Variable-Speed Compressors on Chillers
Presenters: Lee Cline, Brian Sullivan, Mike Filler, Mick Schwedler, Jeanne Harshaw (host)
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
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

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**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
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

- 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

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
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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 ($\eta$) = Ideal Power /Power Input

• Ideal Power:
  A Carnot (isentropic) Refrigeration Cycle defines ideal Work (Power):
  $$\text{COP}_{\text{Carnot}} = \frac{T_{\text{cold}}}{T_{\text{hot}} - T_{\text{cold}}}$$
  $T_{\text{cold}}$ and $T_{\text{hot}}$ are in units of absolute temperature
  $$\text{kW/ton}_{\text{Carnot}} \propto \frac{(T_{\text{hot}} - T_{\text{cold}})}{T_{\text{cold}}}$$
  assuming $T_{\text{cold}}$ is constant
  Ideal Power (kW) $\propto$ Capacity (tons) $\times$ $(T_{\text{hot}} - T_{\text{cold}})$ (F)
  where “Lift” = $(T_{\text{hot}} - T_{\text{cold}}) = (T_{\text{Condenser}} - T_{\text{Evaporator}})$

• Power input (kW) $\propto$ Capacity (tons) $\times$ Lift (F) / Unit Efficiency ($\eta$)

kW/ton Performance vs. Lift

- Ideal target performance
- Constant entering water cond. temp
- Constant leaving evap. water
- Leaving cond. water temp.
**Hot Gas Bypass (HGBP) Cycle**

- **Useful work**
- **Discarded work**

**Condenser**

**Evaporator**

**Compressor**

---

**HGBP Performance**

- **Useful work**
- **Discarded work**

**Condenser**

**Evaporator**

**Compressor**

**Graph:**
- **Chiller performance (kW/ton)**
- **Operating load (%)**

- **HGBP**
- **Ideal target performance**
Fixed-Speed Centrifugal Chiller Performance

- HGBP
- Ideal target performance
- Inlet guide vane

Fixed-Speed Chiller Performance

- 85°F TIC
- 75°F
- 65°F
- 55°F
Fixed-Speed Compressor Map

guide vanes modulate to vary chiller capacity

inlet guide vanes fully open depending on chiller lift, the operating point rides the guide vane curve

flow rate – capacity (cfm-tons)

pressure rise

Fixed-Speed Compressor Map

surge boundary

best efficiency

inlet guide vanes fully open

minimum guide vane position

decreasing efficiency

flow rate – capacity (cfm-tons)

pressure rise
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

- surge boundary
- best efficiency
- inlet guide vanes fully open
- a best efficiency zone is created through the operating map

- 60 Hz
- 50 Hz
- 40 Hz
- minimum guide vane position
- flow rate - capacity (cfm - tons)
Variable-Speed Compressor Map

- Pressure rise
- Surge boundary
- Inlet guide vane modulation
- Best efficiency
- Inlet guide vanes fully open

Flow rate - capacity (cfm - tons)

Variable-Speed Compressor Map

- Pressure rise
- Surge boundary
- Best efficiency
- Fully open

Flow rate - capacity (cfm - tons)

Chiller performance (kW/ton)

Chiller capacity (%)

Chiller capacity (%)

85°F
75°F
65°F
55°F

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900-ton chiller selections at 44°/85°F
Design Point Performance
VS @ 0.585 kW/ton
FS @ 0.513 kW/ton (-12.4%)
AGENDA

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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

Rotary screw capacity vs lift

Rotary Screw Compressor

meshing point

discharge port

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Engineers Newsletter LIVE Series (APP-CMC053-EN)
Slide Valve Unloading

- Slide valve (closed)
- Slide valve (open)

Suction → Discharge

Part Load Efficiency at Fixed Speed

- Chiller performance (kW/ton)

- HGBP

- Slide valve

- Ideal target performance

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Engineers Newsletter LIVE Series (APP-CMC053-EN)
Part Load Efficiency with Slide Valve

![Graph showing chiller performance vs. chiller capacity for different temperatures with slide valve.](image)

Part Load Efficiency with Variable Speed

![Graph showing chiller performance vs. chiller capacity for different temperatures with variable speed.](image)
Slide Valve versus Variable Speed

@ equivalent price

chiller performance (kw/ton)

chiller capacity (%)

leaving condenser water temp. (°F)

85°F
75°F
65°F
55°F

variable-speed
slide valve

Slide Valve versus Variable Speed

leaving condenser water temp. (°F)

chiller capacity (%)
Variable Speed Centrifugal vs. Rotary

- 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
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 vary 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

<table>
<thead>
<tr>
<th>Power input (kW)</th>
<th>Capacity (tons) * Lift (F) / Unit Efficiency (η)</th>
</tr>
</thead>
</table>

- 60 Hz
- 50 Hz
- 40 Hz
- Minimum

**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
AGENDA

• Effects of VSDs on chilled-water system components
• Physics of VSDs on centrifugal 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

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

<table>
<thead>
<tr>
<th>Operation for significant # hours</th>
<th>Centrifugal</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Lift</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Reduced Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below 80% Load</td>
<td>If N+1 turned on</td>
<td>If N+1 turned on</td>
</tr>
<tr>
<td>Perform Analysis?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

High Temperature Datacenter – Cold Climate

• Minneapolis, MN
• High supply air temperature (75°F)
• Economizer
• Buildout loads expected to be constant

<table>
<thead>
<tr>
<th>Operation for significant # hours</th>
<th>Centrifugal</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Lift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform Analysis?</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Operation for significant # hours</th>
<th>Centrifugal</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Lift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Load</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Perform Analysis?</td>
<td>No</td>
<td>Yes, for swing chiller</td>
</tr>
</tbody>
</table>

Ice Storage Retrofit

Helical Rotary OR Centrifugal

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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

<table>
<thead>
<tr>
<th>Operation for significant # hours</th>
<th>Centrifugal</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Lift</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Reduced Load</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Perform Analysis?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Ice Storage Retrofit to Add Capacity #2

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

<table>
<thead>
<tr>
<th>Operation for significant # hours</th>
<th>Centrifugal</th>
<th>Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Lift</td>
<td>Temperate climates</td>
<td>Temperate climates</td>
</tr>
<tr>
<td>Reduced Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform Analysis?</td>
<td>Temperate climates</td>
<td>Temperate climates</td>
</tr>
</tbody>
</table>
### Analysis Using Chiller Plant Analyzer

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

![Chiller Plant Analyzer Image]

### 300-ton VSD Chiller Data – Incorrect Use

<table>
<thead>
<tr>
<th>Percent Load (%)</th>
<th>ECWT</th>
<th>kW</th>
<th>kW./ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>65</td>
<td>20.0</td>
<td>.334</td>
</tr>
<tr>
<td>30</td>
<td>65</td>
<td>26.5</td>
<td>.295</td>
</tr>
<tr>
<td>40</td>
<td>65</td>
<td>34.1</td>
<td>.284</td>
</tr>
<tr>
<td>50</td>
<td>65</td>
<td>42.3</td>
<td>.282</td>
</tr>
<tr>
<td>60</td>
<td>99</td>
<td>58.2</td>
<td>.324</td>
</tr>
<tr>
<td>70</td>
<td>73</td>
<td>79.0</td>
<td>.376</td>
</tr>
<tr>
<td>80</td>
<td>77</td>
<td>100.1</td>
<td>.417</td>
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<tr>
<td>90</td>
<td>81</td>
<td>125.4</td>
<td>.465</td>
</tr>
<tr>
<td>100</td>
<td>85</td>
<td>156.3</td>
<td>.521</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Load (%)</th>
<th>ECWT</th>
<th>kW</th>
<th>kW./ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>85</td>
<td>44.6</td>
<td>.744</td>
</tr>
<tr>
<td>30</td>
<td>85</td>
<td>55.2</td>
<td>.614</td>
</tr>
<tr>
<td>40</td>
<td>85</td>
<td>66.1</td>
<td>.551</td>
</tr>
<tr>
<td>50</td>
<td>85</td>
<td>89.8</td>
<td>.499</td>
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<tr>
<td>60</td>
<td>85</td>
<td>104</td>
<td>.495</td>
</tr>
<tr>
<td>70</td>
<td>85</td>
<td>119.2</td>
<td>.497</td>
</tr>
<tr>
<td>80</td>
<td>85</td>
<td>136.2</td>
<td>.505</td>
</tr>
<tr>
<td>90</td>
<td>85</td>
<td>156.3</td>
<td>.521</td>
</tr>
</tbody>
</table>

80% higher than assumed!
Input That Double Accounts for Lift Reduction

Humid Climate Improper Modeling
AGENDA

- Effects of VSDs on chilled-water system components
- Physics of VSDs on centrifugal compressor chillers
  - Physics – lift vs. load
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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

**Variable Speed Compressors on Chillers**

#### Chiller Condenser Type
- **City Location**: Atlanta, GA
- **Building Type and Airside Economizer**: Hospital air econ

#### Building Peak Load
- **Number of Chillers in Plant**: 2
- **Size of Each Chiller**: 550
- **Plant Capacity (Calculated Point)**: 1650 tons
  - **Assumes equal size chillers in parallel**
  - **ASHRAE 90.1 app G oversize factor (Calculated Point)**: 66%

#### Test and Submittal Points
- **myPLV™ Test and Submittal Points**
  - Enter chiller performance values for four submittal points:
    - **% FL**: 25% (418, 553,766, 9.1%, 68.1°F)
    - **50%**: 275, 1,316,665, 35.6%, 70.0°F
    - **75%**: 243, 1,608,111, 46.3%, 75.0°F
    - **95%**: 517, 318,763, 8.7%, 76.4°F

#### myPLV™ Test and Submittal Points
- **Design Point**: 550
  - **Total ton-hrs**: 3,667,125
  - **Annualized kW-hrs**: 3

#### Peak Loading for Demand Change Calculations
- **Month**:
  - Jan: 500
  - Feb: 450
  - Mar: 635
  - Apr: 567
  - May: 627
  - Jun: 594
  - Jul: 1,000
  - Aug: 873
  - Sep: 394
  - Oct: 793
  - Nov: 192
  - Dec: 596

### Water Cooler Chiller Selections
- **myPLV™ Selections**
  - **Annual kW-hrs**:
  - **Annual Cubic Feet**:
  - **Total Annual Energy Change**
  - **Total Annual Energy Change (Before)**

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A Few Examples…

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

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

Houston – Office, Economizer

<table>
<thead>
<tr>
<th>Condition</th>
<th>CS Min Comp</th>
<th>AFD</th>
<th>Prem Eff</th>
<th>Prem Eff + AFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW/Ton @ 25% load, ECWT = 66.1°F</td>
<td>0.771</td>
<td>0.371</td>
<td>0.734</td>
<td>0.547</td>
</tr>
<tr>
<td>kW/Ton @ 50% load, ECWT = 71.7°F</td>
<td>0.648</td>
<td>0.501</td>
<td>0.607</td>
<td>0.444</td>
</tr>
<tr>
<td>kW/Ton @ 75% load, ECWT = 81.5°F</td>
<td>0.655</td>
<td>0.685</td>
<td>0.612</td>
<td>0.627</td>
</tr>
<tr>
<td>kW/Ton @ 94% load, ECWT = 82.1°F</td>
<td>0.648</td>
<td>0.630</td>
<td>0.589</td>
<td>0.558</td>
</tr>
<tr>
<td>kW/Ton @ 100% load, ECWT = 85.0°F</td>
<td>0.678</td>
<td>0.691</td>
<td>0.612</td>
<td>0.600</td>
</tr>
<tr>
<td>Price</td>
<td>$19,900.00</td>
<td>$17,400.00</td>
<td>$37,600.00</td>
<td></td>
</tr>
</tbody>
</table>

| Annual kW.hrs | 702,062 | 592,042 | 622,793 | 525,913 |
| Annual Consumption Charge | $42,004 | $36,521 | $39,366 | $31,792 |
| Annual Demand Charge (Est) | $38,222 | $38,986 | $34,901 | $35,826 |
| Total Annual Energy Charge | $80,226 | $75,507 | $74,267 | $67,619 |
| Simple Payback (years) | 3.6 Years | 2.7 Years | 2.6 Years |
### Lexington Hospital – No Economizer

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Base</th>
<th>AFD</th>
<th>Prem Eff</th>
<th>Prem Eff + AFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW/Ton @ 25% load, ECWT = 55.0° F</td>
<td>0.475</td>
<td>0.321</td>
<td>0.526</td>
<td>0.297</td>
</tr>
<tr>
<td>kW/Ton @ 50% load, ECWT = 65.4° F</td>
<td>0.523</td>
<td>0.375</td>
<td>0.487</td>
<td>0.352</td>
</tr>
<tr>
<td>kW/Ton @ 75% load, ECWT = 74.4° F</td>
<td>0.592</td>
<td>0.508</td>
<td>0.557</td>
<td>0.480</td>
</tr>
<tr>
<td>kW/Ton @ 94% load, ECWT = 77.9° F</td>
<td>0.603</td>
<td>0.579</td>
<td>0.553</td>
<td>0.515</td>
</tr>
<tr>
<td>kW/Ton @ 100% load, ECWT = 85.0° F</td>
<td>0.678</td>
<td>0.691</td>
<td>0.612</td>
<td>0.600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>myPLV™ (kW/ton)</th>
<th>Base</th>
<th>AFD</th>
<th>Prem Eff</th>
<th>Prem Eff + AFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.556</td>
<td>0.440</td>
<td>0.530</td>
<td>0.404</td>
<td></td>
</tr>
</tbody>
</table>

| Watioed 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)
Scatter Plot for Houston, TX, Office with Econ and (2) 900 ton chillers

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

<table>
<thead>
<tr>
<th>Conditions</th>
<th>LE_Fix</th>
<th>ME_Fix</th>
<th>HE_Fix</th>
<th>LE_Var</th>
<th>ME_Var</th>
<th>HE_Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW/Ton @ 25% load, ECWT = 65.9° F</td>
<td>0.546</td>
<td>0.519</td>
<td>0.507</td>
<td>0.389</td>
<td>0.376</td>
<td>0.371</td>
</tr>
<tr>
<td>kW/Ton @ 50% load, ECWT = 75.9° F</td>
<td>0.554</td>
<td>0.521</td>
<td>0.507</td>
<td>0.525</td>
<td>0.500</td>
<td>0.476</td>
</tr>
<tr>
<td>kW/Ton @ 75% load, ECWT = 80.9° F</td>
<td>0.550</td>
<td>0.519</td>
<td>0.490</td>
<td>0.540</td>
<td>0.512</td>
<td>0.479</td>
</tr>
<tr>
<td>kW/Ton @ 94% load, ECWT = 82.9° F</td>
<td>0.570</td>
<td>0.529</td>
<td>0.498</td>
<td>0.585</td>
<td>0.547</td>
<td>0.515</td>
</tr>
<tr>
<td>kW/Ton @ 100% load, ECWT = 85.0° F</td>
<td>0.574</td>
<td>0.532</td>
<td>0.495</td>
<td>0.589</td>
<td>0.550</td>
<td>0.514</td>
</tr>
</tbody>
</table>

### Houston – Total Plant (all chillers)

<table>
<thead>
<tr>
<th>Conditions</th>
<th>LE_Fix</th>
<th>ME_Fix</th>
<th>HE_Fix</th>
<th>LE_Var</th>
<th>ME_Var</th>
<th>HE_Var</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$0.00</td>
<td>$21,600.00</td>
<td>$118,400.00</td>
<td>$164,400.00</td>
<td>$181,400.00</td>
<td></td>
</tr>
</tbody>
</table>

| 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 |

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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

- All other chillers including all of the VS choices have very long paybacks.
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

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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- ASHRAE Standard 90.1-2010
- ASHRAE Standard 189.1-2011
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- Single-Zone VAV Systems
- Ice Storage Design and Control
- All Variable-Speed Chiller Plant Operation
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• Acoustics: Evaluating Sound Data
• Small Chilled-Water Systems
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.
   e. All of the above

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: ______________________

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Rate the length of the program.   Appropriate   Too long   Too short

Rate the pace of the program.   Appropriate   Too fast   Too slow

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Hanson, S. and E. Sturm, “The Impact of Variable-Speed Drives on HVAC Components,” 2013, volume 42-3


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**Stealth™ Chiller Model RTAE**
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Catalog: RLC-PRC042D-EN

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Sales Brochure: Adaptive Frequency Drive Third Generation, AFD3 - CenTraVac
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Product Catalog - Remote-Mounted Medium Voltage Air-Cooled Adaptive Frequency Drive with Tracer AdaptiView Control (1.5 MB)