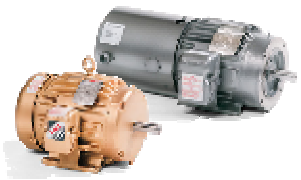

VFDs for Refrigeration Evaporators

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Objective

- Overview of Variable Frequency Drives (VFDs)
- Evaporator fan operation
  - Part-load operational considerations
- Comparison with fixed speed
  - Opportunities
  - Challenges

Notes:

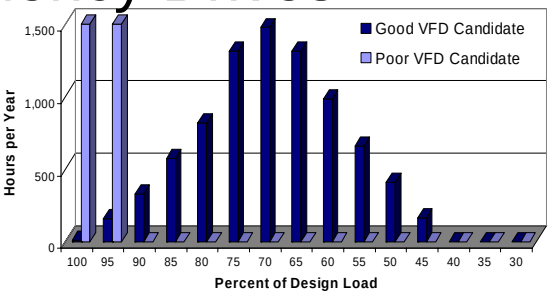
•Other names for a VFD are

•Variable Speed Drive (VSD)

•Adjustable Speed Drive (ASD)

•Adjustable Frequency Drive (AFD)

Variable Frequency Drives



- Good applications
  - Large motors
  - High hours per year operation
  - Frequent part-load operation
  - Variable torque processes
    - As speed is reduced, so is torque
      - Fans and centrifugal pumps
      - Allows application without overheating the motor at low speeds

Variable Frequency Drives

- Motor requirements
  - Inverter-duty may be necessary
- VFD requirements & characteristics
  - Drive must be within 50-100 ft of application†
  - May apply a single drive to more than one motor
    - Size drive for total connected horsepower
    - Individual motor over-current protection required
  - Startup torque is reduced
- Power factor
  - Near unity (1) for VFDs w/harmonics-mitigating equip.

† manufacturer dependent

Variable Frequency Drives

- Applicable fan laws

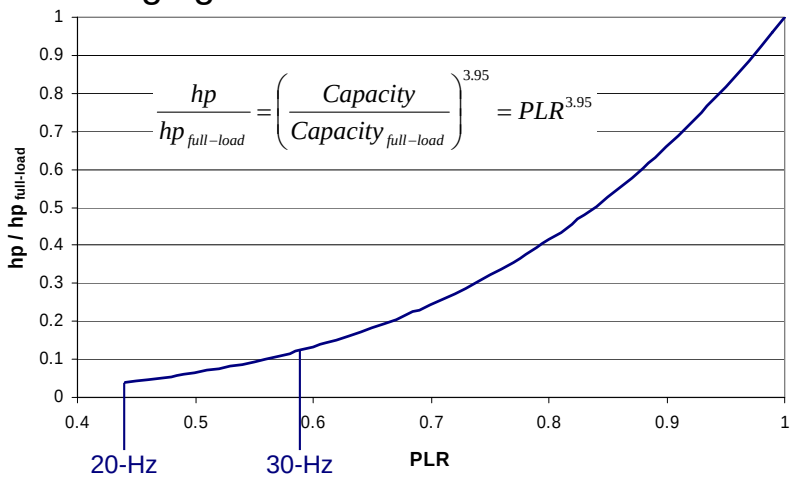
$$\frac{N}{N_{full-load}} = \frac{CFM}{CFM_{full-load}} \qquad \frac{hp}{hp_{full-load}} = \left(\frac{CFM}{CFM_{full-load}}\right)^{3}$$

- Limitations
  - Typical minimum motor speeds between 20-30-Hz
- Impact on heat exchange

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

Fan Horsepower Impact of VFD

- Rearranging results in



VFD Benefits

- Reduced system power
  - Drastically reduced evaporator fan horsepower requirement at part-load
  - Lower refrigeration load from fans
    - (5-hp equals 1 ton of refrigeration)
- Potentially fewer system transients
- Increased motor life
  - Less motor cycling
  - Inherently “soft-start”

VFD Benefits (*continued*)

- Improved power factor
  - (especially on small horsepower motors)
- Decreased noise and “wind-chill”
- Increased control, more stable temperature control

Notes:

•Power factor on a standard efficiency motor less than 1-hp can be as low as 0.59.

•Power factor on a premium efficiency motor less than 1-hp can be as low as 0.78.

VFD Drawbacks

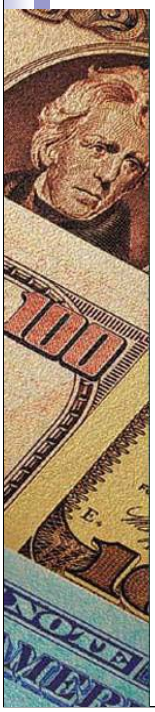
- Drive losses (~4-6%, losses increase at low loads)
- Loss of evaporator “throw”
- Typical systems have large number of small evaporator fan motors (cost)
- Additional equipment to maintain
- Resonance of equipment (natural frequency)
- Power quality
- Siting of the drive

When to considered VFDs

- Load requires close temperature control
- Large fans and motors
  - Blast freezers, penthouse freezer evaporators with ducting, etc.
- Low TD installations
  - Not necessarily requiring low TD for space conditions
- Significant and frequently occurring part-load operation
  - Northern climates
- High electricity rates

Impact of Evaporator Liquid Feed Configuration

- Direct Expansion
  - Care must be taken with sizing of thermal expansion valve and distributor, and coil circuiting for low load conditions
- Gravity Flooded
  - Good fit because liquid feed is proportional to load
- Overfeed
  - Liquid supply rate is independent of load
  - Suction riser should be sized to overfeed at part-load conditions



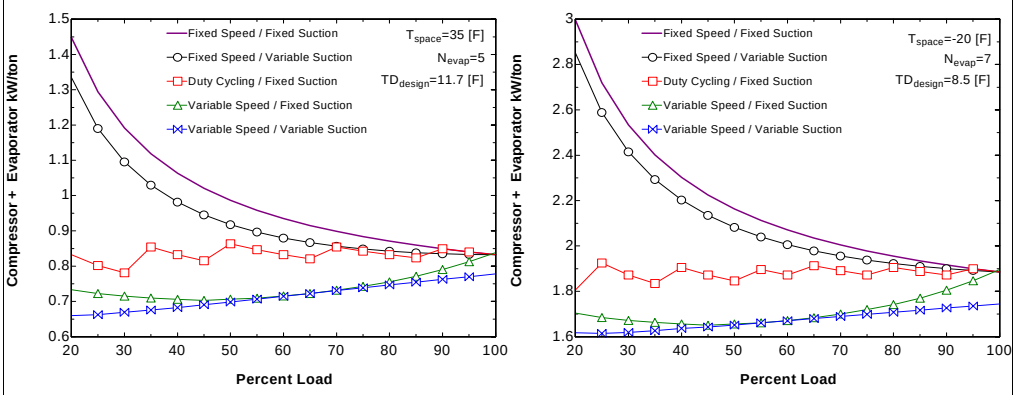
How much can I save?

- Evaporator fan horsepower usually a small fraction of the system horsepower at full-load
  - Low TD load requirements result in larger contribution to the system horsepower & parasitic refrigeration load
- Part-load
  - Defined as actual load divided by the installed evaporator capacity
  - If no fan control, the fan horsepower contribution to the system horsepower is constant

Analysis Assumptions

- Evaporator
  - TD = 12°F for cooler and 8°F for freezer
- VFD costs
  - Assume 3-hp VFD for each evaporator
  - Installation 15 hours/VFD by electrician @ $55/hour
- Energy costs
  - Blended $0.05/kWh

Compressor + Evaporator kW/ton



Assumptions:

Cooler:

•Fully loaded single-stage screw compressor with thermosiphon oil cooling, average discharge pressure of 165 psia (85ºF), includes package losses

•Compressor motor efficiency of 93%

•Evaporator fan motor efficiency of 78% (0.75 hp, 3-phase, 460 volt, 1,140 rpm)

•VFD drive efficiency of 96% at full-load

Freezer:

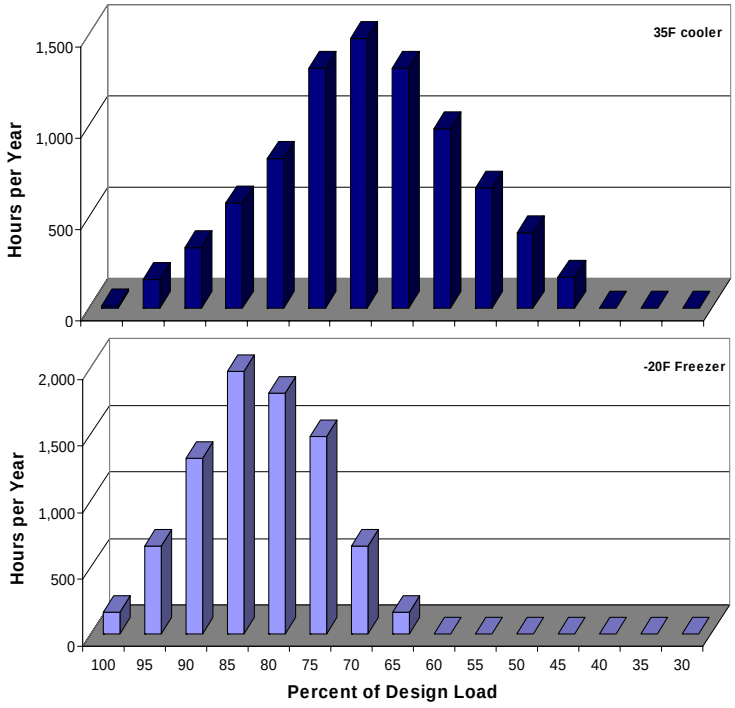
•Fully loaded two-stage screw compressor with thermosiphon oil cooling, average discharge pressure of 165 psia (85ºF), includes package losses

•Compressor motor efficiency of 93%

•Evaporator fan motor efficiency of 78% (0.75 hp, 3-phase, 460 volt, 1,140 rpm)

•VFD drive efficiency of 96% at full-load

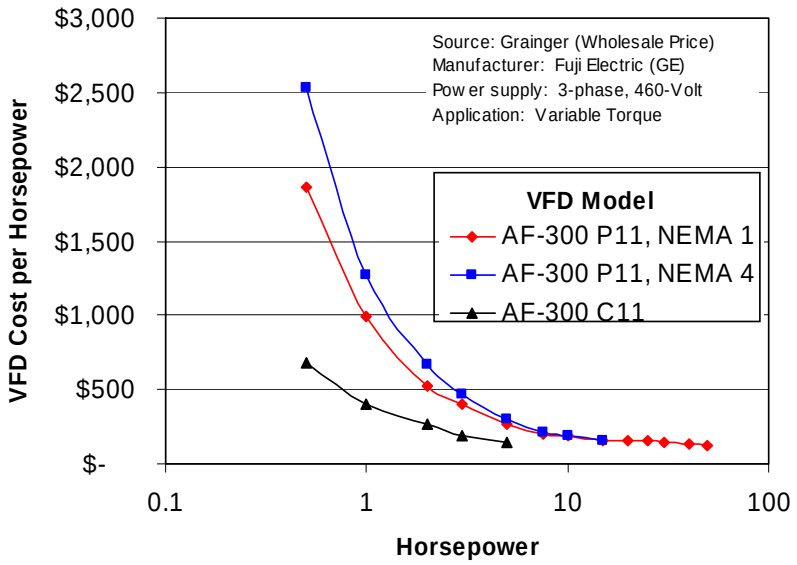
Load Profiles



Assumption:

•22.5 hours per day in refrigeration mode

VFD Cost



Notes:

•Prices taken from www.grainger.com in December, 2003.

•Less expensive VFDs are available if a suitable enclosure already exists or is part of the new installation.

•NEMA 4 (waterproof) requirements results in higher cost, particularly for small horsepower drives.

Economic Analysis

	Cooler (35°F)	Freezer (-20°F)
From always on fan control to VFD		
Savings per ton	$45	$60
Capital cost per ton†	$65	$95
Installation cost per ton	$40	$60
Simple payback	**2.3 years**	**2.6 years**
From cycling fan control to VFD		
Savings per ton	$30	$40
Simple payback	**3.8 years**	**3.6 years**

† Purchase of a single drive to operate all fan motors (4) on evaporator.

Closing Thoughts

- Reasonably short payback (<3 years) compared to always running the fan
  - Payback will be shorter with evaporators requiring larger horsepower drives
  - Longer if cannot use single drive per evaporator
- Ask questions prior to implementation
  - If retrofit
    - Is motor compatible with VFD?
    - Is resonance at lower fan speeds an issue?
  - Check actual current draw on motors prior to sizing drive
    - Fans require and motors can deliver more power at low temperatures

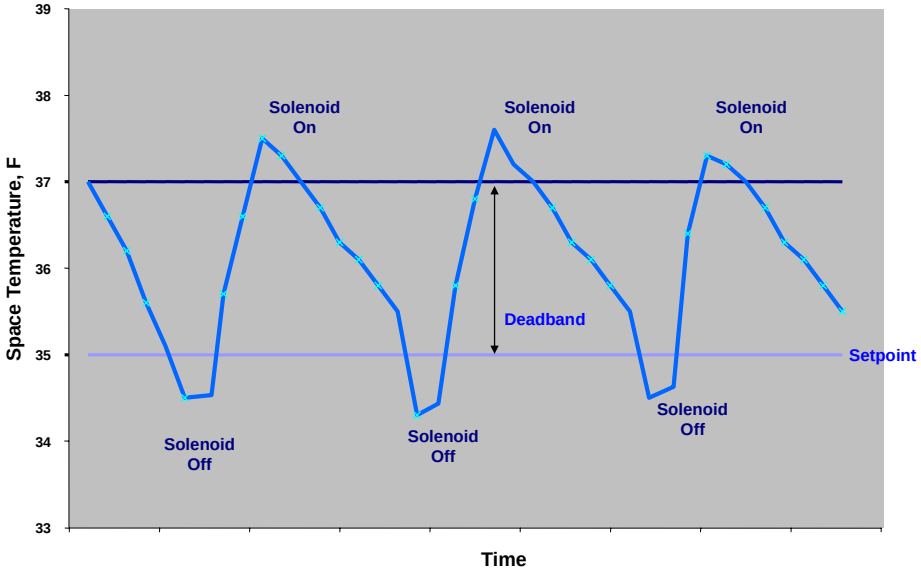
Additional Resources

- 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

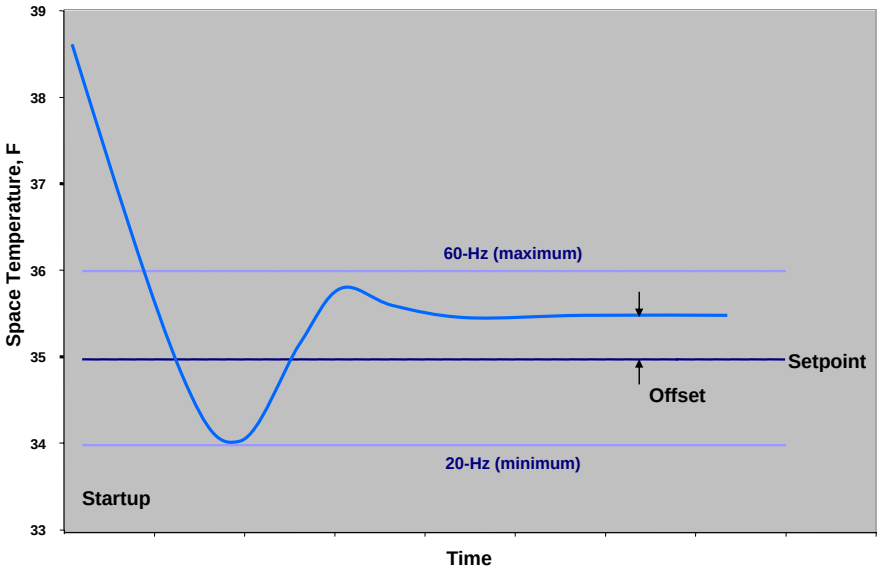
Controls

- On-Off
  - Controller turns liquid feed solenoid on or off to try to maintain set point
- Modulating (solenoid not necessarily controlled)
  - **P**roportional
    - The output of the control element is proportional to the deviation from the set point
  - **P**roportional-**I**ntegral (PI)
    - Adjusts control point based on accumulated deviation from set point
  - **P**roportional-**I**ntegral-**D**erivative (PID)
    - Adjusts control point based on accumulated deviation and on rate of change

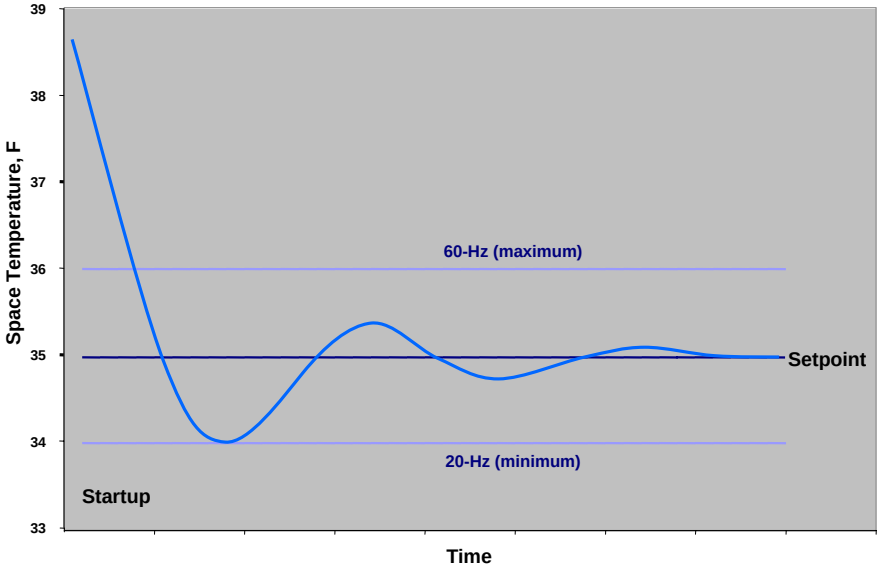
On-Off Control



Proportional Control



PID Control


39
38
37
36
35
34
33
Space Temperature, F
60-Hz (maximum)
Setpoint
20-Hz (minimum)
Startup
Time