Variable Flow Pumps – Control Strategies

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Presented by Steve Thompson
VP - Residential Product Management – Taco Inc.
Mobile (401) 441-2934
E Mail: stetho@taco-hvac.com

Variable Flow Pumps – Control Strategies

Agenda:
• Introduction
• General Descriptors
• VFD or not VFD – That is the Question (VFD Assessment Tool)
• System & Pump Curves
• Selfsensing Pumps
• Applications
• Balancing VFD Pumping Systems
• Delta T
• Warning!!!
• Efficiency
  – To trim or not to trim
    – ECM Permanent Magnet Technology
    – Affinity Laws
• Commissioning Tips
• DOE / ASHRAE / ACEEE
General Descriptors

\(\Delta T\) Differential Temperature
- Net temperature differential between two points (typically supply and return)
- 20 Deg F "Normal" differential temperature design for high mass, medium temperature systems
- 10 to 15 Deg F for radiant
- 10 to 12 Deg F for chilled water primaries

Setpoint Temperature
- Temperature sensed at single location
- If sensor built into the pump, the pump must be installed at sensing location
- Make-up air coil a good example

\(\Delta P\) Differential Pressure
- Pressure measured or sensed across two points
- Typical closed loop system pump inlet pressure is relatively constant
- \(\Delta PC\) – Differential Pressure Constant (flat pump curve)
- \(\Delta PV\) – Proportional Pressure (inclining pump curve)

Self Sensing
- Pump (Circ) adjusts speed without any physical sensors
- Reacts to changes in impeller loading as a result of system flow change

Primary Circuit
- Dedicated to moving fluid to/from heating or cooling source

Secondary Circuit
- Supplies fluid to building conditioned space

Circulator vs Pump
- Pumps boost pressure (Well Pumps, Pressure Booster Pumps, Boiler Feed Pumps)
- Circulators invoke fluid movement by overcoming friction loss (could be any Hp)

Residential vs Commercial

What’s a Variable Flow System Application And Why Does This Matter?
- An HVAC system is like our body
  - Brain = BMS (BAS) system
  - Heart = pump
  - Stomach = boiler or chiller
  - Arteries = piping system
- Working out - system under load
  - Body - heart rate up, increased blood pressure, consumes more energy
  - Building – more BTU’s (flow), more head
- Sleeping - system under low load or setback
  - Body – heart rate and blood pressure down, consumes less energy
  - Building – less BTU’s, lower head

At least that’s the way it is supposed to work!
What if our heart and blood pressure didn’t change?
Conclusion – all HVAC APPS are variable flow!
VFD Assessment – New Systems

Start

- Need to vary duty continuously
  - VFD potentially useful
    - Mostly friction?
      - Yes
        - VFD potentially useful
          - Does the pump run most of the time?
            - Yes
              - VFD almost certainly beneficial
            - No
              - Consider fixed speed pumps, On-Off control, Multiple sizes, etc.
        - No
          - Check overall benefits including non-energy items i.e.: reduced maintenance cost
            - Calculate total annual operating cost with alternative system solutions
              - Is VFD suitable?
                - No
                  - Use fixed speed Viridian
                - Yes
                  - Use VFD

VFD Assessment – Retrofit Systems

Start

- Is duty variable
  - VFD potentially useful
    - Mostly friction?
      - Yes
        - VFD potentially useful
          - Does the pump run most of the time?
            - Yes
              - VFD almost certainly beneficial
            - No
              - Confirm existing fixed speed pump is correctly sized
                - Yes
                  - Retain existing installation if efficient
                - No
                  - Check overall benefits including non-energy items i.e.: reduced maintenance cost
                    - Calculate total annual operating cost with alternative system solutions
                      - Is VFD suitable?
                        - No
                          - Are existing pump and motor suitable for proposed VFD
                            - Yes
                              - Use VFD
                            - No
                              - Consider modification or replacement of equipment
        - No
          - Confirm existing fixed speed pump is correctly sized
            - Yes
              - Retain existing installation if efficient
            - No
              - Check overall benefits including non-energy items i.e.: reduced maintenance cost
                - Calculate total annual operating cost with alternative system solutions
                  - Is VFD suitable?
                    - No
                      - Are existing pump and motor suitable for proposed VFD
                        - Yes
                          - Use VFD
                        - No
                          - Consider modification or replacement of equipment
System Curves

3-Way Control Valve
60 GPM each fan coil
2-Way Control Valves
Fan Coils
Design Operating Point
300 Gallons Per Minute
53 Feet of Head

150 ton system
@ 12deg Delta T
Chiller

System Curves

\[ H_2 = H_1 \left( \frac{Q_2}{Q_1} \right)^{1.85} \]

<table>
<thead>
<tr>
<th>System</th>
<th>Capacity (Q) in GPM</th>
<th>Head (H) in Feet</th>
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<td></td>
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System Curves

KS Model 4009
Test Data at 1760 RPM

<table>
<thead>
<tr>
<th>Capacity (GPM)</th>
<th>Head (Ft)</th>
<th>Efficiency (%)</th>
<th>BHP (HP)</th>
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<td>0.00</td>
<td>59.55</td>
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<td>59.74</td>
<td>44.25</td>
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System Curves

3-Way Control Valve

Pan Cells

2-Way Control Valves

Chiller

KS Model 4009
With an 8.00” impeller
Test Data at 1760 RPM

<table>
<thead>
<tr>
<th>Capacity (GPM)</th>
<th>Pump Head (Ft)</th>
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</table>
SelfSensing Pumps
Variable Loads (Zones Closing)

- 3-Way Valve
- Cooling Loads
- 2-Way Control Valves
- Secondary Loop
- Secondary Pump
- Primary Loop
- Primary Pump
- Chiller

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SelfSensing Pumps

Valves Closed
Minimum Flow

Valves Open
Maximum Flow

- Head (Ft.)
- Flow (GPM)
Integrated VFD with Sensorless Control

Constant Pressure Mode

Proportional Pressure Mode

True System Curve Mode

Applications

Example:
Chilled water primary / secondary system
Constant Flow Mode

Self-sensing CONSTANT flow is self-balancing and automatically adjusts flow to maintain user-defined flow set point.

Used on constant flow chiller / boiler pumps

Benefits:
- Balancing through reduced speed – not false head
- Reduced speed increases equipment life
- Balancing done internally and automatically
- Auto adjust over the life and fouling of the system
- Using full trim impellers
- Allows for design vs. reality differences

Variable Flow Mode

Self-sensing variable flow adapts to system pressure variations and automatically follows the system performance curve to meet demand.

Used on secondary variable speed pumps

Benefits:
- Lower install costs
- No error in setpoint
- Improved system efficiency and performance
- Reduced coordination and construction schedule
Direct Return Piping System
(first in / first out)

- Variable flow ✓
- Constant flow ×
- Balancing complexity - high

Reverse Return Piping System
(first in / last out)

- Variable flow ✓
- Constant flow ×
- Balancing complexity – low
  - Self Balancing
• Variable flow ✓
• Constant flow ×
• Balancing complexity – depends

Primary Secondary Systems
(pumped secondary)

• Variable flow ✓
• Constant flow ×
• Balancing complexity
  • Crossover bridges balance
  • Which circs variable flow?
LoadMatch™ Single Pipe Pumping System

- Variable flow ✓
- Constant flow ×
- Balancing complexity – none req’d
- Circs variable flow?

**Balancing VFD Systems (ASHRAE)**

for fans with fan system power greater than 1 hp, fan speed shall be adjusted to meet design flow conditions.

6.7.2.3.3 Hydronic System Balancing. Hydronic systems shall be proportionately balanced in a manner to first minimize throttling losses; then the pump impeller shall be trimmed or pump speed shall be adjusted to meet design flow conditions.

Exceptions: Impellers need not be trimmed nor pump speed adjusted

a. for pumps with impeller diameters of 10 hp or less, or
b. when throttling results in no greater than 5% of the nameplate horsepower draw, or 3 hp, whichever is greater, above that required if the impeller was trimmed.

6.7.2.4 System Commissioning. HVAC control systems shall be tested to ensure that control elements are calibrated, adjusted, and in proper working condition. For projects larger than 50,000 BTU conditioned area, except warehouses and semihazardous spaces, detailed instructions for commissioning HVAC systems (see Informatie Appendix D) shall be provided by the designer in plans and specifications.

6.8 Minimum Equipment Efficiency Tables
6.8.1 Minimum Efficiency Requirement Listed Equipment—Standard Rating and Operating Conditions
6.8.2 Duct Insulation Tables

The main goal of the secondary chilled water system is to distribute the correct amount of water to satisfy the load. It must first accurately monitor the system for changes in load dynamics.

Secondly, it must respond to these load changes with the "correct" amount of flow

Run VFD’s at constant speed – balance then set pumps to AUTO
SelfSensing Pumps vs. Sensors

- Sensors are frequently placed in the wrong location in the system; this incorrect sensor placement results in system inefficiency.
- In a typical system, trial and error must be used (i.e. physically moving the sensor) until the optimum location is determined.
- Another strategy is to use multiple sensors to increase the odds of correct placement.
- These strategies can become costly.
- Even if correct placement is achieved, correct setpoint is rarely used.

Determining the Set Point for the Differential Pressure Sensor

The sensor must keep enough pressure differential across the supply and return to “push” the design capacity flow through the coil and control valve.

Setpoint = Sum of coil pressure drop + control valve pressure drop at design conditions (17')
Location of ΔP Transmitters

Efficiencies are dramatically affected

80' setpoint

17° setpoint

Differential Temperature

Delta-T lends itself to even more cost effective variable speed pumping. The issues associate with placement and of Delta-P sensors is replaced with ease and simplicity of thermisters. As the Delta-T falls below setpoint, the pumps would slow down. As the Delta-T rises above setpoint, the pumps speed up. Remember that BTUH = GPM x ΔT x 500
Boiler Temperature Sensor Location Consideration

- Be careful with sensor location for boiler plant control
- Sensors right at plant discharge can cause boiler short cycling because of lack of thermal mass
- The short cycling can significantly hurt system efficiency.
- Newer lower mass high efficiency boilers are very sensitive to low flow rates in the system (VFDs) and need a thermal flywheel. (Buffer tank)

Variable Speeds and Mechanical Seals – CAUTION!

- Noise (remember the noise when you turn a pump off during the last few revolutions – it’s dry a dry running seal)
- Seal face lubrication

Rules of Thumb
- 4 Pole (1,750 RPM) min 15 Hz, preferably 20 Hz
- 6 Pole (1,150 RPM) min 25 Hz
Causes of Excess System Flow

- Poor / excessive balancing
- Poor control valve selection (oversizing)
- Improper installation of control sensors
- Set point too high on DP transmitters
- Oversized pumps (with/without VFD’s)
- ΔP transducers in the wrong location is a common mistake (see next slide)

Universal Problems

- The secondary system will try to distribute more chilled water than is needed. This is inefficient and used excess horsepower.
- Higher flow causes low system temperature differentials, excess flow and change in flow direction in the crossover bridge.
- The chiller plant must keep more chillers on-line than is required by the load. The chillers and their chiller pumps are brought on just to keep up with excessive system flow.
- Solution: Designing and installing a variable speed pumping system can help eliminate these problems. A well-designed and commissioned system can greatly improve an owner’s chiller plant utilization and life cycle cost.

Chiller Plants – Things to Consider

- The flow rate of the chiller plant should be equal to or greater than the system flow rate.
- Changes in the direction of flow in the crossover bridge can be used for chiller staging.
- Control valve problems (or balancing) can result in artificially high flows, low temperature differentials, and the need to rerate chillers.
- Watch out for the physical configuration of the crossover bridge, especially 6” and above.
- Make sure that chiller plant loop has sufficient volume to cover chiller minimum run times.

Boilers – Things to Consider

- The flow rate of the primary boiler plant does not need to be greater than the system flow rate.
- Boiler plants and distribution loops can be designed with different temperature differentials to take advantage of smaller pipe sizes and mixing in the bridge.
- The mixing in the bridge can be used to protect non-condensing boilers in a water source heat pump system.
**Energy Savings**

The Pump Affinity Laws are a series of relationships relating, Flow (Q), Head (H), Horsepower (BHP), and Speed (N in units of R.P.M.)

The **Affinity Laws Relating to Speed Change Are:**

- **Flow:** $Q_2 = Q_1 \times \frac{N_2}{N_1}$
- **Head:** $H_2 = H_1 \times \left(\frac{N_2}{N_1}\right)^2$
- **Horsepower:** $BHP_2 = BHP_1 \times \left(\frac{N_2}{N_1}\right)^3$

Reducing the speed has a cubed effect on HP: 1/2 Speed = 1/8 HP

Most systems operate at reduced capacity most of their lives.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Flow</th>
<th>Head</th>
<th>BHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>75%</td>
<td>75%</td>
<td>56%</td>
<td>42%</td>
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<tr>
<td>50%</td>
<td>50%</td>
<td>25%</td>
<td>12.5%</td>
</tr>
<tr>
<td>25%</td>
<td>25%</td>
<td>6%</td>
<td>1.2%</td>
</tr>
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</table>

**Benefits of Variable Speed Pumping**

**Design Point A** - 3,600 USGPM @ 55' TDH, 12” Dia, η 90.7% - BHP = 55.13

**Actual Operating Point B** - 3,900 USGPM @ 52' TDH (throttle), 12” Dia, η 90.5% - BHP = 53.91

**Actual Operating Point C** (57.5 Hz) – 3,600 USGPM @ 44’ TDH, 12” Dia, η 90.7% - BHP = 44.10

**Annual Operating Cost PER PUMP** (Hospital @ 8,736 Hrs/Year, $0.11/kWh)

- **Point A** - Full Trim, no Balance = $52,977.73 (not including chiller efficiency decrease)
- **Point C** - Full Trim, Speed Reduction = $42,378.34

**ANNUAL Savings PER PUMP** = $10,599.39!

**To Trim or Not To Trim**

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ΔPC vs Constant Speed

Design load 1,600,000 BTU's or 160 USGPM @ 20 deg ΔT
25% load (shoulder heating season) 400,000 BTU or 40 USGPM

\[ BHP = \frac{H (\text{ft}) \times Q (\text{USGPM})}{\text{Eff} (0.0) \times 3960} \]

- BHP Design = \[\frac{35 \text{ ft} \times 160 \text{ USGPM}}{0.6 \times 3960}\] = 2.4
- BHP 25% = \[\frac{43 \text{ ft} \times 40 \text{ USGPM}}{0.4 \times 3960}\] = 1.2
- BHP Δpc = \[\frac{35 \text{ ft} \times 40 \text{ USGPM}}{0.6 \times 3960}\] = 0.6
- BHP Δpv = \[\frac{13 \text{ ft} \times 40 \text{ USGPM}}{0.6 \times 3960}\] = 0.2

Design flow – 160 USGPM
25% load flow – 40 USGPM

Let's Talk About Efficiency

<table>
<thead>
<tr>
<th>Flow (% of BEP)</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
<th>25%</th>
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</thead>
<tbody>
<tr>
<td>Motor Load (% Full Load)</td>
<td>15 Hp (100%)</td>
<td>7 Hp (42%)</td>
<td>2 Hp (13%)</td>
<td>0.3 Hp (2%)</td>
</tr>
<tr>
<td>Motor Eff*</td>
<td>93%</td>
<td>92.6%</td>
<td>85%</td>
<td>78%</td>
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<tr>
<td>Drive Eff**</td>
<td>96.5%</td>
<td>93.5%</td>
<td>84.5%</td>
<td>44%</td>
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</table>

* 15 Hp Premium Efficiency  
** VFD interpolated from “Energy Tips – Motor (Motor Tip Sheet #11) July 2008

Calculating Annual Electrical Cost to Operate a Pump – need to know:
- Information above on motor (driver) and drive (VFD) – efficiency at various loads
- # of operating hours at each flow (load) condition (load profile – heating or cooling)
- Average cost of electricity (USA average is $0.11 per kW)
- Head, flow and efficiency of the pump (wet end) - assume constant with VFD

Line to Water kW = \[\frac{H (\text{ft}) \times Q (\text{USGPM}) \times \text{SG}}{\eta P \times \eta M \times \eta D \times 3960}\]

\[ 0.745 \times \frac{500 \times 81 \times 1.0}{0.74 \times 0.93 \times 0.965 \times 3960} \]

“Knowns”
- 500 USGPM @ 81’ (100% load or flow)
- Pump efficiency @ H/Q “design” = 74%
- Motor efficiency @ design = 93%
- Drive efficiency @ design = 96.5%
- Assume SG 1.0
Motor Efficiency – AC Motors

- Optimum operating range 60% to 80%!
- EISA, NEMA and ASHRAE only refer to FULL LOAD minimum efficiency

| Energy Efficient Circulator Options |

- European energy efficient circulator technology is becoming available today in U.S. but acceptance has been slow because:
  - U.S. hydronic heating installed base is much smaller than EU
  - A very small portion of new homes in the U.S. use hydronic heat.
  - U.S. hydronic systems typically only run for small portion of year
  - Electricity in U.S. is less expensive
  - Cost of energy efficient circulators is nearly double traditional wet rotor circulators.
Comparison AC / EC Motor

AC-motor
Non controlled or VFD controlled

Asynchronous-squirrel-cage motor
Rotor is a sheet steel pack with nail like rods parallel to the rotor shaft
The rotor movement is caused by the rotating stator magnetic field

EC-motor
• Viridian ECM Technology
  - Brushless electronically commutated synchronous motor using a permanent magnet rotor
  - The rotor magnetic field “grabs” the rotating stator magnetic field, causing rotor rotation
  - Rotor (impeller) speed is determined by the pre-programmed drive software.

Benefits of ECM Technology
• Viridian is 15 to 20% more efficient than pump / VFD
• Permanent magnet (ECM) motors have flatter torque / efficiency curves than AC motors (better motor efficiency at low motor loads)
  - PM rotor is driven by magnetic field created by the motor windings
  - Opposite polarity attracts, similar polarity attracts at the same time!
• Higher “turn down” ratios (max vs. min speed relationship – Viridian is 6.8 to 1!)
• PM motors have 300 to 400% higher starting torque
• Viridian is soft start (no power surge)
• Doesn’t consume any energy in order to magnetize the rotor
• Creates continuous thrust
HVAC systems are DYNAMIC – loads / flows continually change.

Heating - Pump Operation:
6% time at design load (max)
15% time at 75% design load
35% time at 50% design load
44% time at 25% design load

AC Part Load Analysis - ARI Standard

<table>
<thead>
<tr>
<th>% Load</th>
<th>Old % Hrs</th>
<th>Current % Hrs</th>
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<tbody>
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<td>1</td>
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<tr>
<td>75</td>
<td>39</td>
<td>42</td>
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<td>50</td>
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<td>25</td>
<td>11</td>
<td>12</td>
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### Energy Savings Calculator – Chilled Water

**CW Load Profile and 8000 Hours, $0.11 / kWh**

<table>
<thead>
<tr>
<th>% Load Conditions</th>
<th>% Load</th>
<th>GPM (USGPM)</th>
<th>Head (ft)</th>
<th>Pump Eff</th>
<th>Motor Eff</th>
<th>Drive Eff</th>
<th>Wire to water eff</th>
<th>P1 to P4 Hp</th>
<th>Annual KW</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Speed Pumps, Throttling Valves (no VFD’s)</td>
<td>1%</td>
<td>100%</td>
<td>500</td>
<td>80.65</td>
<td>74%</td>
<td>93%</td>
<td>100%</td>
<td>69%</td>
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<td>100%</td>
<td>23%</td>
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**Chilled Water - Constant Speed Pumps, Throttling Valves (no VFD’s)**

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<td>50%</td>
<td>250</td>
<td>92.75</td>
<td>59%</td>
<td>78%</td>
<td>100%</td>
<td>46%</td>
<td>12.72</td>
<td>4585</td>
</tr>
<tr>
<td></td>
<td>12%</td>
<td>25%</td>
<td>125</td>
<td>95.97</td>
<td>37%</td>
<td>62%</td>
<td>100%</td>
<td>23%</td>
<td>13.21</td>
<td>12877</td>
</tr>
</tbody>
</table>

**Chilled Water - Variable Speed Pumps**

<table>
<thead>
<tr>
<th>% Load Conditions</th>
<th>% Load</th>
<th>GPM (USGPM)</th>
<th>Head (ft)</th>
<th>Pump Eff</th>
<th>Motor Eff</th>
<th>Drive Eff</th>
<th>Wire to water eff</th>
<th>P1 to P4 Hp</th>
<th>Annual KW</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Speed Pumps</td>
<td>1%</td>
<td>100%</td>
<td>500</td>
<td>80.7</td>
<td>74%</td>
<td>93%</td>
<td>97%</td>
<td>66%</td>
<td>15.34</td>
<td>1227</td>
</tr>
<tr>
<td></td>
<td>42%</td>
<td>75%</td>
<td>375</td>
<td>45.4</td>
<td>74%</td>
<td>93%</td>
<td>94%</td>
<td>64%</td>
<td>6.71</td>
<td>25546</td>
</tr>
<tr>
<td></td>
<td>45%</td>
<td>50%</td>
<td>250</td>
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<td>85%</td>
<td>85%</td>
<td>53%</td>
<td>2.40</td>
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<tr>
<td></td>
<td>12%</td>
<td>25%</td>
<td>125</td>
<td>5</td>
<td>74%</td>
<td>78%</td>
<td>44%</td>
<td>25%</td>
<td>0.62</td>
<td>597</td>
</tr>
</tbody>
</table>

**Totals** 10375 $11,371.25

### Energy Savings Calculator - Heating

**Heating Load Profile and 6000 Hours, $0.11 / kWh**

<table>
<thead>
<tr>
<th>% Load Conditions EU Standards</th>
<th>% Load</th>
<th>GPM (USGPM)</th>
<th>Head (ft)</th>
<th>Pump Eff</th>
<th>Motor Eff</th>
<th>Drive Eff</th>
<th>Wire to water eff</th>
<th>P1 to P4 Hp</th>
<th>Annual KW</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Speed Pumps, Throttling Valves (no VFD’s)</td>
<td>6%</td>
<td>100%</td>
<td>500</td>
<td>80.65</td>
<td>74%</td>
<td>93%</td>
<td>100%</td>
<td>69%</td>
<td>14.76</td>
<td>5315</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>75%</td>
<td>375</td>
<td>87.51</td>
<td>70%</td>
<td>91%</td>
<td>100%</td>
<td>64%</td>
<td>13.01</td>
<td>11708</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>50%</td>
<td>250</td>
<td>92.75</td>
<td>59%</td>
<td>78%</td>
<td>100%</td>
<td>46%</td>
<td>12.72</td>
<td>26720</td>
</tr>
<tr>
<td></td>
<td>44%</td>
<td>25%</td>
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<td>95.97</td>
<td>37%</td>
<td>62%</td>
<td>100%</td>
<td>23%</td>
<td>13.21</td>
<td>34863</td>
</tr>
</tbody>
</table>

**Heating - Constant Speed Pumps, Throttling Valves (no VFD’s)**

<table>
<thead>
<tr>
<th>% Load Conditions EU Standards</th>
<th>% Load</th>
<th>GPM (USGPM)</th>
<th>Head (ft)</th>
<th>Pump Eff</th>
<th>Motor Eff</th>
<th>Drive Eff</th>
<th>Wire to water eff</th>
<th>P1 to P4 Hp</th>
<th>Annual KW</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Speed Pumps, Throttling Valves (no VFD’s)</td>
<td>6%</td>
<td>100%</td>
<td>500</td>
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<td>93%</td>
<td>97%</td>
<td>66%</td>
<td>15.34</td>
<td>5523</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>75%</td>
<td>375</td>
<td>45.4</td>
<td>74%</td>
<td>93%</td>
<td>94%</td>
<td>64%</td>
<td>6.71</td>
<td>6039</td>
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<tr>
<td></td>
<td>35%</td>
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<td>85%</td>
<td>85%</td>
<td>53%</td>
<td>2.40</td>
<td>6039</td>
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<tr>
<td></td>
<td>44%</td>
<td>25%</td>
<td>125</td>
<td>5</td>
<td>74%</td>
<td>78%</td>
<td>44%</td>
<td>25%</td>
<td>0.62</td>
<td>1641</td>
</tr>
</tbody>
</table>

**Totals** 78606 $8,646.67

### Energy Savings Calculator - Heating

**Heating Load Profile and 6000 Hours, $0.11 / kWh**

<table>
<thead>
<tr>
<th>% Load Conditions EU Standards</th>
<th>% Load</th>
<th>GPM (USGPM)</th>
<th>Head (ft)</th>
<th>Pump Eff</th>
<th>Motor Eff</th>
<th>Drive Eff</th>
<th>Wire to water eff</th>
<th>P1 to P4 Hp</th>
<th>Annual KW</th>
<th>Annual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Speed Pumps</td>
<td>6%</td>
<td>100%</td>
<td>500</td>
<td>80.7</td>
<td>74%</td>
<td>93%</td>
<td>97%</td>
<td>66%</td>
<td>15.34</td>
<td>5523</td>
</tr>
<tr>
<td></td>
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<td>93%</td>
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<td>64%</td>
<td>6.71</td>
<td>6039</td>
</tr>
<tr>
<td></td>
<td>35%</td>
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<td>250</td>
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</tr>
<tr>
<td></td>
<td>44%</td>
<td>25%</td>
<td>125</td>
<td>5</td>
<td>74%</td>
<td>78%</td>
<td>44%</td>
<td>25%</td>
<td>0.62</td>
<td>1641</td>
</tr>
</tbody>
</table>

**Totals** 18242 $2,006.60
**Payback Analysis**
Based on 6,480 annual operating hours, pump costs and $0.11/kWh cost of power
Data from LCL Excel file for energy comparison – Viridian vs 1900 Series

![Graph showing payback analysis over years for different models](image)

**ECM and Self Sensing Technology**

**FAQs:**

- Availability of larger ECM motors
- ECM motors in Residential markets
- ECM/Variable Flow in Solar – why/why not?
- State Incentive Programs – residential and commercial
- ECM Failure Modes
- Available Voltages
- Sensor Lessons Learned
- ASHRAE and DOE Activities
Federal regulations mandate all states use ASHRAE 90.1 or IECC as a minimum efficiency standard.
ASHRAE 90.1 - 2010

G3.1.3.8 Chilled-Water Design Supply Temperature (Systems 7 and 8). Chilled-water design supply temperature shall be modeled at 44°F and return water temperature at 50°F.

G3.1.3.9 Chilled-Water Supply Temperature Reset (Systems 7 and 8). Chilled-water supply temperature shall be reset based on outdoor dry-bulb temperature using the following schedule: 44°F at 80°F and above, 54°F at 60°F and below, and ramped linearly between 44°F and 54°F at temperatures between 80°F and 60°F.

G3.1.3.10 Chilled-Water Pumps. The baseline building design energy pump power shall be 22 W/gpm. Chilled-water systems with a cooling capacity of 300 tons or more shall be modeled as primary/secondary systems with variable-speed drives on the secondary pumping loop. Chilled-water pumps in systems serving less than 300 tons cooling capacity shall be modeled as a primary/secondary system with secondary pump riding the pump curve.

Exception: The pump power for systems using purchased chilled water shall be 16 W/gpm.

All about ΔT. Either control directly with a temperature reactive VFD pump or valves and a pressure reactive pump

VSD (VFD) pumps are mandated for use on secondary systems on larger systems

6.5.4 Hydronic System Design and Control.

6.5.4.1 Hydronic Variable Flow Systems. HVAC pumping systems having a total pump system power exceeding 10 hp that include control valves designed to modulate or shut off and dose as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate. Individual chilled water pumps serving variable flow systems having motors exceeding 5 hp shall have controls and/or devices (such as variable speed control) which will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure. The differential pressure setpoint shall be no more than 110% of that required to achieve design flow through the heat exchanger. Where differential pressure control is used to comply with this section and DDC controls are used the setpoint shall be reset downward based on valve positions until one valve is nearly wide open.

Exceptions:

a. Systems where the minimum flow is less than the minimum flow required by the equipment manufacturer for proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.

b. Systems that include no more than three control valves.

LoadMatch systems are NOT required to have variable speed pumping as they have no more than 3 control valves.

6.4.2.2 Pump Head. Pump differential pressure (head) for the purpose of sizing pumps shall be determined in accordance with generally accepted engineering standards and handbooks acceptable to the adopting authority. The pressure drop through each device and pipe segment in the critical circuit at design conditions shall be calculated.

6.4.3 Controls

6.4.3.1 Zone Thermostatic Controls

6.4.3.1.1 General. The supply of heating and cooling energy to each zone shall be individually controlled by thermostatic controls responding to temperature within the zone. For the purpose of Section 6.4.3.1, a shafting unit shall be permitted to be considered a single zone.

Reducing pump flow by 50% > 10 Hp on systems with valves

30% wattage at 50% design flow descriptor

Δ P sensor location
6.5.4.2 Hydraulic heat pumps and water-cooled unitary air-conditioners having a total pump system power exceeding 5 hp shall have control and/or drivers (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow.

6.5.4.5 Pipe Sizing. All chilled-water and condenser-water piping shall be designed such that the design flow rate in each pipe segment shall not exceed the values listed in Table 6.5.4.5 for the appropriate total annual hours of operation. Pipe size selections for systems that operate under variable flow conditions (e.g., modulating two-way control valves at valves) and that contain variable-speed pump motors are allowed to be made from the "Variable Flow/Variable Speed" columns. All others shall be made from the "Other" columns.

Exceptions:

a. Design flow rates exceeding the values in Table 6.5.4.5 are allowed in specific sections of pipe if the pipe in question is not in the critical circuit at design conditions and is not predicted to be in the critical circuit during more than 30% of operating hours.

b. Piping systems that have equivalent or lower total pressure drops than the same system constructed with standard weight steel pipe with piping and fittings sized per Table 6.5.4.5.

### Table 6.5.4.5 Piping System Design Maximum Flow Rate in GPM

<table>
<thead>
<tr>
<th>Operating Hours/Year</th>
<th>2000 Hours/Year</th>
<th>3000 and 4000 Hours/Year</th>
<th>4000 Hours/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Pipe Size, In</td>
<td>Other Variable Flow/Variable Speed</td>
<td>Other Variable Flow/Variable Speed</td>
<td>Other Variable Flow/Variable Speed</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>300 180 90</td>
<td>450 270 225</td>
<td>110 73</td>
</tr>
<tr>
<td>1&quot;</td>
<td>550 330 195</td>
<td>650 420 330</td>
<td>190 115</td>
</tr>
<tr>
<td>1 1/2&quot;</td>
<td>650 400 250</td>
<td>750 470 325</td>
<td>210 135</td>
</tr>
<tr>
<td>2&quot;</td>
<td>780 510 310</td>
<td>880 590 390</td>
<td>250 175</td>
</tr>
<tr>
<td>3&quot;</td>
<td>1000 640 400</td>
<td>1100 800 550</td>
<td>300 200</td>
</tr>
<tr>
<td>4&quot;</td>
<td>1200 800 550</td>
<td>1300 900 600</td>
<td>350 250</td>
</tr>
</tbody>
</table>

Maximum Velocity in Pumps over 100 Feet

<table>
<thead>
<tr>
<th>Maximum Velocity in Pumps over 100 Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 ft/s</td>
</tr>
</tbody>
</table>

Higher velocities (smaller pipes) with VFD!

DOE?

Regulation Due this fall – 5 years to comply

Sections 6314 and 6315 concern test procedures and labeling, respectively, for covered equipment. The provisions in these sections, in combination with section 6316(a), give DOE authority to establish test procedures and to prescribe a labeling rule for pumps. Based on the information DOE receives in response to this Request for Information, DOE will determine whether to initiate a rulemaking to establish a test procedure, energy conservation standard, or labeling requirement for commercial and industrial pumps.

2. Evaluation of Pumps as Covered Equipment

EPCA lists several specific types of "covered equipment," including electric motors and pumps. 12 U.S.C. 6311(11)

DOE estimates that commercial, industrial, and agricultural pumps consume approximately 0.63 quads of electricity and that these technologies exist that can reduce this consumption by approximately 0.140 quads annually.

DOE used industry and census data to calculate the average establishment energy use for pumps.
### DOE?
**Full Effect 2019?**

<table>
<thead>
<tr>
<th>In Scope?</th>
<th>Pump Type</th>
<th>ANSI/HI Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>End Suction Frame Mounted/Own Bearings</td>
<td>OH0, OH1</td>
</tr>
<tr>
<td>Yes</td>
<td>End Suction Close Coupled</td>
<td>OH7</td>
</tr>
<tr>
<td>Yes</td>
<td>Inline</td>
<td>OH3, OH4, OH5</td>
</tr>
<tr>
<td>Yes</td>
<td>Radial Split (Multistage) Vertical</td>
<td>VS8</td>
</tr>
<tr>
<td>Yes</td>
<td>Submersible Vertical/Turbine (Multistage)</td>
<td>VS9</td>
</tr>
<tr>
<td>Maybe</td>
<td>Double Suction</td>
<td>BB1, OH4 double suction</td>
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<tr>
<td>Maybe</td>
<td>Axially Split</td>
<td>BB1 (2 stages), BB3</td>
</tr>
<tr>
<td>Maybe</td>
<td>Radial Split - Horizontal</td>
<td>BB2 (2 stages), BB4</td>
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<tr>
<td>Maybe</td>
<td>Radial Split – Vertical (Immersion)</td>
<td>N/A</td>
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<tr>
<td>Maybe</td>
<td>Vertical Turbine</td>
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<tr>
<td>Maybe</td>
<td>Circulators</td>
<td>CF1, CF2, CF8</td>
</tr>
</tbody>
</table>

**Extended Product – Pump/Motor/Drive**
- Probable regulation evaluates variable load line to water efficiency
- Probable regulation evaluates constant load line to water efficiency

---

### State Incentive Programs

![ACEEE](image1.png) ![DSIRE](image2.png)

**ACEEE**
- Energy Efficiency Policies
- Consumer Resources

**DSIRE**
- Database of State Incentives for Renewable and Efficiency
- Summary Maps
- Summary Tables
- Efficiency
- State Incentives Search

DSIRE is the most comprehensive source of information on incentives and policies that support energy efficiency and renewable energy development. The project is primarily funded by the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy.
Facts and Figures
2000 Figures

- 40 Quads (1 Quad = quadrillion Btu’s) of electricity is produced annually in the USA
- 13 Quads (3,800 billion kWh) of electricity is delivered from the source to the point of use – balance is lost via thermal waste heat to the environment!
- Approx 40% of the energy consumed in the USA is used in Commercial Buildings
- 25% of the energy consumed by a commercial building used for fans and pumps (1.5 Quads)
- Of the 1.5 Quads:
  - 5% for heating water pumps
  - 2% for condenser water pumps
  - 2% for chilled water pumps

- Where did the electricity come from?
  - Coal generated 51% (1.968 billion kWh)
  - Nuclear 20% (754 billion kWh)
  - Natural Gas 16.1% (1.141 billion kWh)
  - Hydroelectric 7% (273 billion kWh)
  - Petroleum (oil) 3% (109 billion kWh)

Source – USGBC & EIA Annual Energy Outlook 1998, ref 1

Variable Flow Pumps – Control Strategies
BBT Conference – Feb 4/5, 2015
Presented by Steve Thompson
VP - Residential Product Management – Taco Inc.
Mobile (401) 441-2934
E Mail: stetho@taco-hvac.com