Variable flow apps, effects of system efficiency

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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 56°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.

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

G3.1.3.10 Chilled-Water Pumps. The *baseline building design* 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 *systems* with secondary pump riding the pump curve.

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

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

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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 step open and close 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) that 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 the 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.

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 purposes of Section 6.4.3.1, a *dwelling 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

∆ P sensor location

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

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6.5.4.4.2 Hydronic heat pumps and water-cooled unitary air-conditioners having a total *pump system power* exceeding 5 hp shall have *controls* and/or devices (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 coils) 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 drop than the same *system* constructed with standard weight steel pipe with piping and fittings sized per Table 6.5.4.5.

30% wattage at 50% design flow descriptor

Higher velocities (smaller pipes) with VFD!

TABLE 6.5.4.5 Piping System Design Maximum Flow Rate in GPM

Operating Hours/Year	≤2000 Hours/Year		>2000 and ≤ 4400 Hours/Year		>4400 Hours/Year	
Nominal Pipe Size, in.	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed	Other	Variable Flow/ Variable Speed
2 1/2	120	180	85	130	68	110
3	180	270	140	210	110	170
4	350	530	260	400	210	320
5	410	620	310	470	250	370
6	740	1100	570	860	440	680
8	1200	1800	900	1400	700	1100
10	1800	2700	1300	2000	1000	1600
12	2500	3800	1900	2900	1500	2300
Maximum Velocity for Pipes over 12 in. Size	8.5 fps	13.0 fps	6.5 fps	9.5 fps	5.0 fps	7.5 fps

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DOE?

Framework Document due this month
Regulation due in 2 to 3 years
Enforcement set 2 to 3 years after Regulation

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 "industrial equipment" as "covered equipment," including electric motors and pumps. (42 U.S.C. 6311(1))

DOE estimates that commercial, industrial, and agricultural pumps consume approximately 0.63 quads per year of electricity and that technologies exist that can reduce this consumption by approximately 0.190 quads annually.

DOE used industry and census data to calculate the average establishment energy use for pumps.

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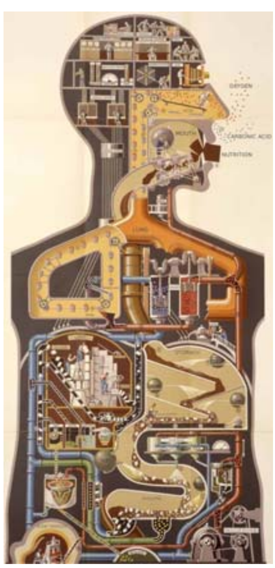

What's a Variable Flow System Application And Why Does This Matter?

- 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!

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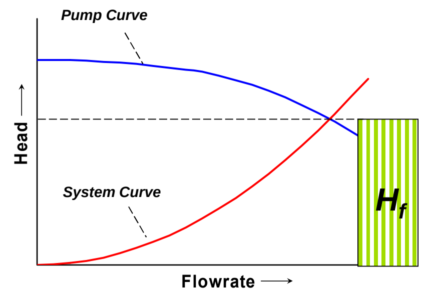
Pure Friction System Curve

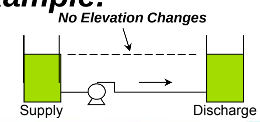
For systems with pure friction the system curve goes to zero at zero flow

Closed systems are always purely frictional

Any pump can produce flow (no elevation to overcome)



Example:



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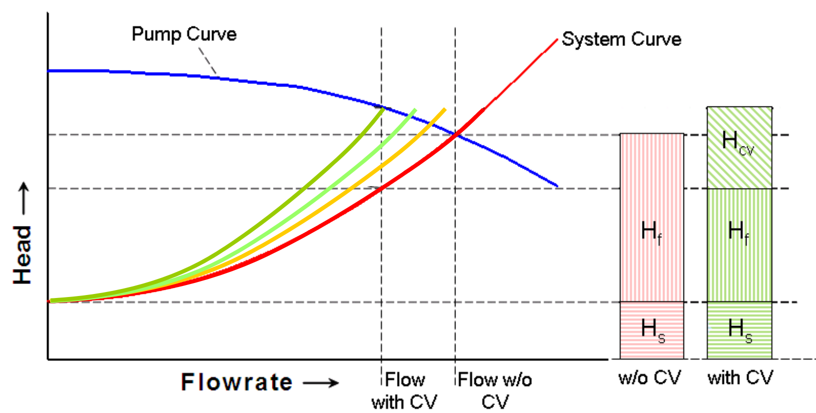
Effect of Control Valves



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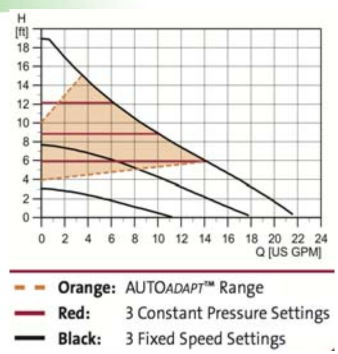
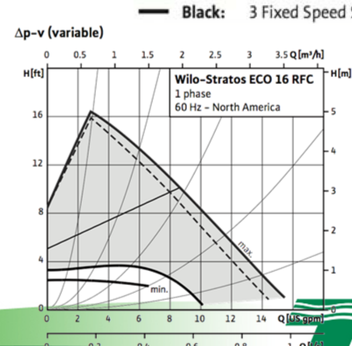
Delta-T v. Delta-P?

- GPM = BTUH ÷ (ΔT × 500)

What Is Delta-P

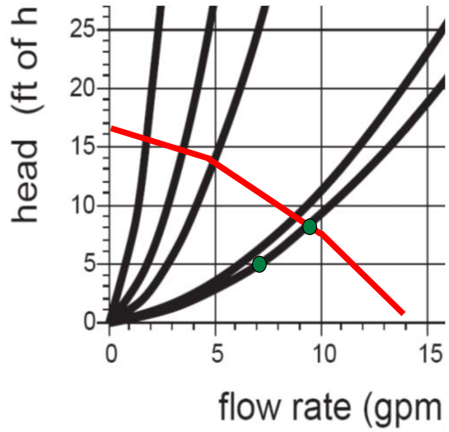
- Sound principles
- Less flow, less head, right?
- Chops off upper portion of pump curve
- Proportional or constant





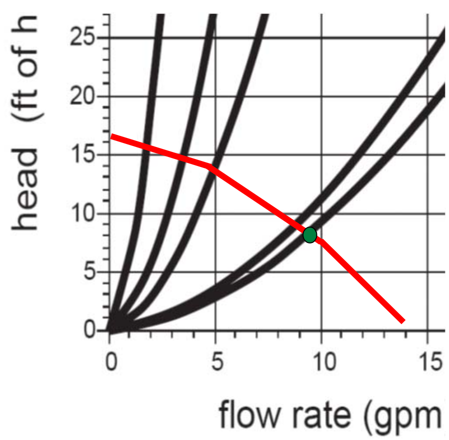
5 Zone System

- 70,000 BTUH
- 7 GPM @ 5’ head
- Where does system *really* work?



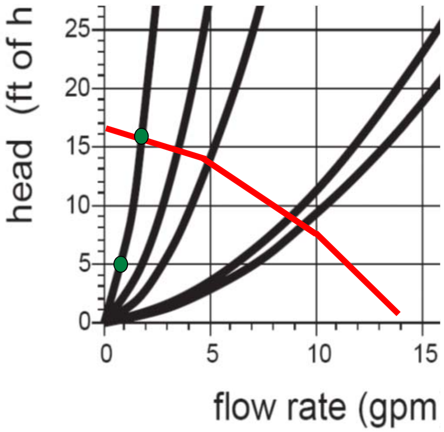
Numbers Don’t Lie…

- $GPM = \frac{BTUH}{\Delta T \times 500}$
- $\Delta T = \left(\frac{BTUH}{GPM}\right) \div 500$
- $\Delta T = \left(\frac{70{,}000}{9.5}\right) \div 500$
- $< 15^0$



1 Zone Calling

- 10,000 BTUH
- 1 GPM @ 5' head
- Where does it *really* work?



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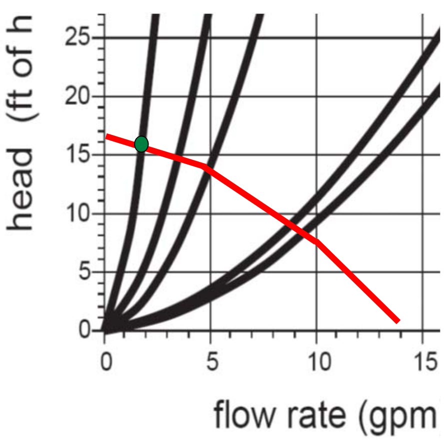
Numbers Still Don't Lie…

- $GPM = \dfrac{BTUH}{\Delta T \times 500}$
- $\Delta T = \left(\dfrac{BTUH}{GPM}\right) \div 500$
- $\Delta T = \left(\dfrac{10{,}000}{2}\right) \div 500$
- 10^0



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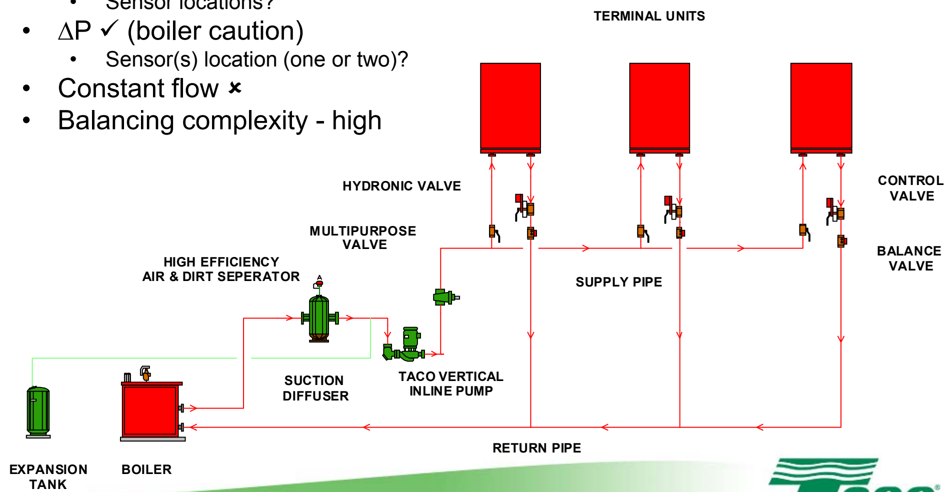
- Variable flow ✓
- ΔT ✓✓ (outdoor reset caution)
  - Sensor locations?
- ΔP ✓ (boiler caution)
  - Sensor(s) location (one or two)?
- Constant flow ×
- Balancing complexity - high

Direct Return Piping System
(first in / first out)



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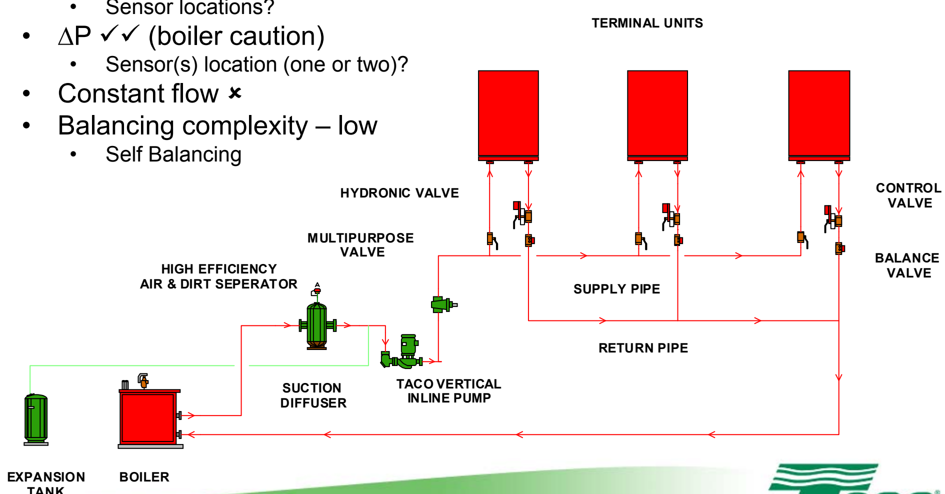
- Variable flow ✓
- ΔT ✓✓ (outdoor reset caution)
  - Sensor locations?
- ΔP ✓✓ (boiler caution)
  - Sensor(s) location (one or two)?
- Constant flow ×
- Balancing complexity – low
  - Self Balancing

Reverse Return Piping System
(first in / last out)



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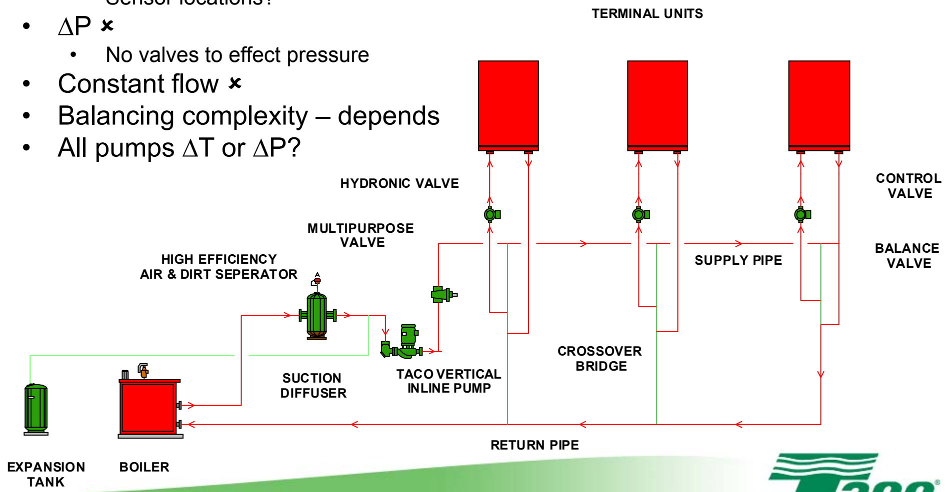
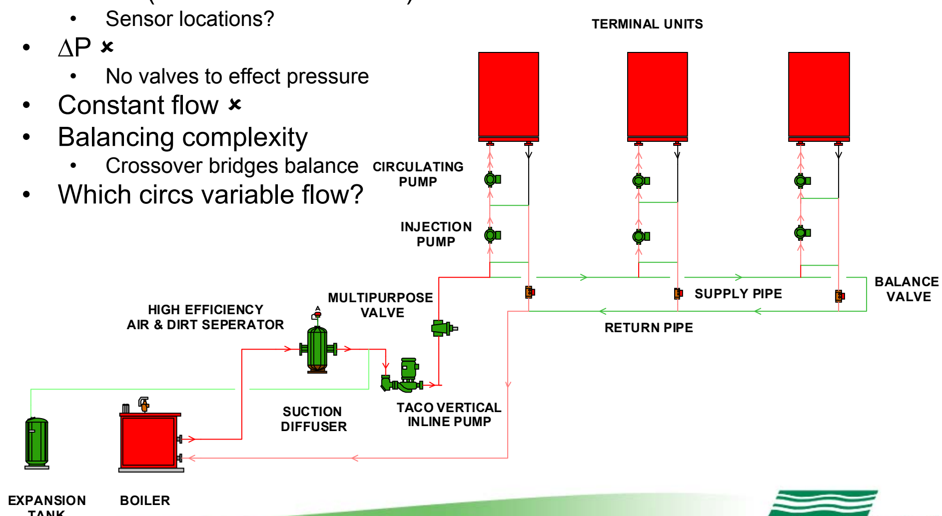
Primary Secondary Systems
(pumped secondary)

- Variable flow ✓
- ΔT ✓✓ (outdoor reset caution)
  - Sensor locations?
- ΔP ✗
  - No valves to effect pressure
- Constant flow ✗
- Balancing complexity – depends
- All pumps ΔT or ΔP?



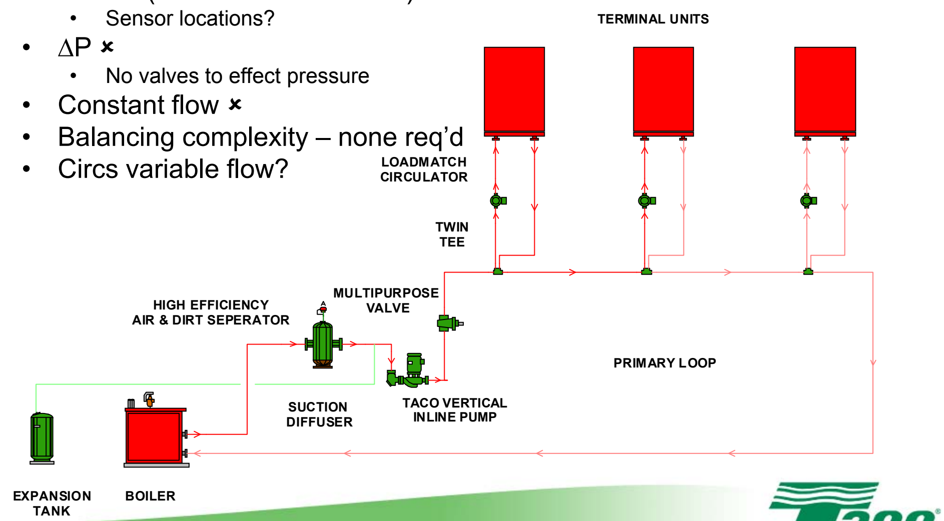
Injection Pumping System

- Variable flow ✓
- ΔT ✓✓ (outdoor reset caution)
  - Sensor locations?
- ΔP ✗
  - No valves to effect pressure
- Constant flow ✗
- Balancing complexity
  - Crossover bridges balance
- Which circs variable flow?



LoadMatch™ Single Pipe Pumping System

- Variable flow ✓
- ΔT ✓✓ (outdoor reset caution)
  - Sensor locations?
- ΔP ✗
  - No valves to effect pressure
- Constant flow ✗
- Balancing complexity – none req'd
- Circs variable flow?



Balancing VFD Systems

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 pump motors 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 ft^2 conditioned area, except warehouses and *semiheated spaces*, detailed instructions for commissioning *HVAC systems* (see Informative Appendix E) 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

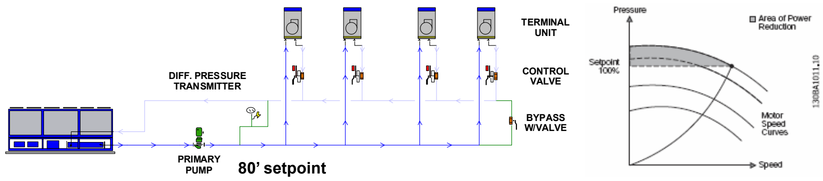
The main goal of the secondary chilled water system is to distribute the correct amount of water to satisfy the load. It must first accurately monitor the system for changes in load dynamics.

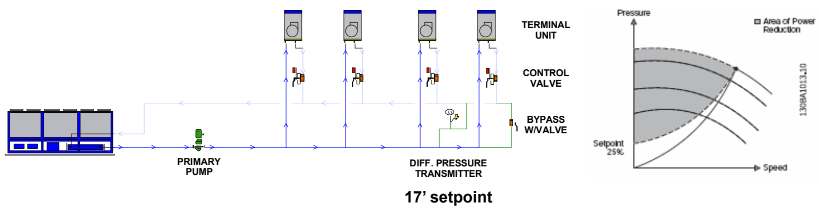
Secondly, it must respond to these load changes with the "correct" amount of flow

Run VFD's at constant speed – balance then set pumps to AUTO

Location of ΔP Transmitters

Effeciencies are dramatically affected





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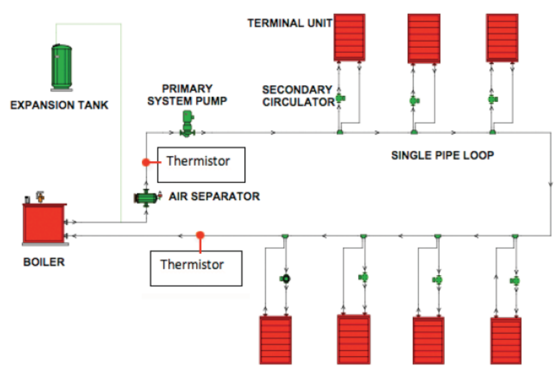
Differential Temperature

- 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 thermistors.
- 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**



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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.

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)

Benefits of Variable Speed Pumping

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: Q2 = Q1 X (N2/N1)

Head: H2 = H1 X (N2/N1)2

Horsepower: BHP2 = BHP1 X (N2/N1)3

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

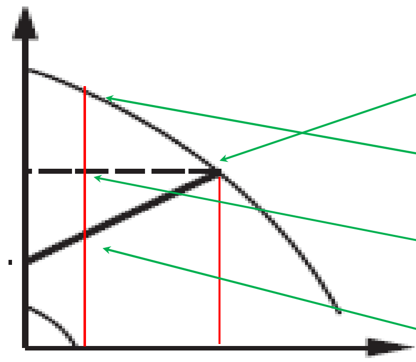
Most systems operate at reduced capacity most of their lives.

Speed	Flow	Head	BHP
100%	100%	100%	100%
75%	75%	56%	42%
50%	50%	25%	12.5%
25%	25%	6%	1.2%

ΔP 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

$$BHP = \frac{H\ (Ft) \times Q\ (Usgpm)}{Eff\ (0.?) \times 3960}$$



$$BHP\ Design = \frac{35\ Ft \times 160\ Usgpm}{0.6 \times 3960} = 2.4$$

$$BHP\ \ 25\ \% = \frac{43\ Ft \times 40\ Usgpm}{0.4 \times 3960} = 1.2$$

$$BHP\ \Delta pc = \frac{35\ Ft \times 40\ Usgpm}{0.6 \times 3960} = 0.6$$

$$BHP\ \Delta pv = \frac{13\ Ft \times 40\ Usgpm}{0.6 \times 3960} = 0.2$$

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

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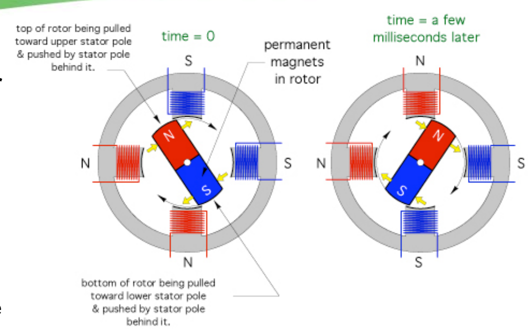
Comparison AC / EC Motor



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

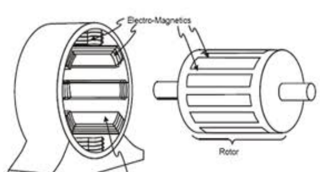


Figure 4: Rotor and Stator

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.

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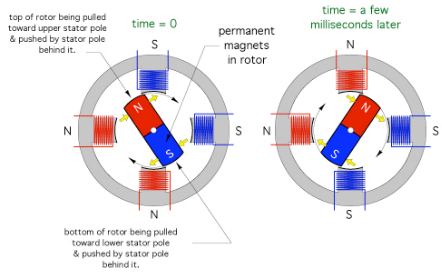

Benefits of Viridian ECM Technology

- 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

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Motor Efficiency – AC Motors

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

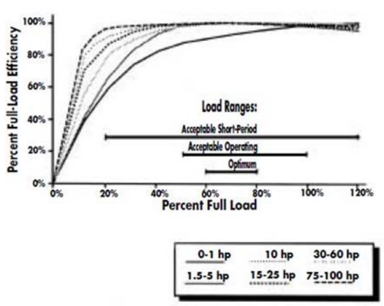

TABLE 10.8A Minimum Nominal Efficiency for General Purpose Design A and Design B Motors Rated 600 Volts or Less[a]

	Minimum Nominal Full-Load Motor Efficiency (%) prior to December 19, 2010					
	Open Drip-Proof Motors			Totally Enclosed Fan-Cooled Motors		
Number of Poles ⇒	2	4	6	2	4	6
Synchronous Speed (RPM) ⇒	3600	1800	1200	3600	1800	1200
Motor Horsepower						
1	NR	82.5	80.0	75.5	82.5	80.0
1.5	82.5	84.0	84.0	82.5	84.0	85.5
2	84.0	84.0	85.5	84.0	84.0	86.5
3	84.0	86.5	86.5	85.5	87.5	87.5
5	85.5	87.5	87.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5	89.5	89.5
10	88.5	89.5	90.2	89.5	89.5	89.5
15	89.5	91.0	90.2	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	91.0	90.2
25	91.0	91.7	91.7	91.0	92.4	91.7
30	91.0	92.4	92.4	91.0	92.4	91.7
40	91.7	93.0	93.0	91.7	93.0	93.0
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.6
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.0	94.1	94.1	93.6	94.5	94.1
125	93.6	94.5	94.1	94.5	94.5	94.1
150	93.6	95.0	94.5	94.5	95.0	95.0
200	94.5	95.0	94.5	95.0	95.0	95.0

[a] Nominal efficiencies shall be established in accordance with NEMA Standard MG1. Design A and Design B are National Electric Manufacturers Association (NEMA) design class designations for fixed-frequency small and medium AC squirrel-cage induction motors.
NR—No requirement

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Let's Talk About Efficiency

Flow (% of BEP)	**100%**	**75%**	**50%**	**25%**
Motor Load (% Full Load)	15 Hp (100%)	7 Hp (42%)	2 Hp (13%)	0.3 Hp (2%)
Motor Eff*	93%	92.6%	85%	78%
Drive Eff**	96.5%	93.5%	84.5%	44%

* 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

$$\text{Line to Water kW} = \frac{H\,(Ft) \times Q\,(Usgpm) \times SG}{\eta P \times \eta M \times \eta D \times 3960}$$

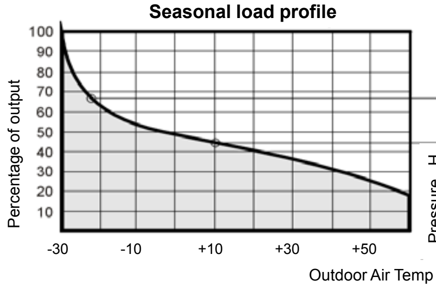
$$0.745 \times \frac{500 \times 81 \times 1.0}{0.74 \times 0.93 \times 0.96.5 \times 3960}$$

"Knowns"

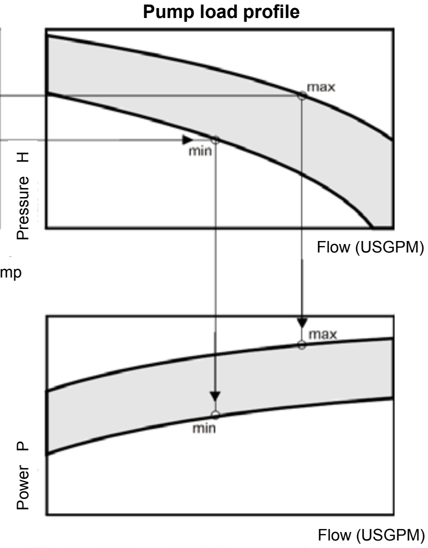
- 500 USGPM @ 81' (100% load or flow)
- Pump efficiency @ H/Q "design" = 74%
- Motor efficiency @ design = 93%
- Drive efficiency @ design = 96.5%
- Assume SG 1.0

(HVAC systems are DYNAMIC – loads / flows continually change)

Seasonal load profile



Pump load profile



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

Energy Savings Calculator – Chilled Water

CW Load Profile and 8000 Hours, $0.11 / kWh

Chilled Water - Constant Speed Pumps, Throttling Valves (no VFD's)										
% Load Conditions ARI Standards	% Load	GPM (USGPM)	Head (ft)	Eff Pump	Eff Motor	Drive NIC	Wire to water eff	P1 to P4 Hp	Annual KW	Annual Cost
1%	100%	500	80.65	74%	93%	100%	69%	14.76	1181	$130
42%	75%	375	87.51	70%	91%	100%	64%	13.01	43711	$4,808
45%	50%	250	92.75	59%	78%	100%	46%	12.72	45805	$5,039
12%	25%	125	95.97	37%	62%	100%	23%	13.21	12677	$1,395
								Totals	103375	$11,371.25

Chilled Water - Variable Speed Pumps										
% Load Conditions ARI Standards	% Load	GPM (USGPM)	Head (ft)	Pump Eff	Motor Eff	Drive Eff	Wire to water eff	P1 to P4 Hp	Annual KW	Annual Cost
1%	100%	500	80.7	74%	93%	97%	66%	15.34	1227	$135
42%	75%	375	45.4	74%	93%	94%	64%	6.71	22546	$2,480
45%	50%	250	20.2	74%	85%	85%	53%	2.40	8638	$950
12%	25%	125	5	74%	78%	44%	25%	0.62	597	$66
								Totals	33008	$3,630.88

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Energy Savings Calculator - Heating

Heating Load Profile and 6000 Hours, $0.11 / kWh

Heating - Constant Speed Pumps, Throttling Valves (no VFD's)										
% Load Conditions EU Standards	% Load	GPM (USGPM)	Head (ft)	Eff Pump	Eff Motor	Drive NIC	Wire to water eff	P1 to P4 Hp	Annual KW	Annual Cost
6%	100%	500	80.65	74%	93%	100%	69%	14.76	5315	$585
15%	75%	375	87.51	70%	91%	100%	64%	13.01	11708	$1,288
35%	50%	250	92.75	59%	78%	100%	46%	12.72	26720	$2,939
44%	25%	125	95.97	37%	62%	100%	23%	13.21	34863	$3,835
								Totals	78606	$8,646.67

Heating - Variable Speed Pumps										
% Load Conditions EU Standards	% Load	GPM (USGPM)	Head (ft)	Pump Eff	Motor Eff	Drive Eff	Wire to water eff	P1 to P4 Hp	Annual KW	Annual Cost
6%	100%	500	80.7	74%	93%	97%	66%	15.34	5523	$608
15%	75%	375	45.4	74%	93%	94%	64%	6.71	6039	$664
35%	50%	250	20.2	74%	85%	85%	53%	2.40	5039	$554
44%	25%	125	5	74%	78%	44%	25%	0.62	1641	$180
								Totals	18242	$2,006.60

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Incentifyers (ROI)

- **Contractors**
  - Easy to install – factory defaults cover 80% of applications
  - Locked out against unauthorised adjustment
  - No pressure by-pass required
  - No excessive pressure when last zone closes (noise and call backs)
  - Simplifies systems (no more 3 pipe systems, fewer accessories)
  - Quieter systems
- **Engineers**
  - Single source responsibility
  - No external sensors
  - Allows for over pumping and changes in load flows
- **Distributors**
  - 4 models (2 are 115 – 240/1/60 volts!) covers many models – fewer SKUs
  - Positions distributor as "Leading Edge"
  - Extremely flexible applications (primary, secondary, gravity conversion, chilled and hot water etc.)
- **LEED or Green Builders**
  - Huge energy savings (pumping power and overall system efficiency)
  - ECM technology might qualify for subsidies
  - Part of LEED program

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Disadvantages of <u>Constant</u> Speed Pumping

Most Constant Speed Pumps in HVAC systems are oversized and are throttled by balancing valves or control valves. Similar to driving your car with your foot on the gas and the brake at the same time.

This means bigger motors whose energy is partially burned off by the valve.

The valve is subjected to higher pressures thus shortening the life of the valve

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Benefits of Variable Speed Pumping

- *Longer Equipment Life*
  - *Soft Start/Stop*
  - *Rotating equipment: life = 1/Speed*
  - *Lower pressure on components*
  - *Valve actuators absorb less pressure*
- *Chiller Plant Optimization*
  - *Less capacity goes further (diversity of Load)*
  - *Better Delta T's*
  - *Chiller staging options: (equal as preferential loading)*
- *Lower System Life Cycle & Installed Cost*
  - *Reduced maintenance*
  - *Lower "In Rush" current reduces wire and circuit breaker size*
  - *Smaller pipe (design 10-12 ft/sec)*
  - *Less required capacity on generation equipment*
- *Lower Noise in Piping Distribution*
- *Allowance for Expansion*
- *Better Control Prevents Cavitation*
- *Better System Balance*

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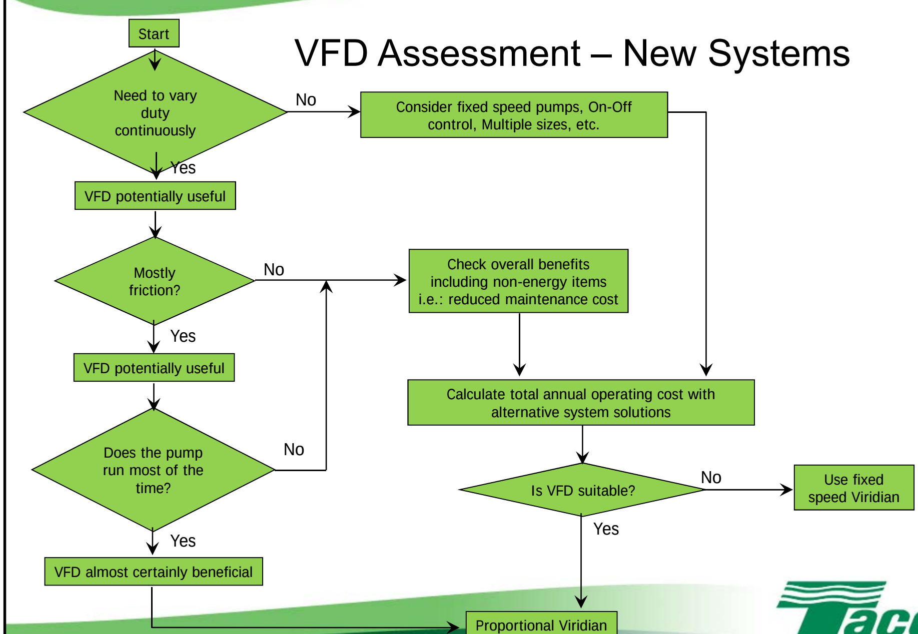
VFD Assessment – New Systems



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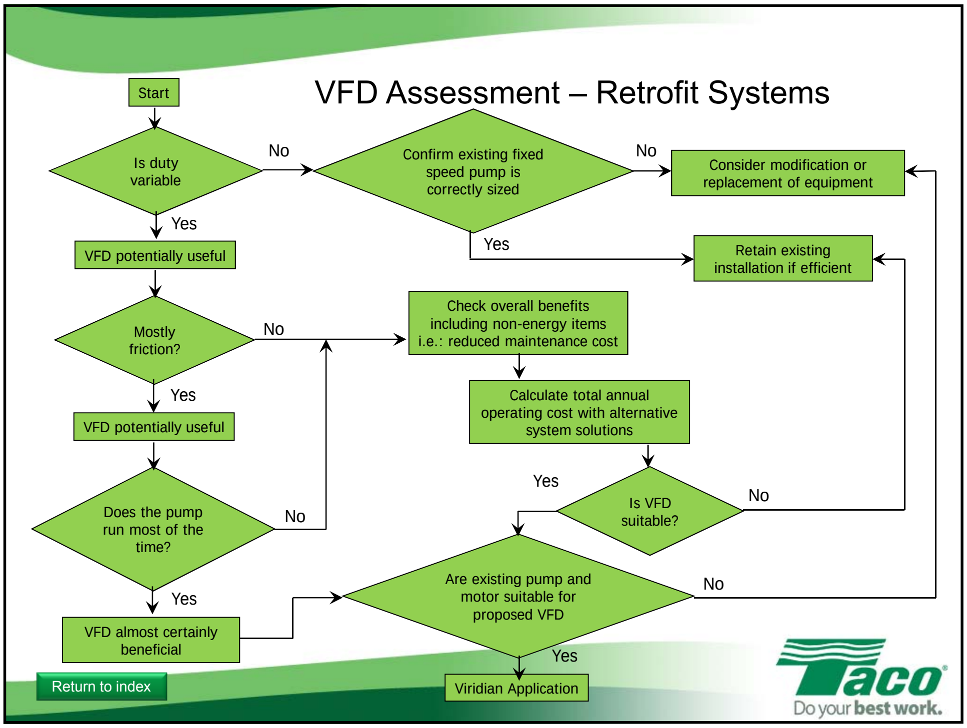

TACO VFD Pumps and Circulators

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- **U.S. Dept of Commerce,** Census Bureau, MA333p Report, Pumps & Compressors Data, 2008 data
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Variable Speed Pumping

Questions???

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Variable flow apps, effects of system efficiency

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