Energy efficient distribution: fans and pumps

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The material covered in this presentation may not be considered as recommendations for your specific systems or buildings. The material is provided only as guidance from publicly available sources.

Any intervention on HVAC systems must be performed by accredited personnel, including any electrical work, refrigerant and pressure vessel work, etc. Each owner and technical manager has the responsibility to ensure any HVAC work is completed in accordance with all adequate safety precautions and by properly trained personnel.

Introduction

- Fans are used in all HVAC systems while pumps are present in many systems.
- The overall efficiency of HVAC systems is strongly impacted by how efficient the equipment and associated distribution system are built, commissioned, controlled and maintained.
- Properly understanding your fan and pump systems plays a crucial role in optimizing their energy efficiency.
- Given the wide variety of configurations, it is important to adapt optimization strategies to each specific system.

Fan and pump fundamentals

The affinity laws

More than a theoretical set of equations, these have large practical implications:

- Applicable to centrifugal pumps and fans
- Provide the relationship between flow, head and power

$$Q_2 = Q_1\left(\frac{N_2}{N_1}\right),\ H_2 = H_1\left(\frac{N_2}{N_1}\right)^2,\ \text{and}\ P_2 = P_1\left(\frac{N_2}{N_1}\right)^3$$

N = fan or pump speed, typically in revolutions per minute
Q = flow, typically in cubic feet per minute (CFM), L/s, m^3/h or gpm
H = head, typically in metres or feet water column for pumps and Pascal or inch water for fans
P = power in bkW or BHP (brake kW, BHP - brake horse power)

- For example, a 10% speed reduction yields a 10% flow reduction, 19% head reduction and a 27% power reduction!

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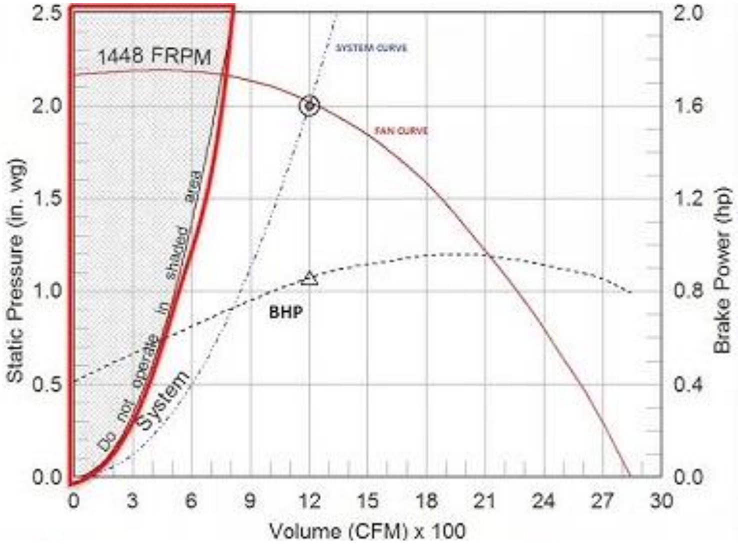
Fan size

- What dictates the size of most heating, ventilation and air-conditioning (HVAC) fans?
    - Ventilation (outside air supply)
    - Cooling
    - Humidification
    - Heating
    - Filtration
- For most systems, other than 100% outside air, the peak cooling load dictates the size of the fan as well as that of the ductwork.
- This peak cooling load is rarely present during a typical year.

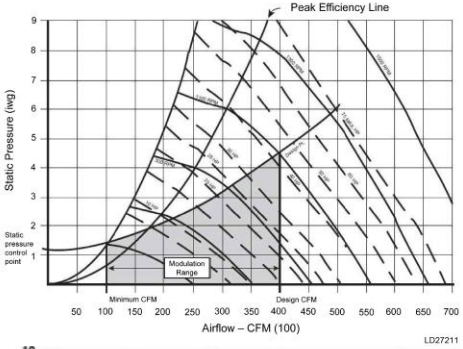
What determines your fan operating point

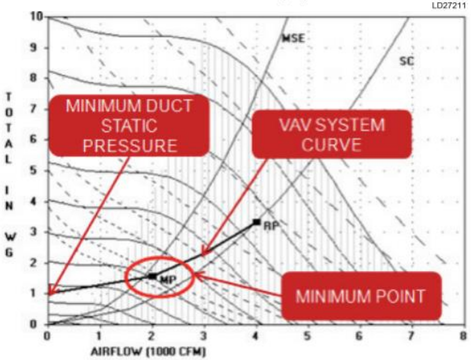
- Fans always operate at the intersection of the **system curve** and the **fan performance curve**.
- System curve graphically shows the head (pressure) the system needs to overcome at different flow rates.
- System curve is quadratic and a single measurement will provide the system curve for a given system configuration. Many systems have more than one curve.



Control curve and minimum point

- For variable flow systems, a minimum static pressure is required to control the flow.
- This minimum pressure differential results in the system curve not starting at 0 on the Y-Axis but at the Delta-P.
- In all cases, the fan flow cannot go below a minimum to avoid going in an unstable section of the fan curve.





System effects

- System effects for HVAC fans are performance losses from non-ideal airflow conditions (turbulence, swirl, non-uniformity) at the fan inlet or outlet, which is caused by poor duct design, fittings, or obstructions leading to less airflow, higher pressure drops, increased noise or vibration and reduced efficiency compared to lab ratings.
- These result in having either lower flow than required or running at higher speed for variable flow systems.

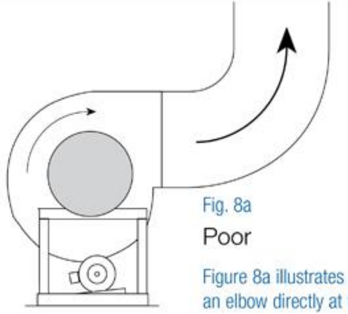


Fig. 8a
Poor
Figure 8a illustrates a poor installation with an elbow directly at the fan discharge.

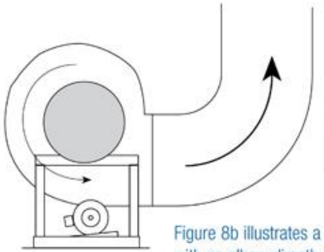


Fig. 8b
Good
Figure 8b illustrates a typical installation with an elbow directly at the fan discharge. Discharge and rotation have been selected to match the fan's field conditions of figure 8a.

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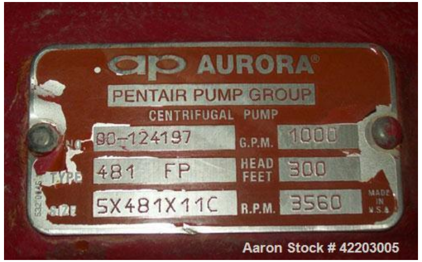
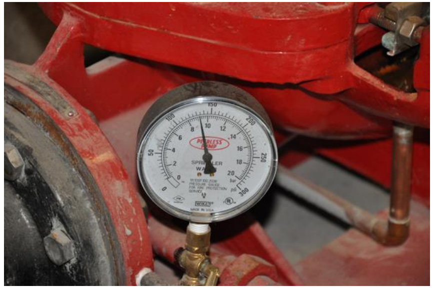
Pump sizing

- Pumps are often sized to meet the peak load for a given design temperature differential (Delta-T) at a design total pressure differential.
- Many pumps are oversized due to multiple factors:
  - Taking a differential pressure measurement at full pump speed provides the answer as to whether a pump meets the design intent (nameplate data).
- Typical Delta-Ts are 10ºF in cooling and 20ºF in heating.





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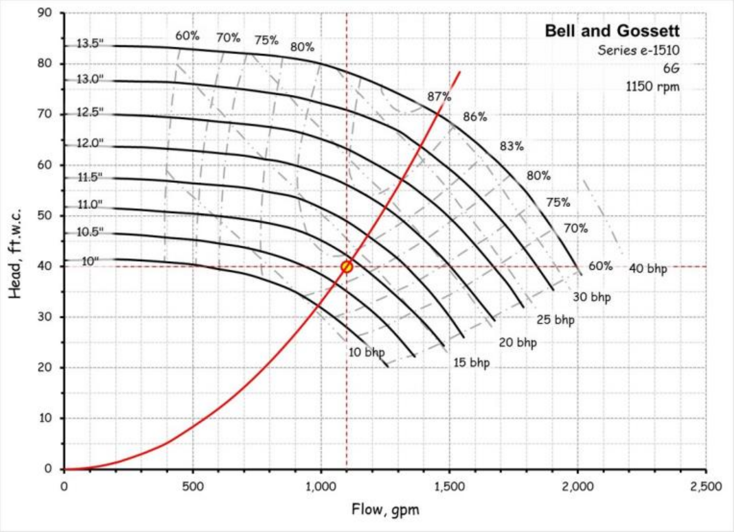
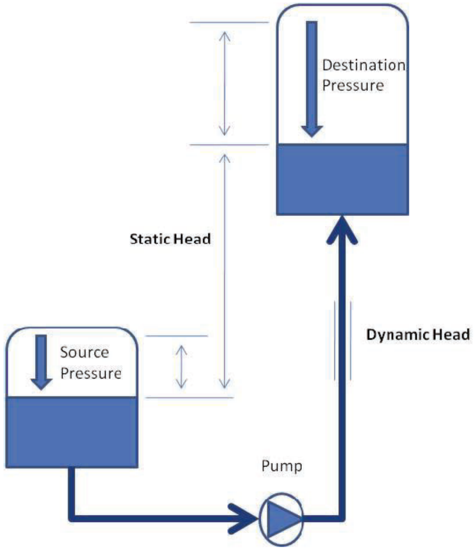
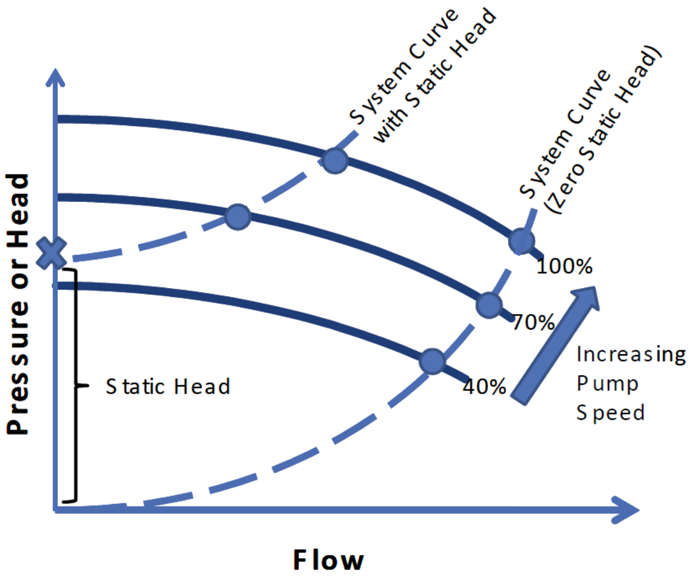


Dynamic and static heads – open versus closed systems

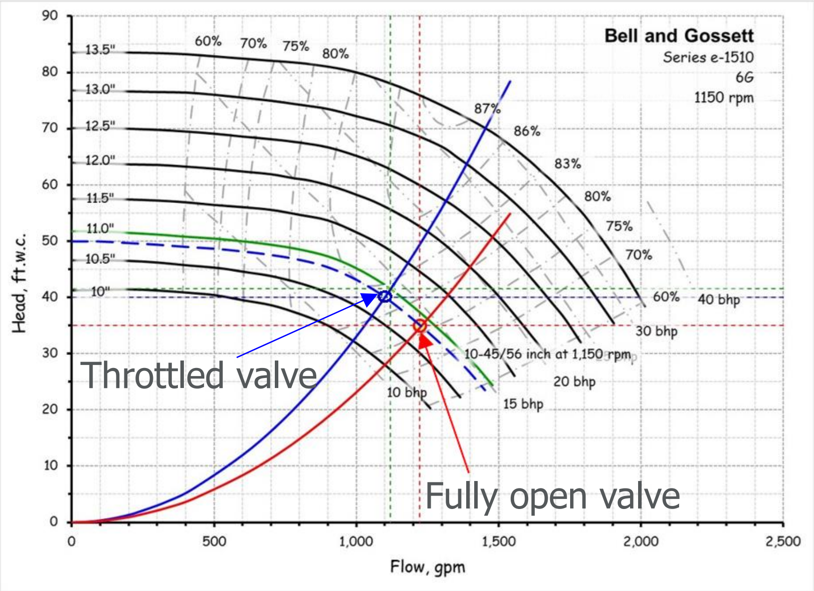




Reference: Pump Systems, Energy Efficiency Reference Guide, CEATI, 2008

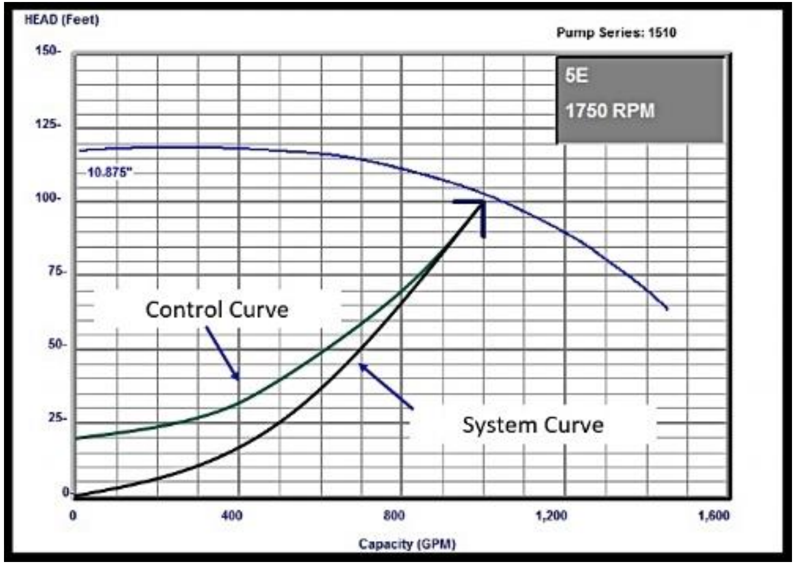
Adjusting the pump flow

- Most HVAC pumps are sized for a required flow, not a total static pressure differential (head).
- To obtain the design flow, the most common methods are:
  - Pump throttling
  - Variable frequency drives (VFDs)
  - Impeller trimming



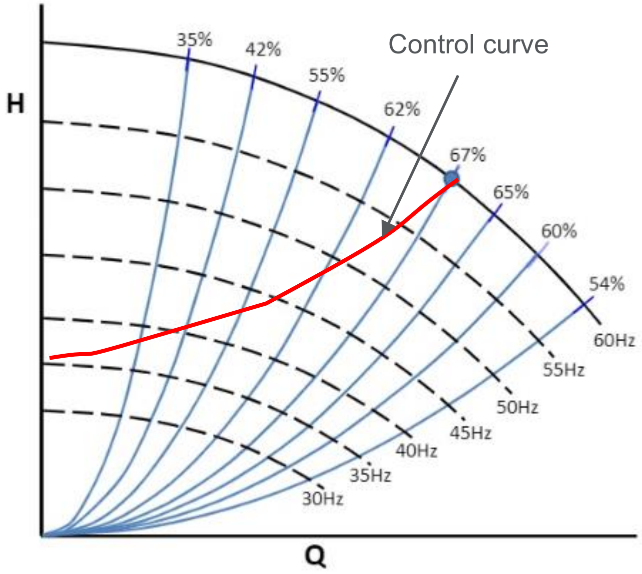
Variable flow loop – control curve

- Control head is the minimum amount of head that must be present in the system at all times in a closed-loop system to establish full flow through the critical coil(s); it is similar to the static head for an open-loop system.
- As flow increases in the loop, the control curve moves closer to the system curve and intersects at full design flow.



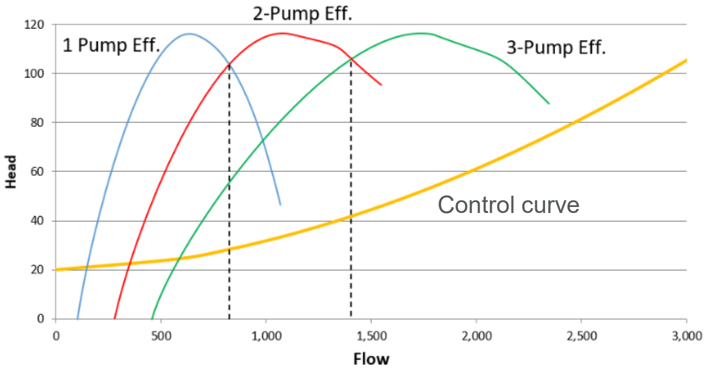
Variable flow loop – pump efficiency curves

- A variable flow pump can only operate at its best efficiency point (BEP) if the control curve follows the constant pump efficiency curves (which is usually not the case).
- For most systems, efficiency decreases as pump speed is reduced, following the control curve.



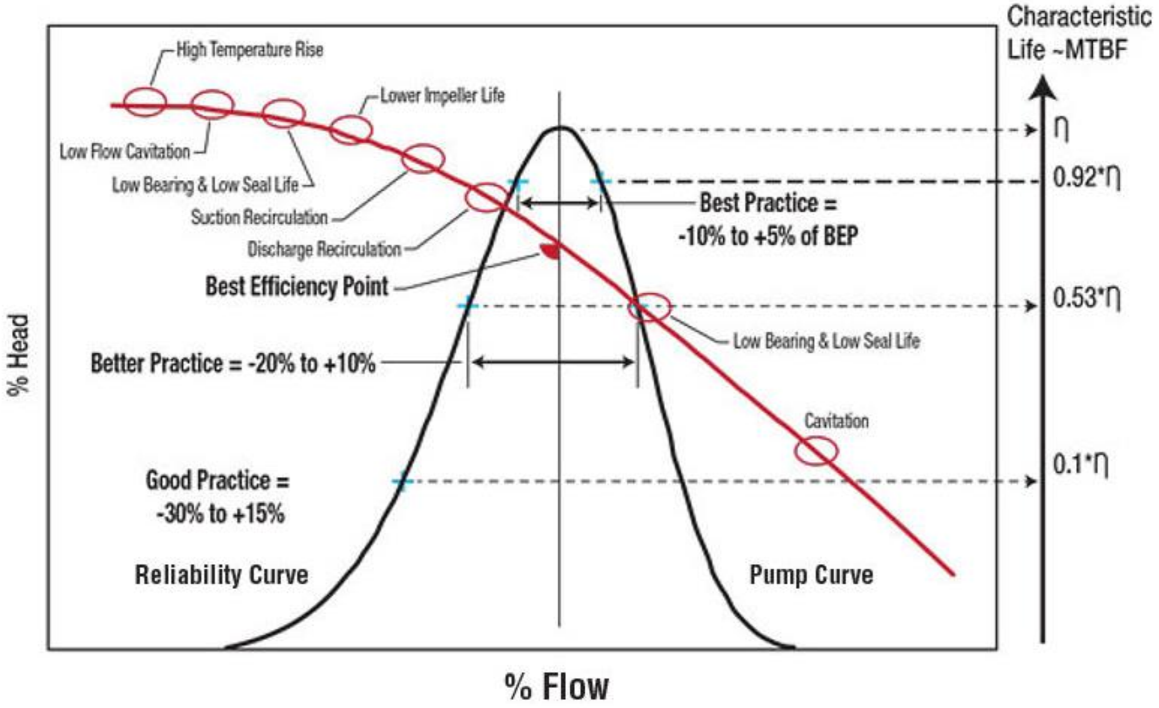
Variable flow loop – parallel pump efficiency sequencing

- This requires establishing the combined demand of the available pumps to determine the point required for the next pump.
- The next pump must always start before the running pumps get to the runout point of the pump curve.
- This is accomplished by using pump curves and control curves, but a more practical approach is by testing the various modes.



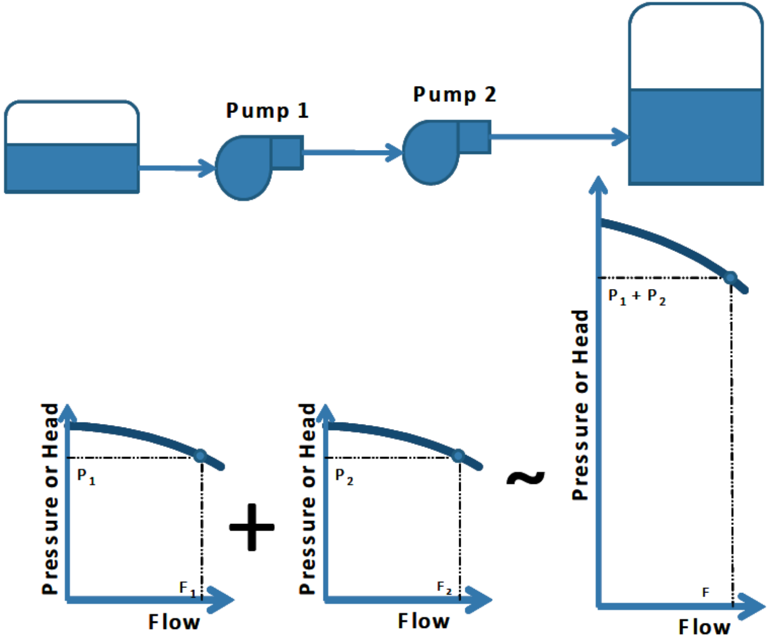
Pump reliability: flow and efficiency

- Operating a pump far from its BEP has an impact on its reliability.



Source: https://www.estabrookcorp.com/post/dangers-when-operating-centrifugal-pumps-outside-operating-range

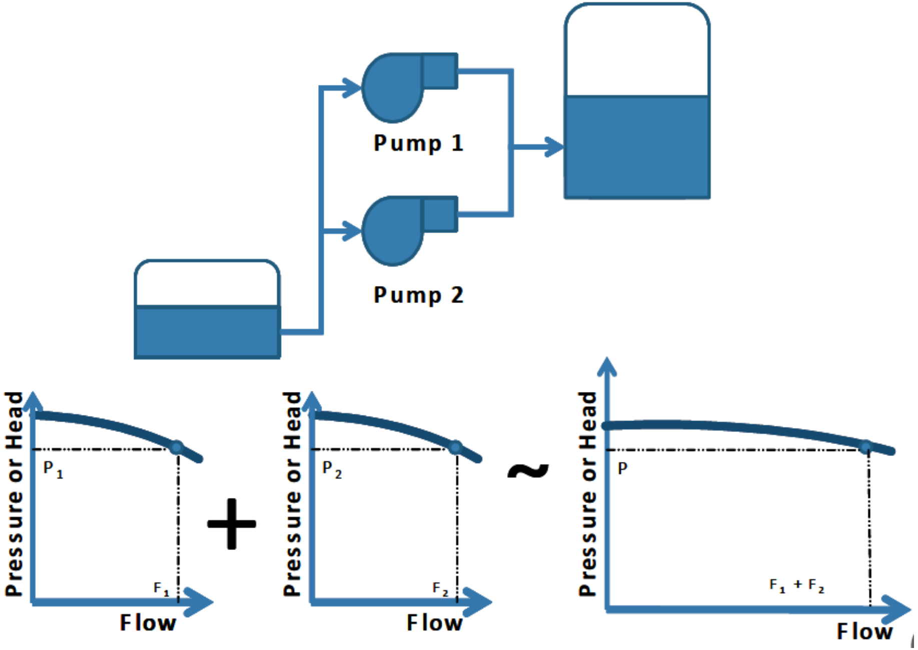
Pumps connected in series…must combine heads at each flow!



Reference: Pump Systems, Energy Efficiency Reference Guide, CEATI, 2008

Pumps connected in parallel must combine flows at each head

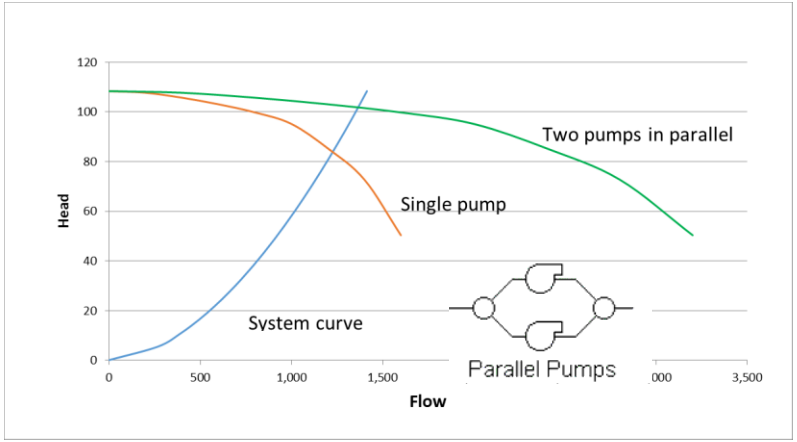
- Successfully running dissimilar pumps in parallel requires operating the system flow within a range where both pumps function safely and efficiently on their curves, to avoid issues due to excessive loads on the impeller, bearings or seals

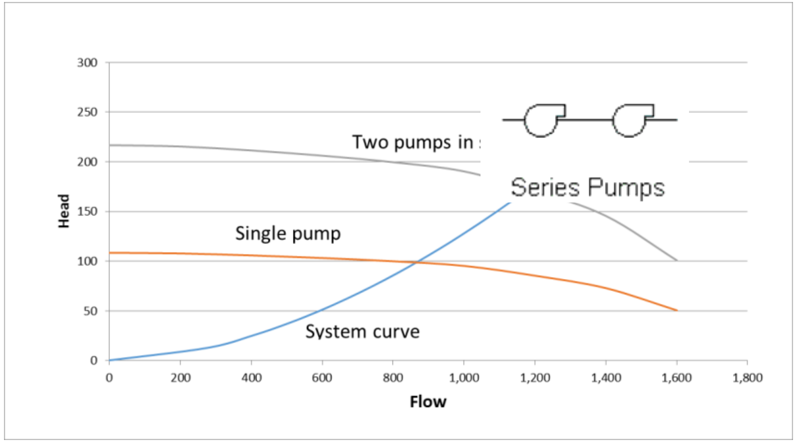


Reference: Pump Systems, Energy Efficiency Reference Guide, CEATI, 2008

Series and parallel pumps

Example of pump curves – parallel and series configuration with identical pumps





Power draw for pumps and fans

- Motors do not draw the nameplate power.
- The power draw is dictated by the driven load – such as pumps and fans.

$$BHP = [Flow \times Load \times \rho] / [Cf \times \eta]$$

Where:

BHP = brake horsepower at pump drive shaft, in HP (Imperial) or kW (SI)
Flow = fluid flow (see table below)
Load = total load on pump or fan (see table below)
ρ = specific gravity of the fluid (vs. air or water)
Cf = conversion factor (see table)
η = pump or fan efficiency (see table)

	Cf		Units – Load/Flow	
	Pumps	Fans	Pumps	Fans
SI	1000	1000	kPa/(L/s)	kPa/(L/s)
Imp	3960	6356	ft.H_2O/gpm	in.H_2O/CFM

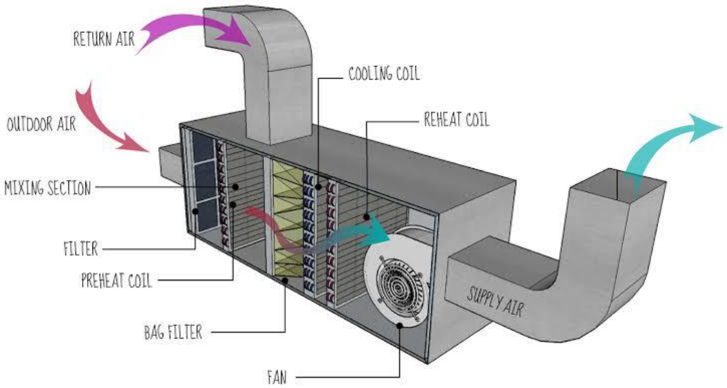
Fan opportunities and optimization

Fan opportunities

- First step is to reduce operating hours!
- Right-size the flow
  - Total and zonal
  - Design flow is rarely ever needed
- Distribute where needed
- Reduce air losses
- Reduce pressure drop
- Reduce system effects
- Wheel alignment – easily 1-3%

Scheduling optimization - purposes of HVAC systems

- Provide space heating (some systems)
- Provide space cooling (many systems)
- Provide humidification (some systems)
- Provide ventilation (i.e. outside air, most systems)
- Remove airborne contaminants – filtration (many systems)



Optimizing fan schedule I

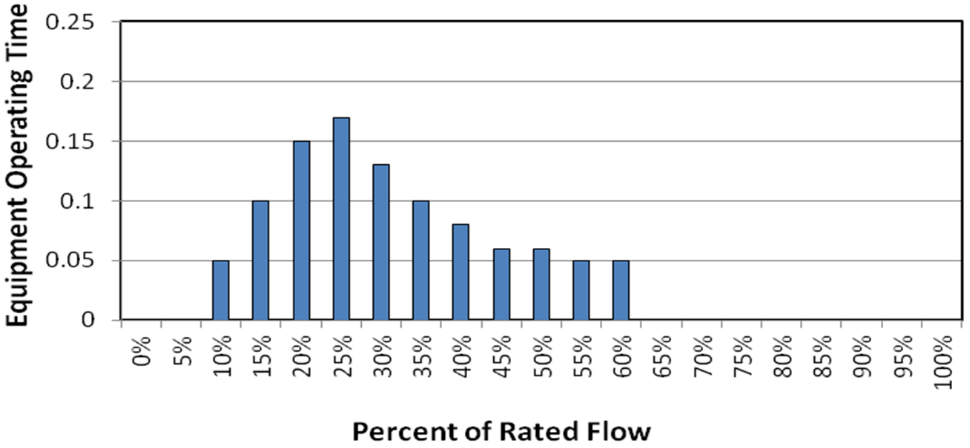
- It is crucial to fully understand the services provided by a system to adjust the operating schedule:
  - Make-up air units do not provide space heating, cooling, filtration or humidification. They pre-condition ventilation air (typically). Schedules can be adjusted to match actual occupancy.
  - Cold-deck systems, such as most variable air volume (VAV) and reheat systems, typically do not provide space heating. Schedules can be adjusted to match actual occupancy during heating periods, with no warmup sequence.

Optimizing fan schedule II

- Fan savings are dictated by the BHP equation.
- For make-up air (MUA) units, heating and cooling savings for pre-conditioning the ventilation air will always be present.
- For cold deck systems, no significant heating savings will result, however reheat savings and cooling savings will typically be achieved.

Right-sizing the flow I

- Many fans in mixed air systems are designed to provide about 0.8 to 1 CFM/ft^2 of conditioned floor area. This flow is rarely required to meet the actual load.
- Even when a VFD is installed, the actual flow modulation is often very limited.
- Ensure flow is modulated, both control and physical elements must be reviewed.



https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/energystar/variable-frequency-drives-eng.pdf

Air distribution

- Getting the ventilation to the proper location!
- Some telltale signs of high losses:
  - No VFD modulation for VAV systems
  - Low return air temperature (lower than typical space temperature)
  - Multiple comfort complaints (too hot)
  - Poor air quality

Air losses in ductwork I

- Ductwork is not perfect, and significant air loss can occur in any given system.
- According to ASHRAE, 70% of systems experience losses in the range of 10% to 26% (reference: ASHRAE Journal October 2025) with an average slightly above 10%.
- Extensive duct sealing can reduce leakage by over 80%.

Air losses in ductwork II

- Typical methods include:
  - Mastic sealant: suitable for small to medium leaks
  - Foil tape: used for quick fixes or as a temporary measure before more extensive sealing work
  - Duct sealant spray: ideal for difficult-to-reach areas in any large building setting
  - Aeroseal technology: particularly beneficial in extensive commercial duct systems where manual sealing would be less feasible; seals up to 90% of leaks
  - Duct insulation: insulating ducts further reduces energy losses

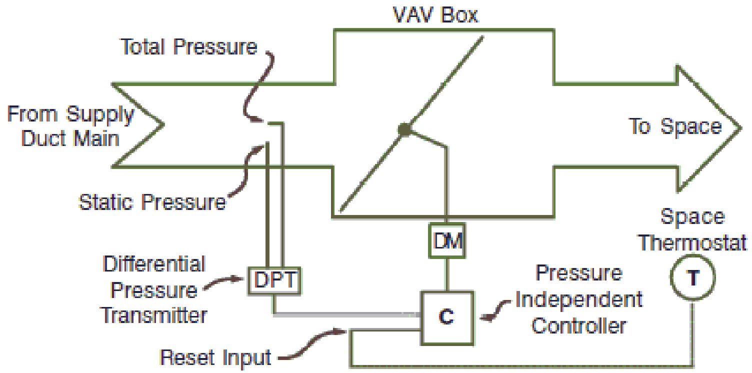
VAV box - ECMs

- ECM – Electronically Commutated Motor
- Commonly found in fan-powered VAV boxes
- An expected service life of 10-15 years
- Pros: High efficiency, built-in speed control, improved comfort
- Cons: Initial costs slightly higher but through Save on Energy incentives you can lower your payback period. (More details at the end)

VAV box flow setpoints and operation

Flow modulation is often hindered by improper setting or operation of VAV boxes:

- VAV box failures
- Maximum flow above requirement
- Minimum flow above requirement
- Inadequate temperature setpoints



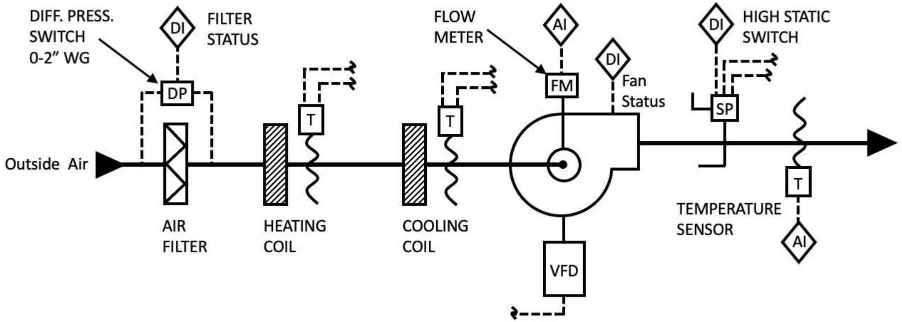
Pressure independent VAV box single-deck without reheat

Controlling the flow

With a good distribution system, flow still needs to be properly controlled.

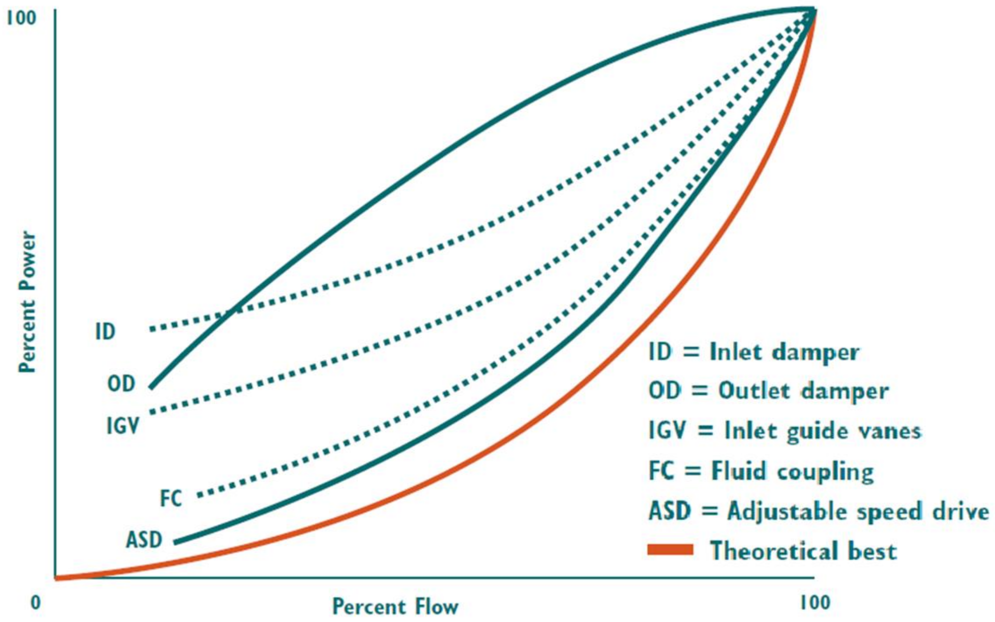
The most common methods:

- Supply static pressure
- Zone-demand (thermal and/or indoor air quality [IAQ])
- Flow stations
- Indirect load indicator
  - For systems with no zonal flow modulation equipment, such as VAV boxes



Modulating the flow efficiently

- To take advantage of the Affinity Laws, VFDs should be used.
- Applicable even for system designs such as constant flow, with some precautions:
    - Gas-fired heating as well as direct expansion (DX) cooling have specific flow requirements



(NRCan-CIPEC – Energy-Efficient Motor Systems – Assessment Guide)

Pressure losses and modulation setpoint I

- Unnecessary pressure losses in variable flow systems can be costly:
  - Verify the Delta-P across the fan and compare to design data
  - Ensure filters are replaced at least per manufacturer recommendations
  - Select lower Delta-P filters
  - Keep coils clean
  - Check for fixable system effects – e.g. use turning vanes
- Flow modulation setpoint must be dynamic:
  - Your building load varies all the time, setpoint should do the same
  - For static pressure control, modulate the setpoint based on zone demand or using a proxy for the load (e.g. Outside air temperature OAT).

Figure 1a: Inefficient (height/width = 1.0)

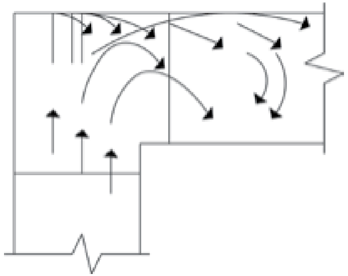
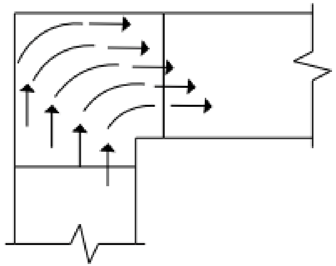


Figure 1b: Efficient (height/width = 1.0)



Pump opportunities and optimization

Pumping system opportunities

- Unlike for fans, there are typically fewer scheduling opportunities for pumps:
  - Heating pumps typically run continuously all winter, except for boiler pumps.
  - Cooling pumps operate based on needed chiller operation and for economizer cycling.
- Largest opportunity is providing the optimal flow for the load
- Other opportunities include reducing pressure losses, optimizing VFD control, better system Delta-T, optimal pump sequencing or adequate balancing

Picture: Pump Systems, Energy Efficiency Reference Guide, CEATI, 2008

Pump flow I

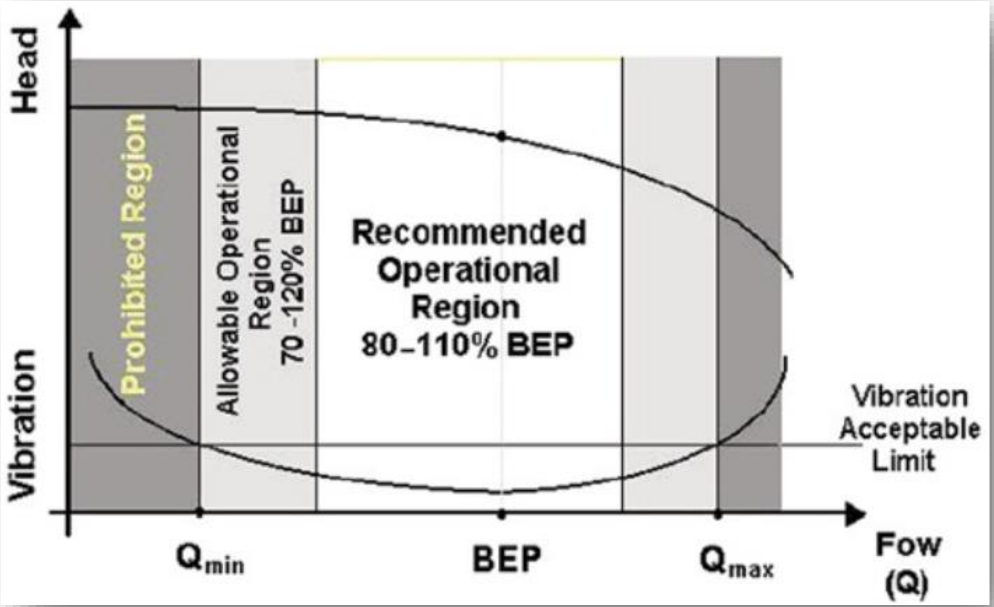
- Savings opportunities are often available for both constant flow systems and variable flow systems.
- For constant flow systems, #1 step is to verify the operating point of the system (system curve versus pump curve):
    - Most pumps are over-sized and use throttling to achieve the design flow. A VFD can be used to replace the central throttling with no adverse effect, with some precaution for open-loop systems.
    - Even without a throttling valve, the flow may exceed needs and must be checked.

Pump flow II

- For variable flow, review the control setpoint and sequence:
  - Most variable flow systems use a static Delta-P for setpoint. Its value is often of unknown origin, and it can also be adjusted dynamically.
  - Use a reset strategy based on demand (e.g. valve opening) or a proxy for the load (e.g. OAT).

Pumping system demonstration

Operating regions (of flow) - prohibited, allowable, recommended

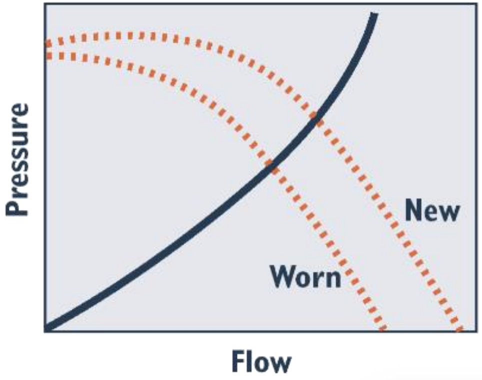


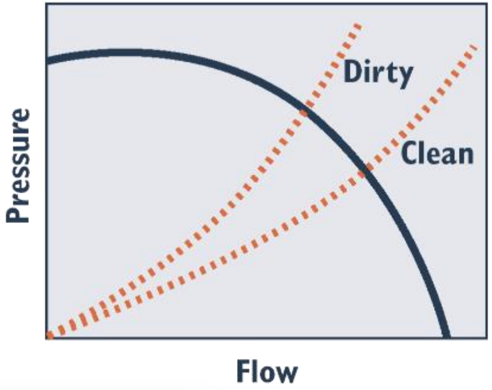
Source: https://blog.craneengineering.net/pump-performance-curves-reliability

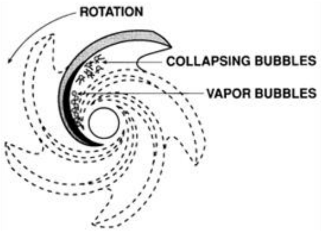
Minimum VFD speed

- The minimum pump speed has an impact on the pump mechanical seal.
- The noise sometimes heard when starting a pump may be due to lack of lubrication on the seal, which can sometimes be due to using a very low minimum speed.
- Motor cooling can also become an issue at very low speed.
- Minimum speed must ensure that the required static head is met.
- Rules of thumb for minimum speed:
  - Four poles (1,750 RPM) – minimum 15 Hz to 20 Hz
  - Six poles (1,150 RPM) – minimum 25 Hz

Equipment wear and system pressure losses



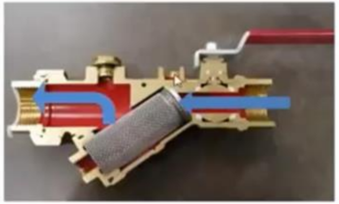




Pipe Fouling!

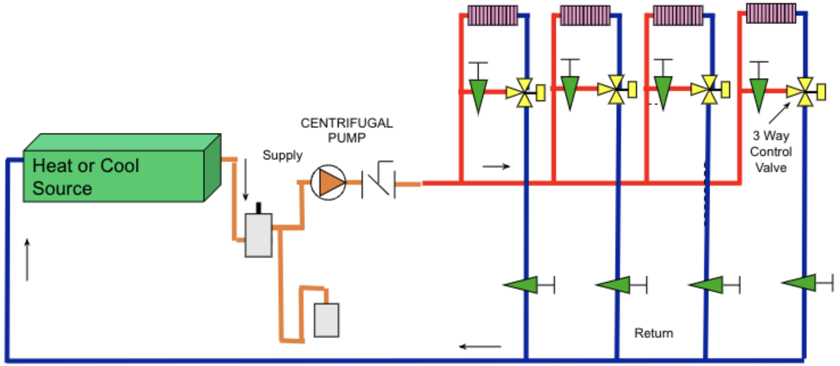
Reduce pressure losses

- Systems have a strainer, sometimes multiple ones.
- Strainers can create significant pressure drops that result in both operational issues and energy waste.
- Balancing valves have strainers in addition to main pump strainers.
- Main strainers should have a Delta-P of no more than 1 psi.

Flow balancing and differential pressure setpoint

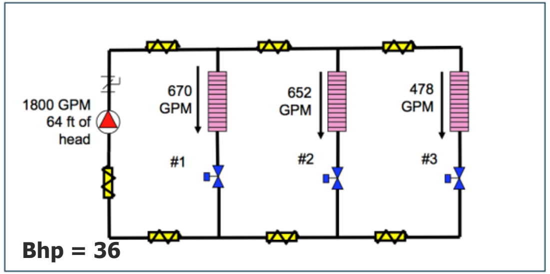
- Both constant flow systems (three-way valves) and variable flow systems often use a loop pressure differential (Delta-P) to set or modulate the flow.
- Delta-P setpoint is adjusted for adequate flow to be sent to all the coils.
- If flow balancing is not done properly, the Delta-P will be set higher to compensate.
- Over-pumping will occur in most coils.
- Lower Delta-T



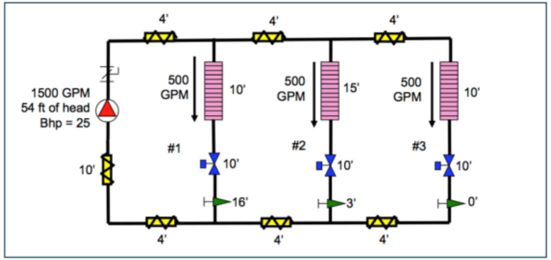
Example of poor and good balancing

- Nameplate: 1,500 gpm, 70 ft w.g.

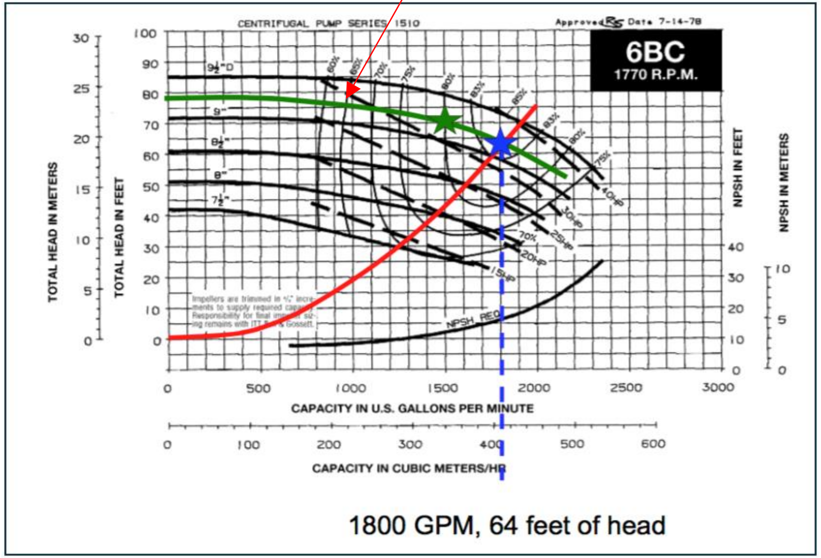
Improper balancing



Rebalanced



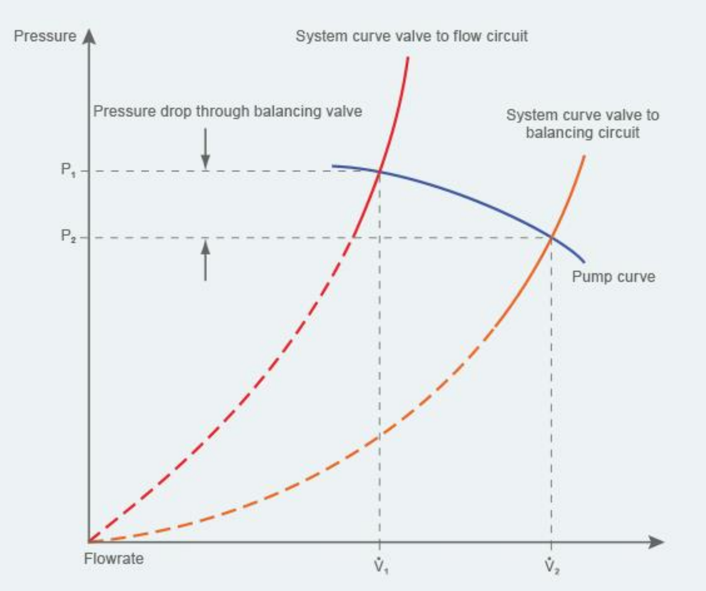
Flow per design



VFD needed to achieve the flow

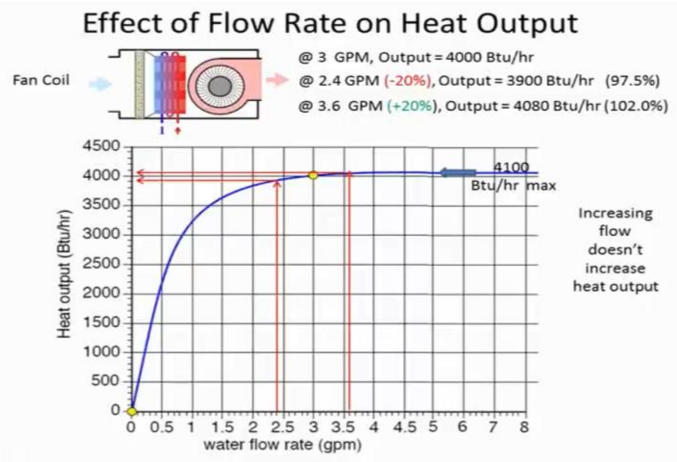
Improper balancing in three-way valve systems with no circuit setters

- Improper balancing, or the complete absence of balancing, on three-way constant flow systems will result in over-pumping, increase electricity usage and lower Delta-T when the coil is being by-passed in part or totally.
- This results in a different system curve with a lower slope.



Looking for further flow reduction

- A common indicator of over-pumping is a low Delta-T under peak load conditions.
- Coil capacity, either heating or cooling, does NOT increase in proportion to the flow.
- Verify the Delta-T and test for lower flows.
- Even a small reduction can provide significant savings through the Affinity Laws!



Save on Energy Incentives

Save on Energy incentives

Optimizing set points, reducing flow, minimizing losses are typical performance optimization measures that can achieve electricity savings. These savings can be incented through performance-type programs, specifically:

- Existing Building commissioning (EBCx) program
- Energy Performance Program (EPP)
- XLerate Program
- Retrofit Program (Custom Stream)

Click here

To determine whether your project is eligible under these programs

Retrofit Program Incentives

Retrofit Program – VFD incentives (prescriptive stream)

- Up to $58,500 incentives per unit (VFD for a maximum of 300 HP)

Retrofit program - ECM fan motors for HVAC application (prescriptive stream)

- Fan-powered VAV box incentive: up to $400/unit
- Fan motor replacement incentive: up to $300/unit

Retrofit Program Incentives

Retrofit Program Custom Stream

- The program calculates the incentive based on energy savings, using either $1,800 per kW of peak demand savings or $0.20 per kWh of annual energy savings, and applies whichever value is higher. However, the final incentive is capped and cannot exceed 50% of the project's eligible costs, with up to 55% of estimated eligible costs in application approved by the IESO.
- Custom M&V is used to measure and verify energy and/or demand savings for larger or more complex projects where engineering calculations alone are insufficient to confidently support incentive claims.

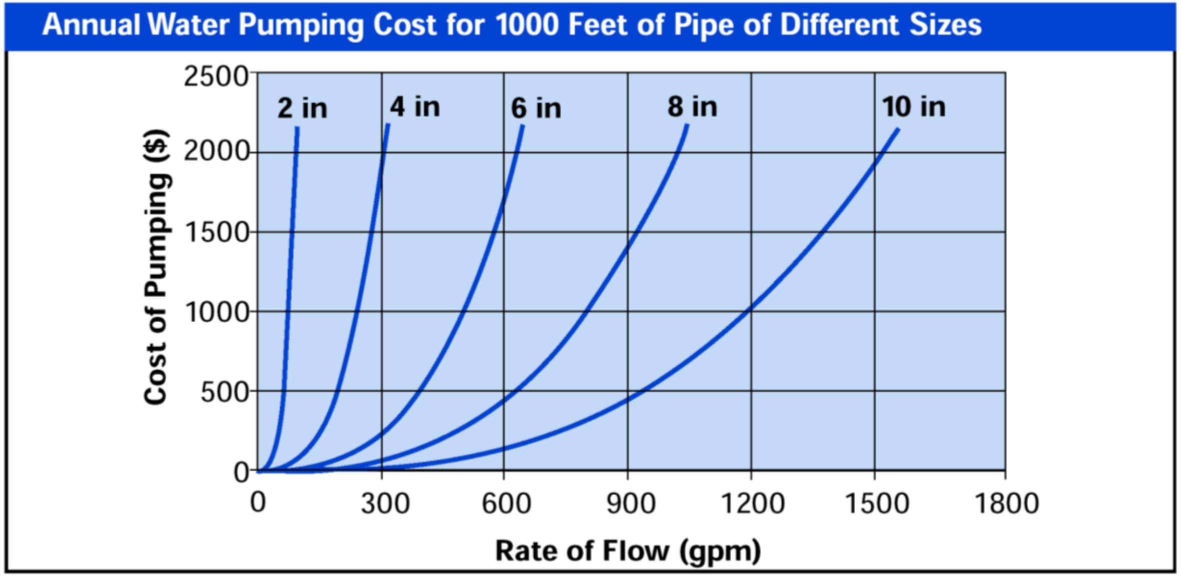
Selected case studies

Case: efficient distribution by design-interface flooring

- Manufacturing plant heat transfer system
- Conventional (initial) design
  - Small pipes, big pumps
  - 92 HP
- Energy optimized (final) design
  - 50% larger pipe
  - Layout of pipe to reduce friction
  - 7 HP
- Effectively, the same capital cost
  - Smaller pump, motor, etc.
  - Insulation easier

Big Pipes, Small Pumps: Interface Inc. available from http://www.rmi.org/

The efficient design – pipe sizing to reduce energy cost



Based on 1000 ft. for clean iron and steel pipes (schedule 40) for pumping 70°F water. Electricity rate—0.05 $/kWh and 8,760 operating hours annually. Combined pump and motor efficiency—70%.

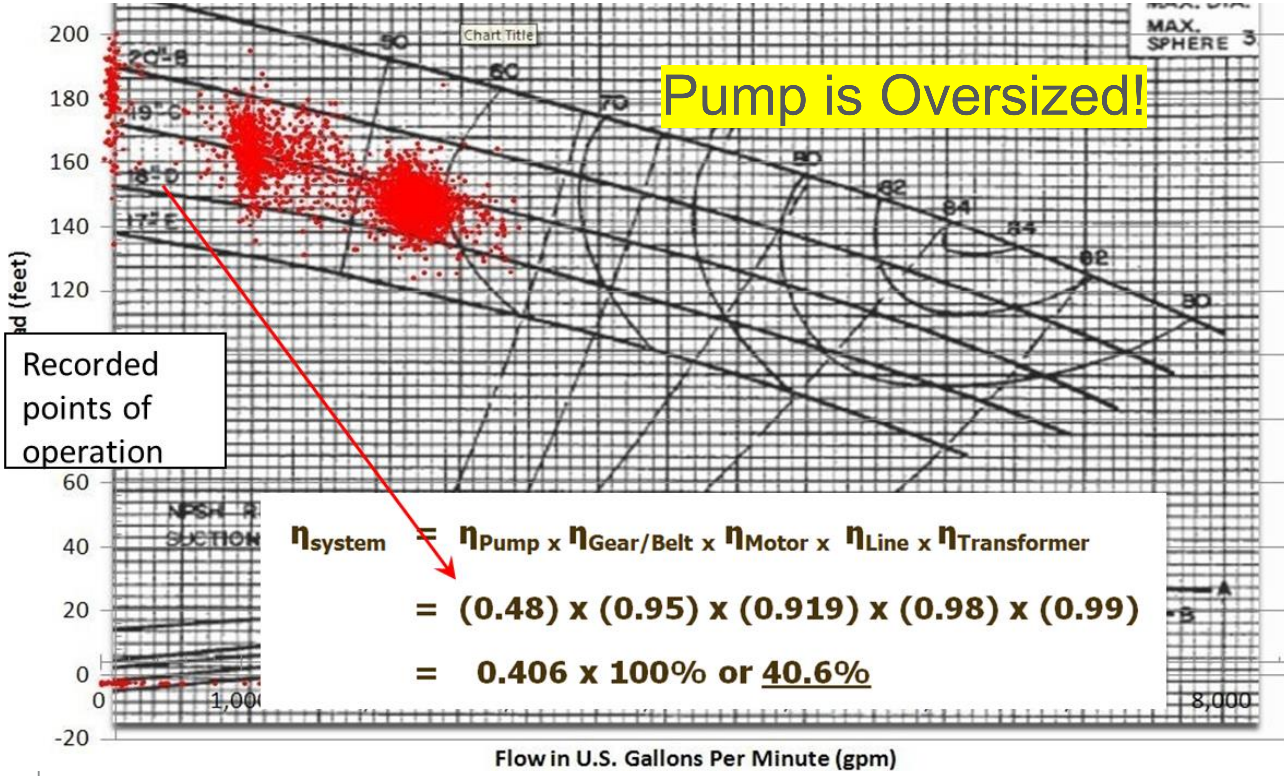
Ref: Reduce Pumping Costs through Optimum Pipe Sizing, Motor Tip Sheet #1,December 1999. DOE/GO-10099-879.
From http://energy.gov/sites/prod/files/2014/05/f16/reduce_pumping_costs.pdf

Oversized: 250 HP pump and motor downsized

- 250 HP motor and pump replaced by 125 HP motor and pump:
  - Pump efficiency improves from 48.2% to 73.9%
  - Motor efficiency improves from 91.9% to 96.2%
  - Original operating power = 167.7 kW
  - Final operating power = 82.4 kW
- For 8,000 hrs/yr at $8.00/kW and $0.1/kWh:
  - 85.3 kW and 682,000 kWh avoided
- **Total annual savings of $76,400**
  - Energy cost savings of $68,200
  - Demand cost savings of $8,200

Project could be ideal for the Save on Energy – Retrofit Program (Custom Incentive)!

The pump curve details: 250 HP motor and pump



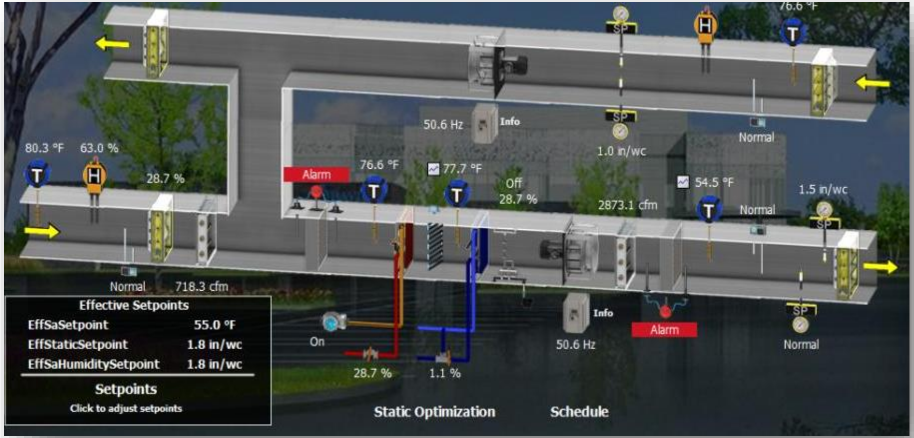
$$\eta_{system} = \eta_{Pump} \times \eta_{Gear/Belt} \times \eta_{Motor} \times \eta_{Line} \times \eta_{Transformer}$$

$$= (0.48) \times (0.95) \times (0.919) \times (0.98) \times (0.99)$$

$$= 0.406 \times 100\% \text{ or } \underline{40.6\%}$$

Case #2: modulate air handling unit fan speed with VFD

- Add VFDs to air handling unit (AHU) to modulate fan speed based on load (temperature)
- Run at 90% in winter
- Stop on weekends
- Start on demand to 75%
- Run at 75%
- Early start-ups
- Electricity: 153,000 kWh
- **$18,400/yr**



https://hvac-talk.com/vbb/threads/1911151-HVAC-Graphics-Library

Case #3: reduce pump speed with existing VFD

- Reduce speed of 150 HP glycol pump to ~ 80%, 24/7
  - VSD exists – currently used at night
- Requires testing to determine the best operating point for the system
- Electricity savings: ~ 300,000 kWh
- **Cost Reduction: ~ $55,000**
  - Including peak demand impact
- Plus, reduced pump maintenance

Stay connected with tools and resources

- Virtual one-on-one coaching: post-webinar support intake form for tailored support for organizations to manage energy resources effectively
- Monthly bulletin: sign up to receive monthly training updates on all Save on Energy training and support new tools and resources
- Live training calendar: visit this page to easily register for upcoming events and workshops
- Training and support webpage: visit this page to access all training and support materials

Post-Webinar Support

One-on-one coaching: tailored support for managing energy resources effectively

Post-webinar support intake form

Coaching sessions conducted virtually: phone, video calls, and email

Designed for organizations, new or old, seeking guidance.

Thank you

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