW/ton & 0.380 IPLV

25 |

Addendum CH

Mandatory: Chiller Efficiency as of 2015

Chiller type/size	Path A	Path B
WC centrif. < 150 tons	0.610 kW/ton & 0.550 IPLV	0.695 kW/ton & 0.440 IPLV
WC centrif. 150 < 300 tons	0.610 kW/ton & 0.550 IPLV	0.635 kW/ton & 0.400 IPLV
WC centrif. 300 < 400 tons	0.560 kW/ton & 0.520 IPLV	0.595 kW/ton & 0.390 IPLV
WC centrif. >= 400 tons	0.560 kW/ton & 0.500 IPLV	0.585 kW/ton & 0.380 IPLV

- Table is for standard rating temperatures
- Non-standard temperatures and flows use equation to modify the requirements

26 |

ASHRAE Standard 90.1-2013

- Mandatory requirements
  - Chiller efficiency
  - Tower efficiency
  - Load and pump head calculations
  - Piping insulation (unless chilled fluid is between 60-105°F)
- Prescriptive hydronic requirements
  - Pump speed or chilled water reset
  - Variable flow
  - Hot gas bypass limitation

27 |

Addendum AZ

Mandatory: Heat Rejection Efficiency

Tower type/size	Rated condition	Requirement
Propeller or axial fan, open-circuit	95°F entering water 85°F leaving water 75°F entering wetbulb	40.2 gpm/hp
Centrifugal fan, open-circuit	95°F entering water 85°F leaving water 75°F entering wetbulb	20.0 gpm/hp
Propeller or axial fan, closed-circuit	102°F entering water 90°F leaving water 75°F entering wetbulb	14.0 gpm/hp
Centrifugal, closed-circuit	102°F entering water 90°F leaving water 75°F entering wetbulb	7.0 gpm/hp

28 |

ASHRAE Standard 90.1-2013

- Mandatory requirements
  - Chiller efficiency
  - Tower efficiency
  - Load and pump head calculations
  - Piping insulation (unless chilled fluid is between 60-105°F)
- Prescriptive hydronic requirements
  - Pump speed or chilled water reset
  - Variable flow
  - Hot gas bypass limitation

Mandatory Requirements

- Load calculations
- Pump head calculations

“The pressure drop through each device and pipe segment in the critical circuit at design conditions shall be calculated.”

ASHRAE Standard 90.1-2013

- Mandatory requirements
  - Chiller efficiency
  - Tower efficiency
  - Load and pump head calculations
  - Piping insulation (unless chilled fluid is between 60-105°F)
- Prescriptive hydronic requirements
  - Pump speed or chilled water reset
  - Variable flow
  - Hot gas bypass limitation

31 |

Addendum AK

Prescriptive: Hydronic Requirements

- Chilled-water reset or pump-pressure reset based on critical valve
- Variable-speed pumping (if > 3 control valves)
- Pipe sizing/gpm
- Cooling tower VFDs (> 5 hp fan motors) – operate as many cells together as you can, 50% turndown required
- Limit on chiller hot gas bypass

32 |

Addendum DN

Prescriptive: Hot-Gas Bypass Limitation

- Previous limits were driven by DX unitary
- DX now required to have smaller first stage and integrated economizer

Rated capacity	Maximum HGBP (% of total capacity)
<= 240,000 Btu/h (<= 20 tons)	15% (formerly 50%)
> 240,000 Btu/h (> 20 tons)	10% (formerly 25%)

33 |

Where There Are No Requirements

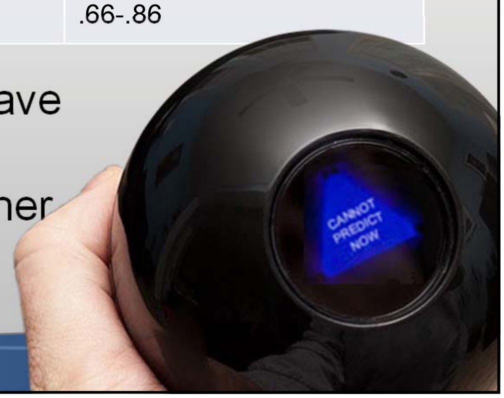
- Delta T/flow rate
- Chiller load turndown
- Chiller surge resistance
- Tower temperature control
- Configurations, system control strategies, staging, types of chillers for the application, etc.

34 |

Minimally-compliant chiller plant

Conventional assumption for code range		.75-.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.



35 |

Agenda

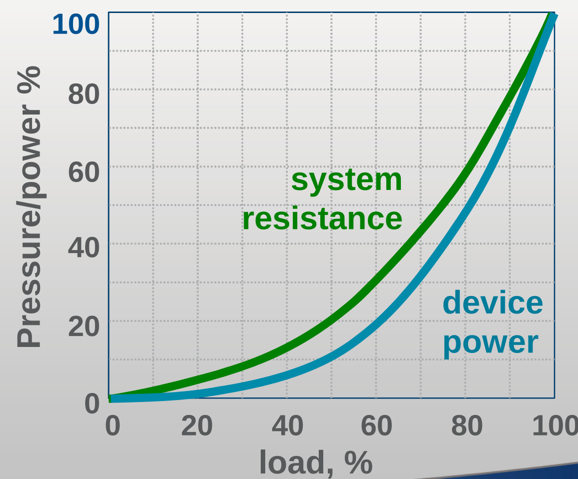
engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

36 |

2006 ENL Summary
VSDs and Their Effect on System Components

- As fans and impellers slow down their power draw reduces to the cube of the speed reduction
- But they can only slow down this way if the system resistance decreases to the square of the load



37 |

2006 ENL Summary
The Affinity Laws Dictate:

- Flow decrease proportional to the speed reduction

  50% speed = 50% flow
- Lift decreases proportional to the square of the speed reduction

  50% speed = 25% lift
- Power decreases proportional to the cube of the speed reduction

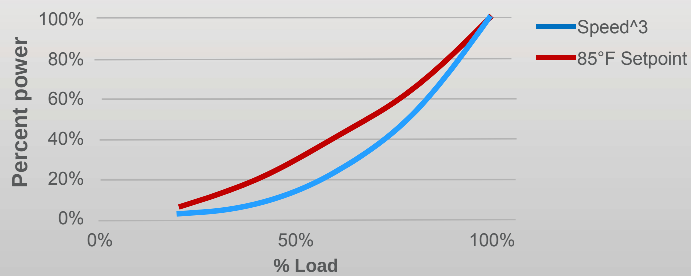
  50% speed = 12.5% power

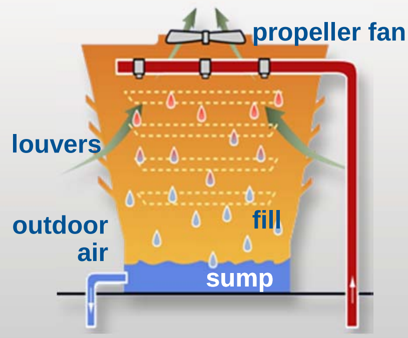
However when any device is put into a system it must respond to the system requirements which often do not follow the affinity laws.

38 |

2006 ENL Summary
VSDs and Their Effect on System Components

- Cooling tower fans –
  Load/power curve *nearly* cubic

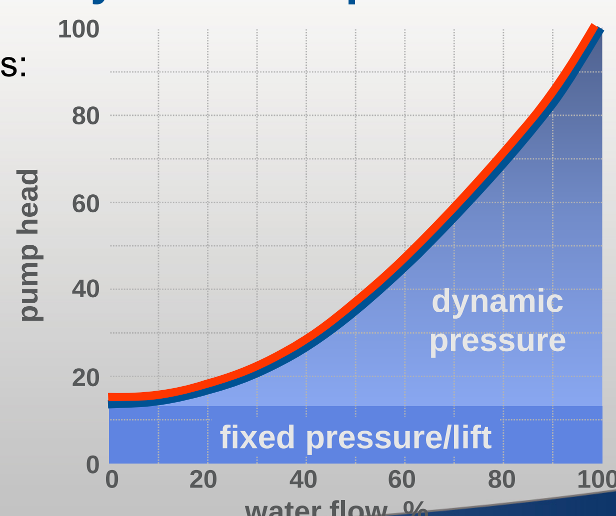




39 | © 2013 Trane, a business of Ingersoll-Rand

2006 ENL Summary
VSDs and Their Effect on System Components

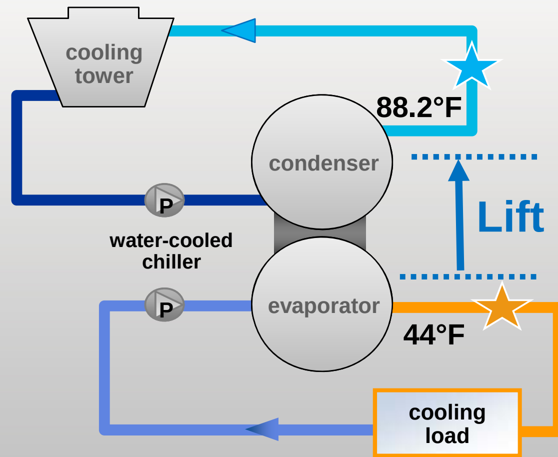
- Chilled-water pumps/HVAC fans:
  Load/power curve not cubic
  - Affected by valves and control method
  - With setpoint optimization it can approach cubic
- Condenser water pumps:
  Load/power curve not cubic
  - Must meet minimum flow and pressure requirements



40 | © 2013 Trane, a business of Ingersoll-Rand

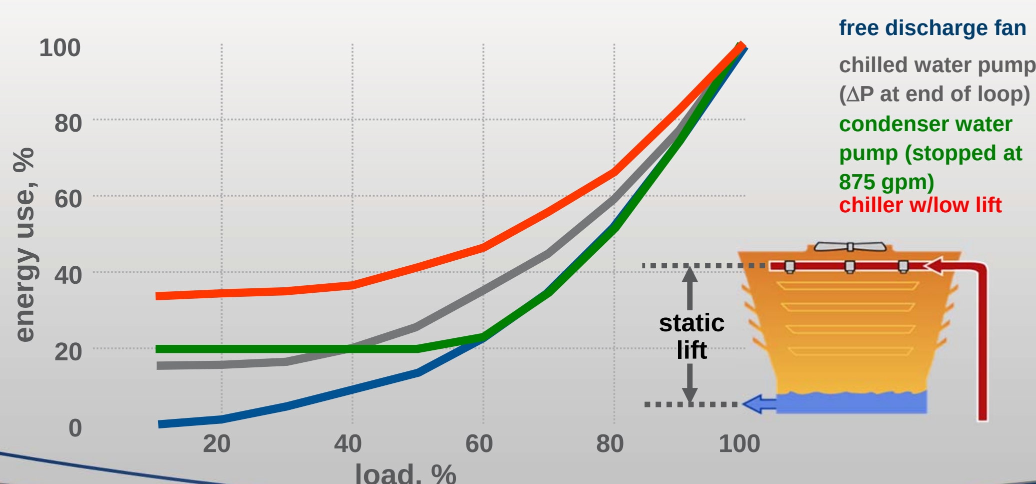
2006 ENL Summary
VSDs and Their Effect on System Components

- Variable speed chillers: Load/power curve not cubic
  - Depends on system operating conditions
  - As with any dynamic variable speed device, power is reduced only if both load and lift decline simultaneously



41 |

2006 ENL Summary
VSDs and Their Effect on System Components



42 |

Agenda

engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

43 |

2011 ENL: Upgrading Existing Plants

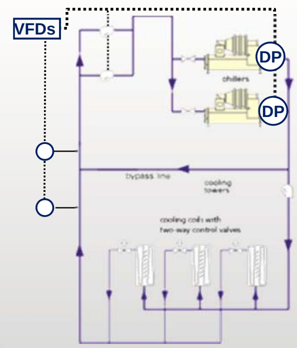
VSDs in Chilled Water Systems

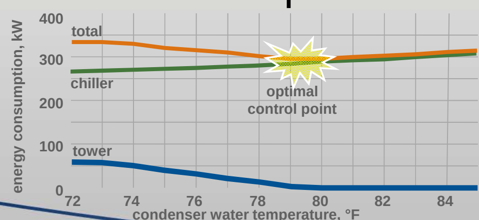
- Chillers
  - VSDs may provide benefits for "low-lift" operation
  - For replacements compare "same price" VSD and premium efficiency chillers
- Tower fans
  - VSDs great for retrofits

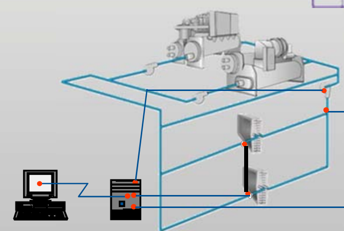
44 |

2011 ENL: Upgrading Existing Plants
Controls

- Convert primary/secondary systems to variable primary/variable secondary
- Pump pressure optimization (required by 90.1-2010 for DDC systems)
- Chiller-tower optimization







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

Agenda

engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

47 |

Potential efficiency of chiller plants What's the payoff?

- Examine effects of VSDs on annual system performance
- Examine
  - Office building with economizer in Chicago
  - Hospital without an economizer in Memphis
  - Hospital with an economizer in Albuquerque
  - Office without an economizer in Miami

48 |

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)

49

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

50

Annual Analysis – What Metric?

- Annual system kWh
  - Chiller
  - Condenser water pump
  - Cooling tower fans
- Annual system ton-hours
- Annual performance metric
  - kWh/ton-hour
  - Referred to as "annualized kW/ton"

51

Base – Number of Chillers

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	
VS	VS	2	VF	Opt	

0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1

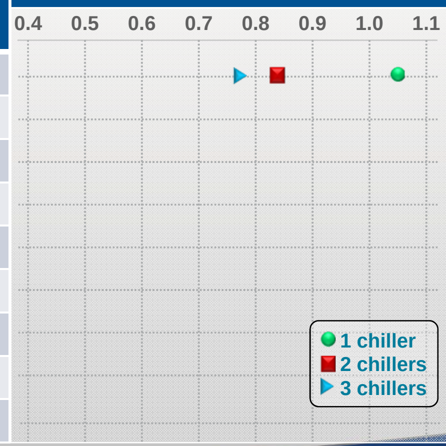
52

Base – Number of Chillers

Annualized System Performance

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
CS	1 Spd	3	CF	85°F

System Performance (Annualized kW/ton)

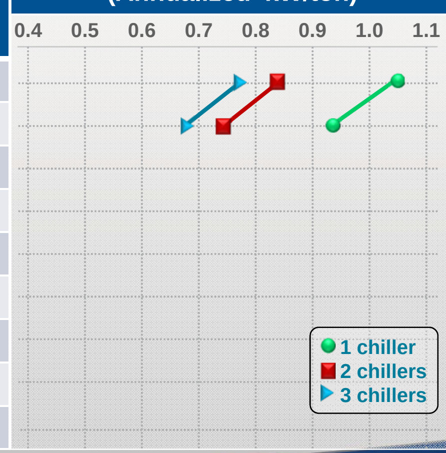


Optimized Tower Control

Annualized System Performance

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

System Performance (Annualized kW/ton)



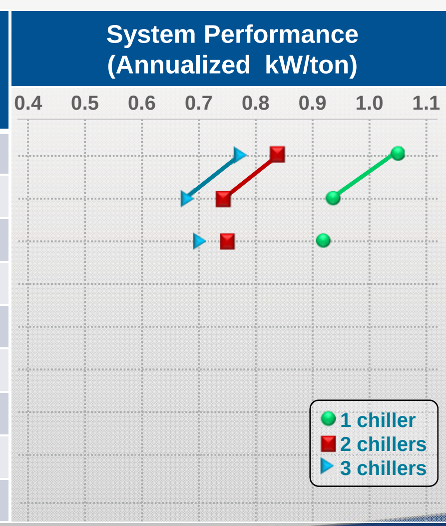
What Did We Learn?

- Multiple chillers improve system efficiency
- Optimal tower fan control saves significant energy

Variable-Speed Tower Fan

Annualized System Performance

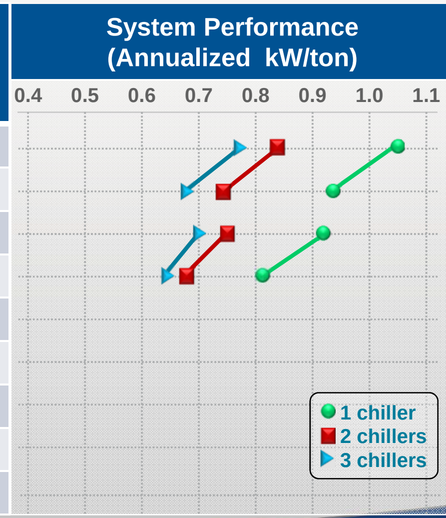
Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
CS	1 Spd	3	CF	85°F
CS	1 Spd	3	CF	Opt
CS	VS	3	CF	85°F



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
CS	1 Spd	3	CF	85°F
CS	1 Spd	3	CF	Opt
CS	VS	3	CF	85°F
CS	VS	3	CF	**Opt**



57 | © 2013 Trane, a business of Ingersoll-Rand

What Did We Learn?

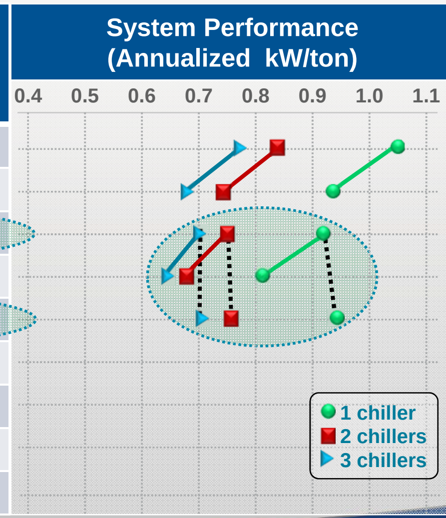
- Variable speed tower fans save energy (fan laws)
- Optimal tower fan control saves significant energy (II)

58 | © 2013 Trane, a business of Ingersoll-Rand

Variable-Speed Chiller

Annualized System Performance

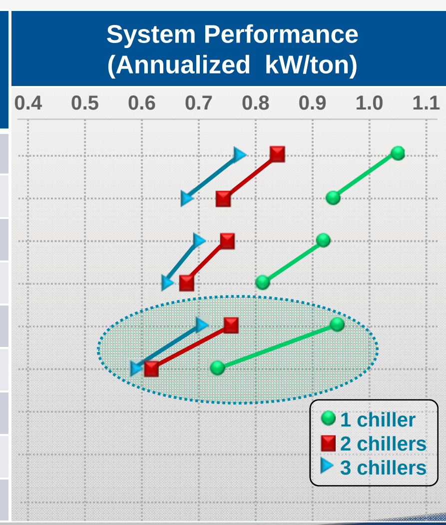
Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method
CS	1 Spd	3	CF	85°F
CS	1 Spd	3	CF	Opt
CS	VS	3	CF	85°F
CS	VS	3	CF	Opt
VS	VS	3	CF	85°F



Variable-Speed Chiller-Optimized Tower Control

Annualized System Performance

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



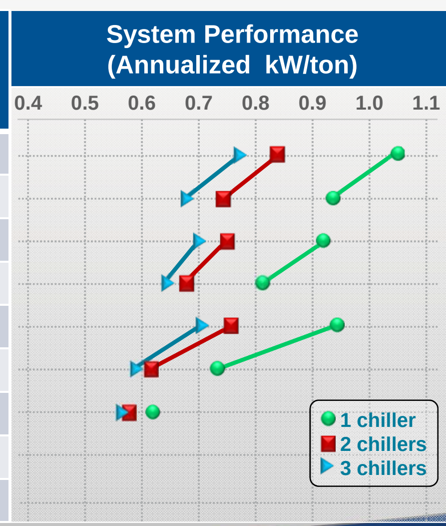
What Did We Learn?

- Tower fan control is absolutely critical to save energy when variable speed chillers are installed
- Optimal tower fan control saves significant energy (III)

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
CS	1 Spd	3	CF	85°F
CS	1 Spd	3	CF	Opt
CS	VS	3	CF	85°F
CS	VS	3	CF	Opt
VS	VS	3	CF	85°F
VS	VS	3	CF	Opt
VS	VS	2	CF	Opt

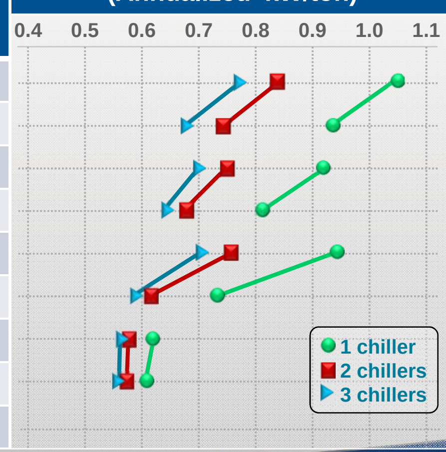


What Did We Learn?

- Proper condenser water design flow rate is very important
- Taylor (ASHRAE Journal December 2011)
  - 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.**"

3 gpm/ton Variable Condenser Flow
Annualized System Performance

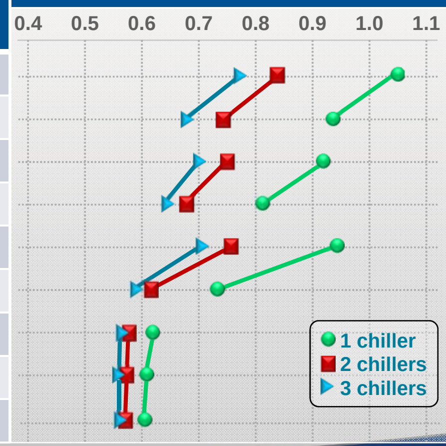
Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	System Performance (Annualized kW/ton)
CS	1 Spd	3	CF	85°F	
CS	1 Spd	3	CF	Opt	
CS	VS	3	CF	85°F	
CS	VS	3	CF	Opt	
VS	VS	3	CF	85°F	
VS	VS	3	CF	Opt	
VS	VS	2	CF	Opt	
VS	VS	3	VF	Opt	



Low-flow System-Optimized
Annualized System Performance

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

System Performance (Annualized kW/ton)



65 |

What Did We Learn?

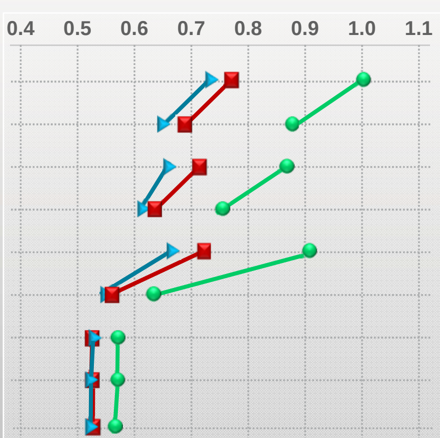
- Optimized condenser water flow **design** saves energy
- On unoptimized condenser water flow design **requires** optimized control to systems to reach the best efficiency levels

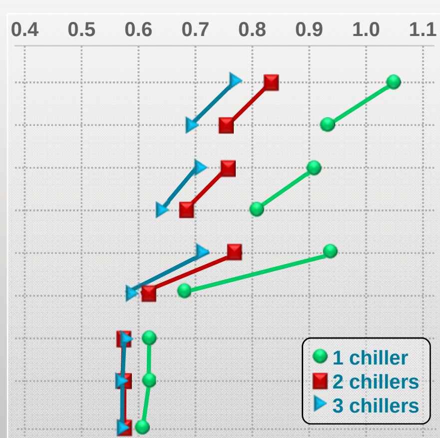
66 |

What Did We Learn?
Summary

- Multiple chillers improve 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) design condenser water flow rate is very important to simplify controls
- Variable condenser water flow can save energy – particularly for systems designed using 3 gpm/ton

Chicago or Memphis?
Hospital or Office?
Economizer or not?

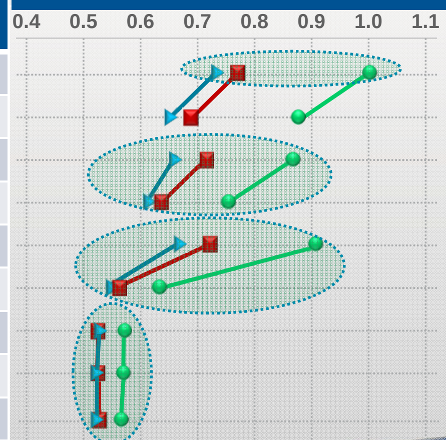




Memphis – (3A) Hospital No economizer

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

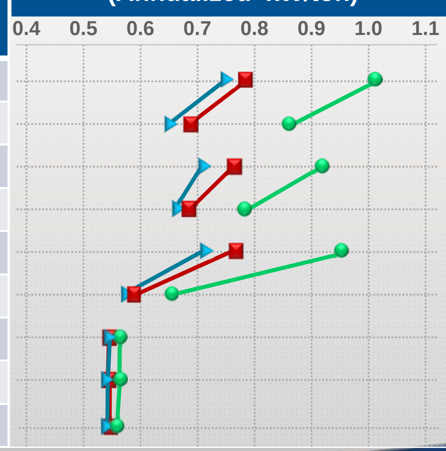
System Performance (Annualized kW/ton)



Albuquerque – (4B) Office Economizer

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

System Performance (Annualized kW/ton)



Miami– (1A) Office
No Economizer

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

71 |

Summary of Summary

- 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

72 |

Agenda

engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

73

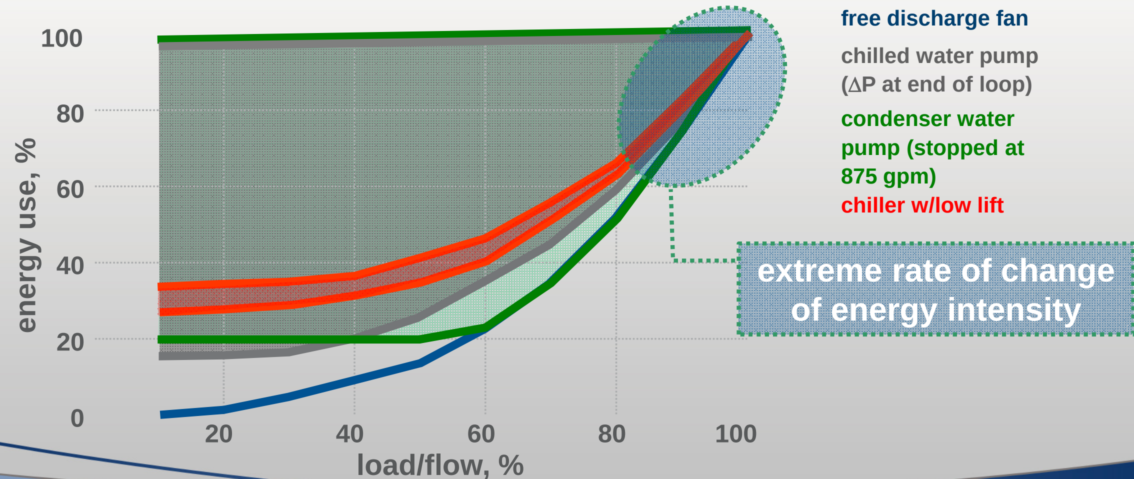
Two Goals of AVSCHWP Optimization?

- Balance!
  - Establish the proper full load design component energy balance
  - Maintain the proper component energy balance as the system operating conditions change
- Avoid improper and potentially damaging component operating conditions

74

2006 ENL

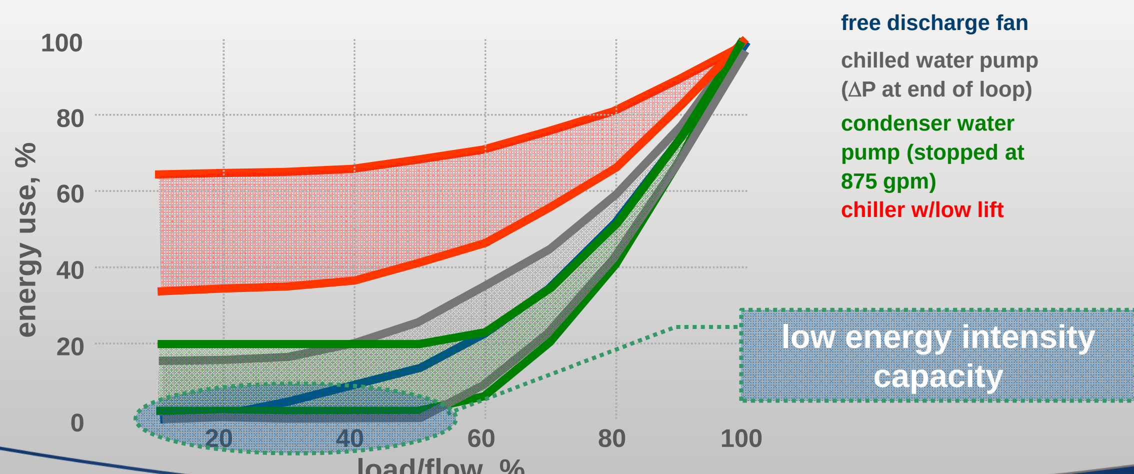
How do we leverage the component unloading curves to achieve balance?



75 | © 2013 Trane, a business of Ingersoll-Rand

2006 ENL

How do we leverage the component unloading curves to achieve balance?



76 | © 2013 Trane, a business of Ingersoll-Rand

How do you achieve operation in the energy balance sweet spot?

1. Eliminate parasitic losses

Proper component capacity control

Eliminate parasitic losses

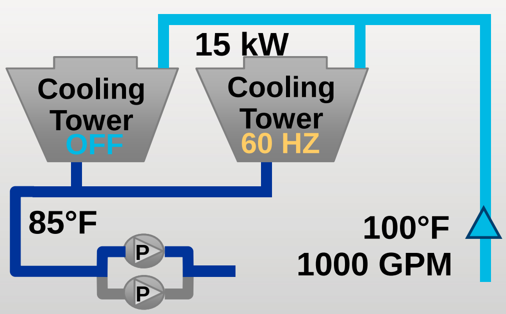
- Reduce excess pressure
  - throttling valves
  - setpoint optimization
    - pump pressure reset
    - fan pressure reset
- Reduce excess flow
  - 3-way valves
  - system low delta T

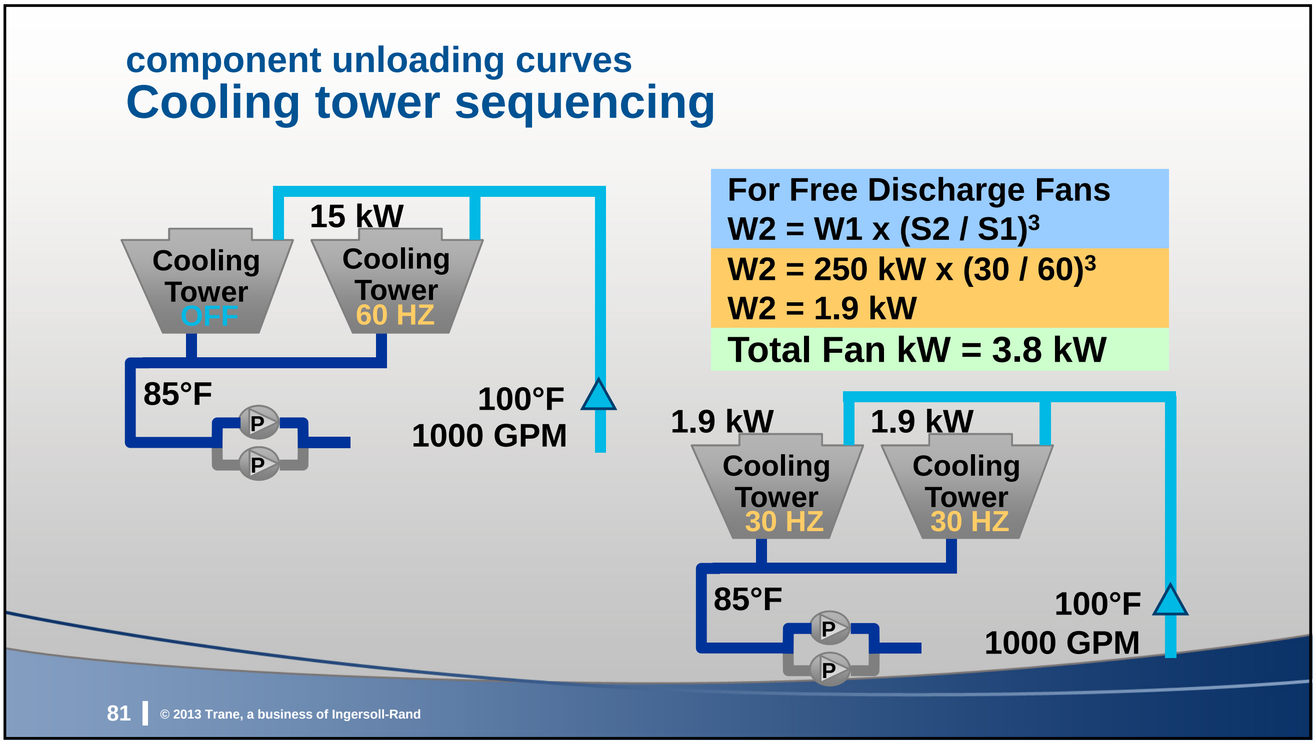
 APP-CMC049-EN

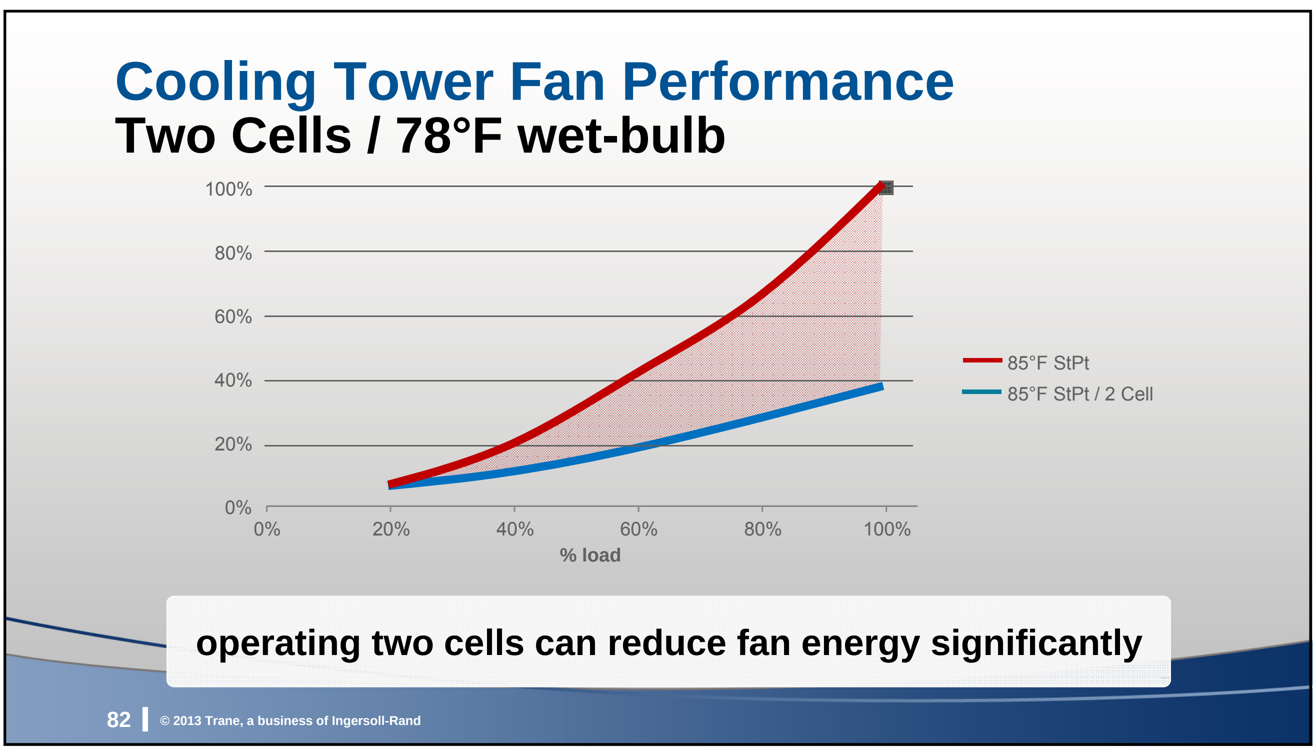
How do you achieve operation in the energy balance sweet spot?

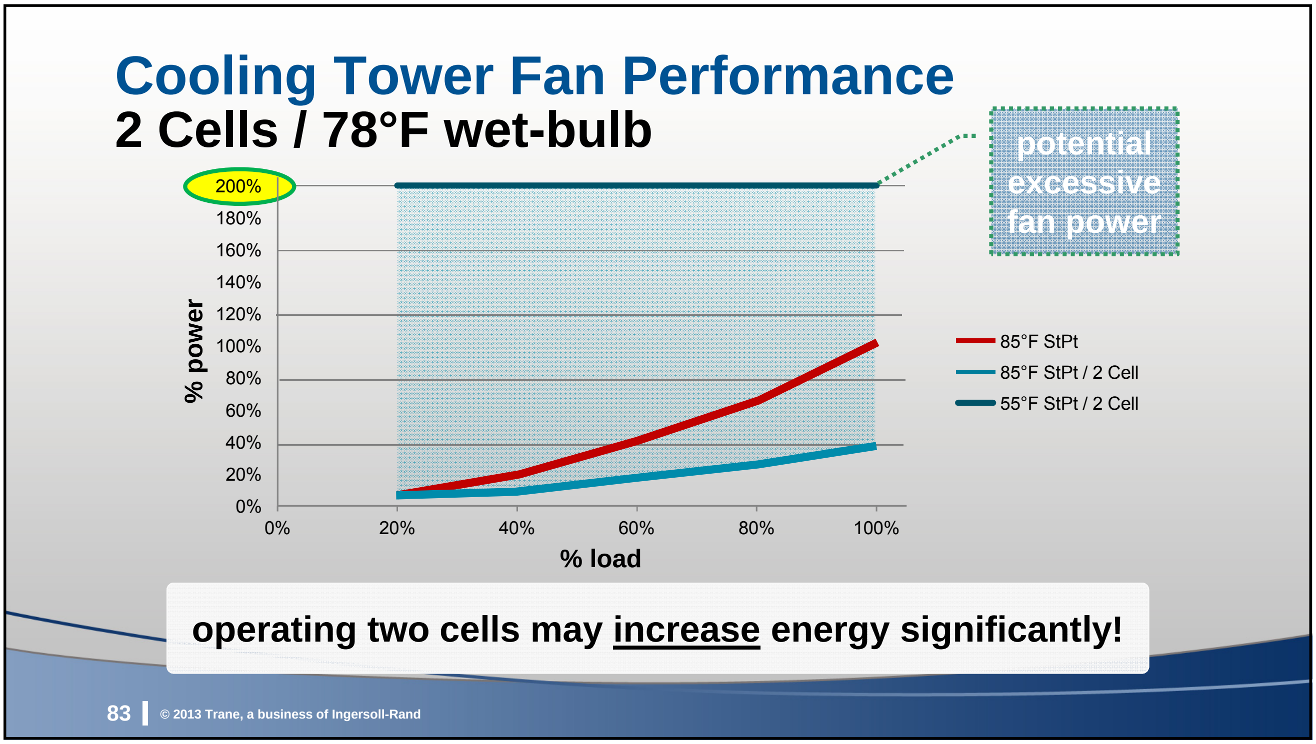
1. Eliminate parasitic losses
2. **Proper component sequencing**
   1. **Consider component unloading curves under actual operating conditions**
   2. Prioritize stability

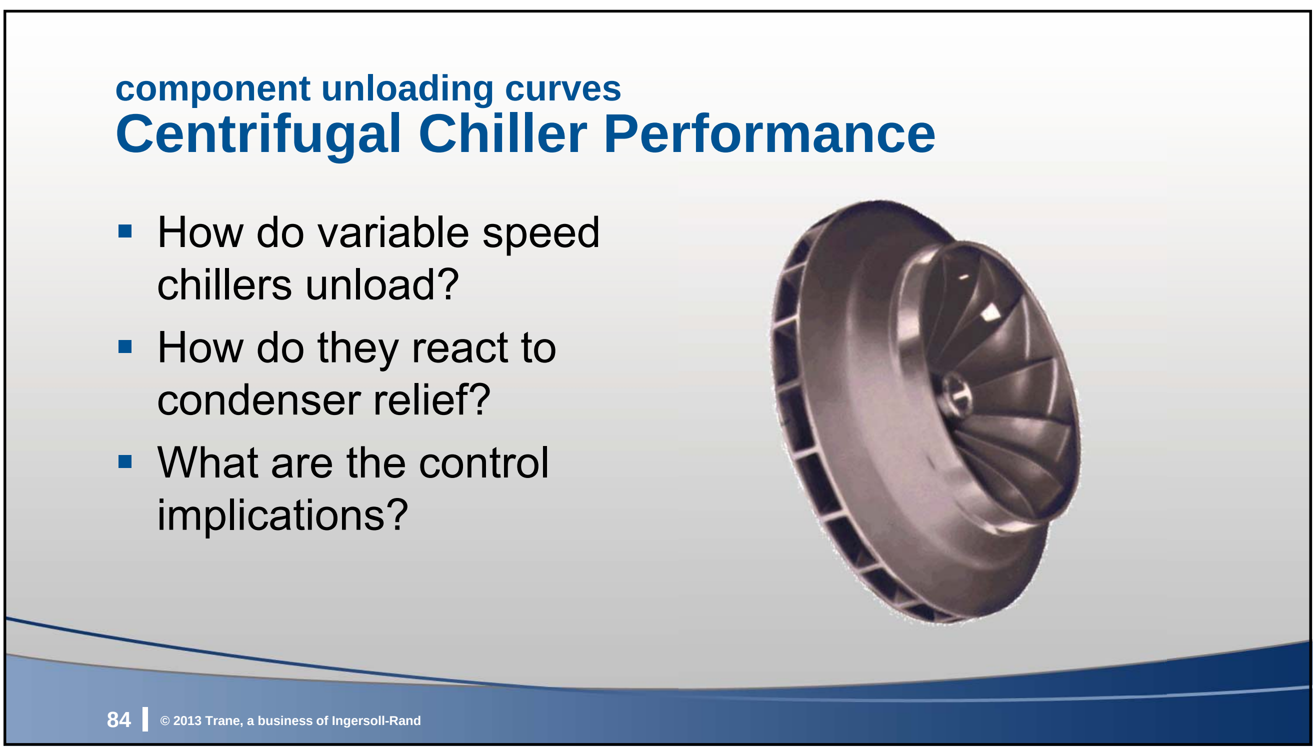
component unloading curves
Cooling tower sequencing

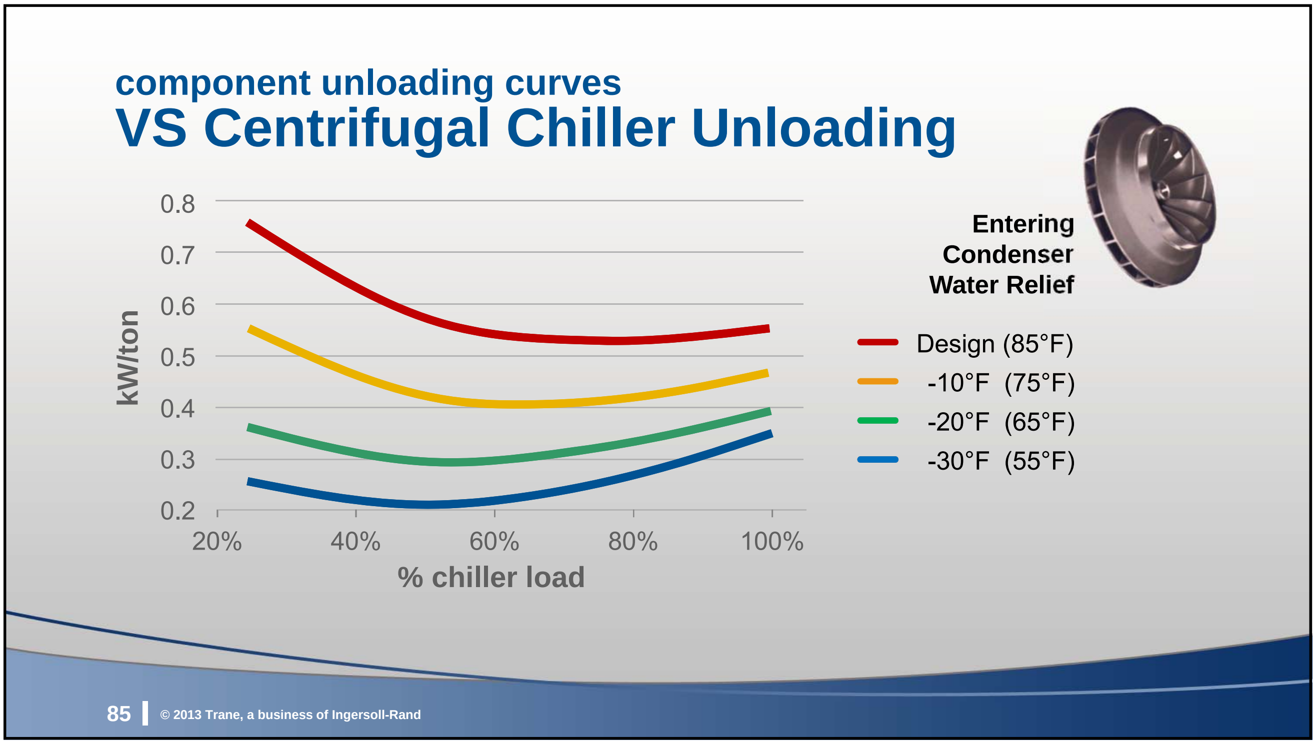


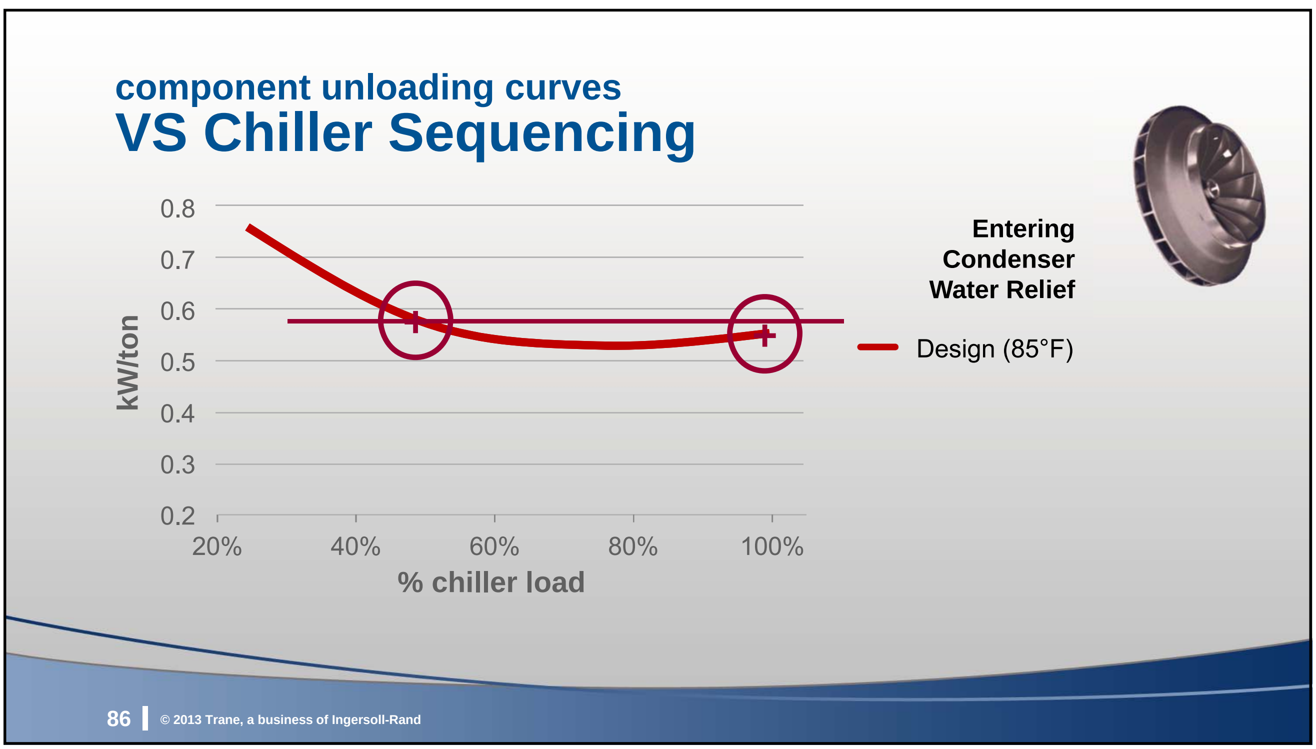

component unloading curves
Cooling tower sequencing
15 kW
Cooling Tower OFF
Cooling Tower 60 HZ
85°F
P
P
100°F
1000 GPM
For Free Discharge Fans
W2 = W1 x (S2 / S1)³
W2 = 250 kW x (30 / 60)³
W2 = 1.9 kW
Total Fan kW = 3.8 kW
1.9 kW
1.9 kW
Cooling Tower 30 HZ
Cooling Tower 30 HZ
85°F
100°F
1000 GPM
81
© 2013 Trane, a business of Ingersoll-Rand


Cooling Tower Fan Performance
Two Cells / 78°F wet-bulb
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
% load
85°F StPt
85°F StPt / 2 Cell
operating two cells can reduce fan energy significantly
82
© 2013 Trane, a business of Ingersoll-Rand


Cooling Tower Fan Performance
2 Cells / 78°F wet-bulb
potential excessive fan power
200%
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
% power
0%
20%
40%
60%
80%
100%
% load
85°F StPt
85°F StPt / 2 Cell
55°F StPt / 2 Cell
operating two cells may increase energy significantly!
83
© 2013 Trane, a business of Ingersoll-Rand

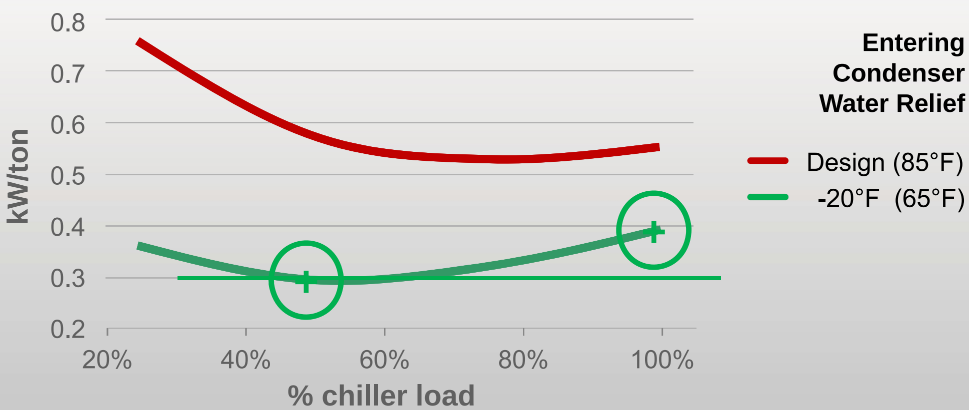

component unloading curves
Centrifugal Chiller Performance
How do variable speed chillers unload?
How do they react to condenser relief?
What are the control implications?
84
© 2013 Trane, a business of Ingersoll-Rand


component unloading curves
VS Centrifugal Chiller Unloading
kW/ton
0.8
0.7
0.6
0.5
0.4
0.3
0.2
20%
40%
60%
80%
100%
% chiller load
Entering Condenser Water Relief
Design (85°F)
-10°F (75°F)
-20°F (65°F)
-30°F (55°F)
85
© 2013 Trane, a business of Ingersoll-Rand


component unloading curves
VS Chiller Sequencing
kW/ton
0.8
0.7
0.6
0.5
0.4
0.3
0.2
20%
40%
60%
80%
100%
% chiller load
Entering Condenser Water Relief
Design (85°F)
86
© 2013 Trane, a business of Ingersoll-Rand

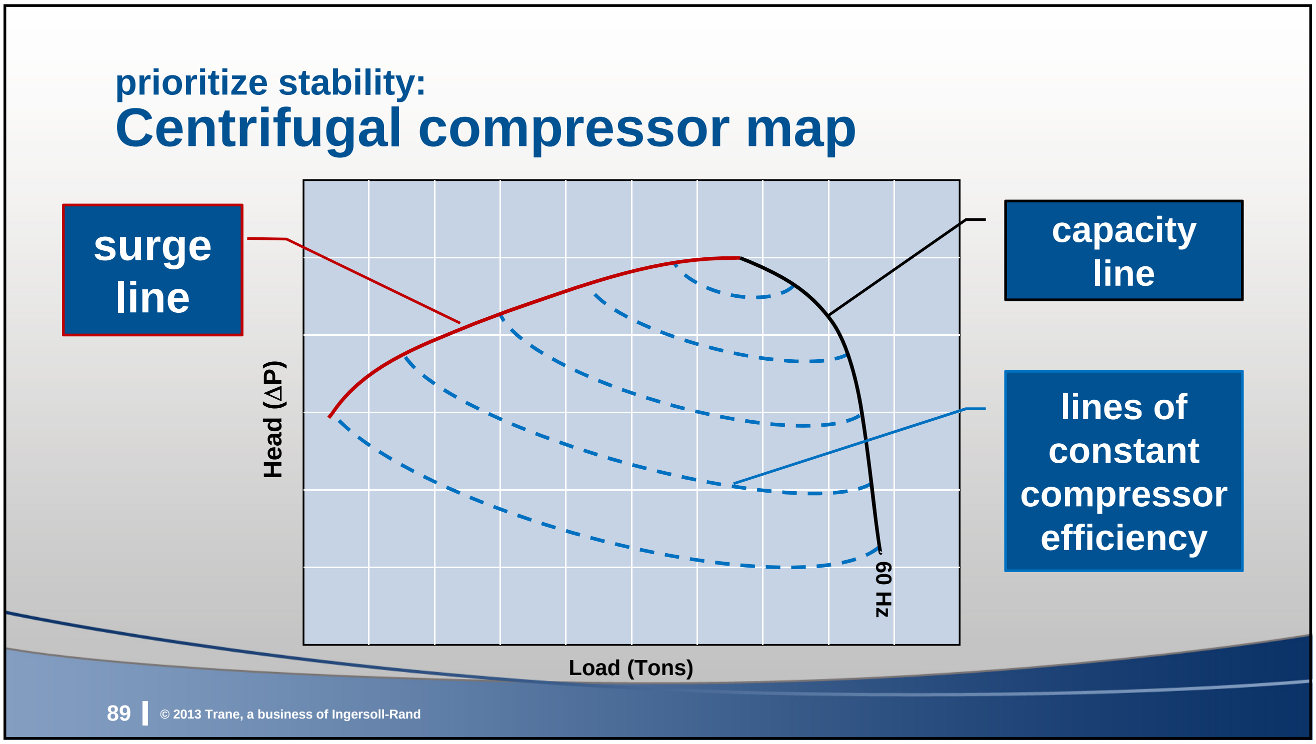
component unloading curves

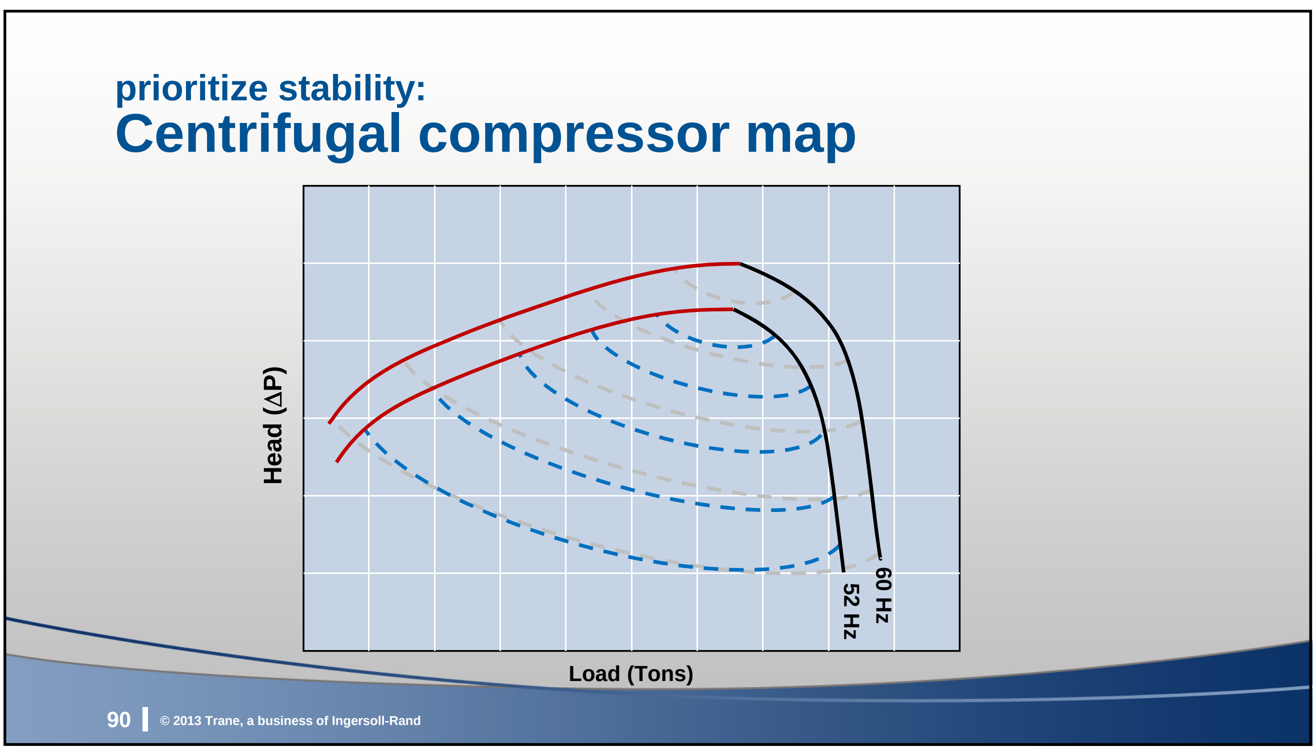
VS Chiller Sequencing



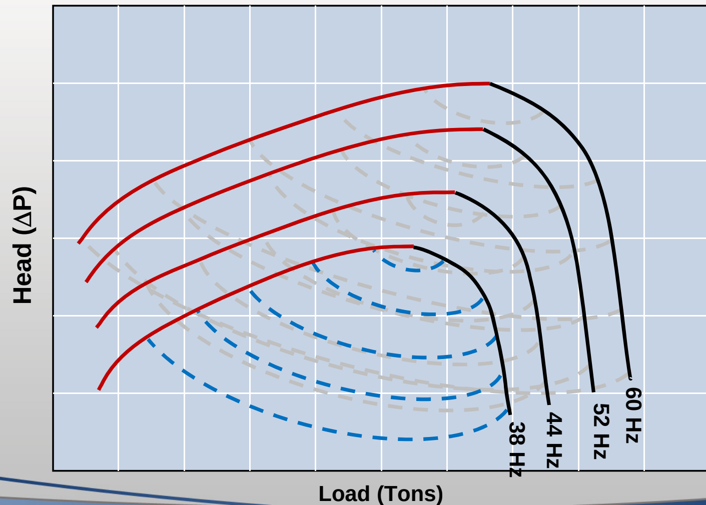
How do you achieve operation in the energy balance sweet spot?

1. Eliminate parasitic losses
2. **Proper component sequencing**
   1. Consider component unloading curves under actual operating conditions
   2. **Prioritize stability**


prioritize stability:
Centrifugal compressor map
surge line
capacity line
lines of constant compressor efficiency
Head (ΔP)
Load (Tons)
60 Hz
89
© 2013 Trane, a business of Ingersoll-Rand

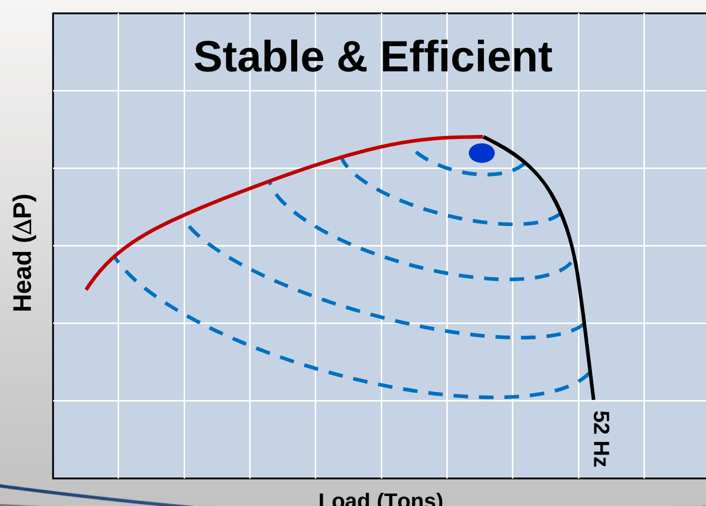

prioritize stability:
Centrifugal compressor map
Head (ΔP)
Load (Tons)
52 Hz
60 Hz
90
© 2013 Trane, a business of Ingersoll-Rand

prioritize stability:
Centrifugal compressor map

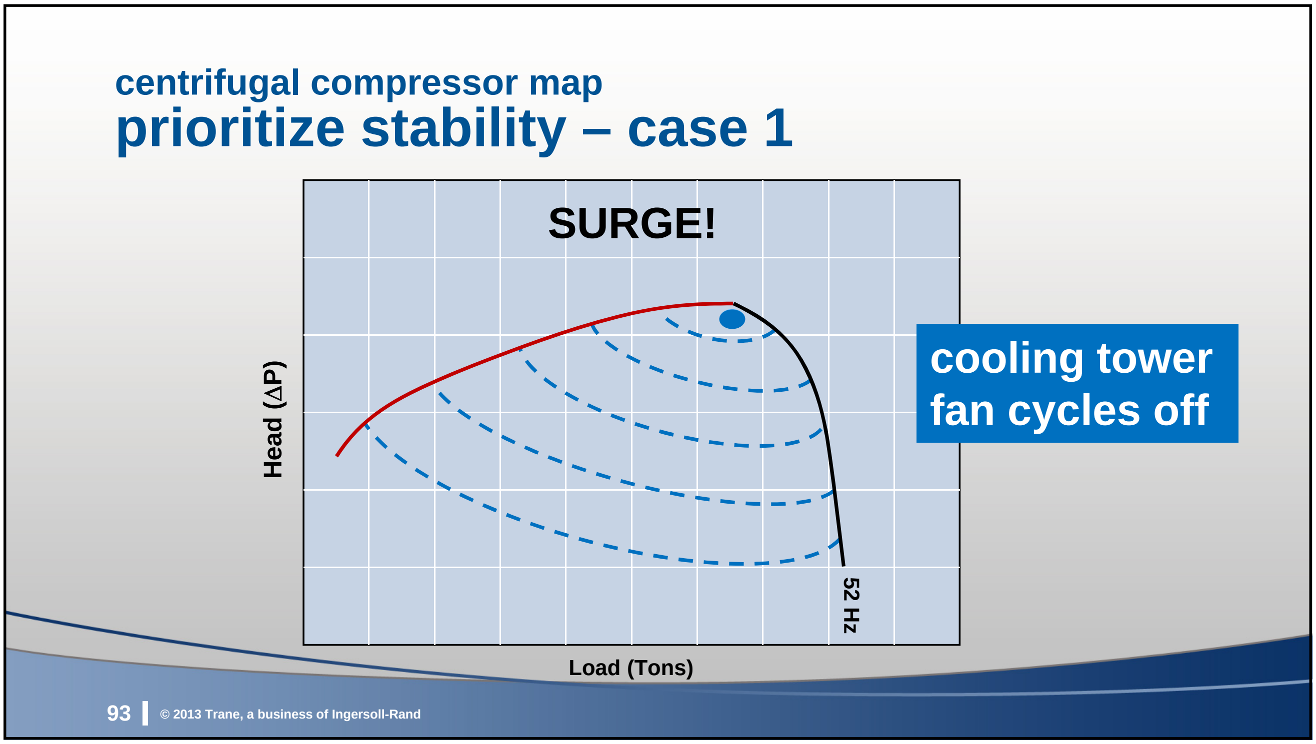


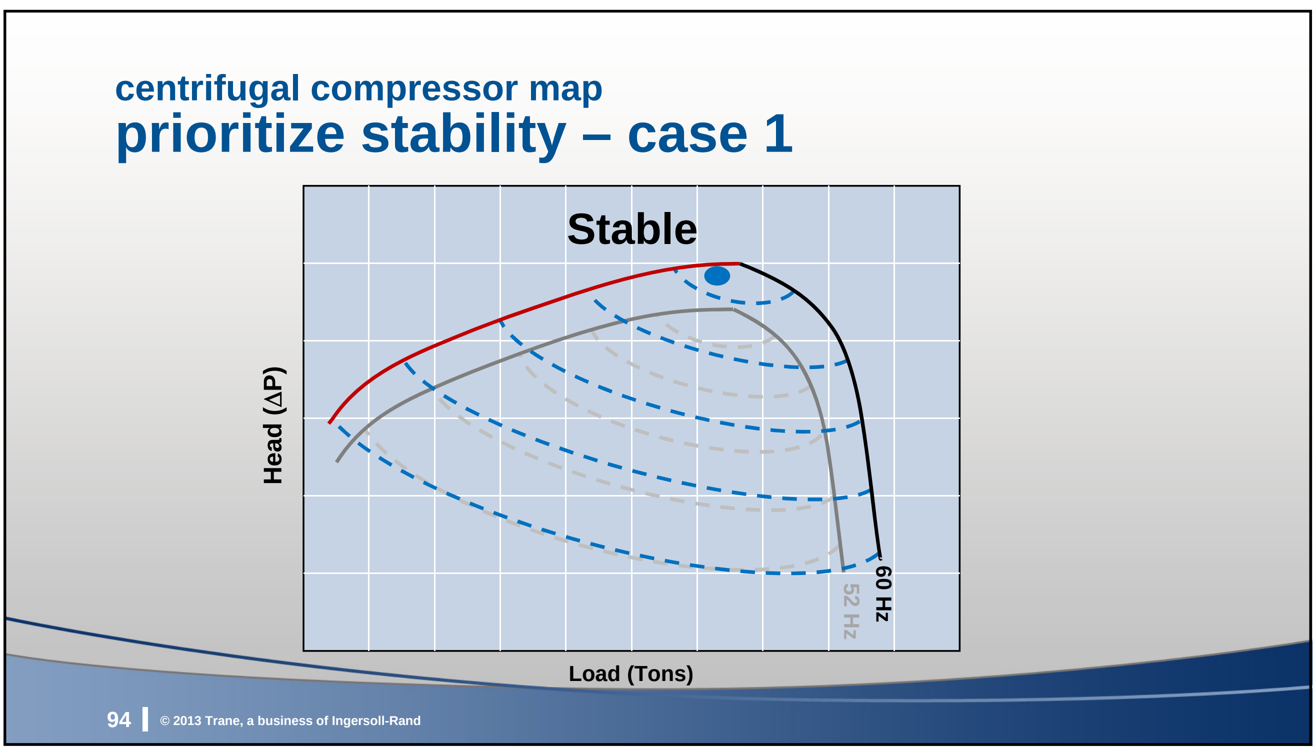
91

centrifugal compressor map
prioritize stability – case 1

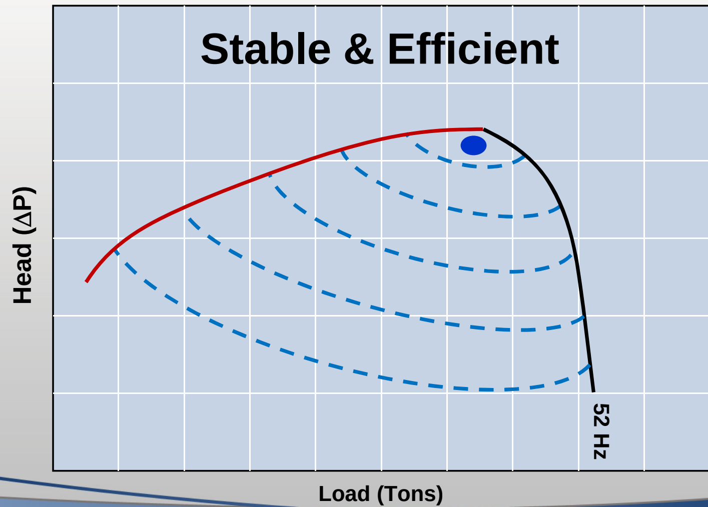


92

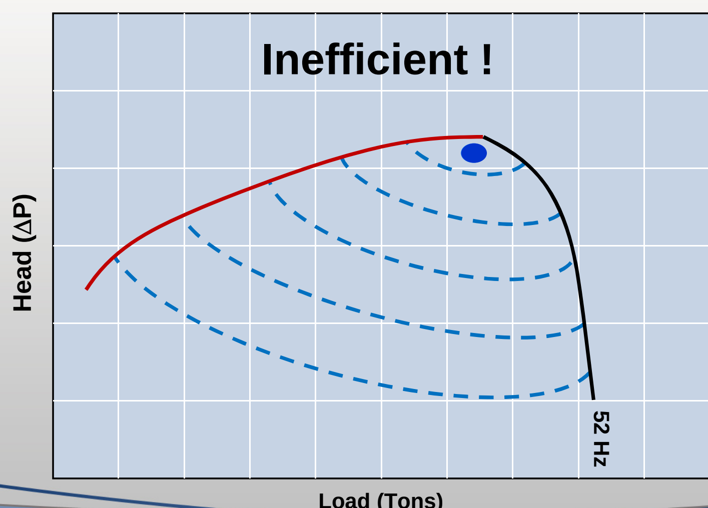

centrifugal compressor map
prioritize stability – case 1
SURGE!
Head (ΔP)
52 Hz
Load (Tons)
cooling tower fan cycles off
93
© 2013 Trane, a business of Ingersoll-Rand


centrifugal compressor map
prioritize stability – case 1
Stable
Head (ΔP)
60 Hz
52 Hz
Load (Tons)
94
© 2013 Trane, a business of Ingersoll-Rand

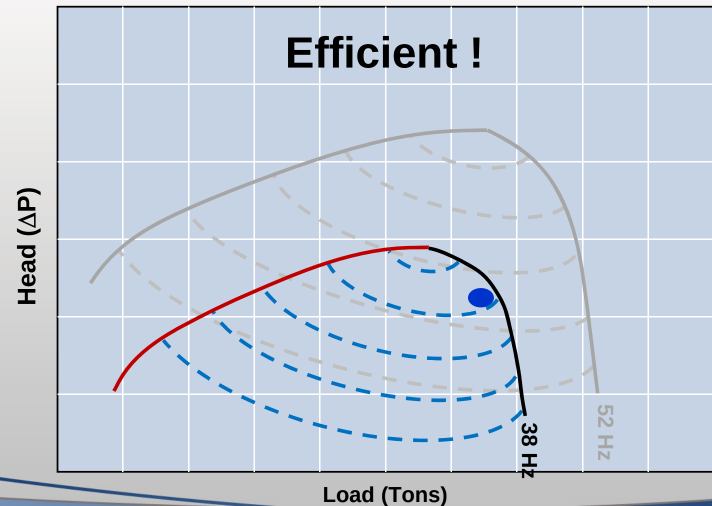
centrifugal compressor map
prioritize stability – case 2



centrifugal compressor map
prioritize stability – case 2



centrifugal compressor map
prioritize stability – case 2



97 | © 2013 Trane, a business of Ingersoll-Rand

How do you achieve operation in the energy balance sweet spot?

1. Eliminate parasitic losses
2. Proper component sequencing
3. **Proper component capacity control**
   - **Balance the component energy investments**
   - **Attention to component limits**

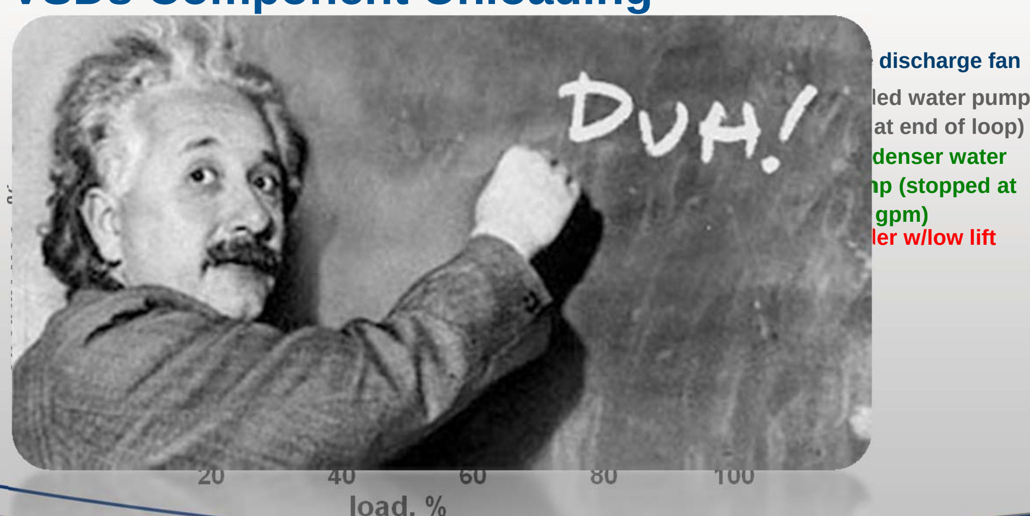
98 | © 2013 Trane, a business of Ingersoll-Rand

Proper component capacity control
Classic Condenser System Control Methods

Pros	Cons
Fixed Temperature ▪ Familiar ▪ Easily understood	▪ Ignores load vs lift and wet bulb opportunities ▪ Prone to control instability
Fixed approach to wet bulb ▪ Recognizes importance of WB	▪ Ignores tower approach variation ▪ Only minimizes chiller lift
Chiller condenser pressure ▪ Keeps the chiller happy (maybe)	▪ Ignores component unloading curves and wet bulb opportunity

99 | © 2013 Trane, a business of Ingersoll-Rand

VSDs Component Unloading



100 | ©2013 Trane, a business of Ingersoll-Rand

Proper component capacity control
Load based control

Pros
- Effectively allocates components power
- Naturally scales lift to load
- Eliminates temperature based control instability
- Provides predictive operation which enhances control stability

Cons
- Must be constrained based on component limitations
- Must be effectively understood and explainable by operators

Proper component capacity control
Load based control

- System load determination
  - Chilled water system load measurement*
  - Condenser water system load measurement
  - Communicated from the chiller unit controls

* Reference ASHRAE Guideline 22 – Instrumentation for Monitoring Central Chilled-Water Plant Efficiency

Component and System Limits

- Component
  - Cooling towers
  - Chillers
  - Condenser water pumps
  - Chilled water pumps
- System
  - Algorithm understanding
  - Operator education

103 |

Cooling Tower Limits

- Approach
  - Decreases with load
  - At a constant load, increases with reduced wet-bulb temperature
- Minimum fan speed
- Tower water flow rate
  - Minimum for normal operation
  - Freeze prevention

104 |

Chiller Limits

- Evaporator and condenser flow rates
- "Lift"
  - Depending on
    - Leaving condenser water temperature
    - Leaving evaporator water temperature
    - Evaporator and condenser approach temperatures
  - Maximum (and surge)
  - Minimum

105 |

Condenser Water Pump Limits

- Pump minimum speed
- Minimum flow rate
  - Cooling tower minimum
  - Chiller condenser minimum
  - Tower lift

106 |

Chilled Water Pump Limits

- Minimum speed
- Minimum flow
  - Chiller evaporator minimum

Examples of Limits Experienced Due to System Operations

- Surge
  - Condenser water pump and cooling tower fan speed reductions at high wet bulb temperatures
- Poor efficiency
  - Condenser water flow rate below tower minimum flow rate

Agenda

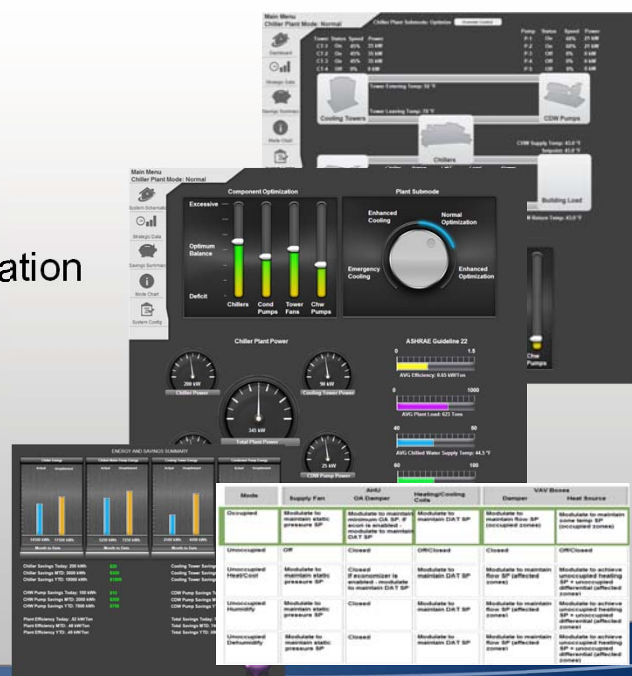
engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

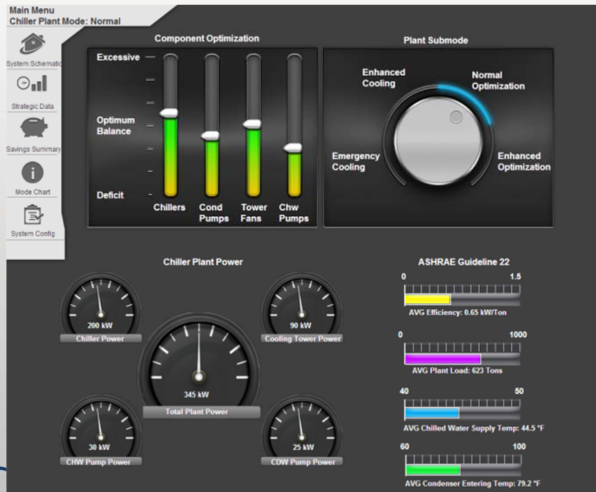
Variable Speed Chiller Plant
User Interaction

System Dashboards

- Overview of system operation
- System schematics
- Performance summaries
- Tuning and intervention
- Mode charts
- Trends & reports



System Operation



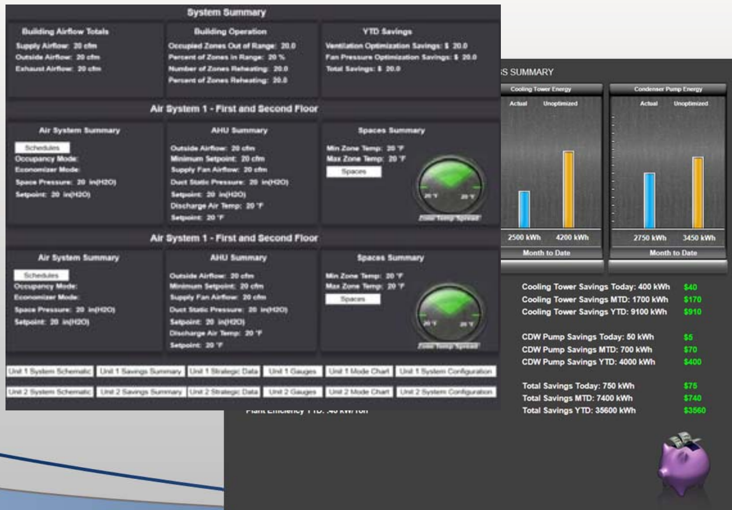
- Schematic system representation
- At-a-glance view of key operating parameters
- Interactive ability to change base sequence and key setpoints
- Quick links to other dashboards

Mode Chart

- Describes behavior of system in different operating modes

Plant Mode	Plant Submode	Component Mode						
		Chillers	Chiller Add	CT Fans	Condenser Water Pumps	CHW Pumps	CHW Setpoint	Bypass Valve
Off		Off	N/A	Off	Off	Off	Design	Open
Startup		Soft Start	Return water cooling rate	Temperature control mode (default)	Design Flow	Delta P	Design	Modulate to maintain minimum flow
Normal	Optimizing	Optimized Loading	Opt	Power Allocation/Max Cells	Power Allocation	Standard Critical Valve Reset (2 zones)	Load Based reset - delta T compensation	Modulate to maintain minimum flow
	Operator Override Enhanced Cooling	Optimized Loading	Meets chw setpoint	Power Allocation/Max Cells	Power Allocation	Min Critical Valve Reset (1 zone)	Design	Modulate to maintain minimum flow
Adative Control	Chiller Low Limit	Optimized Loading	Opt	Temp Limit/fan cycling	Refrigerant Delta P limit	Standard Critical Valve Reset (2 zones)	Load Based reset - refrigerant DP compensation	Modulate to maintain minimum flow
	Tower Freeze Protection	Optimized Loading	Opt	Power Allocation/Temp Limit/Match HX	Design Flow	Standard Critical Valve Reset (2 zones)	Load Based reset - delta T compensation	Modulate to maintain minimum flow

Building Summary Pages



- At-a-glance view of key operating parameters for overall building, chilled water system and each air system
- Tabular view of energy and dollar savings for building
- Quick links to other dashboards

Agenda

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- Application to existing systems

Applying AVS to Existing System – Take Stock

- What have you inherited (what must you keep)
- What are you replacing (what could you replace)
- What are the constraints of the original design
  - Flow rates
  - Equipment limits
  - Configuration

115 |

Fundamentally…

- Adding variable flow to a high flow system turns it effectively into a low flow system – some of the time
  - What are the chiller limits
  - Pump and tower limits
- Are you adding a drive to a chiller?
- Blend of old and new, variable and constant speed, and/or some chillers with higher lift capability

116 |

System Capability Check – Options

- Call the chiller, tower and pump manufacturers
- Turn the condenser flow down until it surges
  - What happens to the tower fill? Can you tell?
- Turn the condenser flow down until the pump “makes too much noise”?
  - Is this the limit on the pump turndown?
  - Are you doing this with a VSD pump or with a valve?
  - Can the pump motor be fitted with a VSD or not?

The Importance of Chiller Selection

- Chillers selected for 2 gpm_c/ton can run at 3
- Chillers selected for 3 gpm_c/ton cannot probably run at 2 all the time
  - Are you replacing your cooling tower for one with a tighter design approach?
  - Is there a potential modification to the chiller – reselect and re-nameplate at higher amps
  - Would you trade some chilled water reset (spare lift available)
- Buying a new chiller or a new tower?

Rebalance flow/temp with same tower

- For a tower originally selected for 3 gpm_c/ton and 85°F setpoint
- Lower flow rate effects tower performance
  - Tower leaving water temperature will be colder
  - Chiller leaving condenser water will be warmer

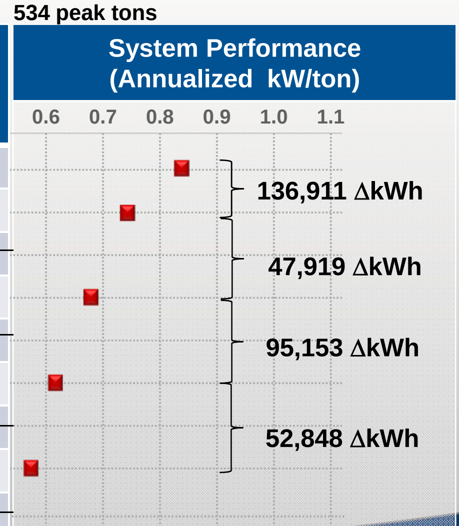
GPMc/ton	Entering Cond.	Leaving Cond.	Delta T (Range)
3	85	94.4	9.4
2.8	84.7	94.8	10.1
2.6	84.4	95.3	10.9
2.4	84.1	95.9	11.8
2.2	83.7	96.6	12.9
2.0	83.3	97.5	14.2

119

Low-flow System-Optimized
Annualized System Performance

Chicago Hospital, no econ:
1369115 ton-hours
534 peak tons

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Estimated Cost
CS	1 Spd	3	CF	85°F	Base
CS	1 Spd	3	CF	Opt	$15,000
~~CS~~	~~VS~~	~~3~~	~~CF~~	~~85°F~~	~~$3,000~~
CS	VS	3	CF	Opt	$18,000
~~VS~~	~~VS~~	~~3~~	~~CF~~	~~85°F~~	~~$38,000~~
VS	VS	3	CF	Opt	$53,000
~~VS~~	~~VS~~	~~2~~	~~CF~~	~~Opt~~	~~New chiller~~
VS	VS	3	VF	Opt	$65,000
~~VS~~	~~VS~~	~~2~~	~~VF~~	~~Opt~~	~~New chiller~~

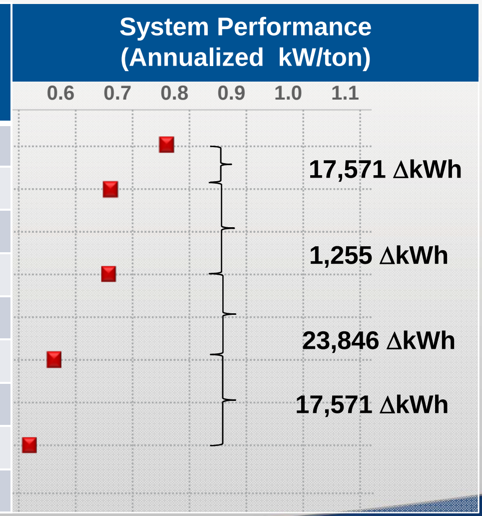


120

Albuquerque – (4B) Office Economizer

Albuquerque office, econ:
251, 017 ton-hours
244 peak tons

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Estimated cost
CS	1 Spd	3	CF	85°F	Base
CS	1 Spd	3	CF	Opt	$10,000
~~CS~~	~~VS~~	~~3~~	~~CF~~	~~85°F~~	~~$1,200~~
CS	VS	3	CF	Opt	$11,200
~~VS~~	~~VS~~	~~3~~	~~CF~~	~~85°F~~	~~$25,000~~
VS	VS	3	CF	Opt	$36,200
~~VS~~	~~VS~~	~~2~~	~~CF~~	~~Opt~~	
VS	VS	3	VF	Opt	$46,400
~~VS~~	~~VS~~	~~2~~	~~VF~~	~~Opt~~	



121 | © 2013 Trane, a business of Ingersoll-Rand

Where are the opportunities?

- Buildings with year-round loads
  - Load driven by internal loads
  - Buildings without airside economizing
- Systems with high condenser flow rates (2.8 gpm per ton or higher)
  - With or without new chillers going in if the existing chillers can be reselected at lower condenser flows

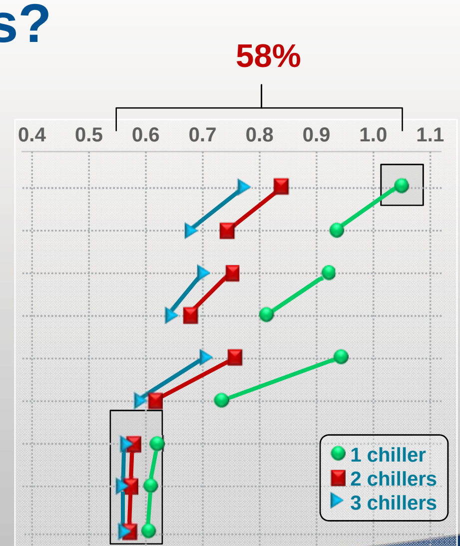
122 | © 2013 Trane, a business of Ingersoll-Rand

Where are the opportunities?

- Systems with constant speed cooling towers or 2-speed fans
  - Drive retrofits are very attractive financially and provide better stability over 2-speed towers
- Oversized plants with lots of extra chiller capacity and flow rates – auxiliary power is high proportion of total

Where are the opportunities?

- Constant speed single-chiller installations – 58% improvement
- Installing a new air-cooled chiller
  - Variable speed air-cooled chillers optimization is “in the box”
  - System integration complexity reduced or eliminated



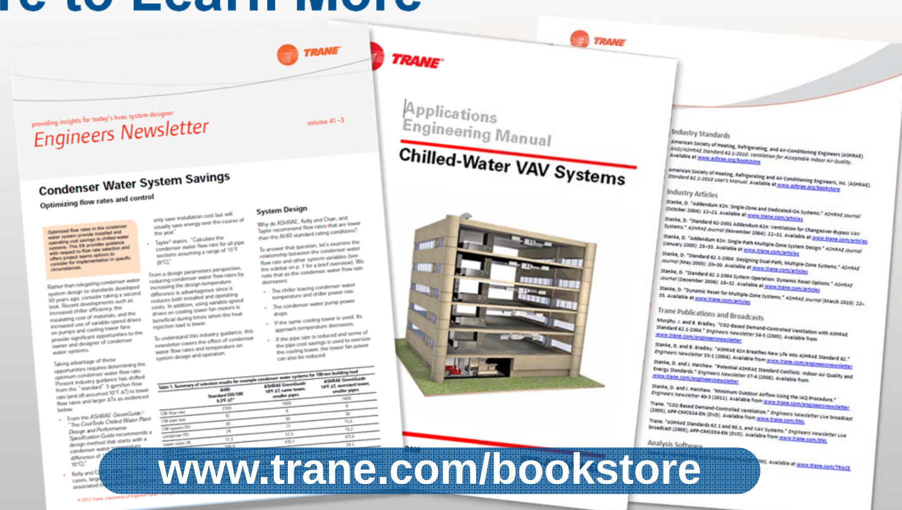
Agenda

engineers newsletter LIVE

- History of variable-speed drive (VSD) use in chiller plants
  - Potential efficiency of chiller plants?
  - VSDs impact on HVAC components
  - Existing system review
- System configuration examples – what's the payoff?
- All variable-speed chiller plant operation
- User interaction
- **Application to existing systems**

125 |

references for this broadcast
Where to Learn More



www.trane.com/bookstore

126 |

www.trane.com/ENL

Past programs include:

- Air-to-Air Energy Recovery
- ASHRAE Standards 189.1, 90.1, 62.1
- High-performance VAV Systems
- Chilled-water plants
- WSHP/GSHP systems
- Control strategies
- USGBC LEED®
- Energy and the environment
- Acoustics
- Ventilation
- Dehumidification
- Ice storage
- Central geothermal systems

EDUCATION PROVIDER

GBCI CMP

LEED Continuing Education Courses

on-demand, no charge, 1.5 CE credits

- ASHRAE Standards 62.1 and 90.1 and VAV Systems
- ASHRAE Standard 62.1: Ventilation Rate Procedure
- ASHRAE Standard 90.1-2010
- ASHRAE Standard 189.1-2011
- High-Performance VAV Systems
- Single-Zone VAV Systems
- Ice Storage Design and Control
- Energy Saving Strategies for WSHP/GSHP Systems

GBCI CMP

EDUCATION PROVIDER

www.trane.com/ContinuingEducation

Join Us in 2014

- LEED v4
- Applying Variable Refrigerant Flow (VRF)
- Energy-saving Strategies for Chilled-water Terminal Systems

129 |

TRANE®

All-Variable-Speed Chilled-Water Plants

engineers newsletter LIVE

Ingersoll Rand