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Applying Variable Speed Drives In Industrial Refrigeration Systems

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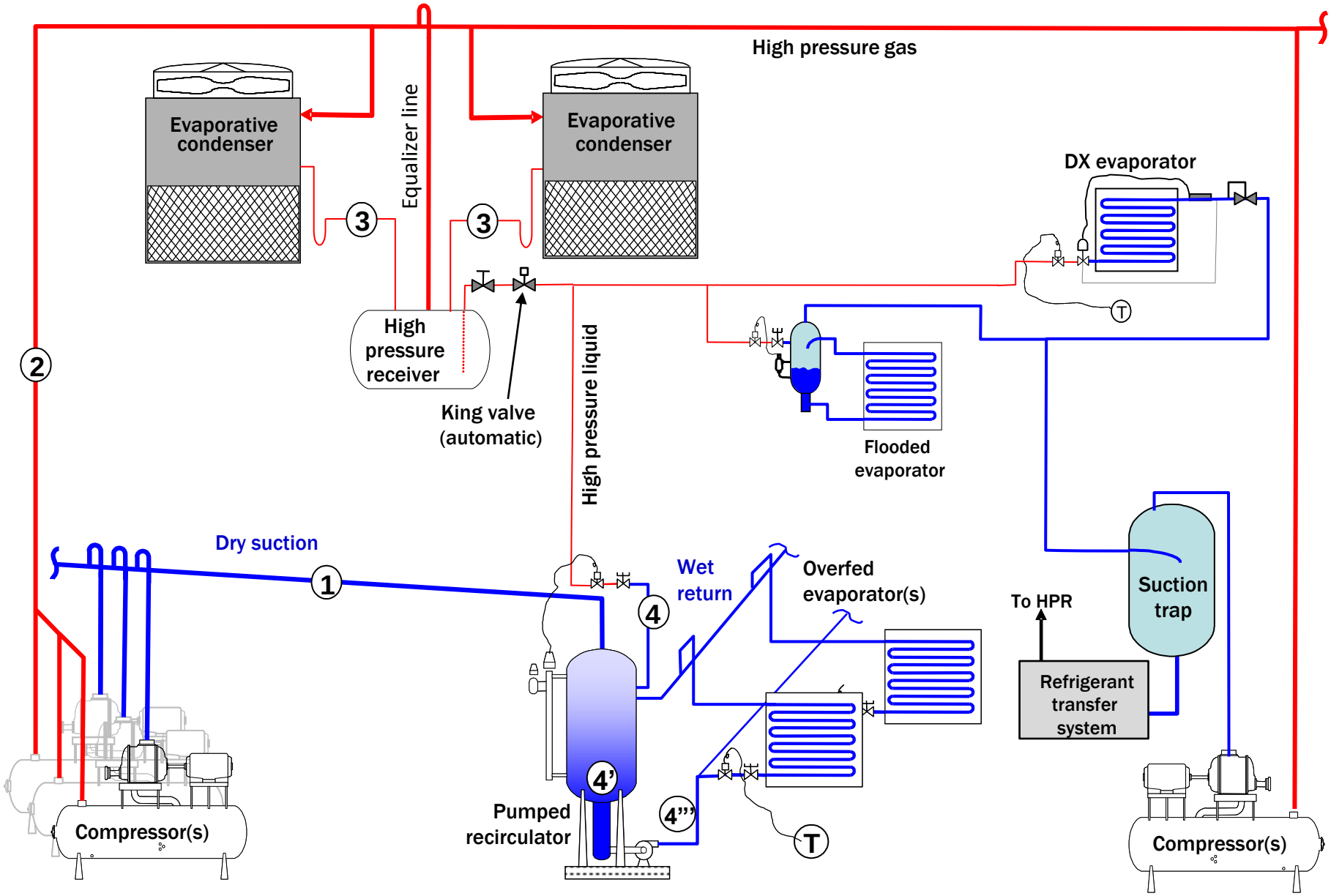
Single Stage Compression System



Where Can VFDs Be Applied?

- Condenser fans
  - All or none – expect 2-3% savings
- Evaporator fans
  - 2-4% savings range
  - Simple paybacks 1-5 years
- Compressors
  - At most, one VFD comp per suction level
  - Simple paybacks 1-4 years

VFD Basic Principles

- Common terms – AFD, ASD, VFD, VSD, drive
- What it is – an electronic controller device capable of adjusting speed of electric motor by modulating power being delivered
- What it can do:
  - Vary motor speed to match variable load requirement
  - Soft start to eliminate mechanical, electrical, hydraulic surges/transients
  - Potentially save energy, energy cost

How VFDs Work

Rectifier

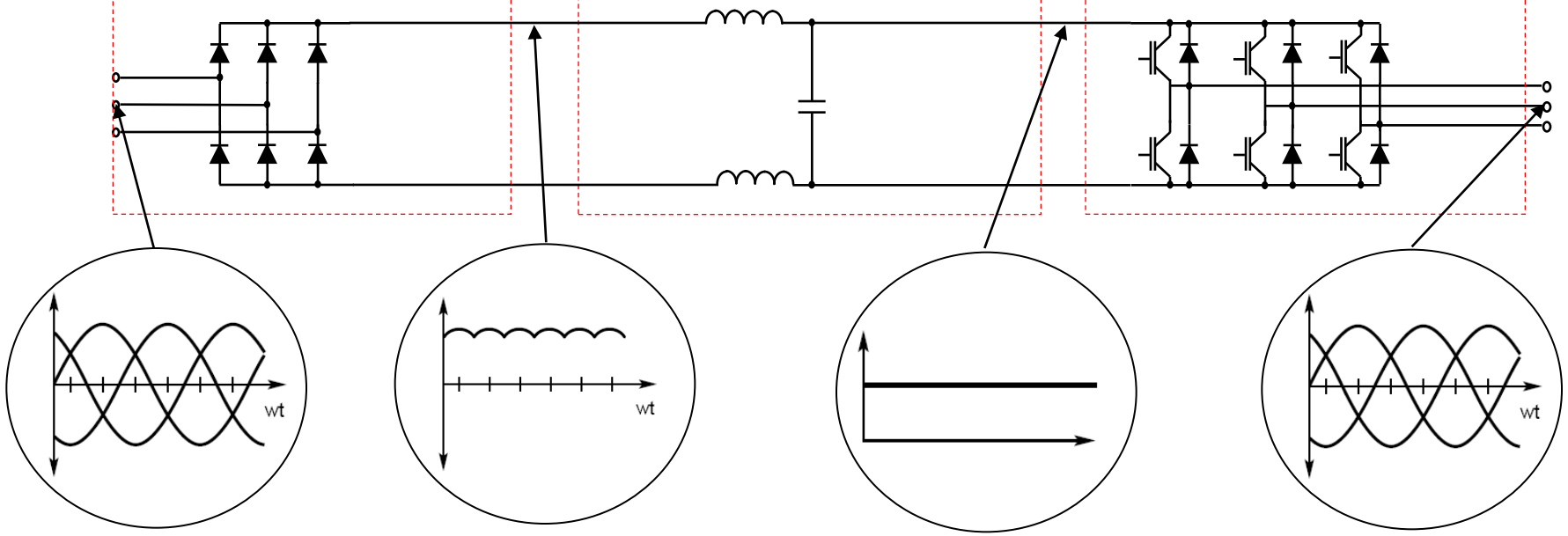
Converts 3 phase AC voltage to pulsating DC voltage

Intermediate circuit

Stabilizes the pulsating DC voltage

Inverter

Converts DC voltage to variable voltage, variable frequency AC



Source: Ohme – "Fundamentals of VFDs and Refrigeration Applications", IRC R&T Forum (2009)

VFD Basic Principles

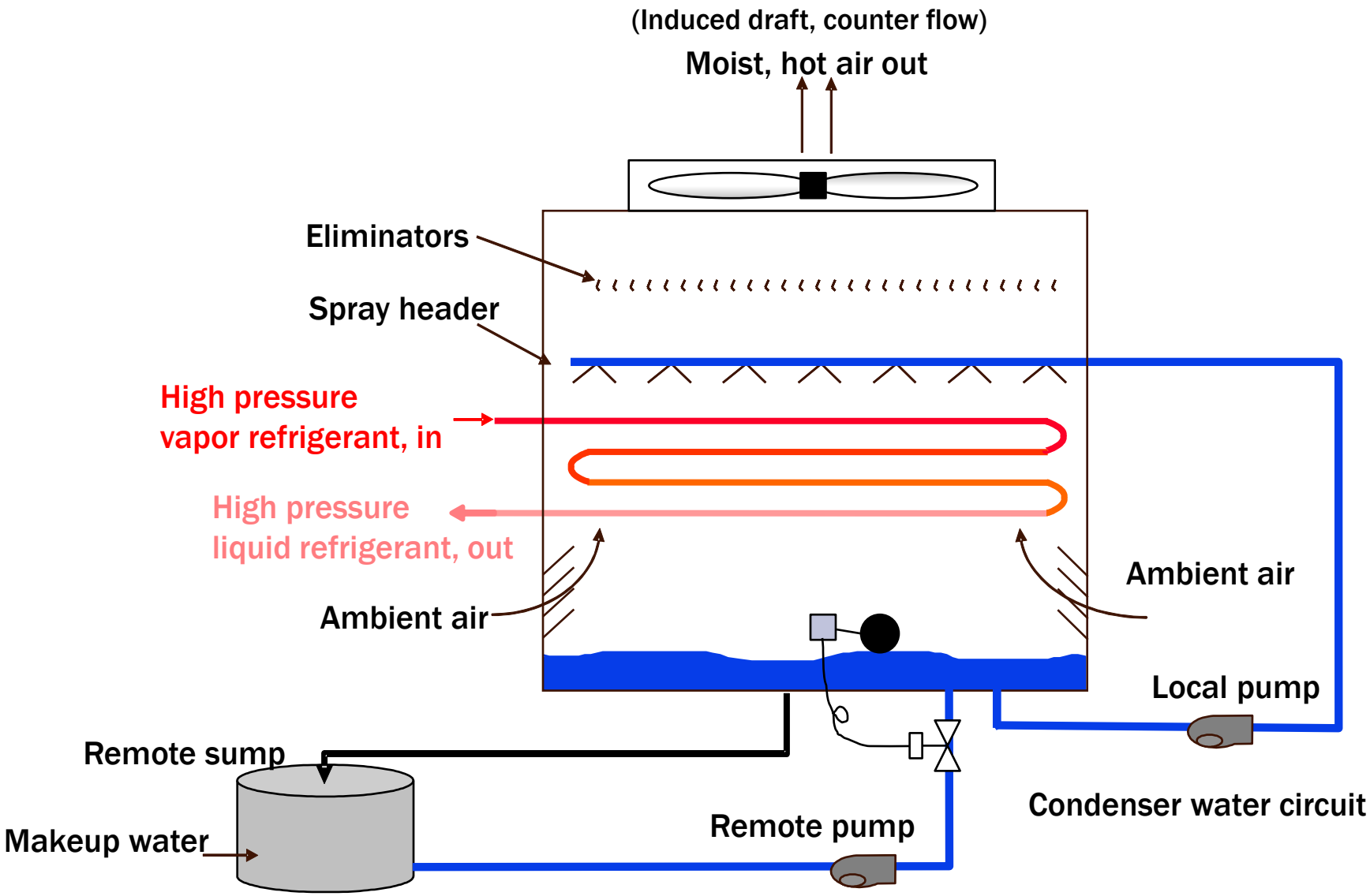
- Rating
  - Voltage
  - Required current to motor
  - Load type
  - Overload requirements

- Variable torque – required torque increases as speed increases (condenser, evaporator fans)
- Constant torque – required torque independent of speed (compressors)

VFDs – Condenser Fans

A variable torque application.

Evaporative Condenser Operating Principles



Condenser Fan Control Options

- Single speed fan with on/off control
  - Most common method of head pressure control
  - Need to set cut-in (e.g. 150 psig), cut-out pressures (e.g. 145 psig)
  - Simple control method except:
    - Highest energy consumption option
    - Higher maintenance (fan motors, belts)
    - Potential for liquid management problems in multiple condenser systems
- Two-speed fan control

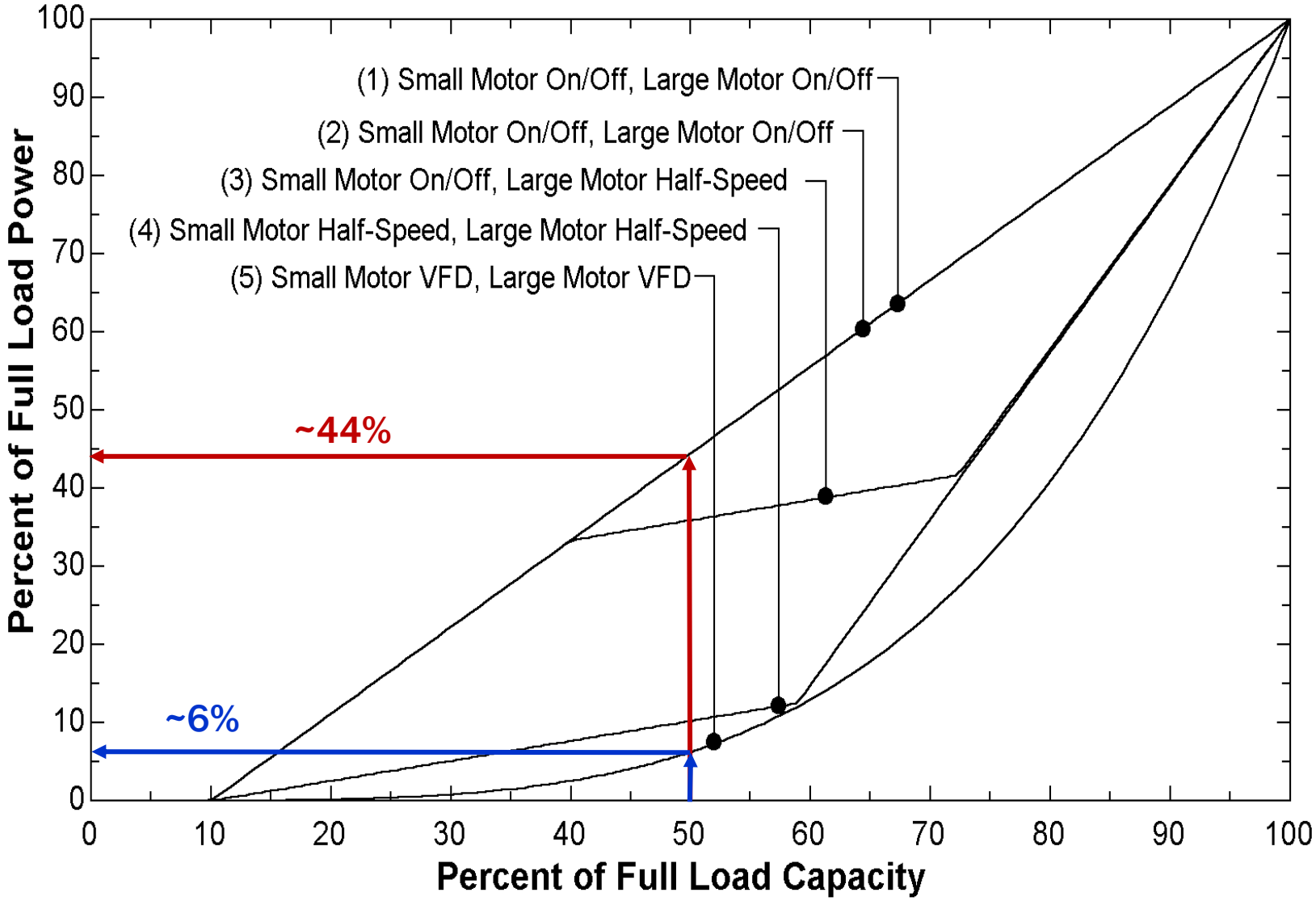
Condenser Fan Control Options (continued)

- Variable frequency drive
  - Set target head pressure, modulate fan speed to maintain
  - Simple to implement:
    - Slightly higher capital cost versus fixed speed
    - Lowest energy consumption control alternative
    - Multiple condenser systems, modulate ALL condensers together
    - Smooth system operation with minimal transients

Condenser Fan Control Map Example

Strategy		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	Small Motor	off	on	off	on	
	Large Motor	off	off	on	on	
2	Small Motor	off	off	on		
	Large Motor	off	on	on		
3	Small Motor	off	on	on	on	
	Large Motor	off	off	half-speed	on	
4	Small Motor	off	half-speed	half-speed	on	on
	Large Motor	off	off	half-speed	half-speed	on
5	Small Motor	off	variable speed			
	Large Motor	off	variable speed			

Comparative Condenser Fan Performance



Simple Two Condenser System

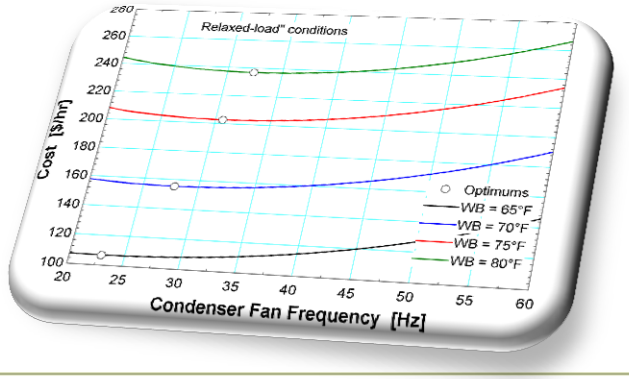
Heat rejection load	Fixed speed control		Variable speed drive	
	# condensers	HP	# condensers	HP*
100%	2	30	2 @ 100%	30
75%	1 + 1/2	21.6	2 @ 75%	9.8
50%	1	15	2 @ 50%	1.8

* Sans drive losses

Each condenser equipped with 15 HP fan.

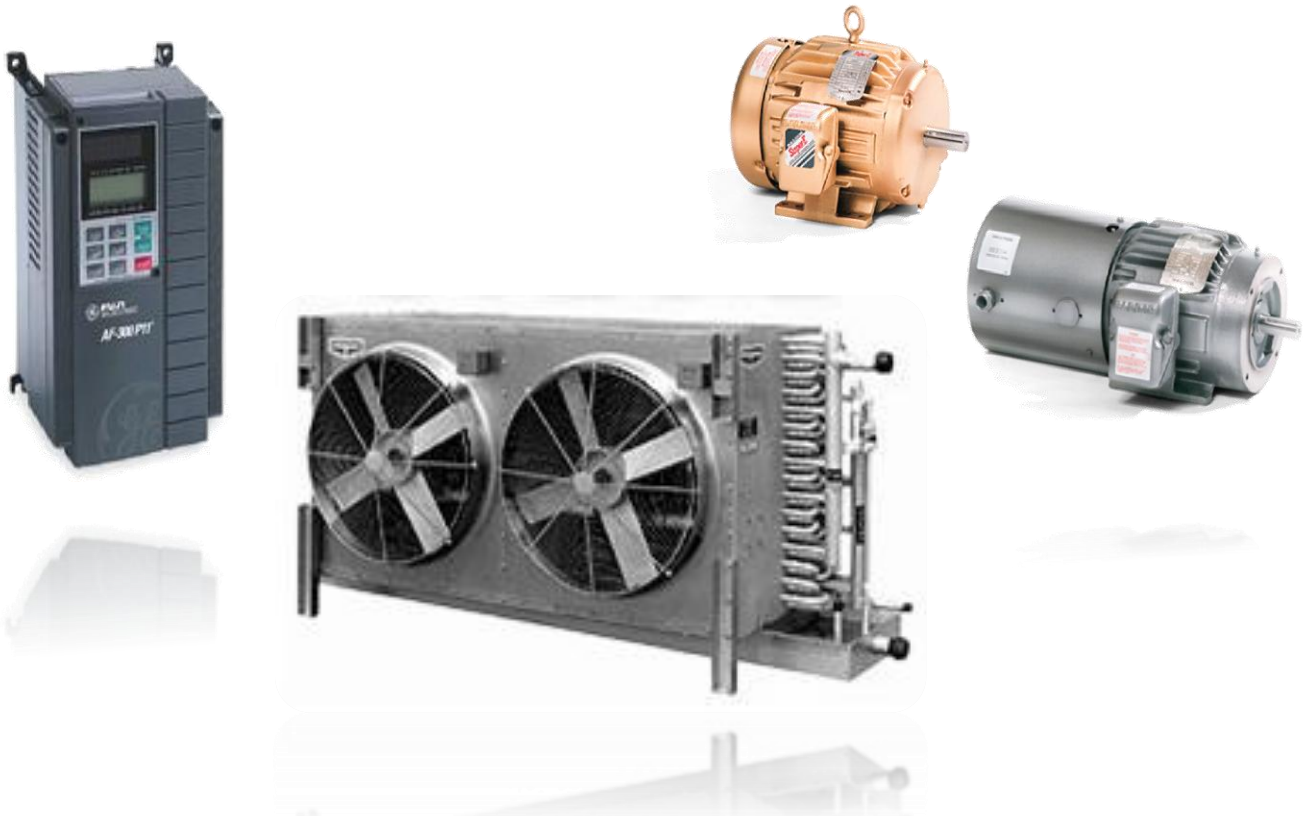
VFDs – Condenser Fans

- Benefits
  - Stable head pressure
  - Reduced maintenance on shafts, bearings, belts
  - Allows ability to optimize head pressure
  - Reduced energy consumption and operating costs
- Look to achieve optimal/near-optimal performance with a simplified control strategy



Questions on
VFDs for condenser fans?

VFDs – Evaporator Fans



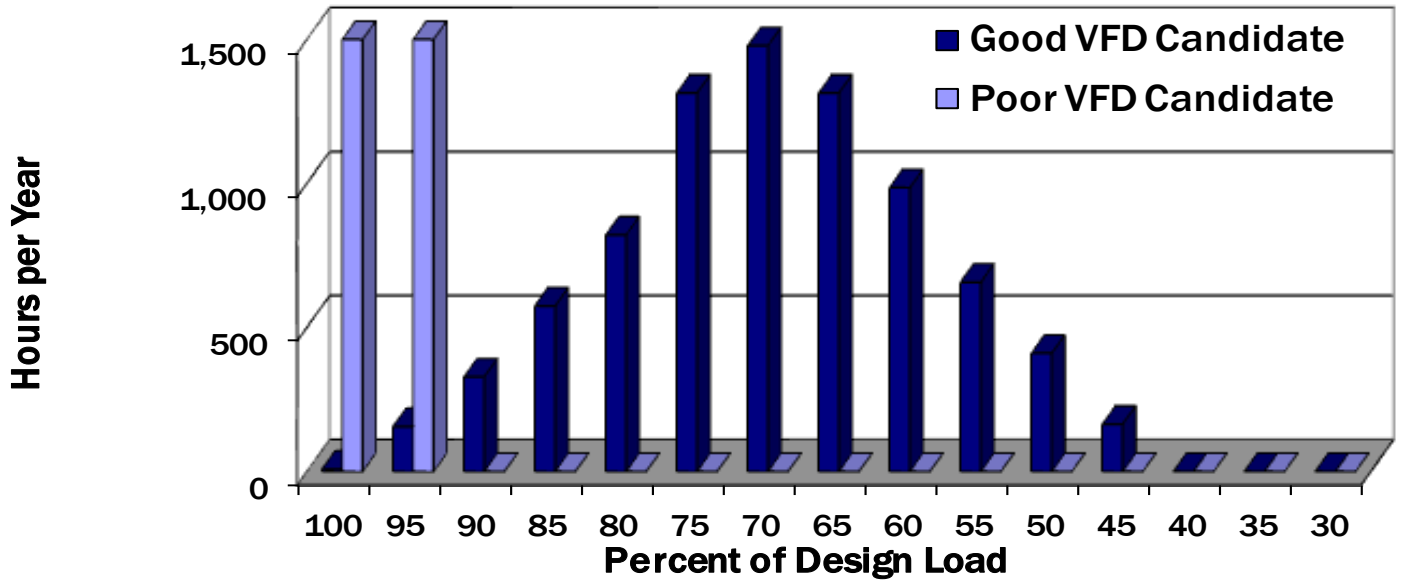
A variable torque application.

Evaporator Fans Opportunity

- Load variability essential
- Best choices for modulating evaporator capacity as space load is reduced:
  - Cycle refrigerant feed, always run fans (normal situation)
  - Cycle refrigerant feed + cycle fans after period of time with no call for refrigerant feed (duty cycle)
  - Raise suction pressure, always run fans (often not possible)
  - Cycle refrigerant feed with VFD control frequency (best practice)
- Which is best?

Good Applications For Evaporator Fan VFDs

- Larger fan motors
- High hours/year operation
- Frequent part-load operation



First Principles

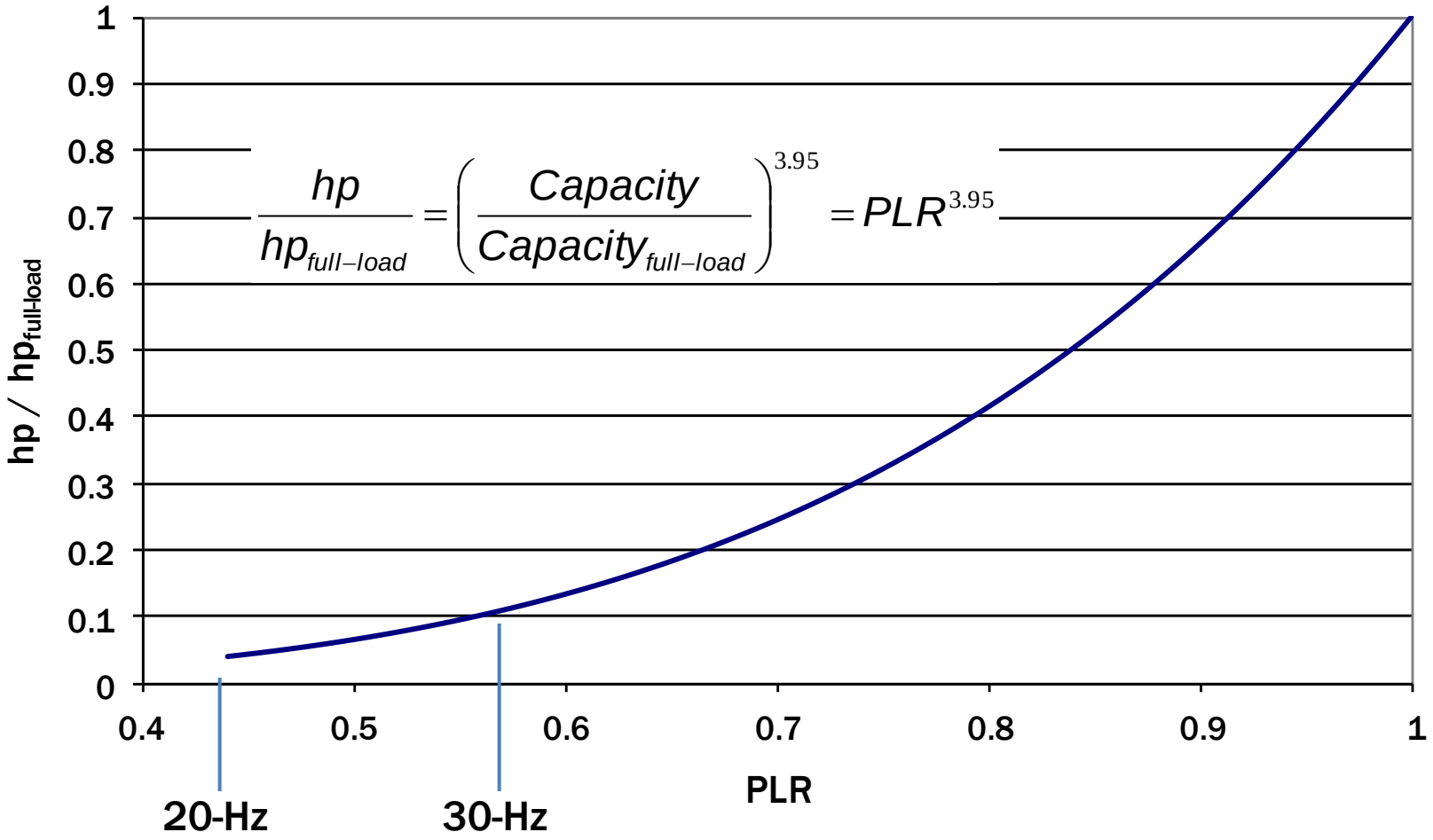
- **Applicable fan laws**

$$\frac{N}{N_{full-load}} = \frac{CFM}{CFM_{full-load}} \qquad \frac{hp}{hp_{full-load}} = \left(\frac{CFM}{CFM_{full-load}}\right)^{3}$$

- **Limitations – typical minimum motor speeds between 20-30 Hz**
- **Heat exchange impact**

$$\frac{Capacity}{Capacity_{full-load}} = \left(\frac{CFM}{CFM_{full-load}}\right)^{0.76}$$

Speed Control Impact On Fan Power

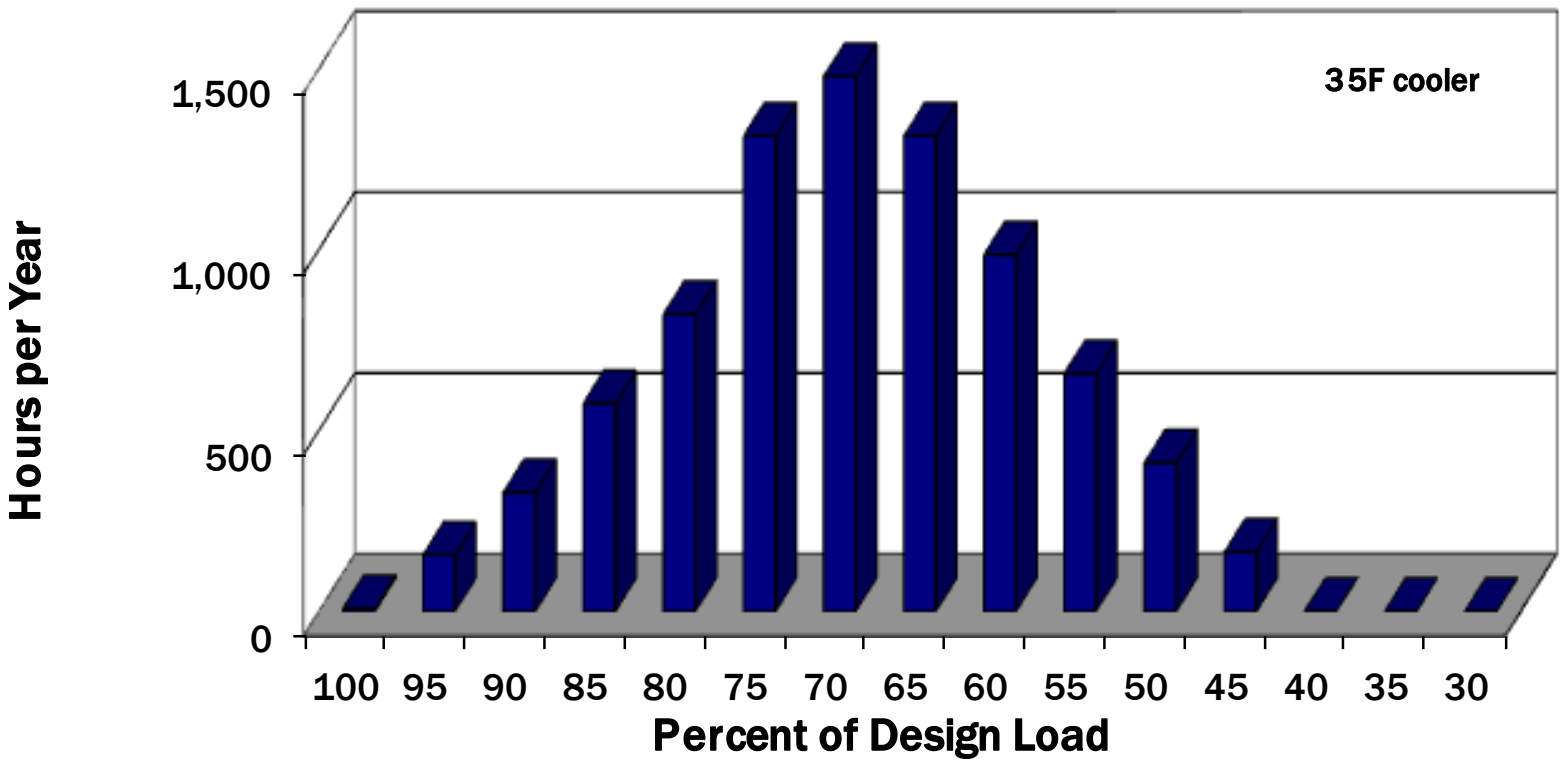


Evaporator Fan VFD Savings Example

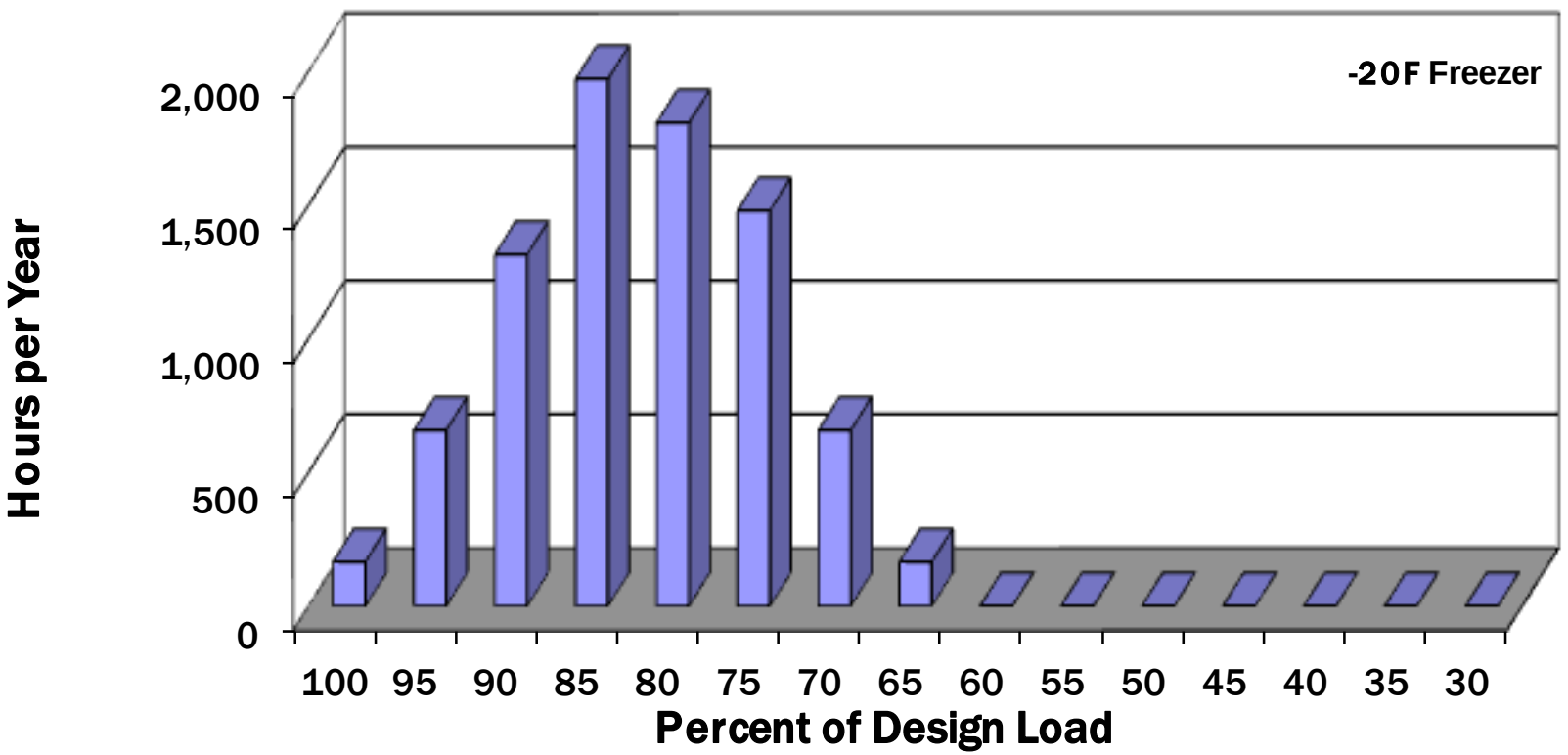
- Evaporator – TD* = 12ºF for cooler and 8ºF for freezer
- VFD costs
  - Assume 3 HP VFD for each evaporator
  - Installation 15 hours/VFD by electrician @ $65/hour
- Energy costs
  - Blended $0.08/kWh

* TD = Temperature difference (T_{room} – $T_{refrigerant}$)

Comparative Load Profiles – Cooler



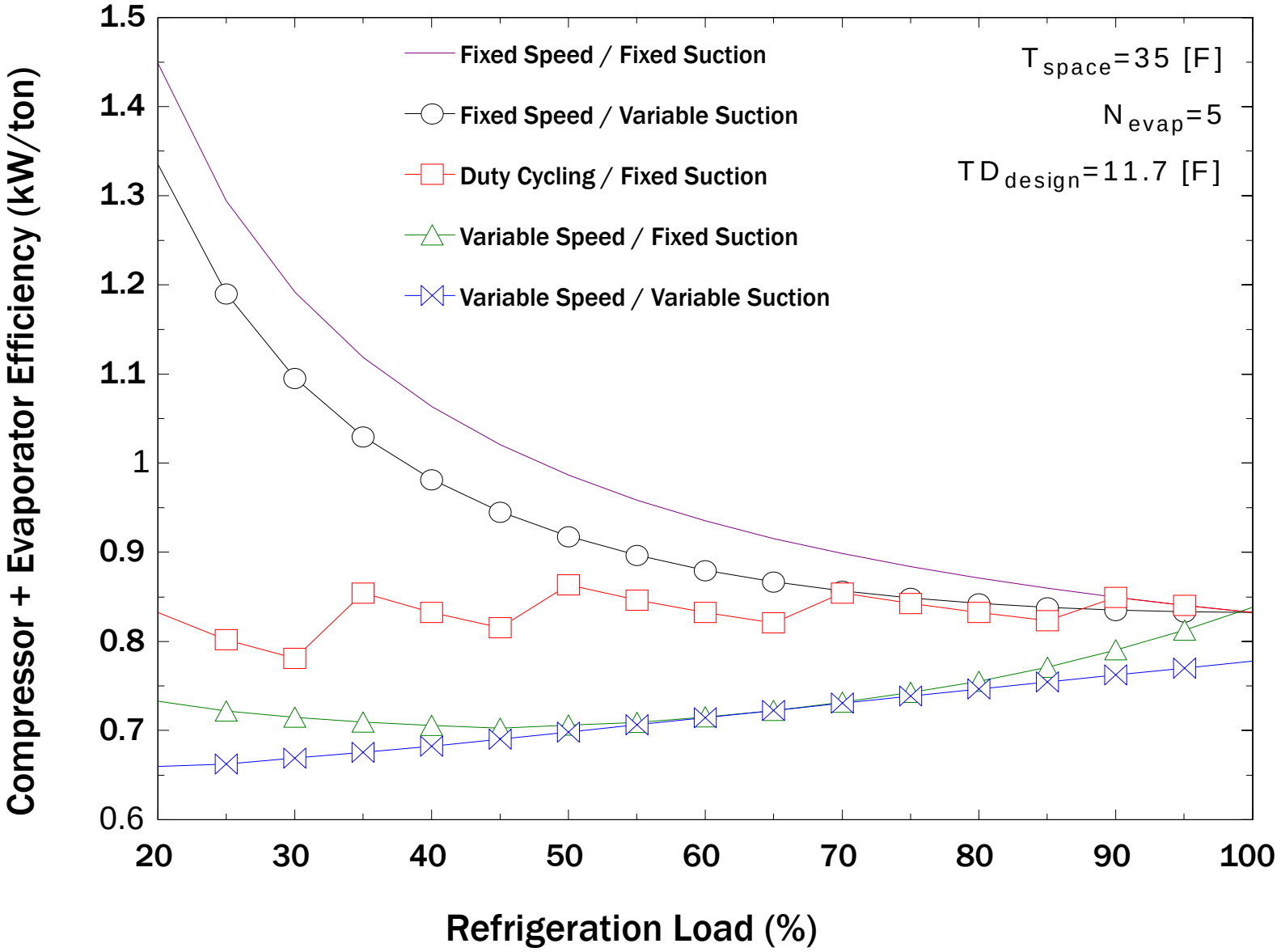
Comparative Load Profiles – Freezer



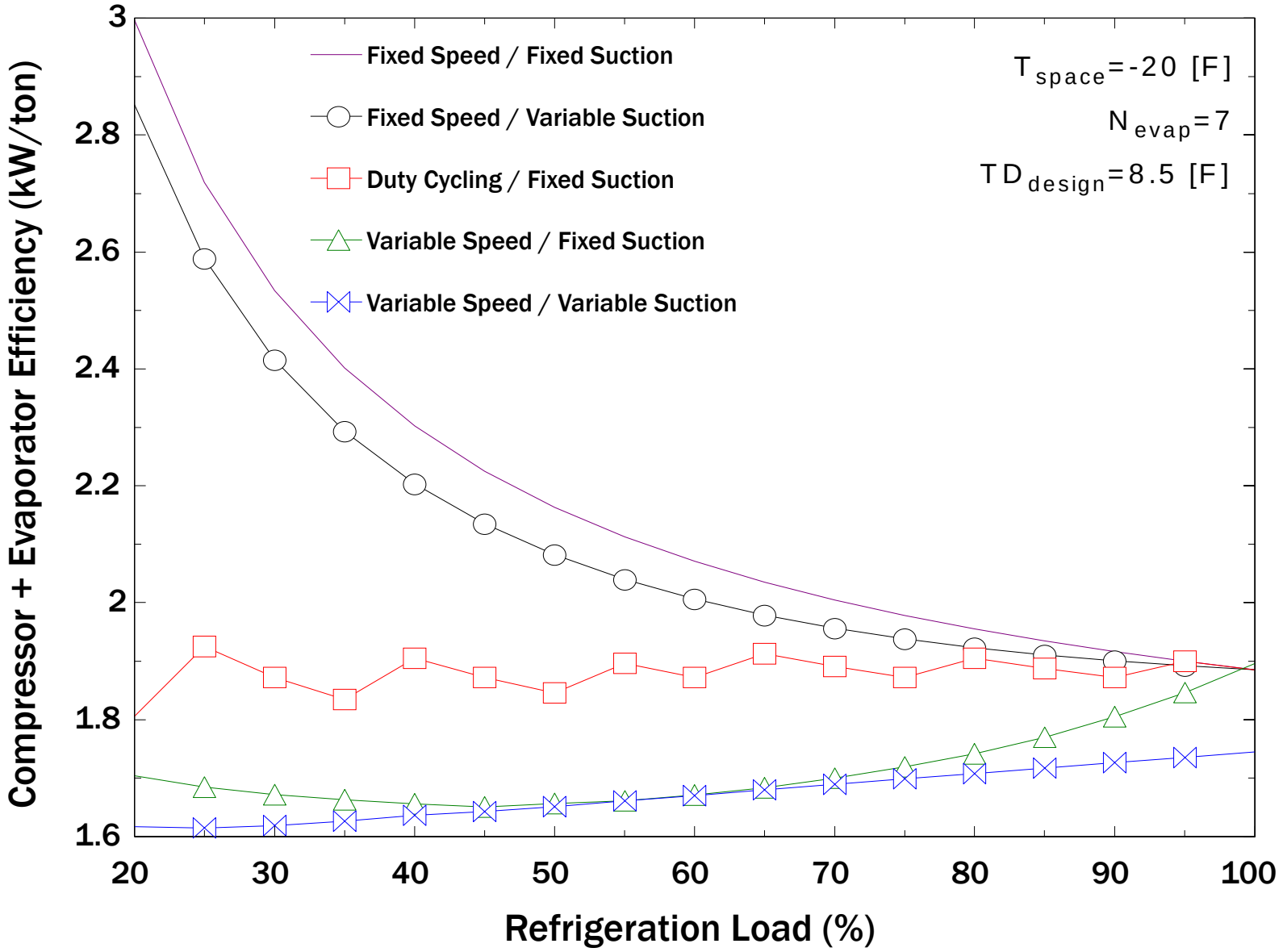
Control Options

	Fan Speed Control	Suction Pressure Control
#1	Fixed	Fixed
#2	Fixed	Variable
#3	Duty Cycle	Fixed
#4	Variable	Fixed
#5	Variable	Variable

Comparative Energy Performance – Cooler



Comparative Energy Performance - Freezer



Economic Analysis Results

	Cooler (35ºF)	Freezer (-20ºF)
From always on fan control to VFD		
Savings per ton	$72	$96
Capital cost per ton†	$65	$95
Installation cost per ton	$48	$71
Simple payback	**1.6 years**	**1.7 years**
From cycling fan control to VFD		
Savings per ton	$48	$64
Simple payback	**2.4 years**	**2.6 years**

† Assumes single drive operates all fan motors (4) on individual evaporators

VFDs – Evaporator Fans

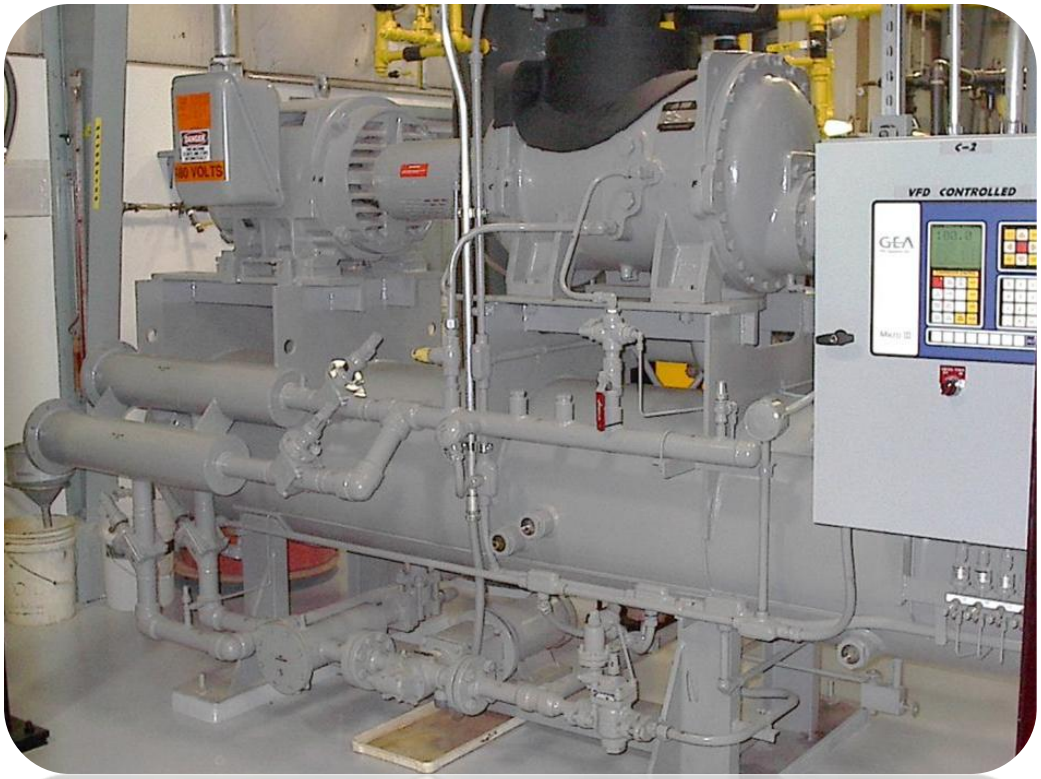
- Reduced system power
  - Evaporator fan power drastically reduced at part-load
  - Compressor power reduced due to lower parasitic space refrigeration loads attributable to lower fan energy use (5 HP = 1 ton of refrigeration)
- More stable suction pressure
- Increased motor life
  - Less motor cycling, inherently soft-start
- Improved power factor
- Decreased noise, “wind-chill”

VFD 'Heads Up'

- Drive losses (~3-6%, losses increase at low loads)
- Evaporator "throw" loss
- Typical systems have large number of small evaporator fan motors (cost)
- Additional equipment to maintain
- Resonance of equipment (natural frequency)
- Power quality
- Siting the drives
- Minimum fan speed/drive frequency
- Requires low temperature bearing lubrication/grease

Questions on
VFDs for evaporator fans?

VFDs – Compressors

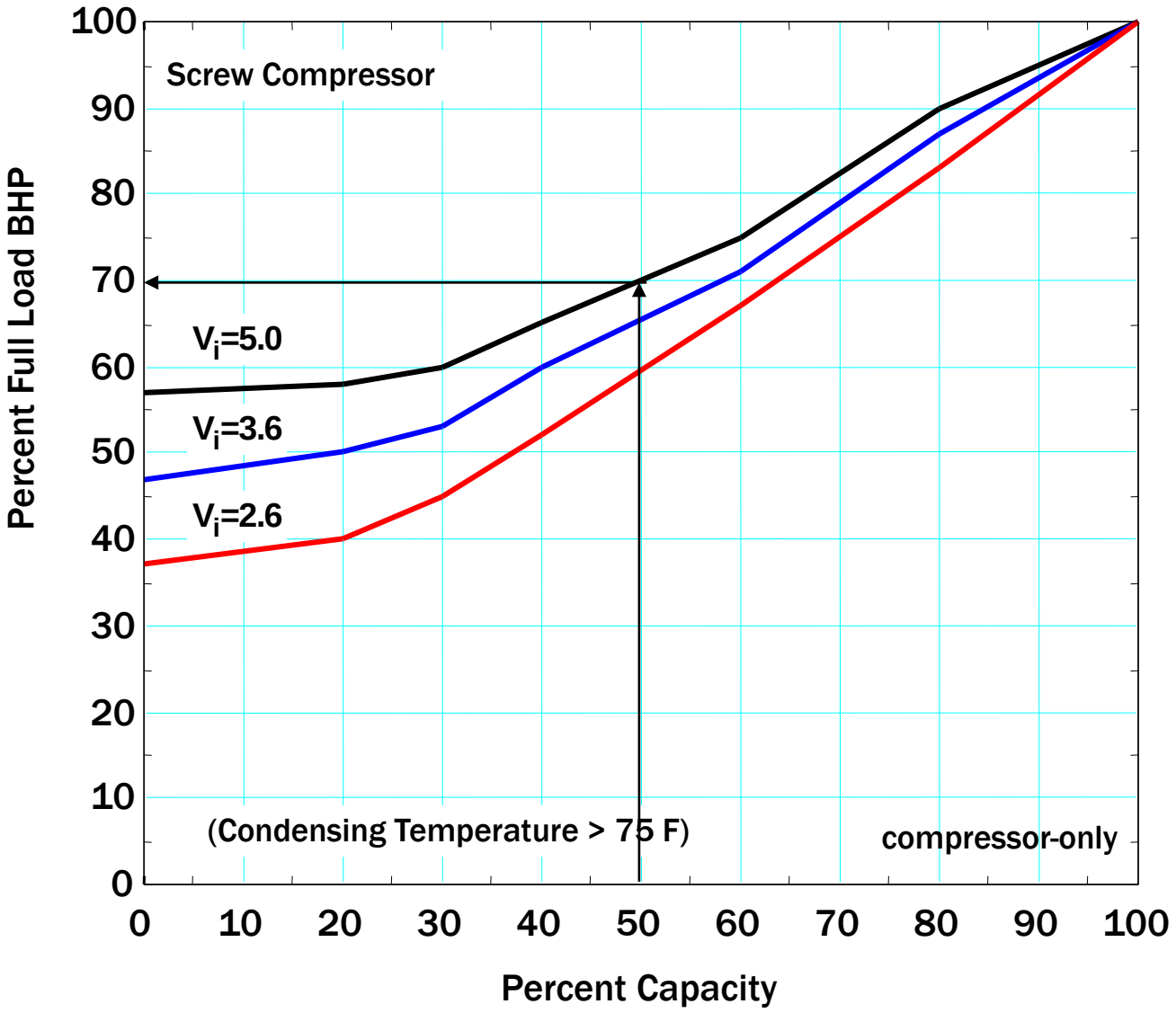


A fixed torque application.

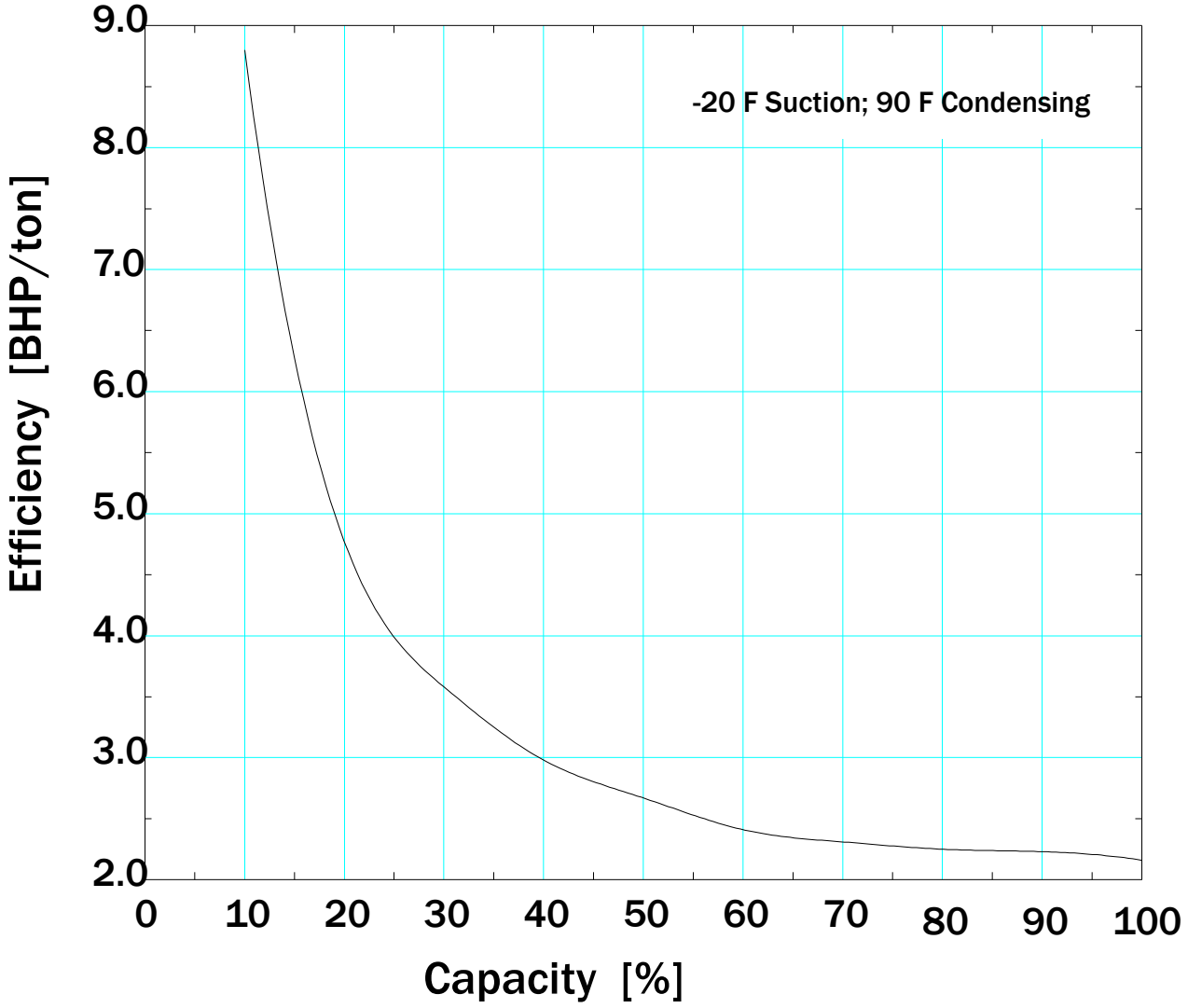
Compressor Capacity Control

- Reciprocating
  - Start/stop individual compressors (rack system)
  - Discrete cylinder unloaders
  - Hot gas bypass (not preferred)
  - Variable speed drive?
- Screw – single, twin
  - Continuous slide valve, poppet valves, etc.
  - Hot gas bypass (not preferred)
  - Variable speed drive?

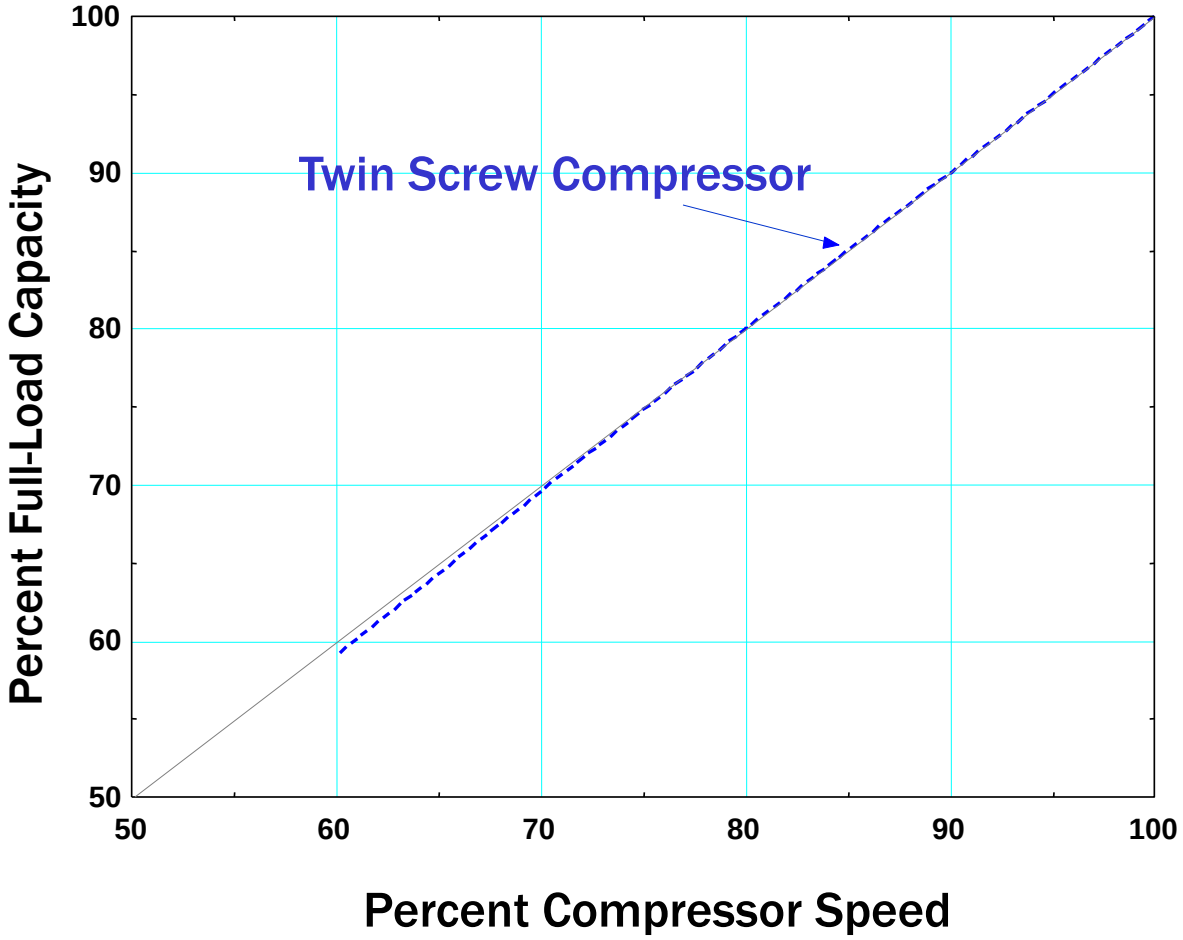
Screw Compressor Part-load Characteristics



Inefficient Part-load Operation!

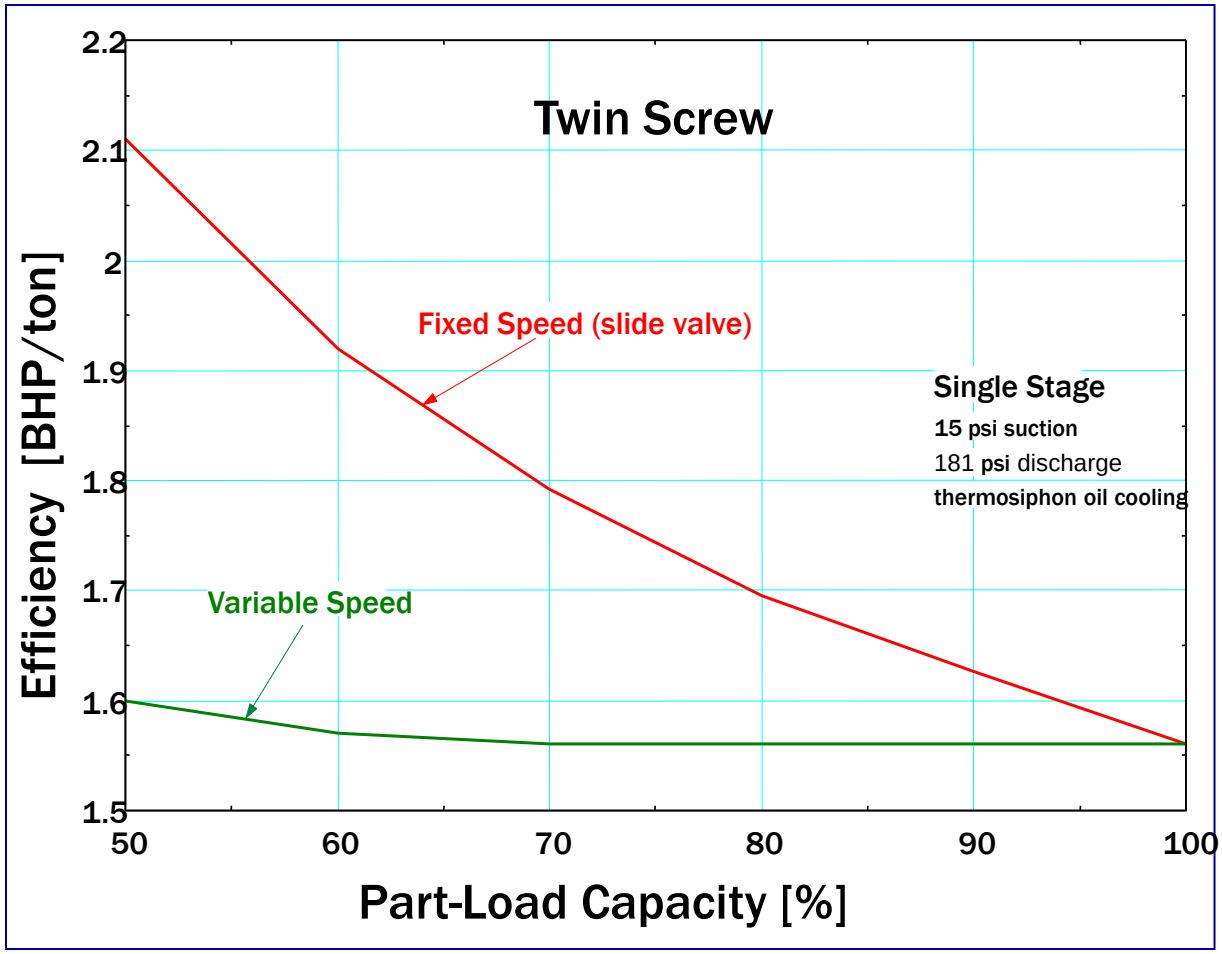


Compressor Capacity Control



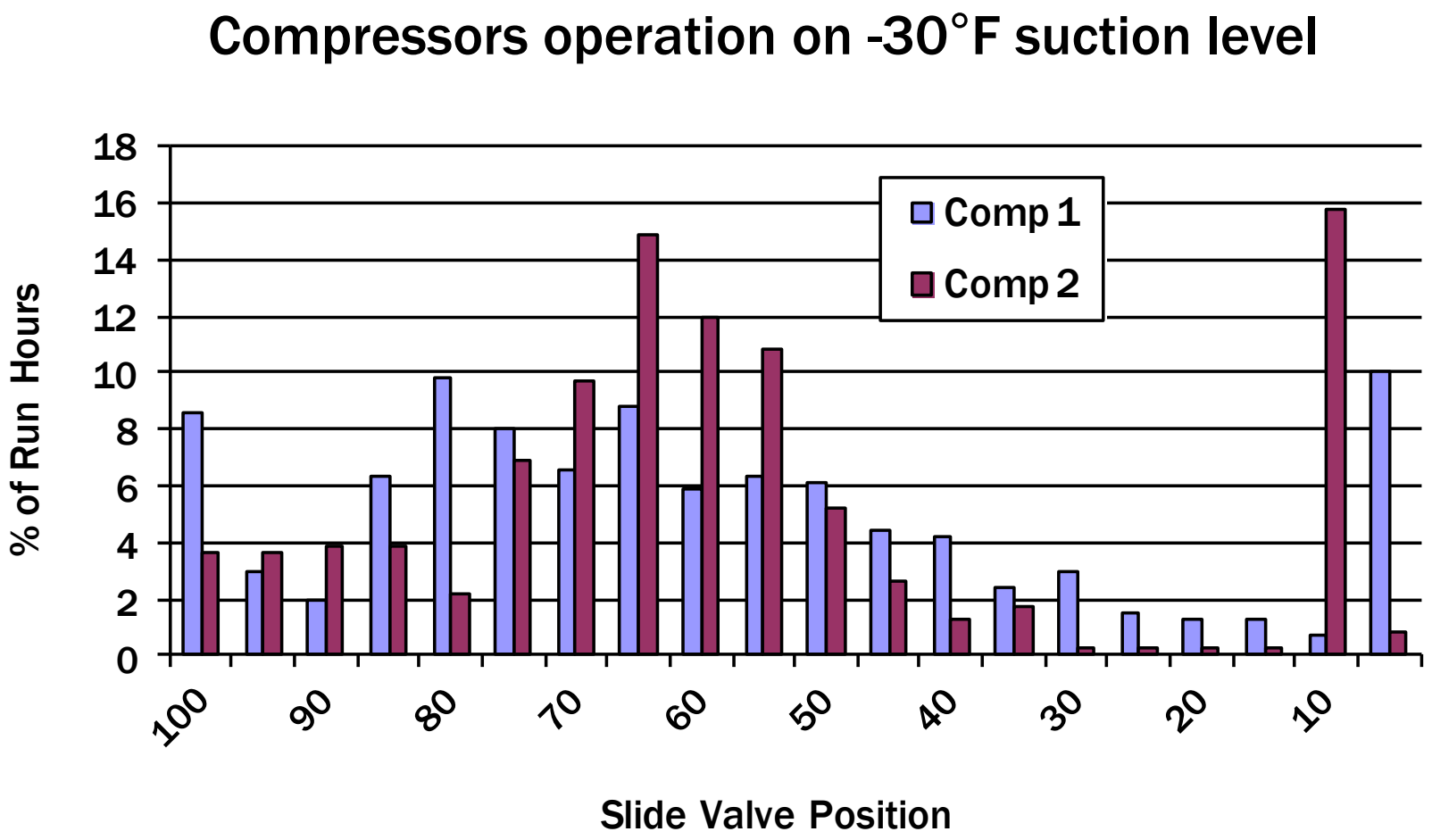
Compressor capacity is directly proportional to shaft speed

Speed Control Efficiency Benefit



VFDs perform well at part-load conditions!

Screw Compressor Field Retrofit



Ref: Campbell, "VFDs in Industrial Refrigeration - Lesson's Learned", IRC R&T Forum (2006).

Compressor VFD Retrofit

- Installed 500 HP VFD on -30 suction level (trim machine)
- Implemented 1st level of capacity control using speed rather than slide valve
- All other compressors base loaded at 100%

500 HP inverter rated motor (North Ice Cream Plant)

Ref: Campbell, “VFDs in Industrial Refrigeration - Lesson's Learned”, IRC R&T Forum (2006).

Compressor VFD Retrofit Positive Results

5% compressor run time reduction

25% booster energy consumption reduction

Savings analysis

160 kW peak demand reduction

Simple payback 1.2 yr

Ref: Campbell, "VFDs in Industrial Refrigeration - Lesson's Learned", IRC R&T Forum (2006).

Compressor VFD Application Considerations

- One VFD-equipped compressor per suction level
- Operating sequence considerations
  - Base load fixed speed screws at 100% slide valve
  - Trim with VFD-equipped compressor
    - Use speed as first level of capacity control
    - Use slide valve as second level of capacity control
  - Monitor, tune PI control to avoid speed cycling

Compressor VFD Application Considerations
(continued)

- Not cost effective for medium voltage (4160 V) motors
- Speed control range – essential to field verify compressor is free from excessive vibration at all frequencies/speeds
- Adhere to minimum speed
  - Required for adequate oil circulation
  - Required to maintain rotor tip velocity
  - May require supplemental fan for motor cooling

Questions on VFDs for compressors?

Closing Thoughts

- Condenser fans
  - All or none – expect 2-3% savings
- Evaporator fans
  - 2-4% savings range
  - Simple paybacks range 1-5 years
- Compressors
  - At most, one VFD comp per suction level
  - Simple paybacks range 1-4 years

Questions?

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Thank you!

Additional Resources

Industrial Refrigeration Consortium – www.irc.wisc.edu

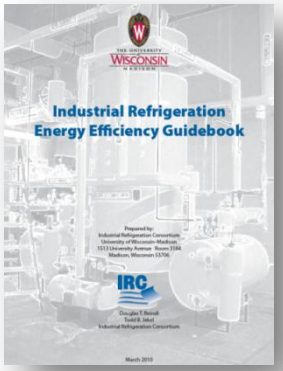
Research and Technology Forum Presentations

- "Fundamentals of VFDs and Refrigeration Applications" Ohme (2009)
- "VFDs for Evaporators" Runsey (2009)
- "VFDs for Compressors" Cosner (2009)
- "Case Studies of VFD Applications" Zanutto (2009)
- "VFDs in Industrial Refrigeration – Lesson's Learned" Campbell (2006)

Cold Front Newsletters

- "VFDs for Evaporative Condenser Fans" Vol. 4 No. 2 (2004)
- "VFDs for Screw Compressors" Vol. 4 No. 3 (2004)
- "VFDs for Evaporator Fans" Vol. 4 No. 4 (2004)

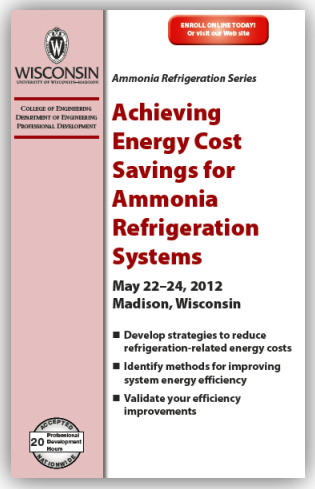
Industrial Refrigeration Energy Efficiency Guidebook, Reindl & Jekel, 2nd Edition, (2011)



Additional Resources (continued)

University of Wisconsin-Madison/IRC

- Short course – "Achieving Energy Cost Savings for Ammonia Refrigeration Systems" May 22-24, 2012
- http://epd.engr.wisc.edu/ammoniarefrigeration



Northwest Energy Efficiency Alliance *Evaporator Fan VFD Initiative*

- Baseline Market Evaluation Report, April 1999
- Market Progress Evaluation Report No 2., November 2000
- Market Progress Evaluation Report No 2., June 2002
- Reports available at www.nwalliance.org