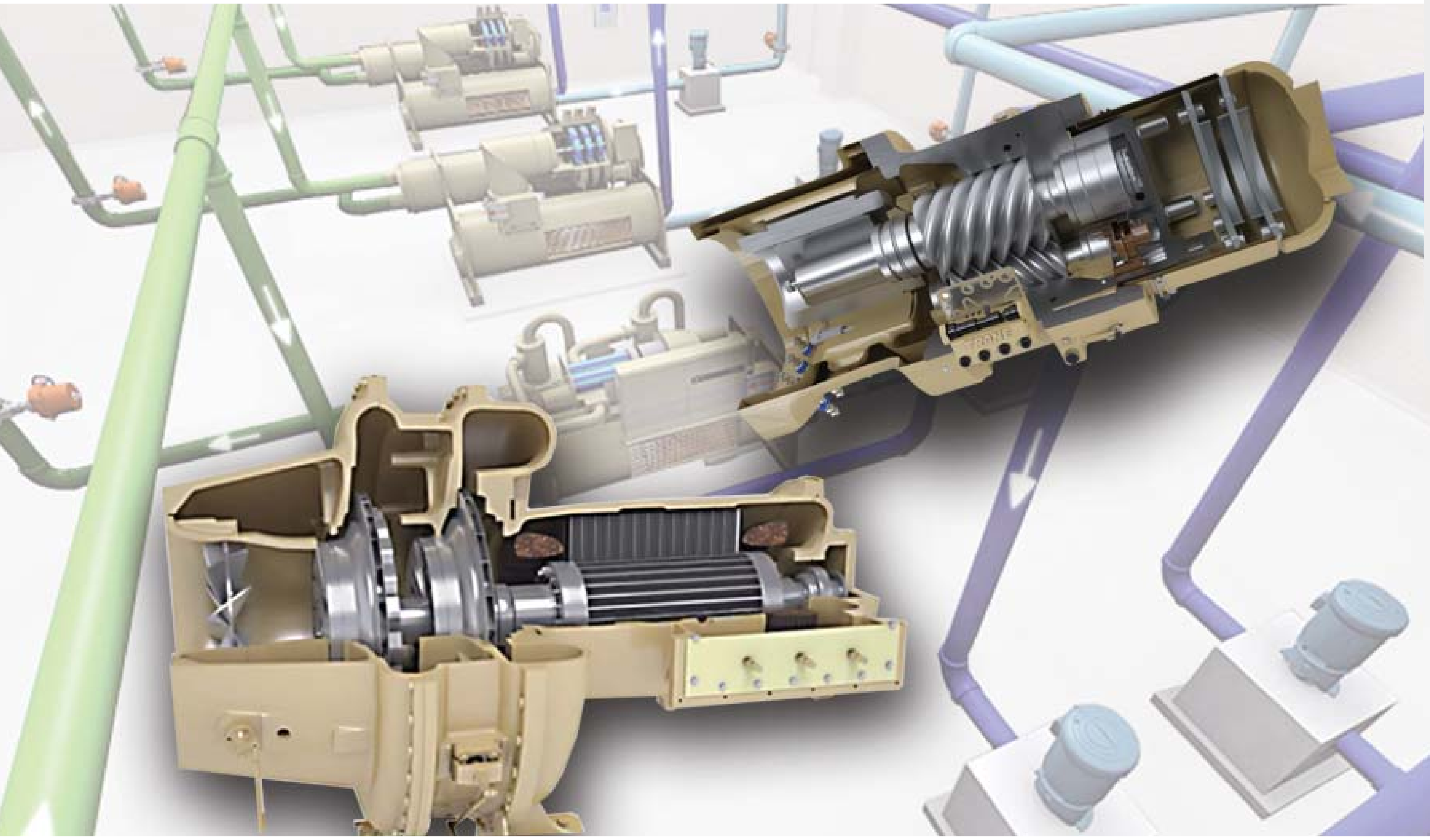
Trane Engineers Newsletter Live

Variable-Speed Compressors on Chillers

Presenters: Lee Cline, Brian Sullivan, Mike Filler, Mick Schwedler, Jeanne Harshaw (host)



Ingersoll Rand

TRANE

Agenda

Trane *Engineers Newsletter Live* Series

Variable-Speed Compressors On Chillers

Abstract

This ENL discusses the operational, performance and application differences for centrifugal (dynamic compression) and helical-rotary (positive displacement) compressors. Discussion includes an overview of how variable-speed drives affect chilled-water system components, physics of centrifugal compressor chillers and screw compressor chillers, applications that benefit from each technology, importance of proper life-cycle analysis supported by examples and application considerations. Attendees will leave with an understanding of which technologies bring real value to different system applications.

Presenters: Trane engineers Brian Sullivan, Lee Cline, Mick Schwedler and Mike Filler

After viewing attendees will be able to:

1. Summarize the effects of VFDs on centrifugal and screw compressors in terms of physics (load/lift and performance)
2. Identify applications that offer customer benefits for each technology
3. Understand the importance of accurate life-cycle analysis (and provide examples)
4. Application considerations

Agenda

- Effects of variable-speed drives (VSDs) on chilled-water systems
- Physics of VSDs on centrifugal compressor chillers
  - Physics (lift vs. load)
  - Performance (work)
- Physics of VSDs on screw compressor chillers
  - Physics (lift vs. load)
  - Performance (work)
- Applications that benefit from each technology
- Importance of life-cycle analysis
- VSD chiller application considerations
- Summary

Ingersoll Rand

Presenter biographies

Variable-Speed Compressors on Chillers

Brian Sullivan | systems engineer | Trane

Brian Sullivan is a staff engineer in the Systems Engineering group specializing in chilled-water plant optimization. He started at Trane in 1976 as a laboratory engineer and has since held various positions in research, product development, and engineering management with most of his experience with product development for the centrifugal product line.

Brian earned his Bachelors degree in mechanical engineering from the University of Missouri at Rolla. He is a member of ASHRAE and past chair for the water-cooled AHRI engineering committee.

Mike Filler | product manager | Trane

Mike Filler is the Product Manager for Trane Water-Cooled Rotary Chillers, based in Pueblo, Colorado. Mike started his career with Trane, training and supporting design and analysis software, such as TRACE™ 700. He has since held roles internally and externally in various applications, marketing and product support positions.

Mike graduated from Clarkson University with a Mechanical Engineering degree in 2000 and recently completed an MBA with Indiana University. He is a Registered Professional Engineer in the state of Colorado and an ASHRAE-certified High-performance Building Design Professional.

Mick Schwedler | applications engineer | 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. Mick provides one-on-one support, writes technical publications, and presents seminars.

A recipient of ASHRAE's Distinguished Service and Standards Achievement Awards, Mick Chairs ASHRAE's Advanced Energy Design Guide (AEDG) Steering Committee and is past Chair of SSPC 90.1. He also contributed to the ASHRAE GreenGuide and is a member of the USGBC Pilot Credits Working Group. 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 | systems 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.

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Learning objectives

- Summarize how VSDs effect centrifugal and screw compressors (physics, load/lift characteristics and performance)
- Identify applications that offer customer benefits for each technology
- Understand how to properly model variable-speed chillers in TRACE™ 700
- Identify application mistakes to avoid

AGENDA

- Effects of VSDs on chilled-water system components
- Physics of VSDs on centrifugal compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Physics of VSDs on screw compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Applications that benefit from each technology
- Importance of life-cycle analysis
- VSD chiller application considerations

Today's Presenters

Mike Filler
Product Manager, screw and scroll chillers

Brian Sullivan
Systems Engineer

Lee Cline
Systems Engineer

Mick Schwedler
Applications Engineering Manager

AGENDA

- **Effects of VSDs on chilled-water system components**
- Physics of VSDs on centrifugal compressor chillers
  - Physics – lift vs. load
  - Performance (work)
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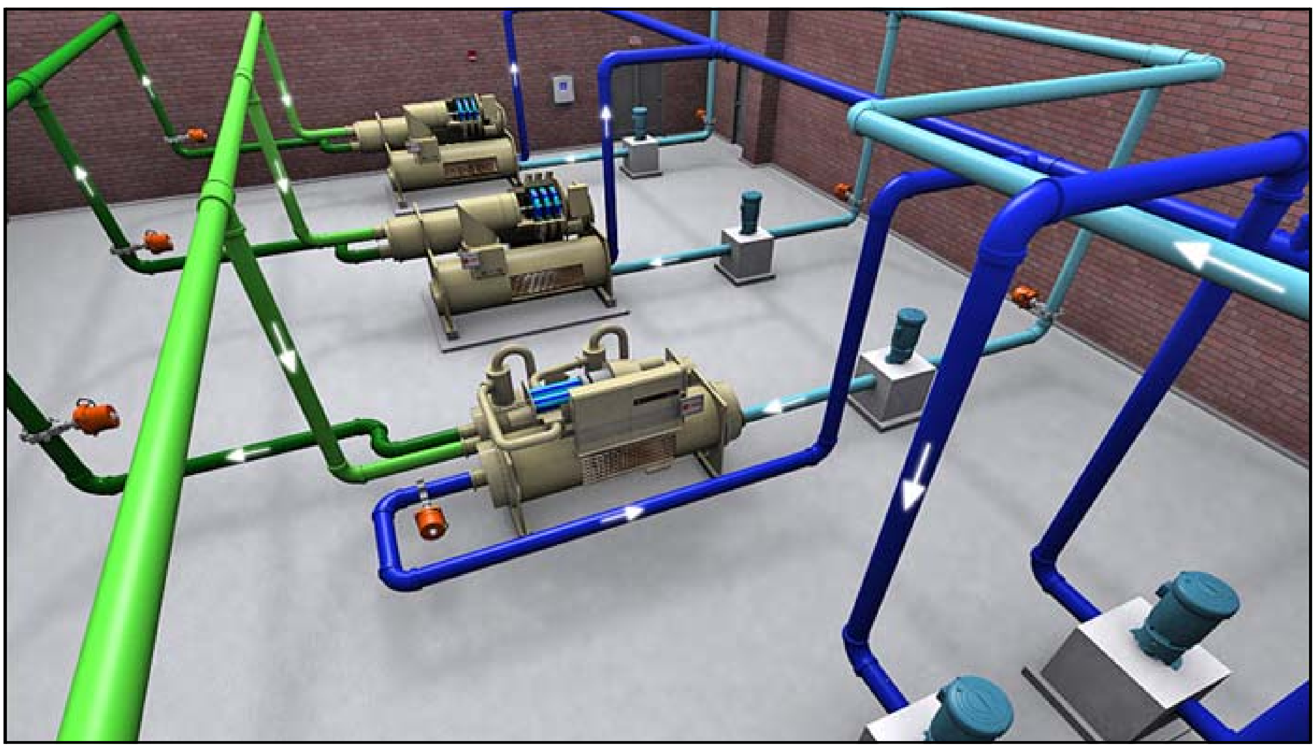
Affinity Laws

2012 ASHRAE Handbook HVAC Systems and Equipment

1. “Flow (capacity) varies with rotating speed”
2. “Head varies as the square of the rotating speed”
3. “Brake horsepower varies as the cube of the rotating speed”

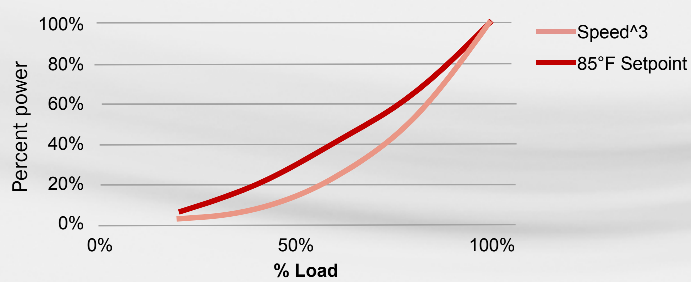
“The (third) affinity law assumes that the system curve is known and that head varies as the square of the flow.”

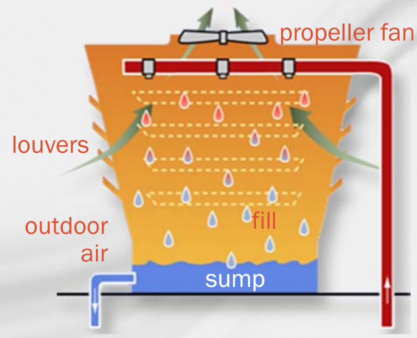
Many systems don’t follow this assumption



2006 ENL Summary
VSDs and Their Effect on System Components

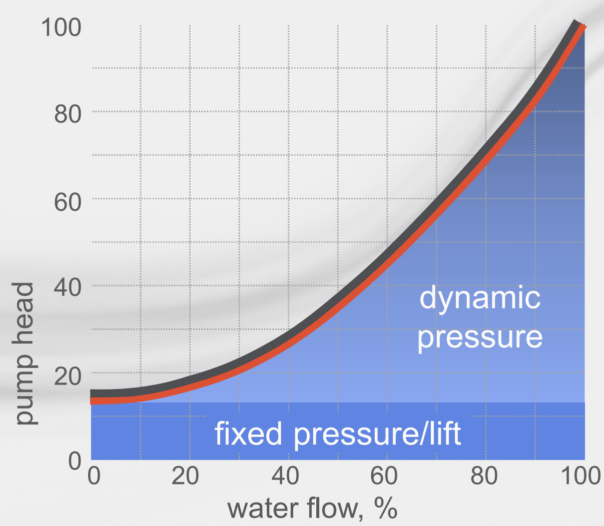
- Cooling tower fans –
  Load/power curve *nearly* cubic





2006 ENL Summary
Chilled and Condenser Water Pumps

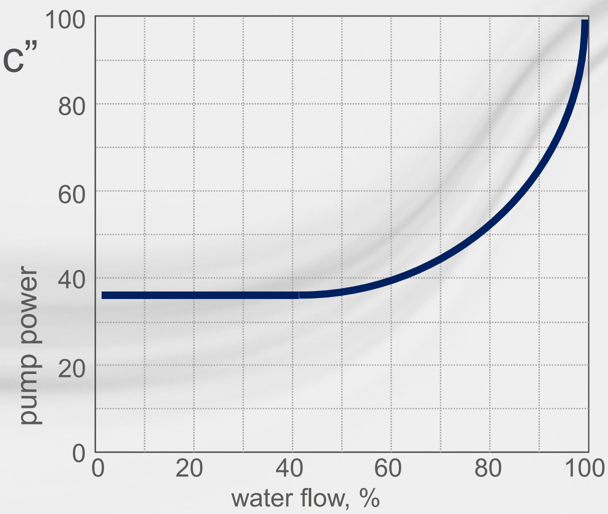
- Head/flow curve not "squared"
  - Control setpoint
  - Cooling tower static "lift"



2006 ENL Summary

Chilled and Condenser Water Pumps

- Power/flow curve not "cubic"
  - DP curve not squared
  - Minimum flow rates

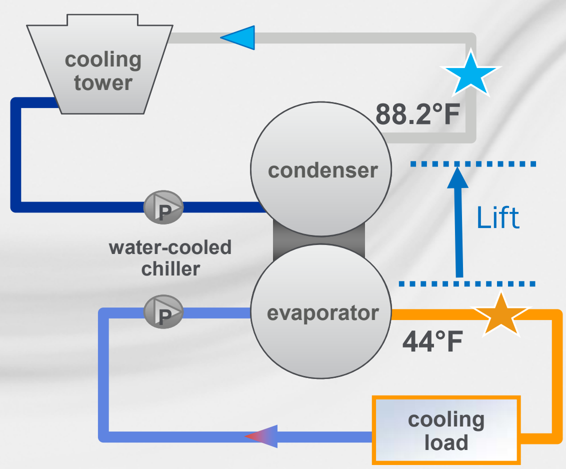


2006 ENL Summary

VSDs and Their Effect on System Components

Variable speed chillers:
Load/power curve not cubic

- Lift depends on system operating conditions
- Power is dependent on load and lift
- The relationship of power changes for different compressor types



AGENDA

- Effects of VSDs on chilled-water system components
- **Physics of VSDs on centrifugal compressor chillers**
  - **Physics – lift vs. load**
  - **Performance (work)**
- Physics of VSDs on screw compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Applications that benefit from each technology
- Importance of life-cycle analysis
- VSD chiller application considerations

Centrifugal Compressors on Chillers

Key Points

- Ideal kW/ton performance is a function of the temperature lift across the chiller
- Fixed speed centrifugal and screw chillers have unloading devices that reduce tonnage and take advantage of reduced lift
- Variable speed modulating capability provides a means to maintain the compression efficiency for chillers as the lift and load is reduced
- We can obtain both fixed speed and variable speed chillers – which is best?

Centrifugal Compressors on Chillers

Terms

- Efficiency (η) = Ideal Power /Power Input
- Ideal Power:

  A Carnot (isentropic) Refrigeration Cycle defines ideal Work (Power):

  $COP_{Carnot} = T_{cold} / (T_{hot} – T_{cold})$

  T_{cold} and T_{hot} are in units of absolute temperature

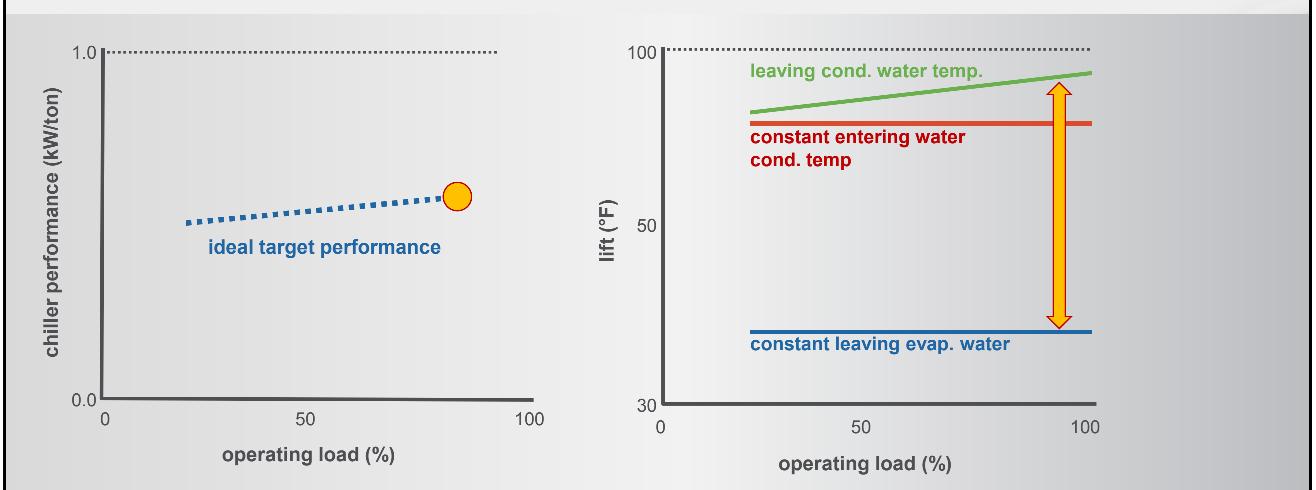
  kW/ton_{Carnot} α $(T_{hot} – T_{cold})/T_{cold}$,

  assuming T_{cold} is constant

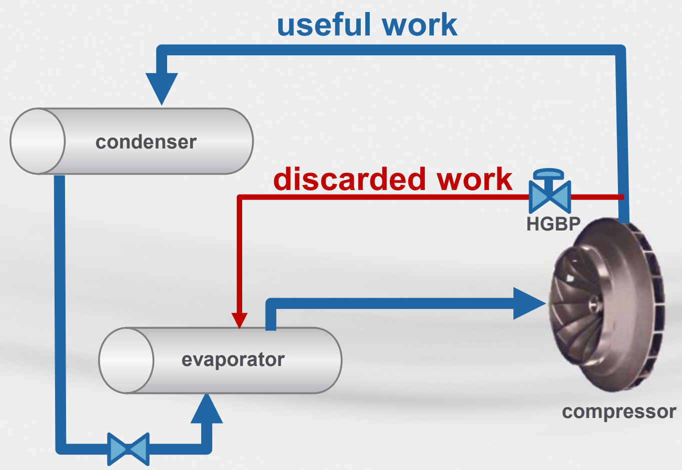
  Ideal Power (kW) α Capacity (tons) * $(T_{hot} – T_{cold})$ (F)

  where “Lift” = $(T_{hot} – T_{cold}) = (T_{Condenser} – T_{Evaporator})$
- Power input (kW) α Capacity (tons) * Lift (F) / Unit Efficiency (η)

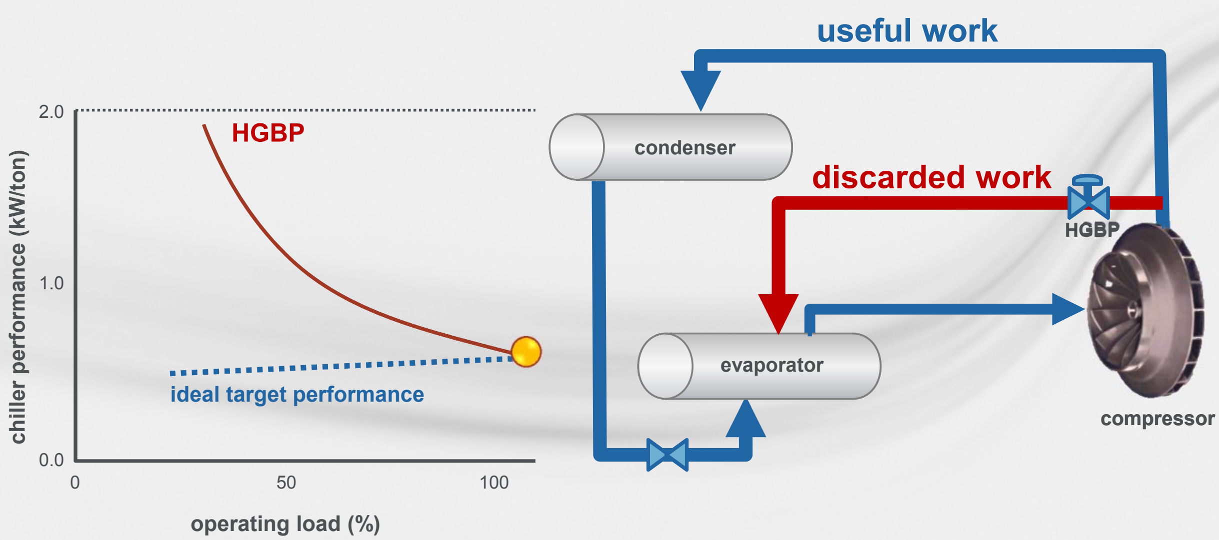
kW/ton Performance vs. Lift



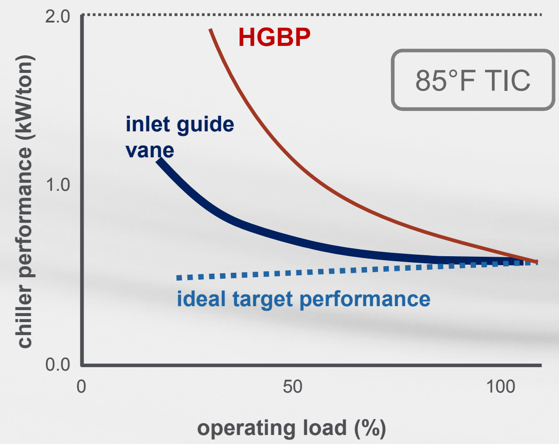
Hot Gas Bypass (HGBP) Cycle

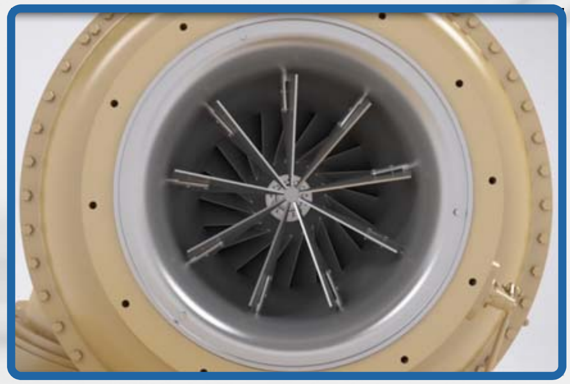


HGBP Performance

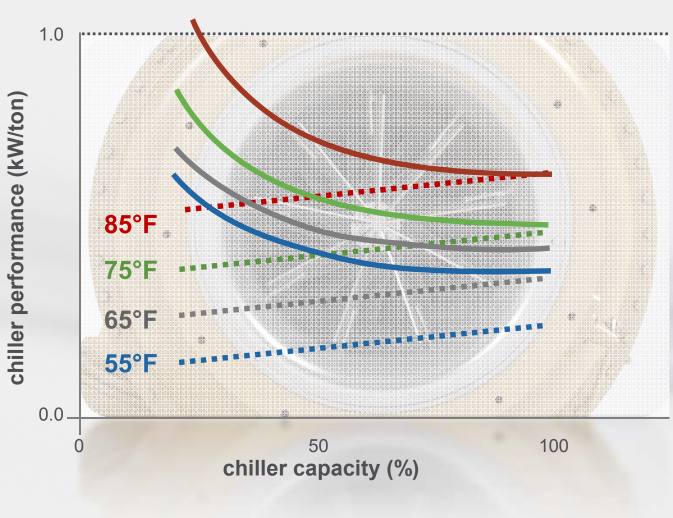


Fixed-Speed Centrifugal Chiller Performance

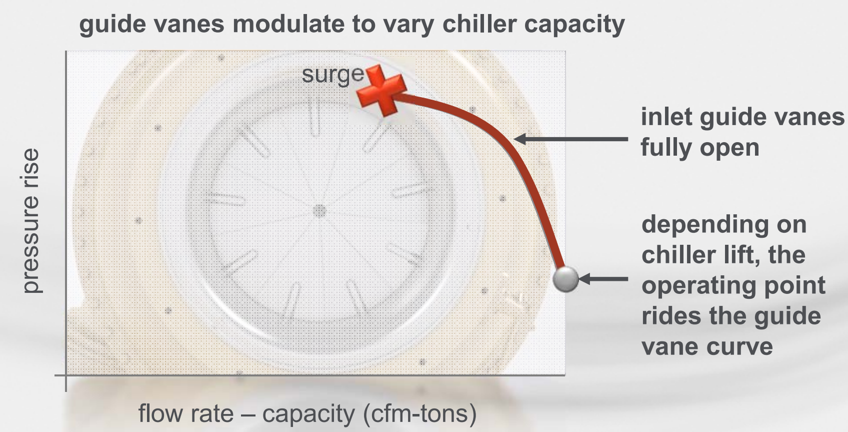




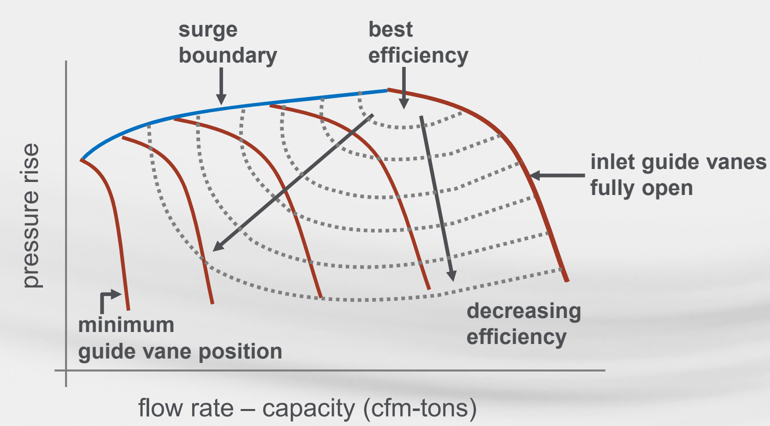
Fixed-Speed Chiller Performance



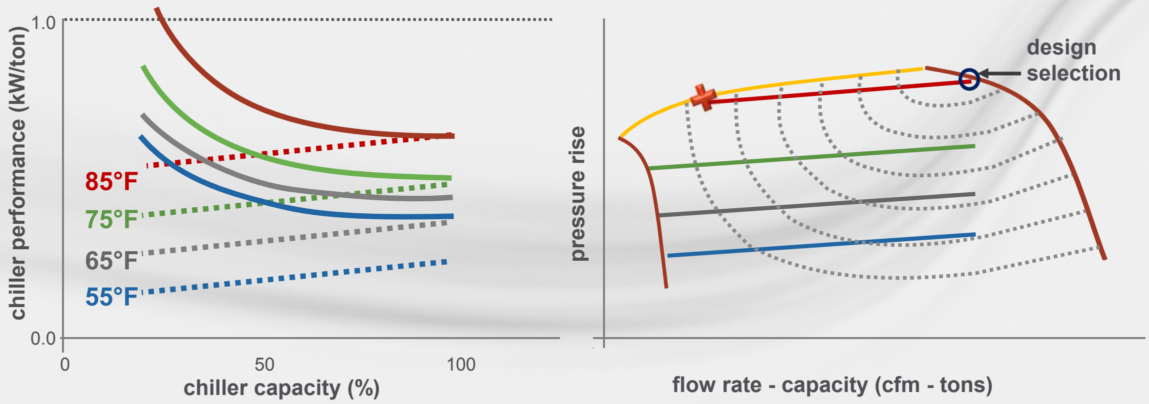
Fixed-Speed Compressor Map



Fixed-Speed Compressor Map



Fixed-Speed Compressor Map

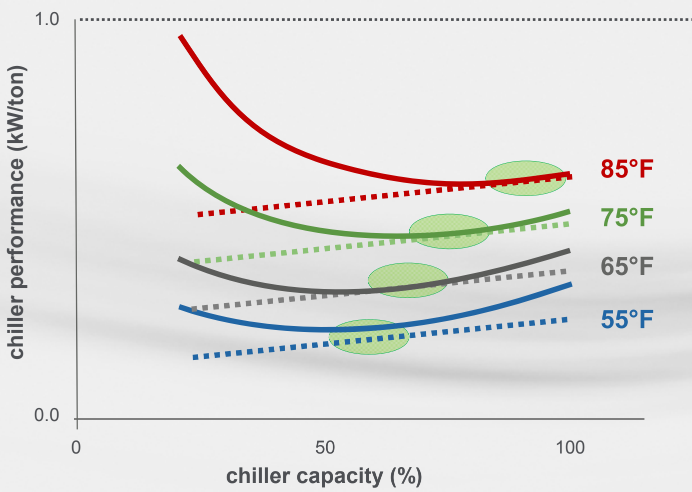


Centrifugal Compressors on Chillers

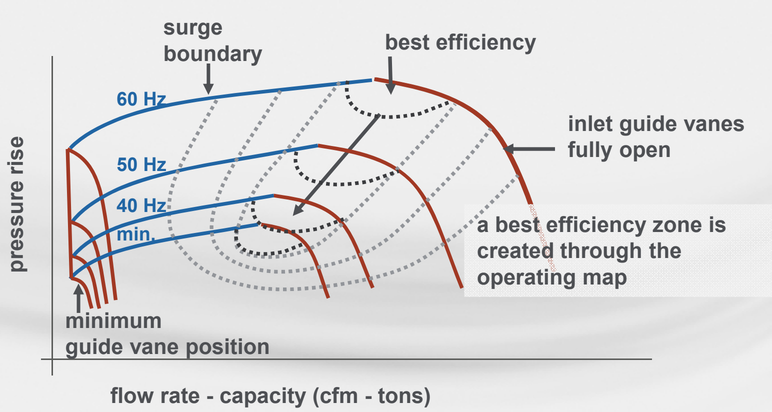
Key Points

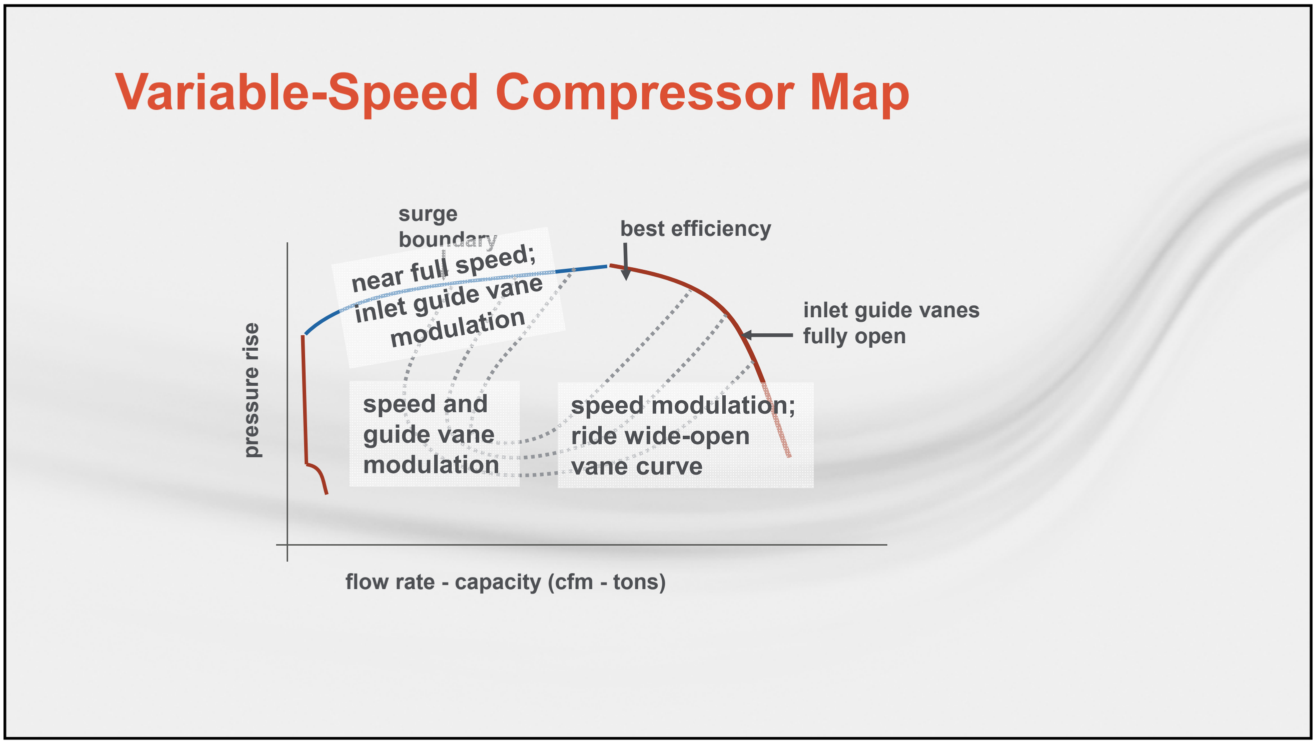
- Ideal and actual kW/ton performance is a function of the temperature lift across the chiller
- Fixed speed centrifugal and screw chillers with mechanical unloading devices effectively reduce tonnage and take advantage of reduced lift

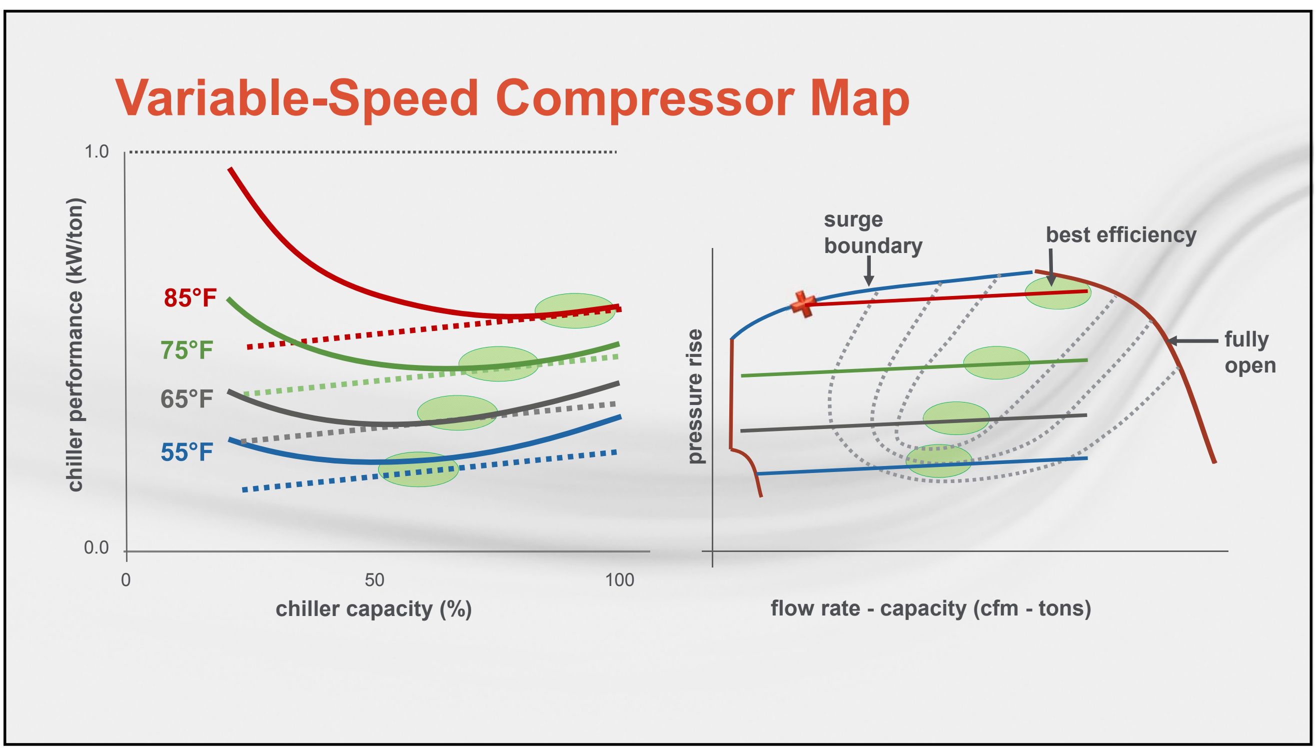
Variable-Speed Centrifugal Chiller Performance

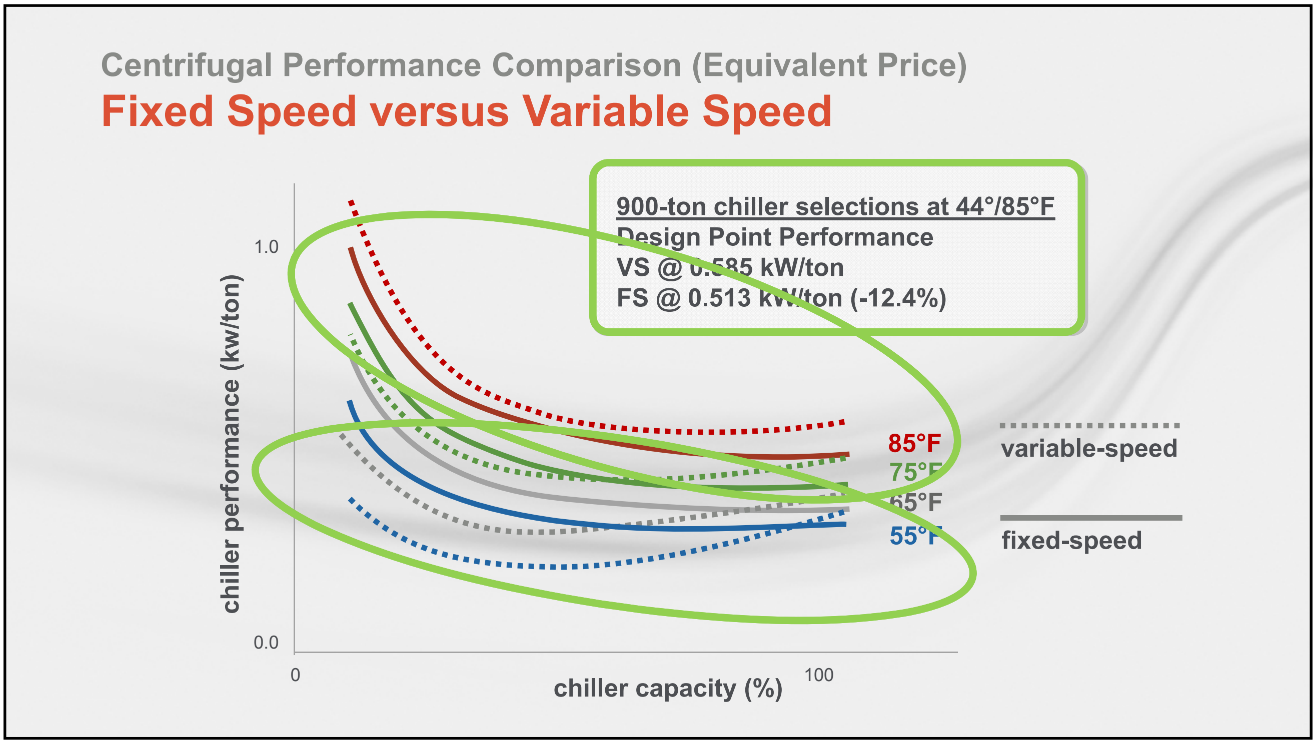


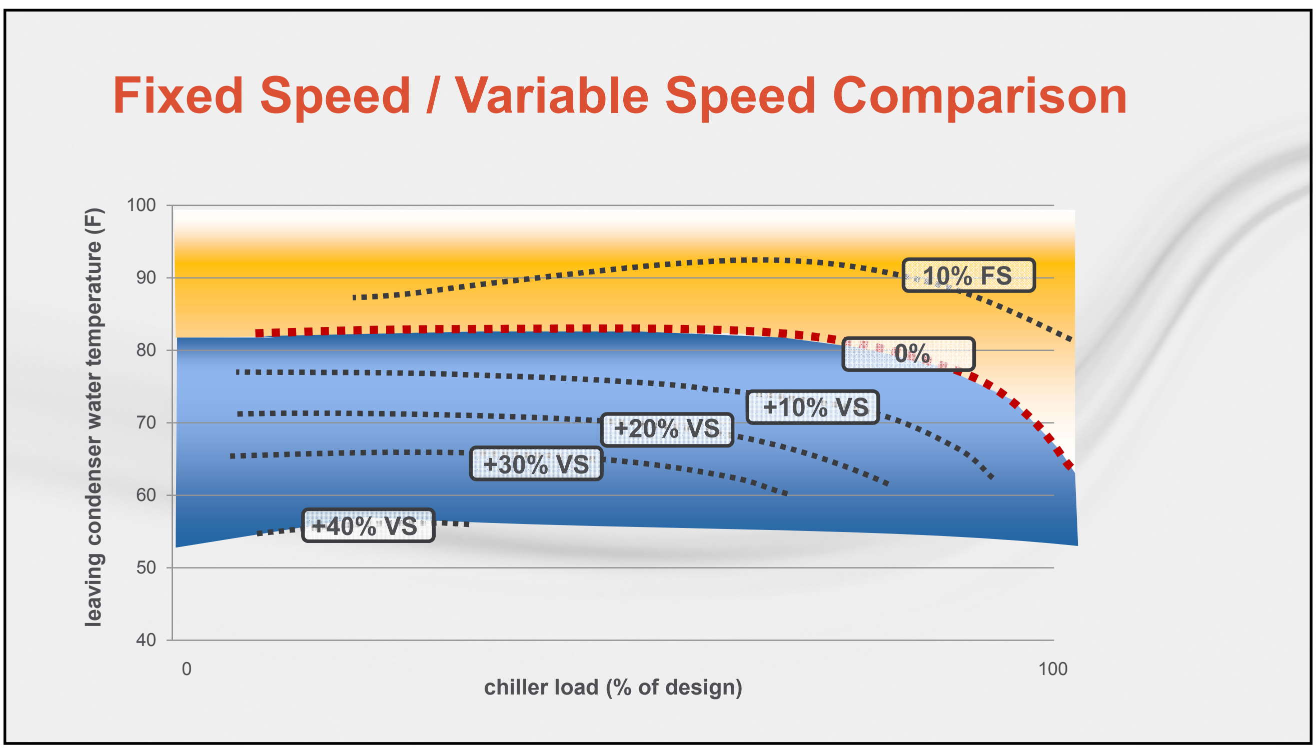
Variable-Speed Compressor Map




Variable-Speed Compressor Map
surge
boundary
best efficiency
near full speed;
inlet guide vane
modulation
inlet guide vanes
fully open
pressure rise
speed and
guide vane
modulation
speed modulation;
ride wide-open
vane curve
flow rate - capacity (cfm - tons)


Variable-Speed Compressor Map
1.0
0.0
chiller performance (kW/ton)
85°F
75°F
65°F
55°F
0
50
100
chiller capacity (%)
surge
boundary
best efficiency
fully
open
pressure rise
flow rate - capacity (cfm - tons)


Centrifugal Performance Comparison (Equivalent Price)
Fixed Speed versus Variable Speed
900-ton chiller selections at 44°/85°F
Design Point Performance
VS @ 0.585 kW/ton
FS @ 0.513 kW/ton (-12.4%)
chiller performance (kw/ton)
1.0
0.0
0
100
chiller capacity (%)
85°F
75°F
65°F
55°F
variable-speed
fixed-speed


Fixed Speed / Variable Speed Comparison
leaving condenser water temperature (F)
100
90
80
70
60
50
40
0
100
chiller load (% of design)
10% FS
0%
+10% VS
+20% VS
+30% VS
+40% VS

AGENDA

- Effects of VSDs on chilled-water system components
- Physics of VSDs on centrifugal compressor chillers
    - Physics – lift vs. load
    - Performance (work)
- **Physics of VSDs on screw compressor chillers**
    - **Physics – lift vs. load**
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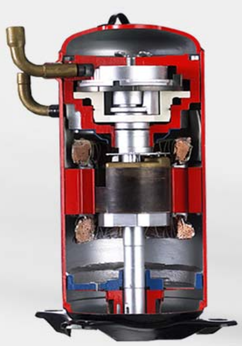
- Applications that benefit from each technology
- Importance of life-cycle analysis
- VSD chiller application considerations

Positive Displacement Compressors

Scroll

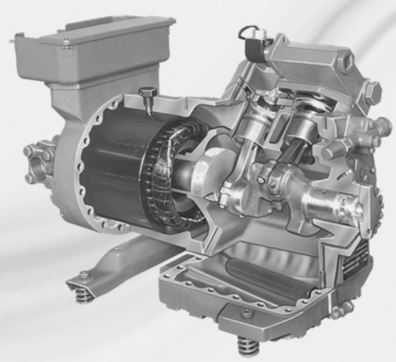


- 10-40 tons
- Few moving parts

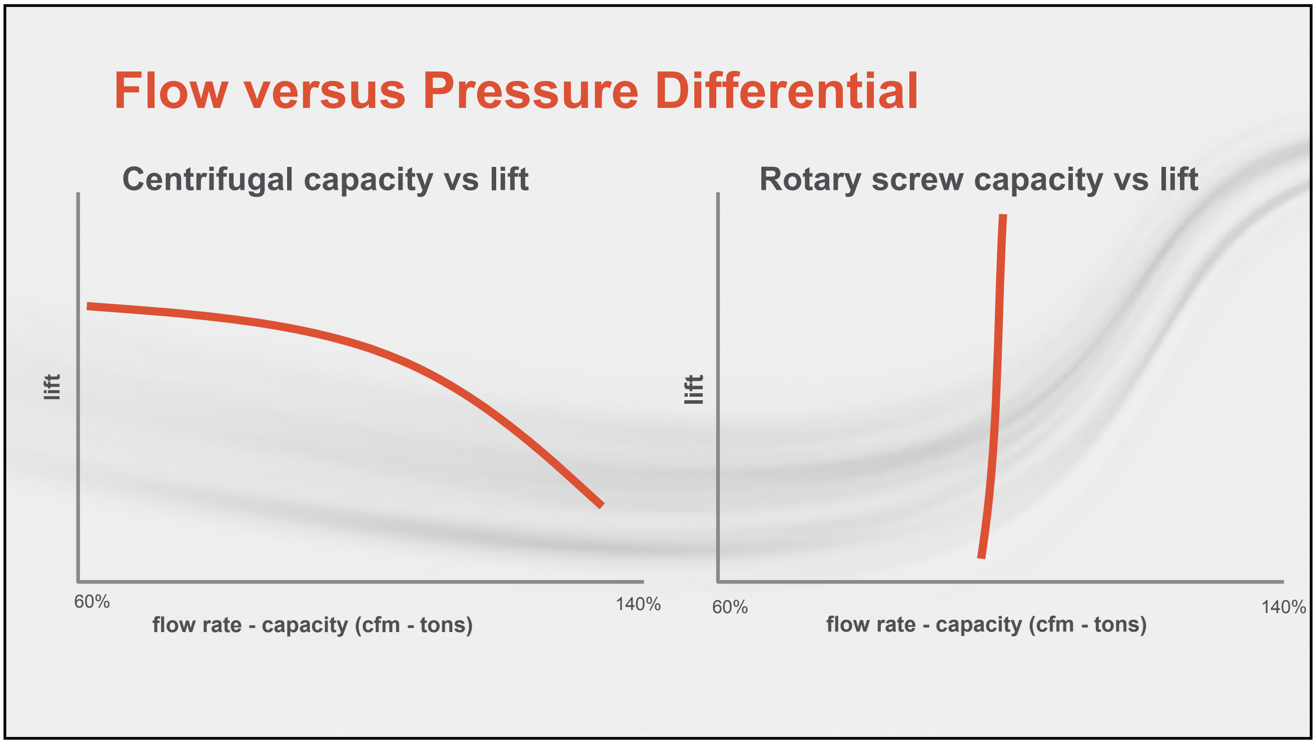
Rotary Screw

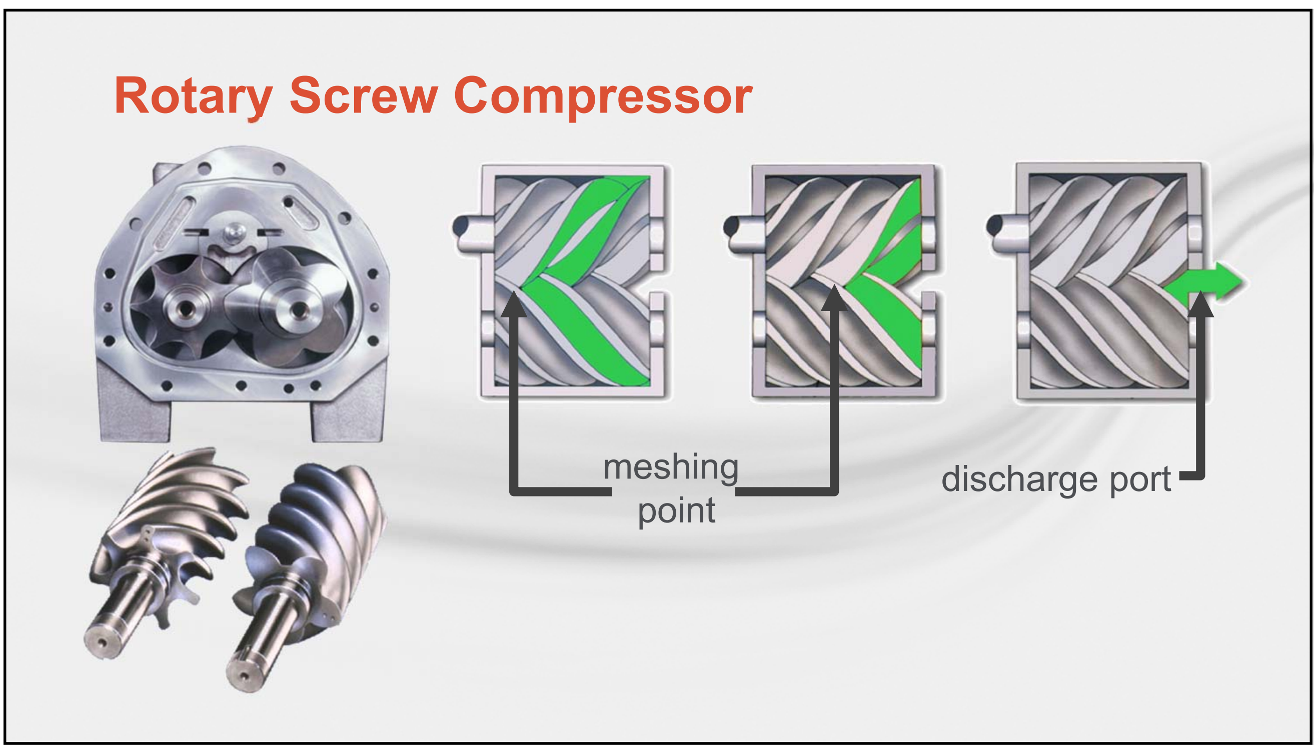
- 35-450 tons
- Few moving parts

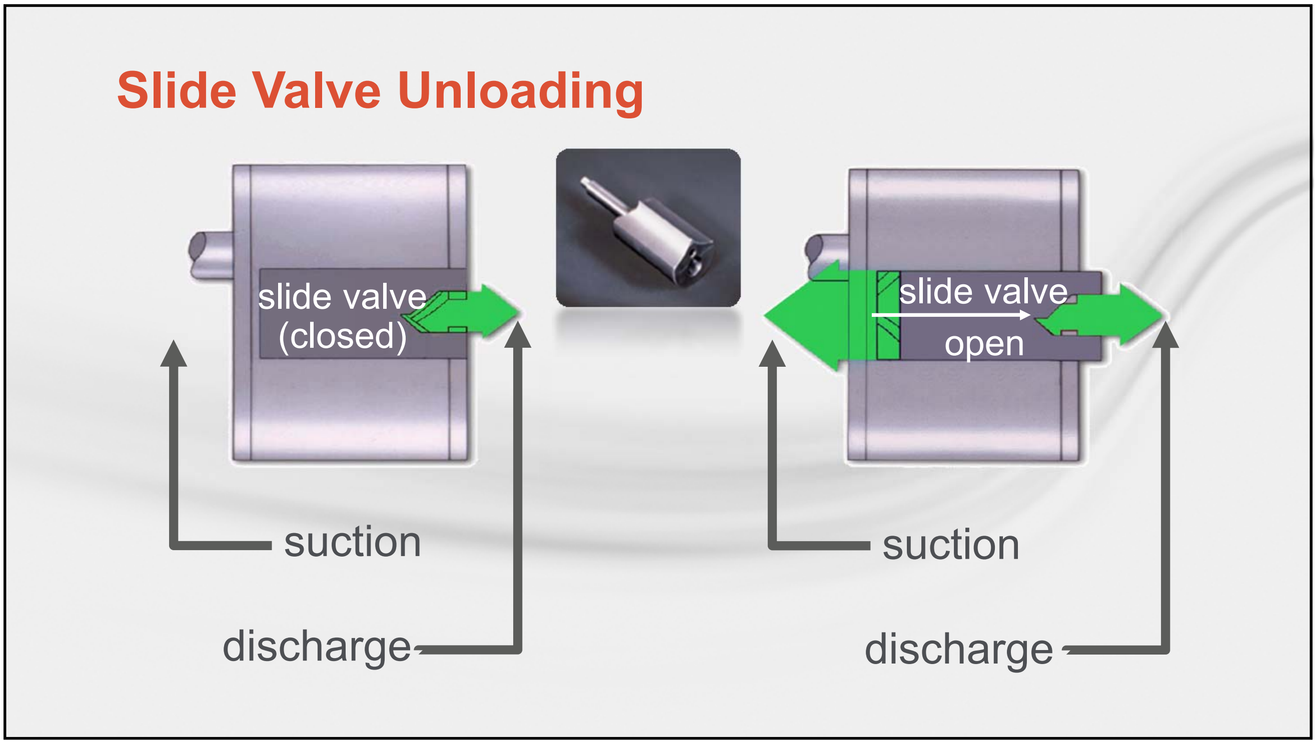
Reciprocating

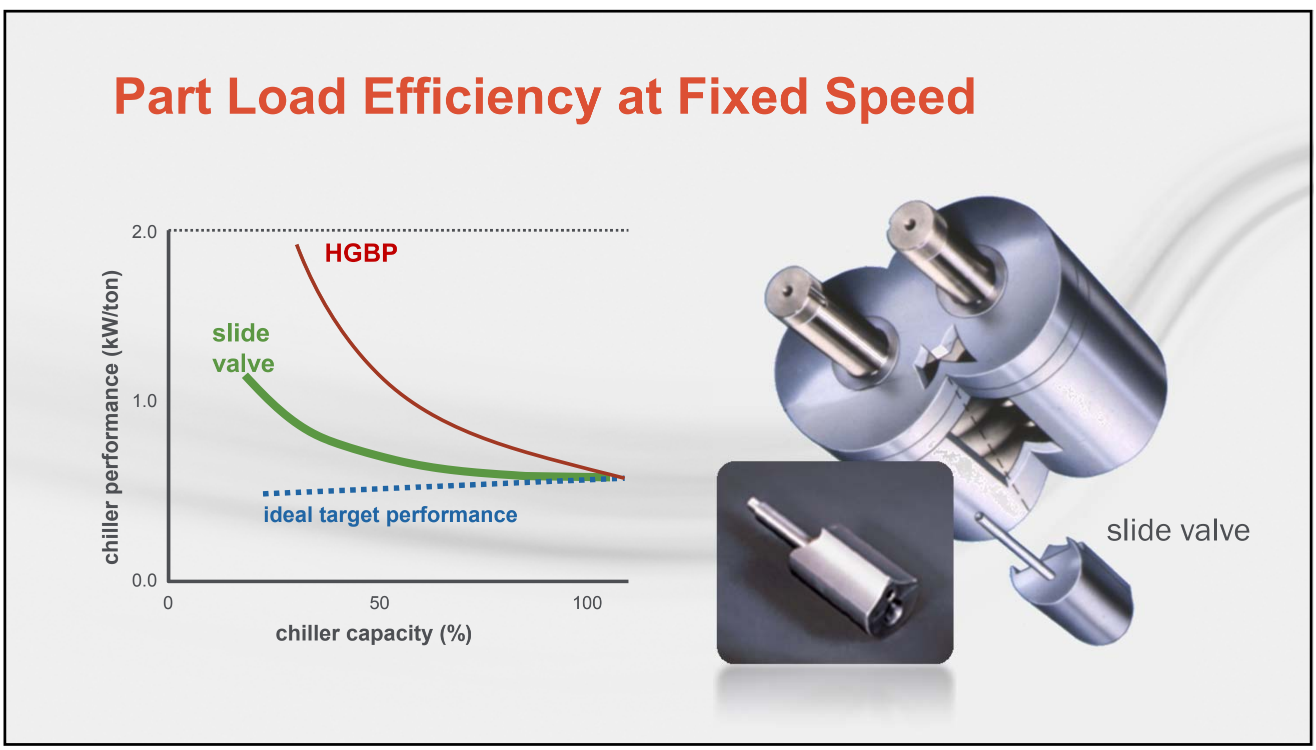


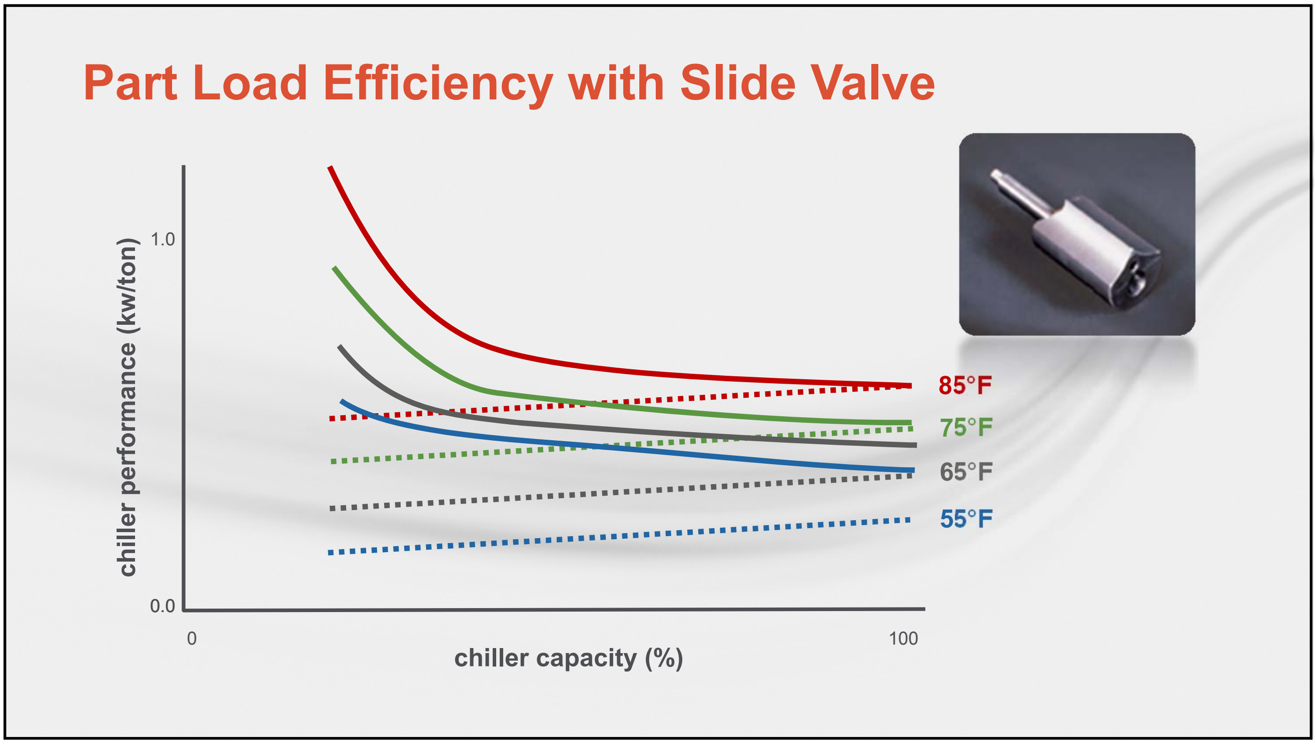
- 10-100 tons
- Many parts

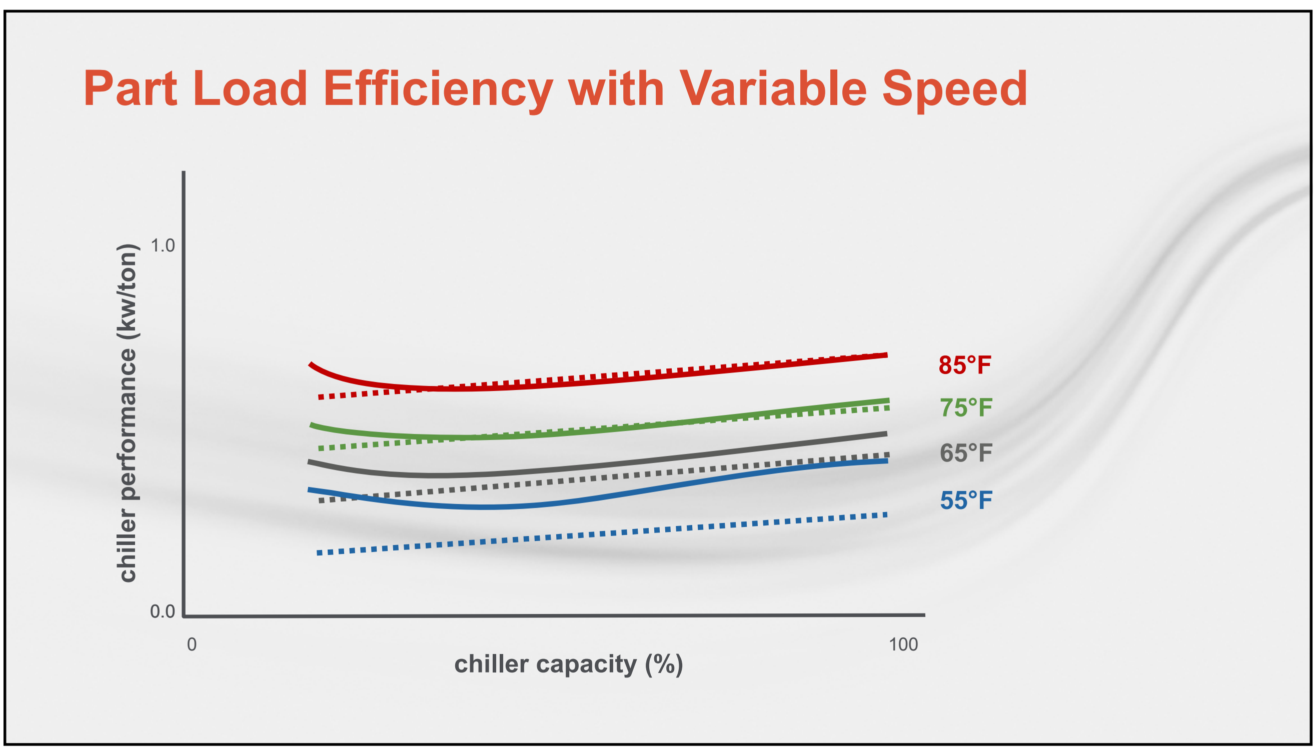

Flow versus Pressure Differential
Centrifugal capacity vs lift
lift
60%
140%
flow rate - capacity (cfm - tons)
Rotary screw capacity vs lift
lift
60%
140%
flow rate - capacity (cfm - tons)

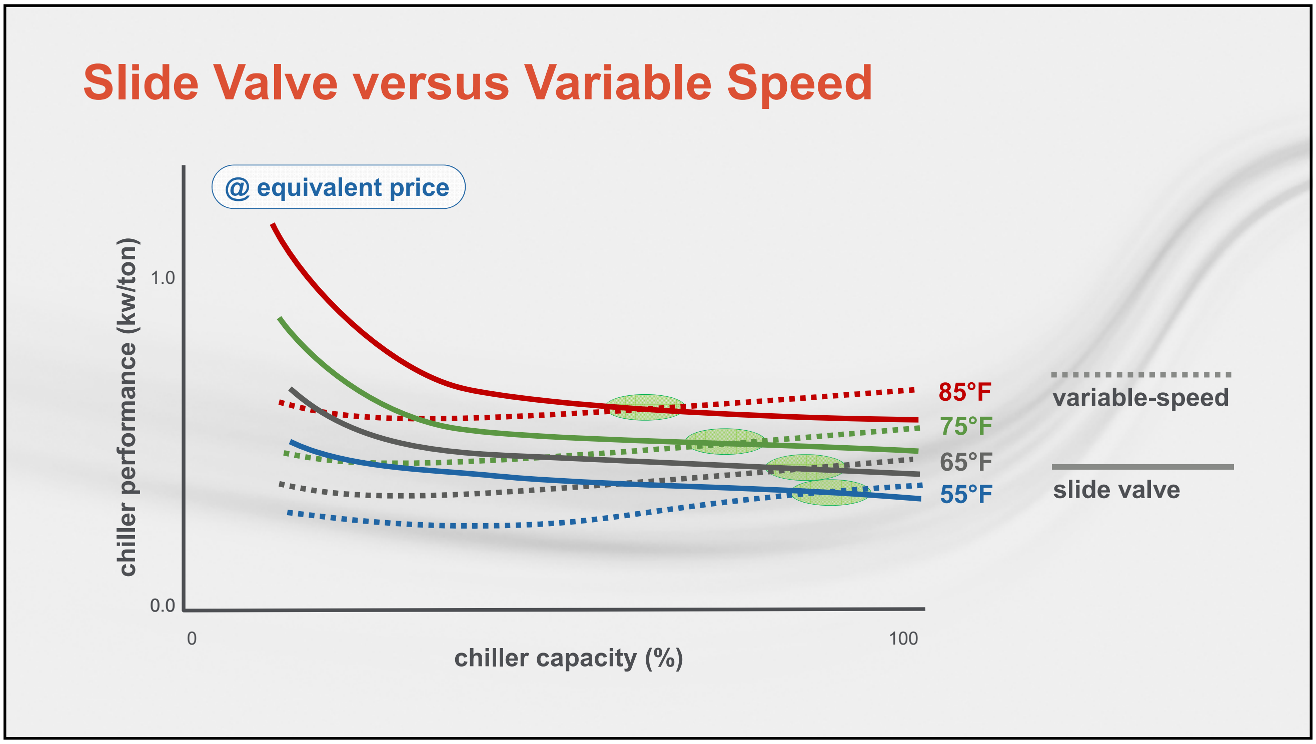

Rotary Screw Compressor
meshing point
discharge port

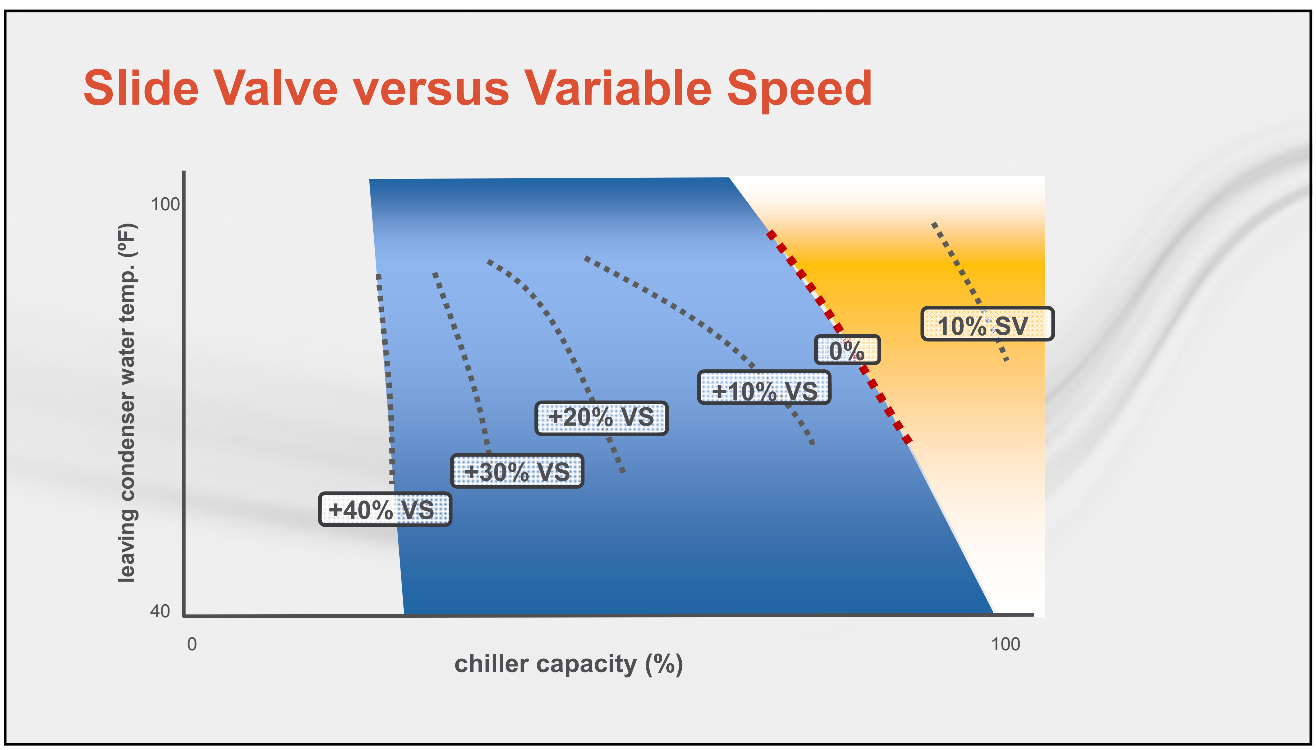

Slide Valve Unloading
slide valve
(closed)
suction
discharge
slide valve
open
suction
discharge


Part Load Efficiency at Fixed Speed
chiller performance (kW/ton)
2.0
1.0
0.0
0
50
100
chiller capacity (%)
HGBP
slide
valve
ideal target performance
slide valve

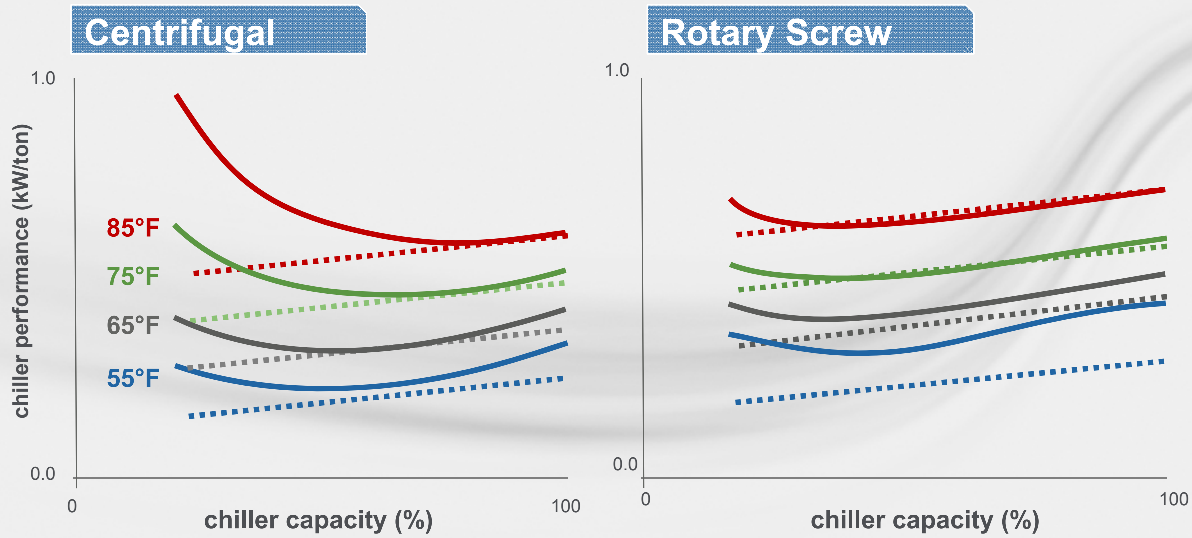

Part Load Efficiency with Slide Valve
chiller performance (kw/ton)
1.0
0.0
0
100
chiller capacity (%)
85°F
75°F
65°F
55°F


Part Load Efficiency with Variable Speed
chiller performance (kw/ton)
1.0
0.0
0
100
chiller capacity (%)
85°F
75°F
65°F
55°F


Slide Valve versus Variable Speed
@ equivalent price
chiller performance (kw/ton)
1.0
0.0
0
100
chiller capacity (%)
85°F
75°F
65°F
55°F
variable-speed
slide valve


Slide Valve versus Variable Speed
leaving condenser water temp. (°F)
100
40
0
100
chiller capacity (%)
+40% VS
+30% VS
+20% VS
+10% VS
0%
10% SV

Variable Speed Centrifugal vs. Rotary



Key Points on Rotary Screw Compressors

- Speed modulation is a function of capacity
- Variable speed efficiently fills gaps in capacity
- If sound levels are important, specify them
- Use life cycle cost analyses for comparing different chillers
- Capacity range of 35-450 tons

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Summary of performance differences

The Physics of Operation are Different

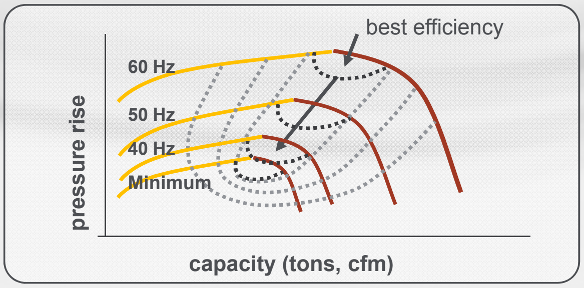
- Centrifugal impellers operate on the principle of dynamic compression
- Rotary compressors operate on the principle of positive displacement
- Unloading Performance may varies greatly for different modulation technologies
- For a given modulation technology the performance across different compressor types is similar

Summary of performance differences

Full Load and Part Load Efficiency

- Reduced *load* and *lift* benefit equally
  - Each reduces the work the compressor has to perform

Power input (kW) α Capacity (tons) * Lift (F) / Unit Efficiency (η)



Summary of performance differences

Full Load and Part Load Efficiency

- Centrifugal compressors are optimized and manufactured per the specified operating conditions
- Screw compressors are selected and applied from discrete families based on required capacity and lift
- Centrifugal chiller's design efficiencies can be better than screw chillers and with normally reduced lift the part load performance results are similar

Summary of performance differences

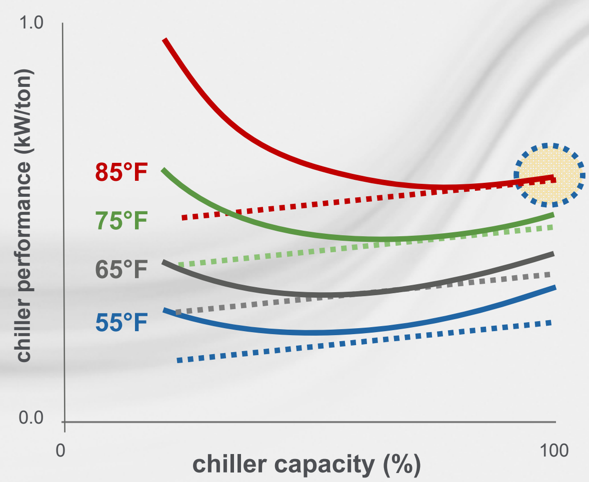
Operating Limitations

- Operating limitations for variable speed chillers are very similar to constant speed chillers.
  - Operating range
  - Minimum load point
  - Operating stability
- Screw chillers have no risk of surge with a constant entering condenser water temperature
- Trane CenTraVacs™ normally unload to 10%-15% with constant entering condenser water temperature without energy wasting hot gas by-pass (aka “Range Extension System”)

Summary of performance differences

Full Load and Part Load Efficiency

- Full Load performance establishes the chiller's ultimate part load performance



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Beneficial Applications of Chiller VSDs

- Centrifugal
  - **Must** have reduced lift
  - Chiller loads below 80% also beneficial
- Screw
  - Reduced load or lift
- Qualitative examples – is further analysis warranted?

Datacenter – Temperate Climate

- No economizer
- Temperate climate (Kansas City, MO)
- Buildout loads expected to be constant
- 2 chillers
- N+1 design

Operation for significant # hours	Centrifugal	Screw
Reduced Lift	+	+
Reduced Load		
Below 80% Load	If N+1 turned on	If N+1 turned on
Perform Analysis?	Yes	Yes

High Temperature Datacenter – Cold Climate

- Minneapolis, MN
- High supply air temperature (75ºF)
- Economizer
- Buildout loads expected to be constant

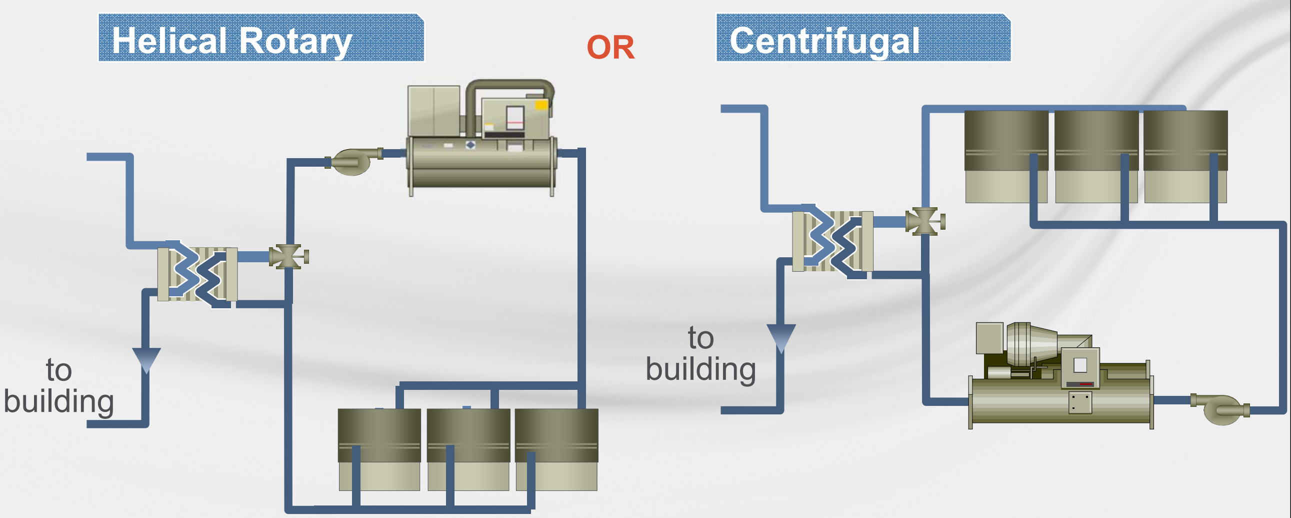
Operation for significant # hours	Centrifugal	Screw
Reduced Lift		
Reduced Load		
Perform Analysis?	No	No

Hotel – Hot and Humid Climate

- Caracas, Venezuela (always hot and humid)
- 3 chillers
  - Two 400-ton
  - One 200-ton “swing” for nighttime or low occupancy operation

Operation for significant # hours	Centrifugal	Screw
Reduced Lift		
Reduced Load	+	+
Perform Analysis?	No	Yes, for swing chiller

Ice Storage Retrofit



Ice Storage Retrofit to Add Capacity #1

- Make ice at night
- Operate ice chillers during the day at "chilled water temperatures" to augment ice tanks

Operation for significant # hours	Centrifugal	Screw
Reduced Lift	+	+
Reduced Load	+	+
Perform Analysis?	Yes	Yes

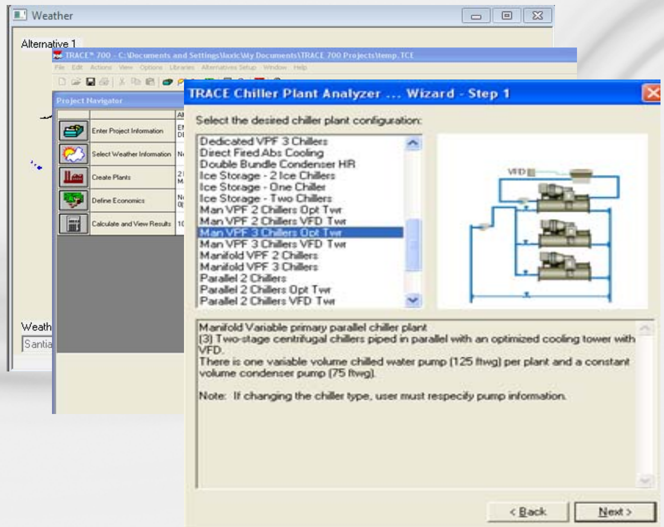
Ice Storage Retrofit to Add Capacity #2

- Make ice at night
- Ice chillers off during the day (full storage)

Operation for significant # hours	Centrifugal	Screw
Reduced Lift	Temperate climates	Temperate climates
Reduced Load		
Perform Analysis?	Temperate climates	Temperate climates

Analysis Using Chiller Plant Analyzer

- Inputs
  - Location
  - Building type
    - Economizer?
  - Chilled water system type
  - Design load



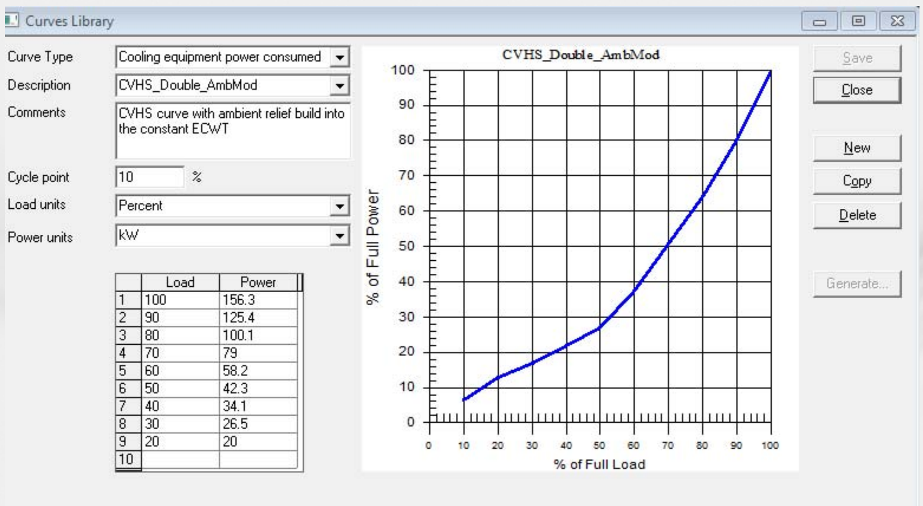
300-ton VSD Chiller Data – Incorrect Use

Percent Load (%)	ECWT	kW	kW./ ton
20	65	20.0	.334
30	65	26.5	.295
40	65	34.1	.284
50	65	42.3	.282
60	69	58.2	.324
70	73	79.0	.376
80	77	100.1	.417
90	81	125.4	.465
100	85	156.3	.521

Percent Load (%)	ECWT	kW	kW./ ton
20	85	44.6	.744
30	85	55.2	.614
40	85	66.1	.551
60	85	89.8	.499
70	85	104	.495
80	85	119.2	.497
90	85	136.2	.505
100	85	156.3	.521

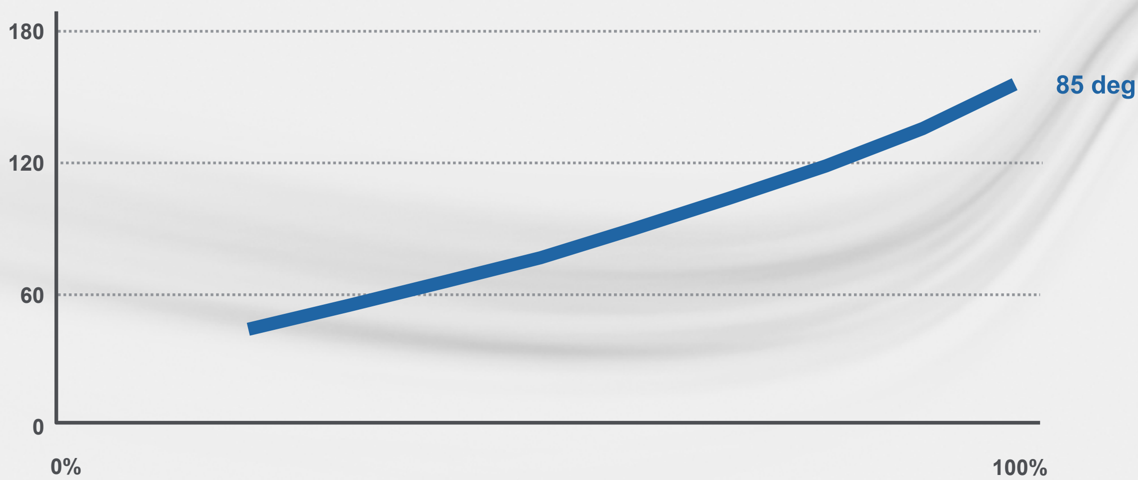
80 % higher than assumed!

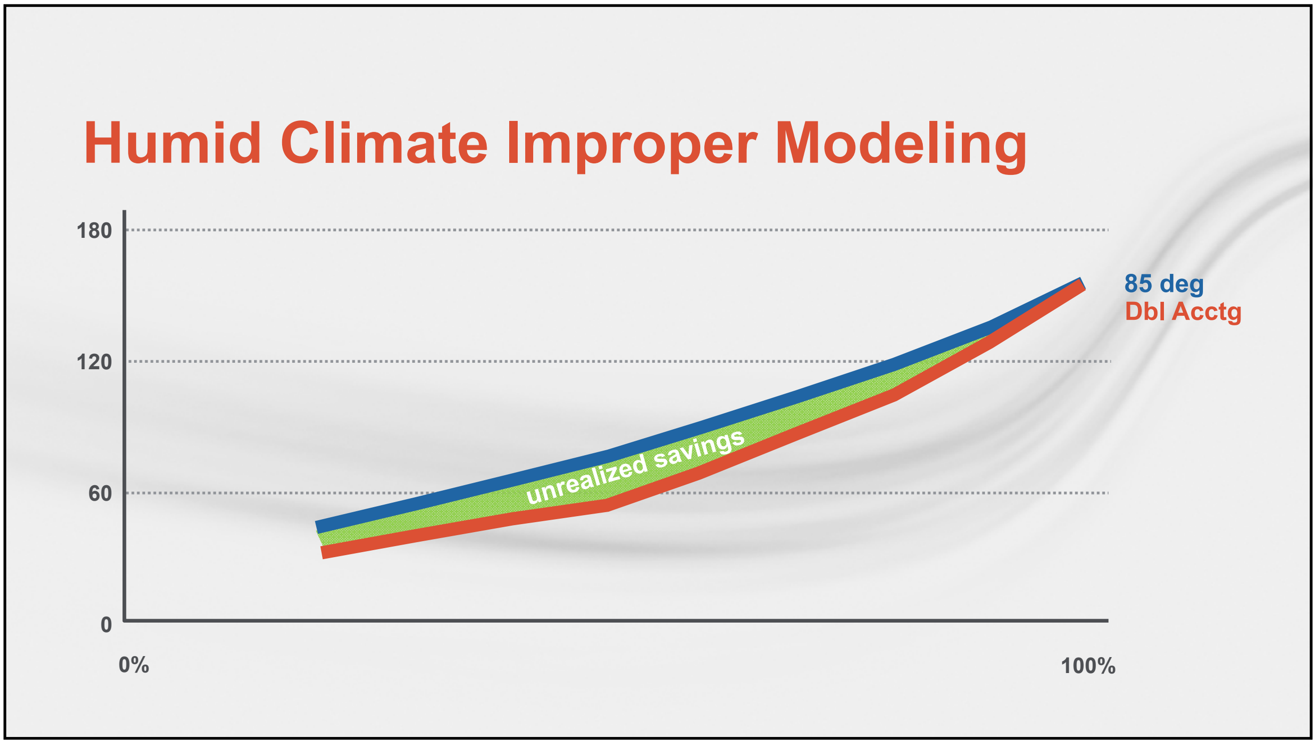
Input That Double Accounts for Lift Reduction

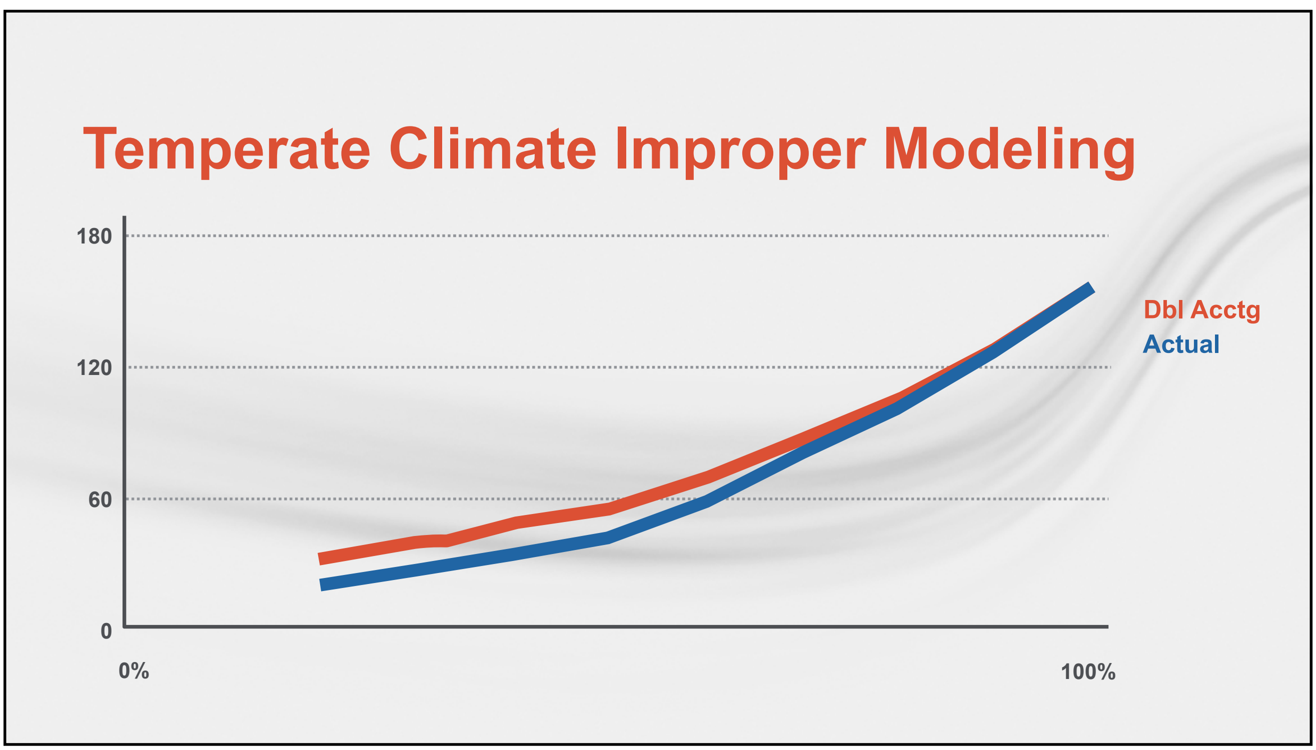


	Load	Power
1	100	156.3
2	90	125.4
3	80	100.1
4	70	79
5	60	58.2
6	50	42.3
7	40	34.1
8	30	26.5
9	20	20
10		

Humid Climate Improper Modeling




Humid Climate Improper Modeling
180
120
60
0
0%
100%
85 deg
Dbl Acctg
unrealized savings

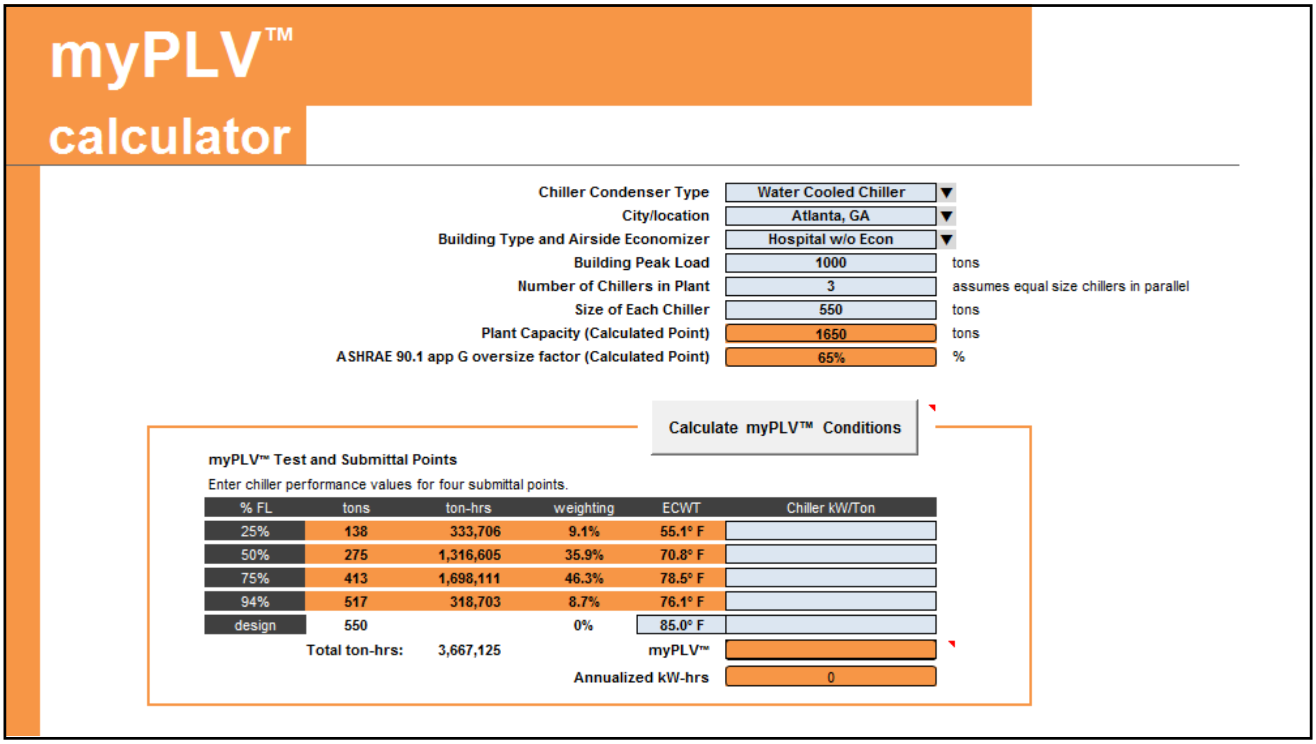

Temperate Climate Improper Modeling
180
120
60
0
0%
100%
Dbl Acctg
Actual

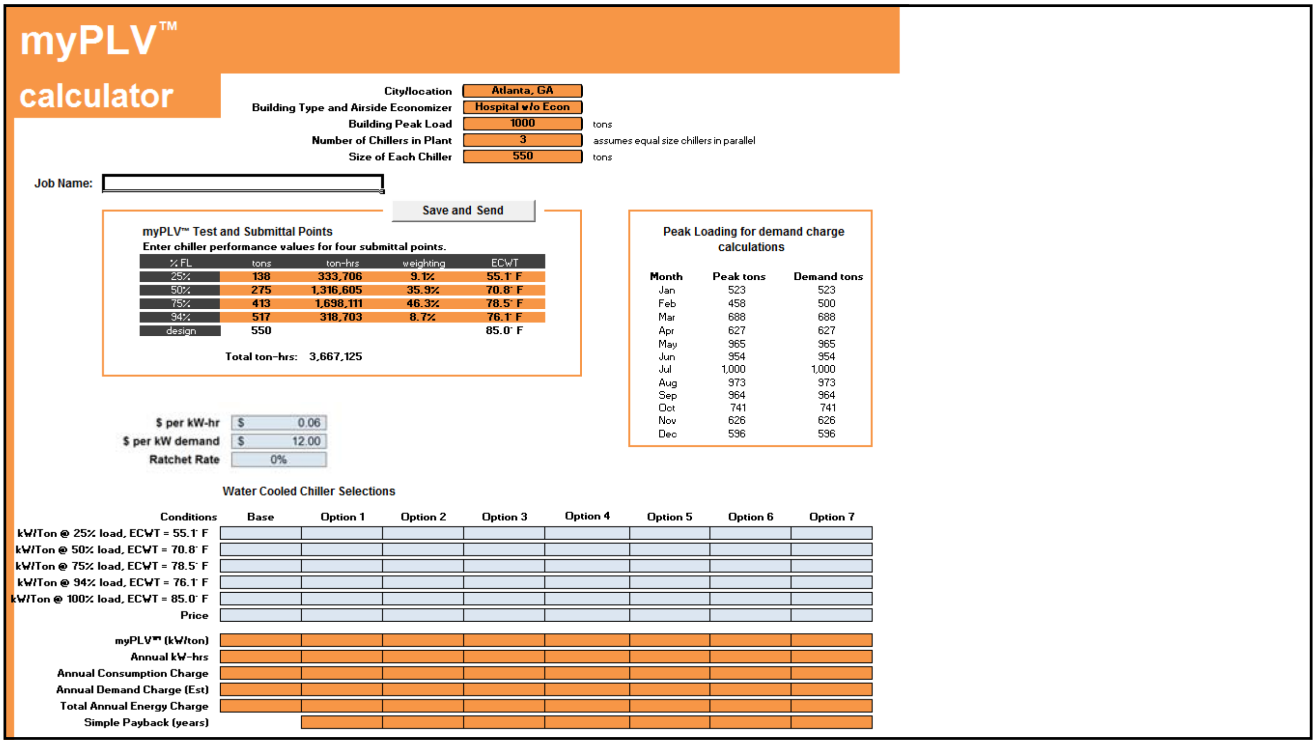
AGENDA

- Effects of VSDs on chilled-water system components
- Physics of VSDs on centrifugal compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Physics of VSDs on screw compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Applications that benefit from each technology
- **Importance of life-cycle analysis**
- VSD chiller application considerations

Use Actual Utility Rates
(Demand and Consumption)

- Compare same price chillers
  - Spend money on VSD
  - Spend money on more heat transfer surface (premium efficiency)
- Premium efficiency has 12.5% lower demand (kW) than variable speed
- So-called “combined rates” underestimates operating costs
  - Especially the VSD chiller
    (does not account for 12.5% demand difference)


myPLV™ calculator
Chiller Condenser Type: Water Cooled Chiller
City/location: Atlanta, GA
Building Type and Airside Economizer: Hospital w/o Econ
Building Peak Load: 1000 tons
Number of Chillers in Plant: 3 assumes equal size chillers in parallel
Size of Each Chiller: 550 tons
Plant Capacity (Calculated Point): 1650 tons
ASHRAE 90.1 app G oversize factor (Calculated Point): 65%
Calculate myPLV™ Conditions
myPLV™ Test and Submittal Points
Enter chiller performance values for four submittal points.
% FL | tons | ton-hrs | weighting | ECWT | Chiller kW/Ton
25% | 138 | 333,706 | 9.1% | 55.1° F
50% | 275 | 1,316,605 | 35.9% | 70.8° F
75% | 413 | 1,698,111 | 46.3% | 78.5° F
94% | 517 | 318,703 | 8.7% | 76.1° F
design | 550 | | 0% | 85.0° F
Total ton-hrs: 3,667,125
myPLV™
Annualized kW-hrs 0


myPLV™ calculator
City/location: Atlanta, GA
Building Type and Airside Economizer: Hospital w/o Econ
Building Peak Load: 1000 tons
Number of Chillers in Plant: 3 assumes equal size chillers in parallel
Size of Each Chiller: 550 tons
Job Name:
Save and Send
myPLV™ Test and Submittal Points
Enter chiller performance values for four submittal points.
% FL | tons | ton-hrs | weighting | ECWT
25% | 138 | 333,706 | 9.1% | 55.1° F
50% | 275 | 1,316,605 | 35.9% | 70.8° F
75% | 413 | 1,698,111 | 46.3% | 78.5° F
94% | 517 | 318,703 | 8.7% | 76.1° F
design | 550 | | | 85.0° F
Total ton-hrs: 3,667,125
Peak Loading for demand charge calculations
Month | Peak tons | Demand tons
Jan | 523 | 523
Feb | 458 | 500
Mar | 688 | 688
Apr | 627 | 627
May | 965 | 965
Jun | 954 | 954
Jul | 1,000 | 1,000
Aug | 973 | 973
Sep | 964 | 964
Oct | 741 | 741
Nov | 626 | 626
Dec | 596 | 596
$ per kW-hr $ 0.06
$ per kW demand $ 12.00
Ratchet Rate 0%
Water Cooled Chiller Selections
Conditions | Base | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7
kW/Ton @ 25% load, ECWT = 55.1° F
kW/Ton @ 50% load, ECWT = 70.8° F
kW/Ton @ 75% load, ECWT = 78.5° F
kW/Ton @ 94% load, ECWT = 76.1° F
kW/Ton @ 100% load, ECWT = 85.0° F
Price
myPLV™ (kW/ton)
Annual kW-hrs
Annual Consumption Charge
Annual Demand Charge (Est)
Total Annual Energy Charge
Simple Payback (years)

A Few Examples…

- 530-ton load
- Two, 265-ton screw chillers
- $0.06/kWh; $12/kW

	Chiller type	Full load (kW/ton)	Added Price (two chillers)
Base	CS	0.678	NA
AFD	VSD	0.691	$19,900
Prem Eff	CS	0.612	$17,400
Prem Eff + AFD	VSD	0.600	$37,600

Houston – Office, Economizer

Water Cooled Chiller Selections

Condition	CS Min Comp	AFD	Prem Eff	Prem Eff + AFD
kW/Ton @ 25% load, ECWT = 66.1° F	0.771	0.371	0.734	0.347
kW/Ton @ 50% load, ECWT = 78.1° F	0.648	0.501	0.607	0.444
kW/Ton @ 75% load, ECWT = 81.5° F	0.655	0.585	0.612	0.527
kW/Ton @ 94% load, ECWT = 82.1° F	0.646	0.630	0.589	0.558
kW/Ton @ 100% load, ECWT = 85.0° F	0.678	0.691	0.612	0.600
Price		$19,900.00	$17,400.00	$37,600.00
myPLV™ (kW/ton)	0.656	0.547	0.611	0.490
Annual kW-hrs	700,062	592,042	652,799	529,913
Annual Consumption Charge	$ 42,004	$ 35,523	$ 39,168	$ 31,795
Annual Demand Charge (Est)	$ 38,222	$ 38,955	$ 34,501	$ 33,825
Total Annual Energy Charge	$ 80,226	$ [illegible]	$ [illegible]	$ [illegible]
Simple Payback (years)		3.5 Years	2.7 Years	2.6 Years

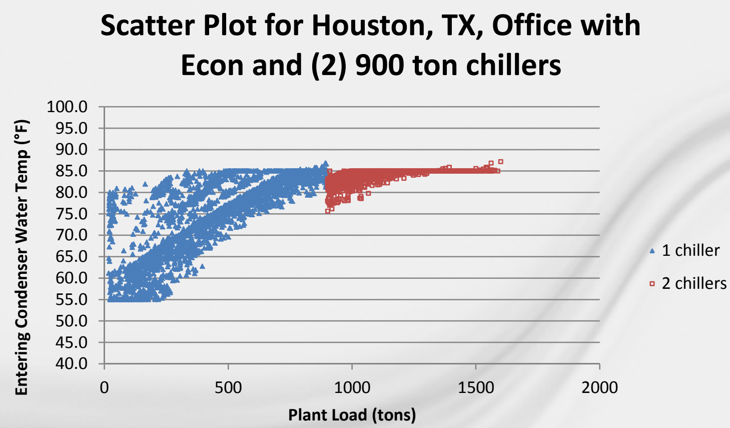
Lexington Hospital – No Economizer

Water Cooled Chiller Selections

Conditions	Base	AFD	Prem Eff	Prem Eff + AFD
kW/Ton @ 25% load, ECWT = 55.0° F	0.475	0.321	0.526	0.297
kW/Ton @ 50% load, ECWT = 65.4° F	0.523	0.375	0.487	0.352
kW/Ton @ 75% load, ECWT = 74.4° F	0.592	0.508	0.557	0.460
kW/Ton @ 94% load, ECWT = 77.9° F	0.603	0.579	0.553	0.515
kW/Ton @ 100% load, ECWT = 85.0° F	0.678	0.691	0.612	0.600
Price	$0.00	$19,900.00	$17,400.00	$37,600.00
myPLV™ (kW/ton)	0.556	0.440	0.530	0.404
Annual kW-hrs	922,488	754,615	876,765	688,256
Annual Consumption Charge	$ 55,349	$ 45,277	$ 52,606	$ 41,295
Annual Demand Charge (Est)	$ 36,284	$ 36,980	$ 32,752	$ 32,110
Total Annual Energy Charge	$ 91,633	$ 82,257	$ 85,358	$ 73,405
Simple Payback (years)		2.1 Years	2.8 Years	2.1 Years

MyPLV – Houston Load Profile

- A large office building with an airside economizer
- 1600 tons peak load with two 900 ton CVHF chillers
- The cooling tower is running a Chiller Tower Optimization algorithm (leaving tower water temperature moves with outdoor wet bulb)

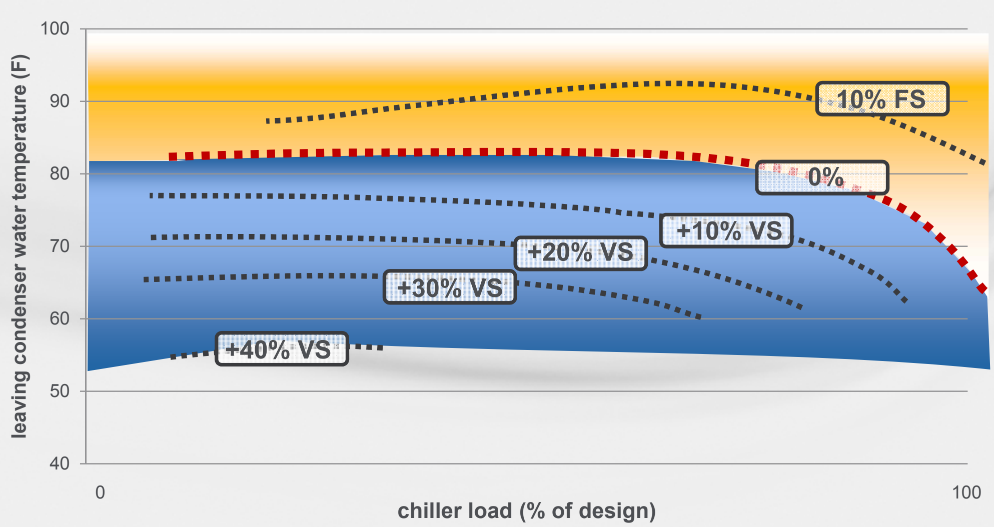


Overall Chiller Weighting by ton-hrs

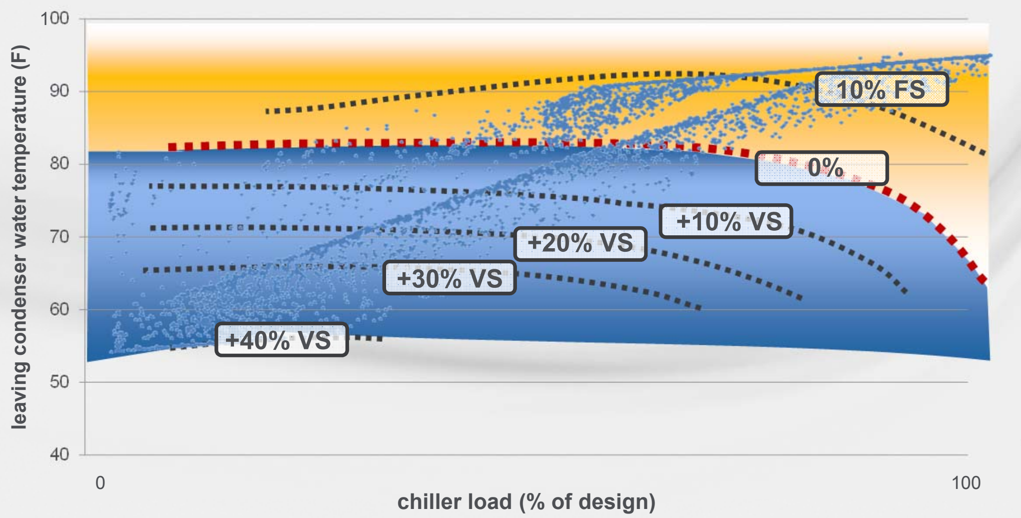
Chiller	%
1	76.2%
2	23.8%

Chiller		All Chillers			CH1			CH2		
% Load	tons	ton-hrs	Weighting	ECWT	ton-hrs	Weighting	ECWT	ton-hrs	Weighting	ECWT
25%	225	20[illegible]	6.3%	68.0	20[illegible]931	8.3%	68.0	-	0.0%	
50%	450	1,093,800	34.0%	80.7	771,533	31.5%	79.5	322,267	42.1%	83.6
75%	675	1,531,480	47.6%	84.6	1,089,910	44.5%	83.9	441,570	57.6%	86.5
94%	846	387,608	12.0%	85.9	385,226	15.7%	85.9	2,382	0.3%	87.1
	Summary	3,216,819			2,450,600	76.2%		766,219	23.8%	

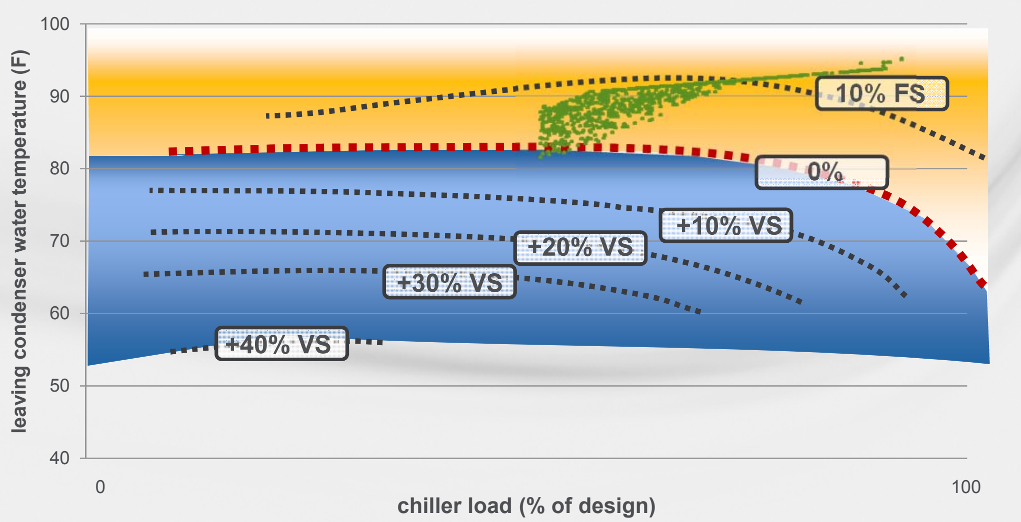
Fixed Speed/Variable Speed Comparison



Load Profile for Chiller #1



Loading Profile for Chiller #2



myPLV Analysis - Houston

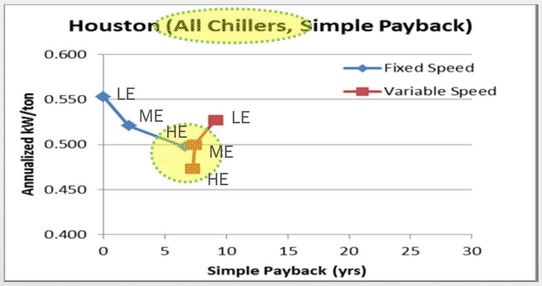
- A large office building with an air-side economizer
- 1600 tons peak load with two 900 ton CVHF chillers
- The cooling tower is running a Chiller Tower Optimization algorithm (Leaving tower water temperature moves with outdoor wet bulb)
- Payback based on $0.10/kWH for energy usage (no demand charges)
- 3 chiller efficiencies considered (Low, Med, High)

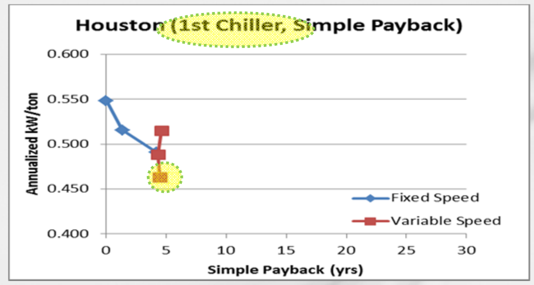
Design kW/ton at AHRI Conditions	Fixed Speed	Var Speed
Low Efficiency (LE)	0.574	0.589
Medium Efficiency (ME)	0.532	0.550
High Efficiency (HE)	0.495	0.514

Houston – Total Plant (all chillers)

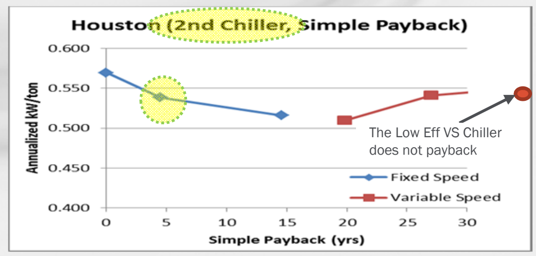
Conditions	LE_Fix	ME_Fix	HE_Fix	LE_Var	ME_Var	HE_Var
kW/Ton @ 25% load, ECWT = 65.9° F	0.548	0.519	0.507	0.389	0.376	0.371
kW/Ton @ 50% load, ECWT = 75.9° F	0.552	0.521	0.507	0.525	0.500	0.476
kW/Ton @ 75% load, ECWT = 80.9° F	0.550	0.519	0.490	0.540	0.512	0.479
kW/Ton @ 94% load, ECWT = 82.9° F	0.570	0.529	0.498	0.585	0.547	0.515
kW/Ton @ 100% load, ECWT = 85.0° F	0.574	0.532	0.495	0.589	0.550	0.514
Price	$0.00	$21,600.00	$118,400.00	$64,400.00	$118,400.00	$181,400.00
myPLV™ (kW/ton)	0.553	0.521	0.497	0.527	0.500	0.473
Annual kW-hrs	1,778,738	1,675,252	1,600,642	1,708,153	1,619,177	1,529,722
Annual Consumption Charge	$ 177,874	$ 167,525	$ 160,064	$ 170,815	$ 161,918	$ 152,972
Annual Demand Charge (Est)	$ -	$ -	$ -	$ -	$ -	$ -
Total Annual Energy Charge	$ 177,874	$ 167,525	$ 160,064	$ 170,815	$ 161,918	$ 152,972
Simple Payback (years)	0	2.1 Years	6.6 Years	9.1 Years	7.4 Years	7.3 Years

Chiller Payback Analysis – myPLV Houston

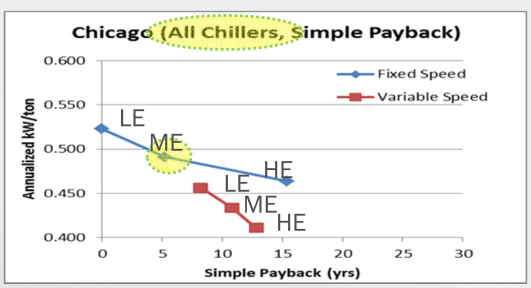


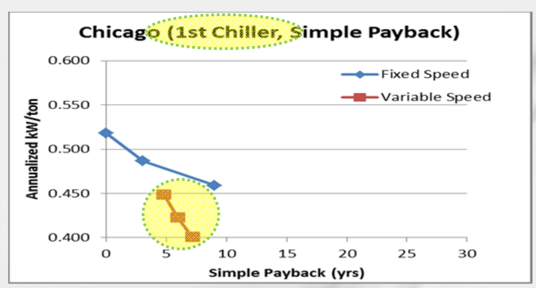


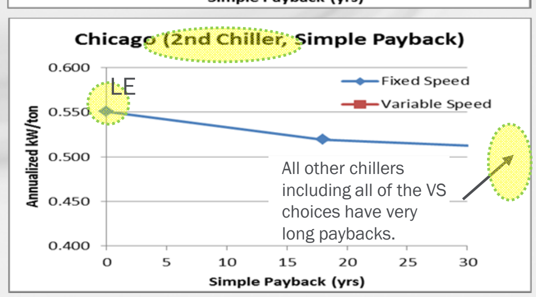
- Likely choices are High Eff Fixed Speed or High Eff Variable Speed
- Achieve a better payback if the first chiller is a High Eff Variable Speed with the 2nd chiller a Med Eff Fixed Speed



Chiller Payback Analysis – myPLV Chicago





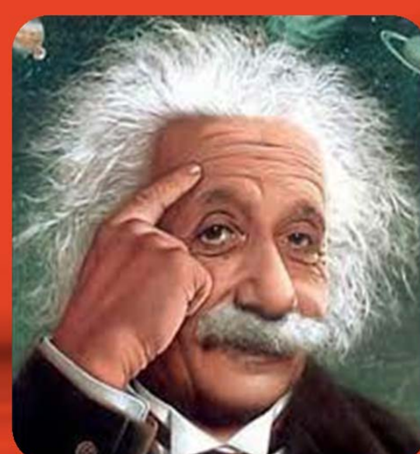


AGENDA

- Effects of VSDs on chilled-water system components
- Physics of VSDs on centrifugal compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Physics of VSDs on screw compressor chillers
  - Physics – lift vs. load
  - Performance (work)
- Applications that benefit from each technology
- Importance of life-cycle analysis
- **VSD chiller application considerations**

Everything should be made as simple as possible, but not simpler.

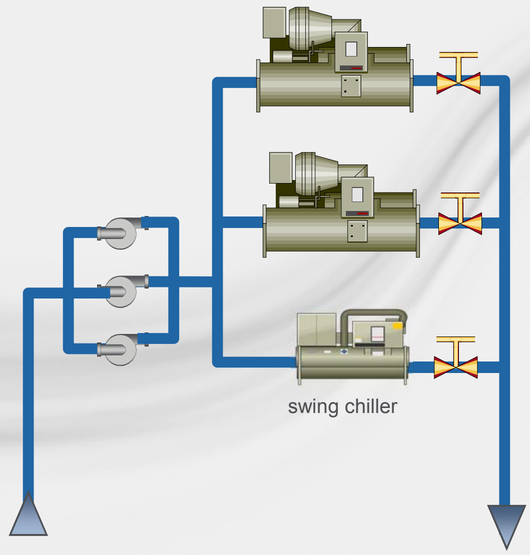
Albert Einstein



VFD chiller application considerations

Swing Chillers

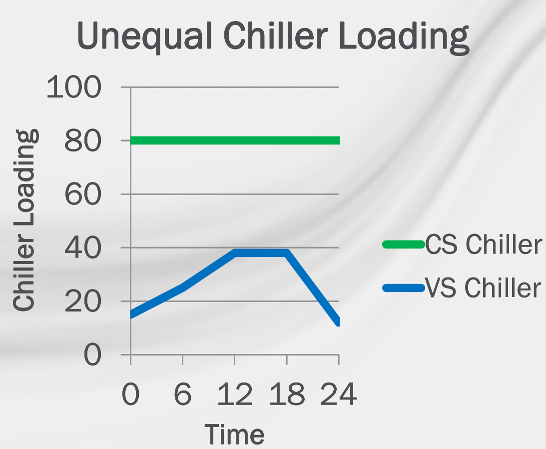
- Why a swing chiller?
  - ~~Save CHW pump energy~~
    - Variable Primary Flow
  - ~~Save CDW pump energy~~
    - Low Flow / Variable Flow
  - ~~Save chiller energy~~
    - VSD on compressor
- Why not a swing chiller?
  – Variable Primary Flow Sequencing



VFD chiller application considerations

Uneven Loading of Chillers

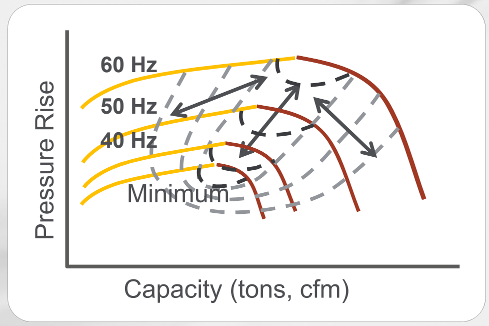
- Why uneven loading?
  - ~~Efficiency~~
    - Run the most efficient chiller the most lightly loaded?
- Why not uneven loading?
  - Hard to control
  - Drives the unloaded chiller into unstable operation
  - Operators will override it



VFD chiller application considerations

Stable Operating Conditions

- Causes of instability
  - Staged tower fans
  - Unstable tower fan speed control
  - Hunting AHU control valves
  - Unstable VPF by-pass valve control
- Benefits of stable system operation
  - Accurate LWT control
  - Higher chiller efficiency
  - Reduced maintenance costs



Summary

- VSDs on centrifugal chillers benefit from reduced lift
- VSDs on screw chillers benefit from reduced load or lift
- Analysis needs to account for
  - Chiller comparison
    - Same-price VSD or premium efficiency chillers
    - Additional investment premium efficiency **AND** VSD
  - Actual chiller performance
  - Actual utility rates

Summary

- Quick analysis tools
  - Chiller Plant Analyzer
  - myPLV
- Due to VSD chiller performance, paradigms might change
  - Hot gas bypass is inefficient and not necessary
  - Swing chillers may not be necessary
  - Keeping sequences simple is preferable – and enhances system stability

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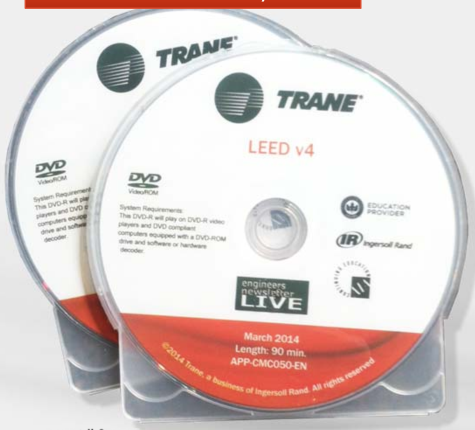

Past Program Topics:

- **NEW!** Chilled-Water Terminal Systems
- **NEW!** Applying Variable Refrigerant Flow
- LEED® v4
- All Variable-Speed Chilled-Water Plants
- Air-to-air Energy Recovery
- ASHRAE Standards 189.1, 90.1, 62.1
- High-performance VAV Systems
- WSHP/GSHP Systems
- Control Strategies
- Acoustics
- Demand-controlled Ventilation
- Dedicated Outdoor-air Systems
- Ice Storage

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Trane *Engineers Newsletter LIVE*
APP-CMC053-EN QUIZ

1. Hot gas-by-pass should be considered as a viable option for a chiller:
    a. When a chiller is required to unload below 50% load.
    b. When renamed as "Range Extension System" by marketing.
    c. To eliminate the possibility for compressor surge.
    d. When a process application requires the chiller to idle at zero (0) load without cycling the compressor.
    e. For low-lift / low-load operation.
2. Which do not correctly complete the following statement? Choose all that apply.-
   Stability of system and chiller operation can be enhanced by…
    a. Oversizing system components.
    b. Applying variable speed control rather than cycling control on cooling tower fans.
    c. Applying variable speed or optimized constant condenser water flow.
    d. Careful commissioning of system operation during startup.
3. Which of the following impact chiller part load energy consumption? Choose all that apply.
    a. Chiller full load energy efficiency
    b. Leaving chilled water temperature
    c. Leaving condenser water temperature
    d. Chiller load point
    e. All of the above
4. Which compressor style(s) can be selected from 35 to 450 tons or more:
    a. Scroll only
    b. Rotary Screw only
    c. Centrifugal only
    d. Rotary Screw & Centrifugal
5. Which of the following statements is correct for hot and humid climates:
    a. Always use a variable speed drives on all components, including chiller compressors.
    b. Never use a variable speed drive on a water-cooled chiller, since there won't be enough hours with condenser relief.
    c. Variable speed rotary screw chillers can make sense even on applications where all variable speed drives in a plant with centrifugal chillers would not be justified.
    d. Select the least-expensive, least-efficient chiller, since there will be so many hours of economizer operation
6. Assuming a constant 85 entering condenser water temperature, unloading a rotary screw chiller with a variable speed drive from 100% to 75% of maximum capacity will improve its efficiency.
    a. True
    b. False
7. An equation for ideal cooling performance is credited to
    a. Carnot
    b. Newton
    c. Aristotle
    d. Hartman

8. Variable speed Centrifugal Compressors control their capacity by modulating (best answer)
    a. Hot Gas Bypass
    b. Inlet guide vanes only
    c. Inlet guide vanes and motor speed
    d. Motor speed only

9. Which is affected the most by varying the speed of a centrifugal compressor
    a. The peak pressure rise the compressor is capable of producing at a given speed
    b. The refrigerant volume flow rate
    c. The chilled water temperature
    d. The pressure rise of the compressor at full speed
10. High Voltage (>600 Volts) variable speed drives cost (complete the sentence)
    a. Less than low voltage (<600 volts) variable speed drives
    b. About the same as low voltage variable speed drives
    c. More than low voltage variable speed drives
    d. Trick question – they don't make high voltage variable speed drives

Engineers Newsletter Live - **Audience Evaluation**

Variable Speed Compressors on Chillers

Please return to your host immediately following program.

Your Name ____

Company name: ____

Business address: ____

Business Phone: ____

Email address:____

Event location: ____

AIA member Number: _________________________

PE license No.:_______________________________

How did you hear about this program? (Check all that apply)

☐ Flyers, email invitations
☐ Trane Web site
☐ Sales Representative
☐ Other. Please describe______________________

What is your ***preferred*** method of receiving notification for training opportunities (check one)?

□ Email □ fax □ US mail □ Trane Website

Was the topic appropriate for the event?	Yes	No	
Rate the content of the program.	Excellent	Good	Needs Improvement
Rate the length of the program.	Appropriate	Too long	Too short
Rate the pace of the program.	Appropriate	Too fast	Too slow

What was most interesting to you?

What was least interesting to you?

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:

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March 2015

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Refrigeration Compressors (2000) TRG-TRC004-EN

Helical Rotary Water Chillers (1999) TRG-TRC012-EN.

Centrifugal Water Chillers (1999) TRG-TRC010-EN

Analysis Software

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

myPLV™ chiller performance evaluation tool available at www.trane.com/myplv

Product Information:

Optimus™ Chiller Model RTHD
Sales Brochure: RLC-SLB031-EN
Catalog: RLC-PRC020F-EN

Stealth™ Chiller Model RTAE
Sales Brochure: RLC-SLB026-EN
Catalog: RLC-PRC042D-EN

EarthWise™ CenTraVac™ Chillers
Sales Brochure: Adaptive Frequency Drive Third Generation, AFD3 - CenTraVac Chiller Models CVHE and CVHF 575V to 600V 60 Hz applications (508.4 KB)

Product Catalog: EarthWise CenTraVac Water-Cooled Liquid Chillers 120-3950 Tons, 50 and 60 Hz, Product Catalog (3.9 MB)
Product Catalog - Remote-Mounted Medium Voltage Air-Cooled Adaptive Frequency Drive with Tracer AdaptiView Control (1.5 MB)