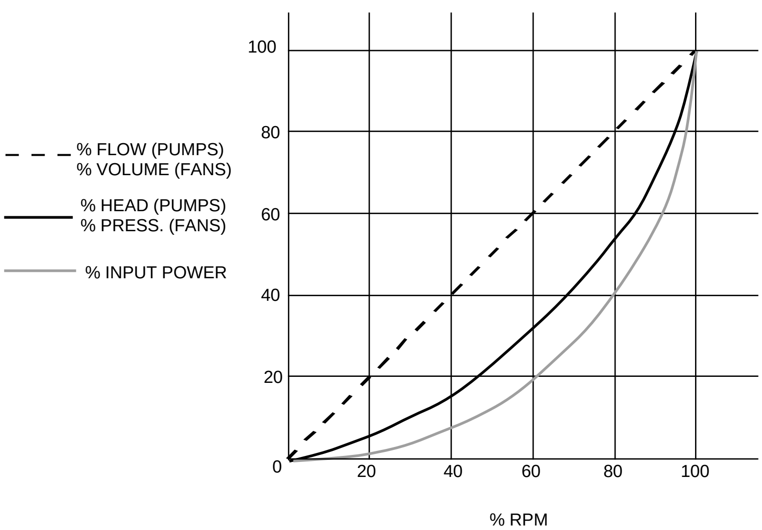
Centrifugal Fans and Pumps are sized to meet the maximum flow rate required by the system. System conditions frequently require reducing the flow rate. Throttling and bypass devices – dampers and valves – are installed to adjust pump and fan output. The throttling and bypass devices are effective, but not energy efficient. Another method can vary the flow and also reduce energy losses. The method: adjust the fan and pump impeller speeds so the units deliver only the required flow.

Adjustable Speed drives are available in many different types, adjustable speed drives offer the optimum method for matching pump and fan flow rates to system requirements. The adjustable frequency drive (inverter) is most commonly used. It converts standard plant power (230 or 460 V, 60 Hz) to adjustable voltage and frequency to power the AC motor. The frequency applied to the AC motor determines the motor speed.

The AC motors are usually the same standard motors that can be connected across the AC power line. When employed in critical situations, a bypass capability is added to provide redundant motor control to insure continued motor operation.



SPEED	VOLUME OR FLOW	INPUT HP
100%	100%	100%
90%	90%	73%
80%	80%	51%
70%	70%	34%
60%	60%	22%
50%	50%	13%
40%	40%	6%
30%	30%	3%

Figure 1. Physical Laws for Centrifugal Loads

Adjustable speed drives also offer an additional benefit – increased mechanical equipment life. For example, by maintaining only the pressure needed in the pump to satisfy system requirements, the pump is not subjected to any higher pressures than necessary. Therefore, the bearing and pump seal components last longer.

The same benefits also apply to fan bearings and drive belts operated by adjustable speed drives.

To obtain optimum efficiencies and reliability, many specifiers obtain detailed information from the manufacturers on drive efficiency, required maintenance, diagnostic capabilities within the drive, and general operational features. Then, they make detailed analyses to determine which system will give the best return on the investment.

Pump Energy Savings

Pumps are generally grouped into two broad categories, positive displacement pumps and centrifugal pumps. The vast majority of pumps used today are the centrifugal type, and they are the only type discussed in this paper.

Centrifugal pump operation is defined by two independent curves. One is the pump curve, which is solely a function of the pump characteristics. The other is the system curve, which depends on the size of pipe, the length of pipe, the number and location of elbows, etc. The intersection of these two curves is called the natural operating point, because the pump pressure matches the system losses.

If the system is part of a process that requires adjustable flow rates, then some method is needed to continuously alter the pump characteristics or the system parameters. As mentioned, these include valves for throttling or bypassing, which change the system curve, or variable speed control of the pump, which modifies the pump curve.

Figure 2 shows two installation methods for bypass valves in a pumping system. These systems maintain relatively constant pressure while bypassing flow from the pump discharge to the pump suction. This modulates the useful system flow but maintains constant pump flow rate and energy consumption by the pump motor.

Figure 3 shows the curves for a throttling system with two operating conditions – one with the valve open and the other with the valve throttled or partially closed. Closing the valve effectively increases the system head that, in turn, decreases the flow.

Figure 4 shows the curves for a bypassing system with two operating conditions – one with the bypass valve closed and the other with the bypass open. When the bypass is open, the system head is held at a constant maximum level.

By comparison, the variable speed method, shown in Figure 5, changes the pump characteristics when the pump impeller speed is changed.

Of these three, only the adjustable speed method uses considerably less energy with the reduced flow, thus offering significant energy savings.

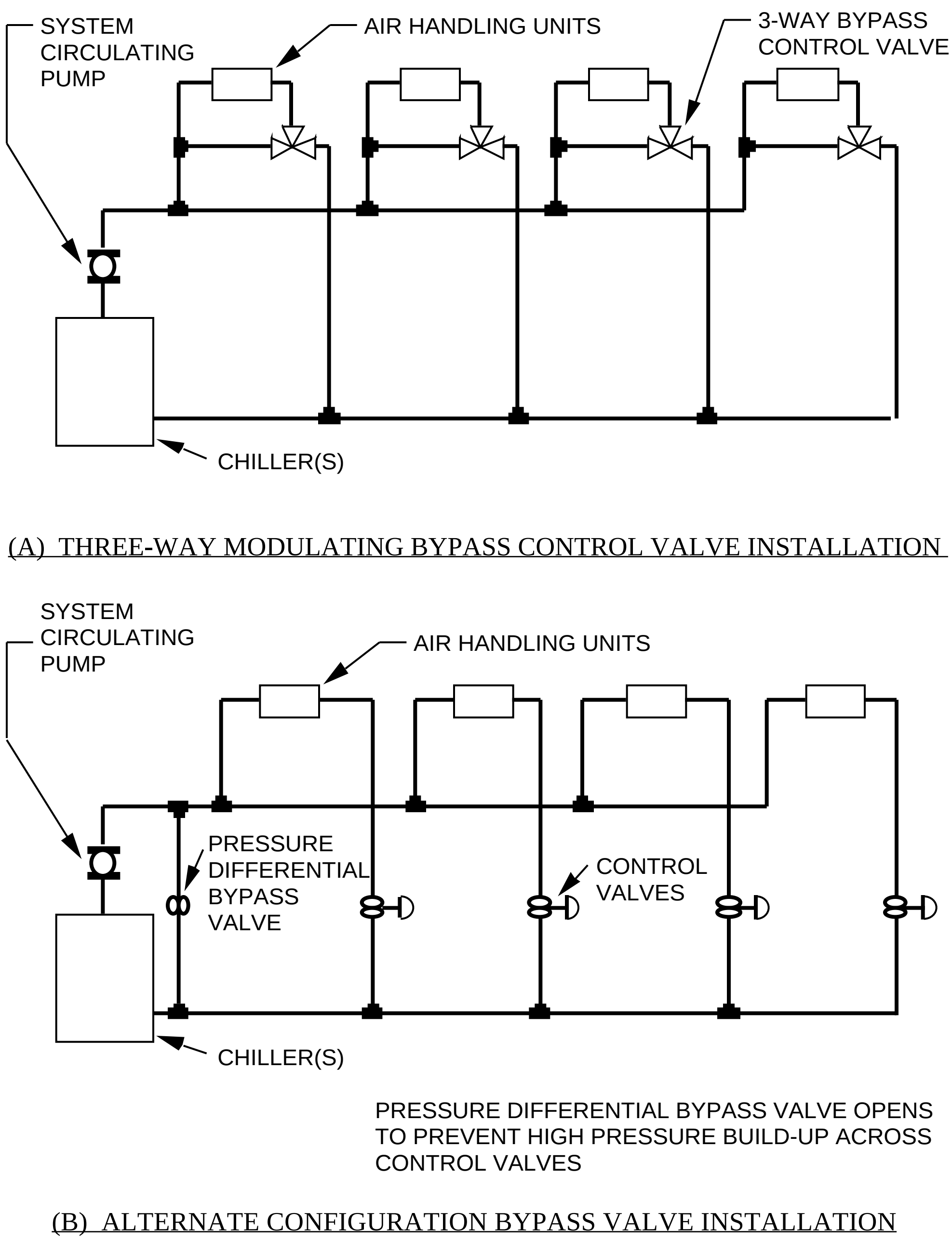


Figure 2. Pumping Installations With Bypass Control Valves

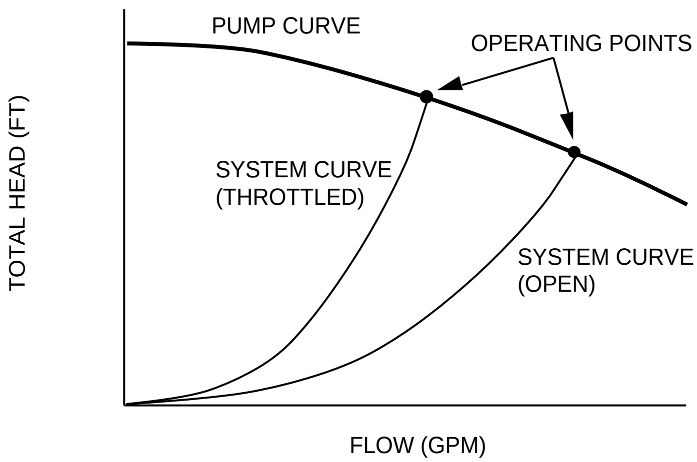


Figure 3. Typical Curves for Throttling Valve Flow Control

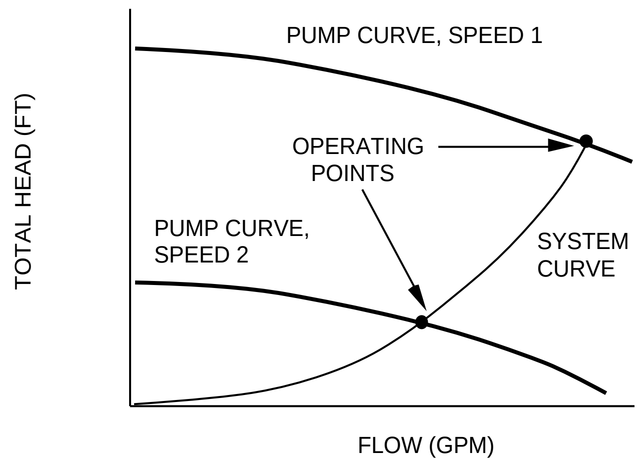


Figure 5. Typical Curves for Adjustable Speed Flow Control

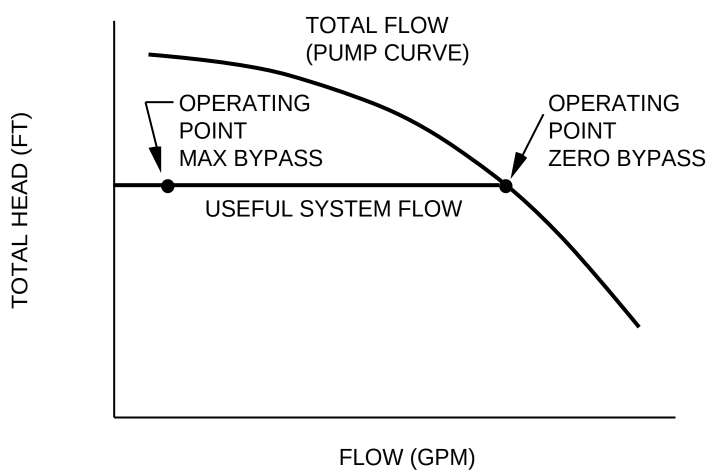


Figure 4. Typical Curves for Bypass Valves Flow Control

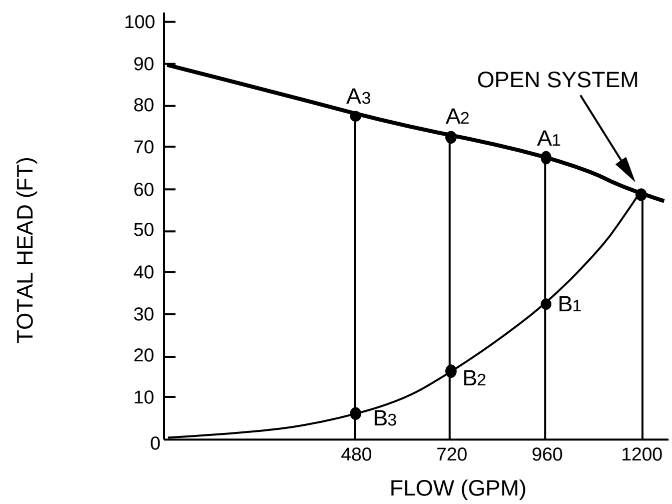


Figure 6. Comparison of Operating Points for Throttling (A) and Adjustable Speed (B) Flow Control

For example, in a throttling system, a particular pump with a 14 in. impeller operates at a base speed of 1150 rpm in a system with a 63 ft. head (no static head), and delivers 1200 gpm when the system is not throttled (see the Open System operating point in Figure 6). The process requires flow rates of 1200 (100%), 960 (80%), 720 (60%), and 480 (40%) gpm.

For a specific flow rate, the difference between points A and B in Figure 6 gives a visual indication of possible energy savings. Also, changes in pump efficiency should be included in the calculation to determine brake horsepower.

Table 1

FLOW (GPM)	THROTTLING			ADJUSTABLE SPEED		
	HEAD (FT)	PUMP EFFICIENCY	BHP	HEAD (FT)	PUMP EFFICIENCY	BHP
1200 (100%)	63	76.3%	25	63	76.3%	25
960 (80%)	69	73%	23	40	75%	13
720 (60%)	75	65%	21	23	75%	5.6
480 (40%)	81	54%	18	10	75%	1.6

Table 2

USEFUL FLOW (GPM)	BYPASSING				ADJUSTABLE SPEED		
	PUMP FLOW (GPM)	HEAD (FT)	PUMP EFFICIENCY	BHP	HEAD (FT)	PUMP EFFICIENCY	BHP
1200 (100%)	1200 (100%)	63	76.3%	25	63	76.3%	25
960 (80%)	1200 (100%)	63	76.3%	25	40	75%	13
720 (60%)	1200 (100%)	63	76.3%	25	23	75%	5.6
480 (40%)	1200 (100%)	63	76.3%	25	10	75%	1.6

Table 1 lists the comparative brake horsepower values required by throttling and adjustable speed methods for the four operating points. Table 2 lists the comparative brake horsepower values required by bypassing and adjustable speed methods for the four operating points. Figure 7 graphically shows the power requirements and savings for the various flow rates, comparing both throttling and bypass methods to adjustable speed method.

This example does not include a static head. The magnitude of the static head will affect the possible power savings. The less the static head is in relation to the total head, the greater the power savings that will be achieved by using adjustable speed drives.

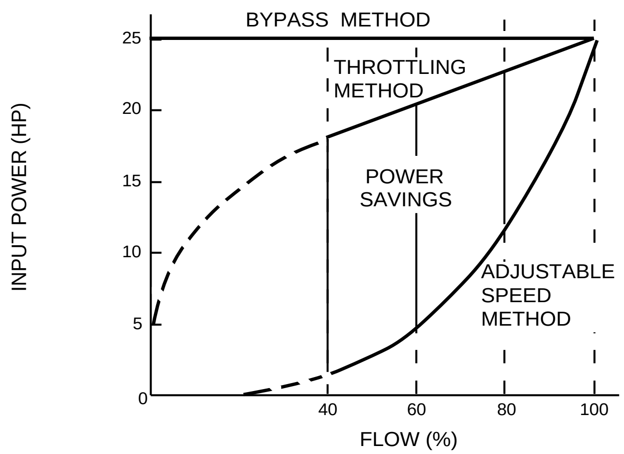


Figure 7. Power Requirements for Throttling and Adjustable Speed Methods, and Resultant Power Savings

For example, Figure 8 shows a pump curve with three system curves – one with no static head, and two with different amounts of static head. For a given flow rate, the difference between operating points A and B indicates the possible power savings with adjustable speed. Thus, the difference between points A and B_3 (no static head) is greater – and offers greater power savings – than between points A and B_1, with a 40 ft static head.

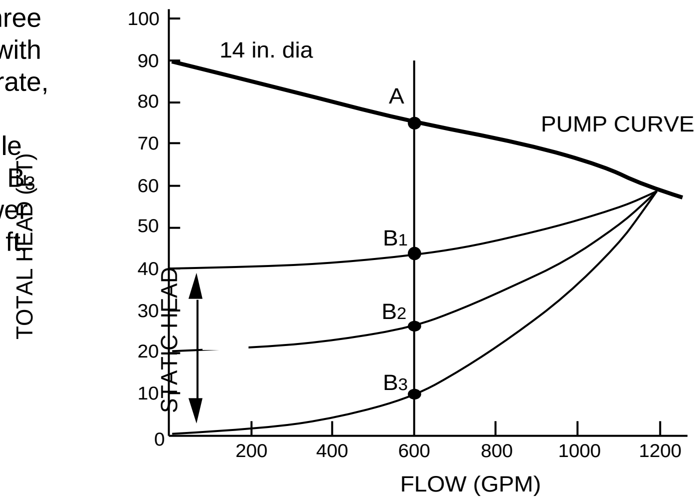


Figure 8. Operating Points With Different Static Heads

Determining Pump Curves

Pump curves are readily available from pump manufacturers. However, system curves are more difficult to establish. One quick method gives a fairly reliable approximation:

1. Determine the unthrottled (open) system flow rate (gpm) at the location under consideration.
2. Measure static head.
3. Plot these two points on a copy of the pump curve.
4. Connect these two points using approximately a square function ($Y = X^2$, or head = $flow^2$).

Duty Cycle and Energy Costs

Before the dollar savings can be calculated, it is first necessary to establish the average duty cycle – percent of time the pump delivers the various flow rates. The horsepower requirements for each duty cycle can then be weighed to give the average value (see Table 3).

In this example, the average power requirement is 10.1 HP. This value divided by the motor and drive efficiency and multiplied by the cost of electricity will give the monthly operating cost.

Table 3

FLOW (GPM)	REQ'D HP FOR FLOW RATE	PORTION OF DUTY CYCLE	WEIGHTED POWER REQUIREMENT (HP)
1200	25	10%	2.5
960	13	40%	5.2
720	5.6	40%	2.2
480	1.6	10%	0.2
		100%	10.1

For this example, assume the drive is 85% efficient, the pump operates for 400 hours per month, and the electricity costs 7¢ per kWh. Then:

$$\text{Operating cost} = \frac{10.1\ \text{HP}}{.85\ (\text{Mtr Eff.})} \times \frac{.746\ \text{kW}}{\text{HP}} \times \frac{400\ \text{h}}{\text{month}} \times \frac{\$0.07}{\text{kWh}} = \$258\ /\ \text{month}$$

The operating costs can be determined for each type of flow regulation method to establish payback periods. Also, some companies offer a computer analysis to give many cost and payback comparisons.

Fan Energy Savings

The basic operation of centrifugal fans is similar to pump operation, and energy savings are equally obtainable. However, the common units are slightly different. Outlet pressure (static inches of water) is used in place of head (feet of water) and flow is usually expressed in cubic feet per minute (cfm).

Several different methods are used to throttle or regulate fan outputs. The most common include outlet dampers, bypass dampers, and variable inlet vanes. Figures 10 and 11 are typical examples of these devices in air handling unit applications. Outlet dampers affect the system curve (see Figure 9) by increasing the resistance to air flow much the same as a valve throttles a pump output.

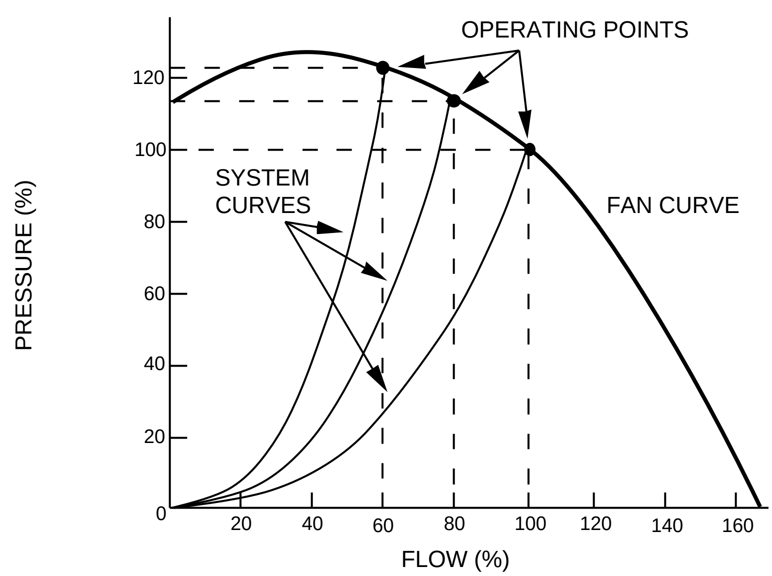


Figure 9. Typical Fan Curve With System Curves for Outlet Damper Settings

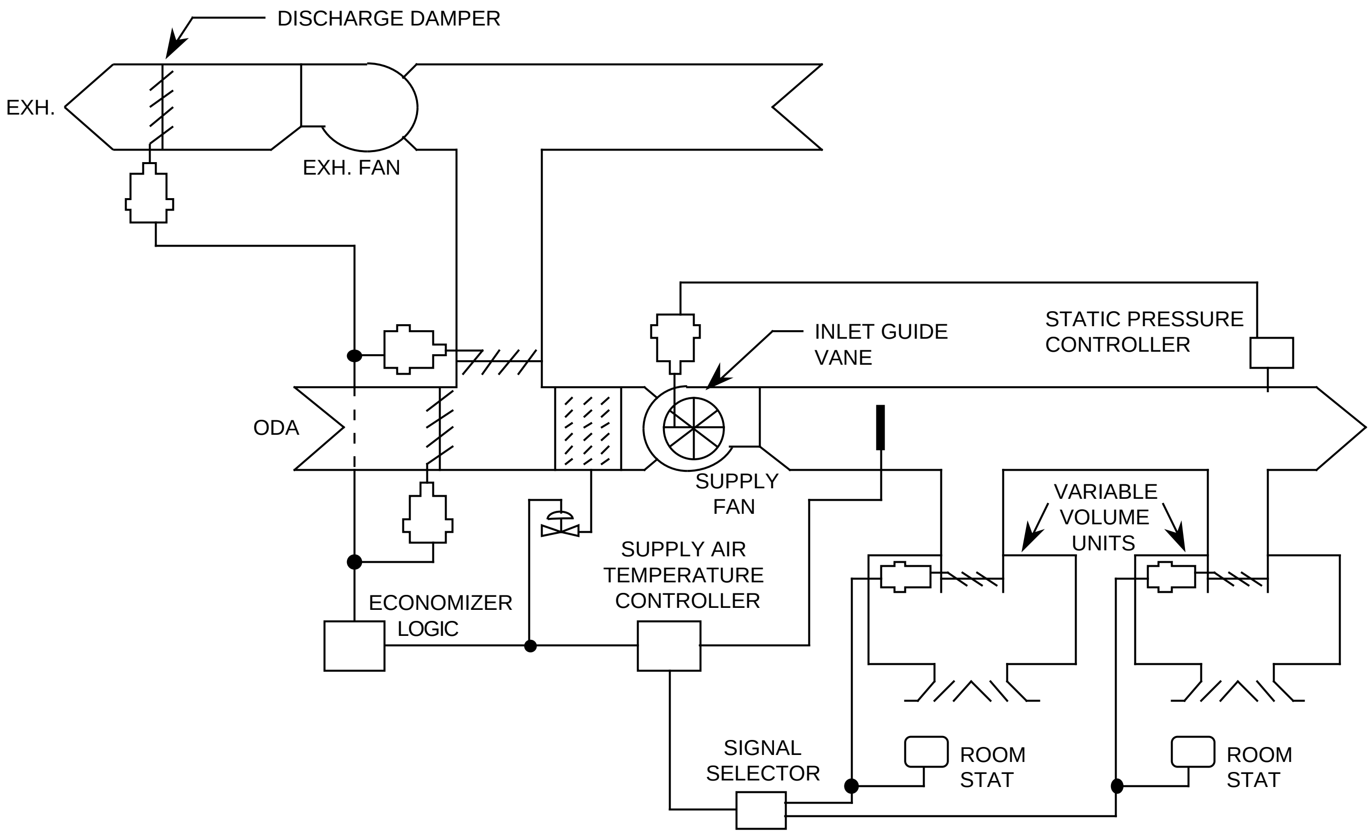


Figure 10. Typical Variable Volume Control Using Inlet Guide Vane on Supply Fan and Discharge Damper on Exhaust Fan

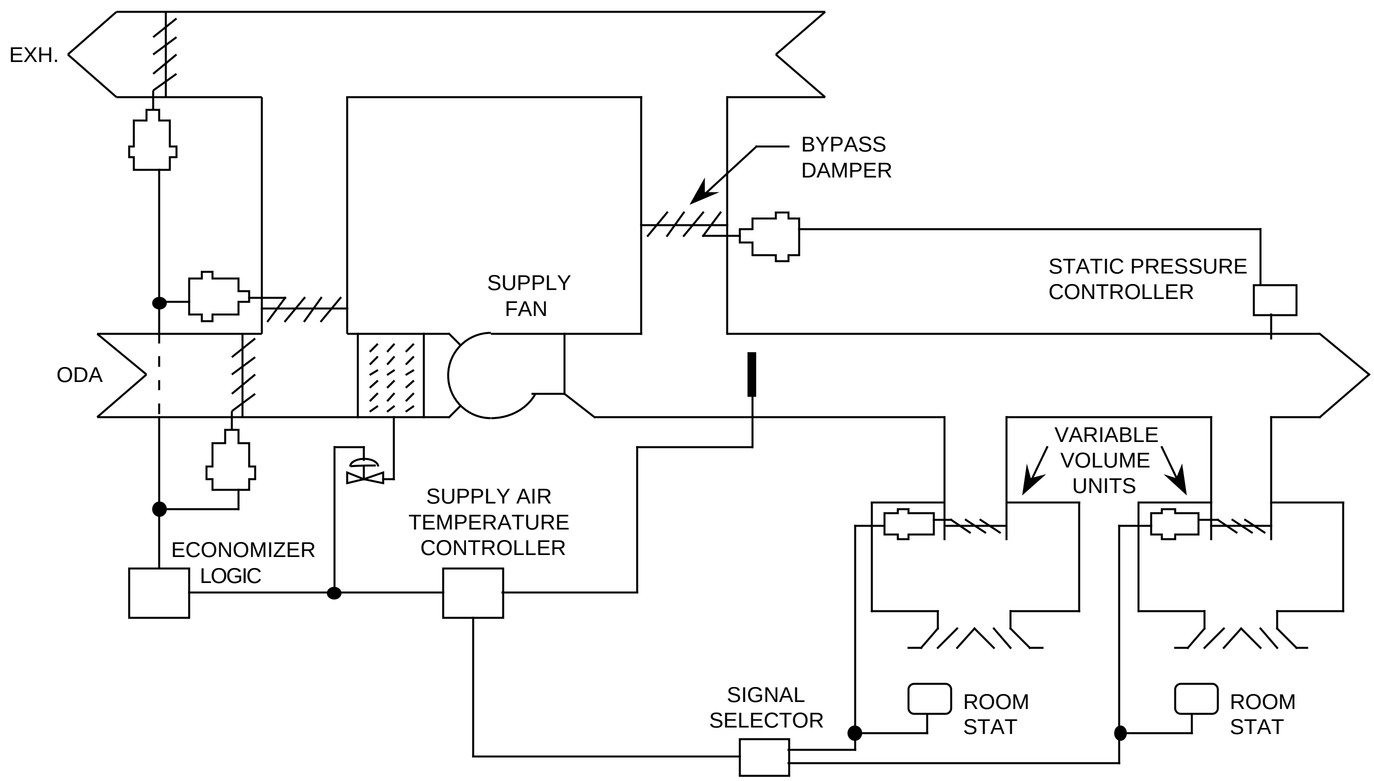


Figure 11. Typical Variable Volume Control Using a Bypass Damper

Bypass dampers (Figures 12 and 14) are the least effective method; they accomplish air flow modulation to the system by bypassing air flow from the fan discharge to the fan intake. This is simple and low in first cost, but does nothing for energy conservation.

Figure 13 shows that as the flow is decreased, the power requirement is reduced only slightly.

Variable inlet vanes direct the air flow as the air enters the fan, and in effect modify the fan curve (Figure 15). With these vanes, power requirements are significantly reduced as flow is decreased (Figure 16).

As with pumps, adjustable speed drives offer the greatest savings for fans. This adjustable flow method changes the fan curve (Figure 17) and drastically reduces the power requirements (Figure 18) even more than for inlet vanes.

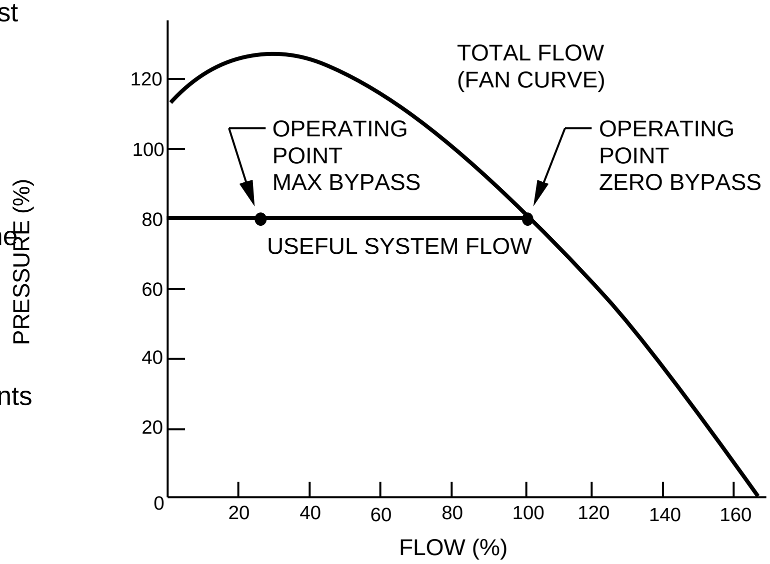


Figure 12. Typical Fan Curve With Bypass Damper Control

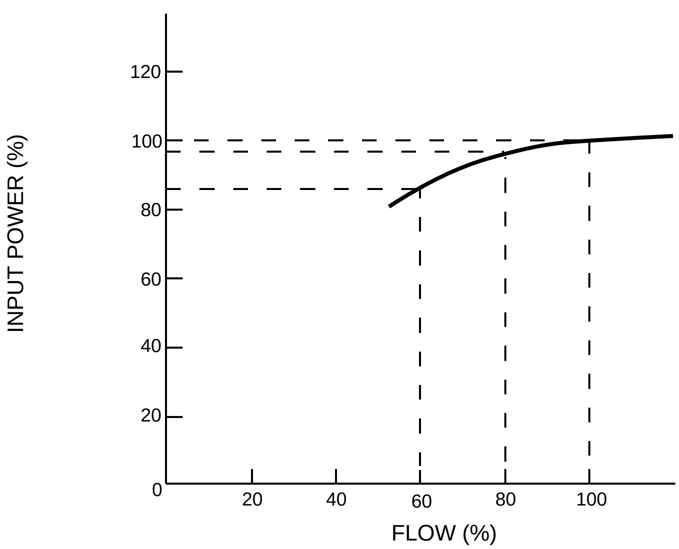


Figure 13. Power Requirements vs Flow for Outlet Damper Settings

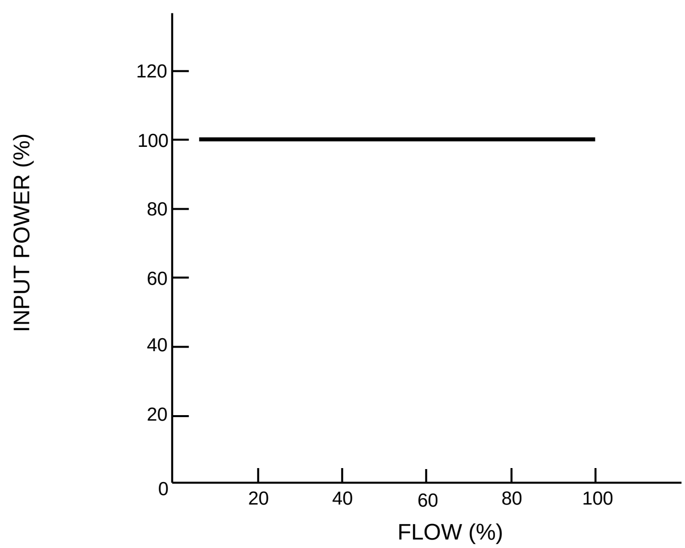


Figure 14. Power Requirements vs Flow for Bypass Damper Control

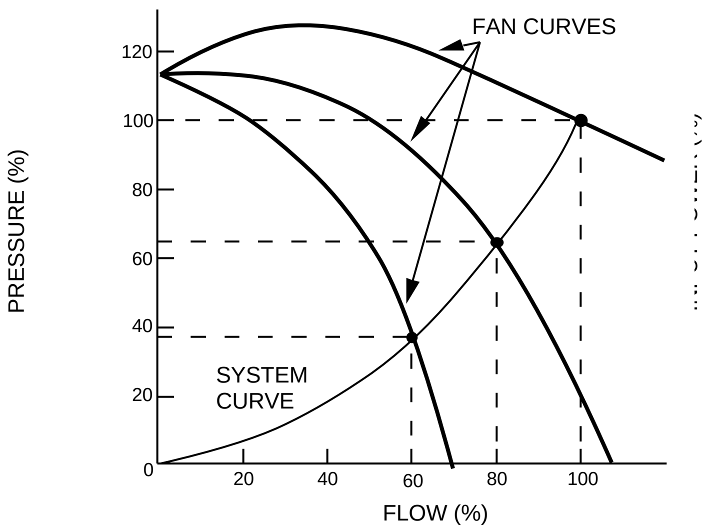


Figure 15. Typical System Curve With Fan Curves for Inlet Vanes Settings

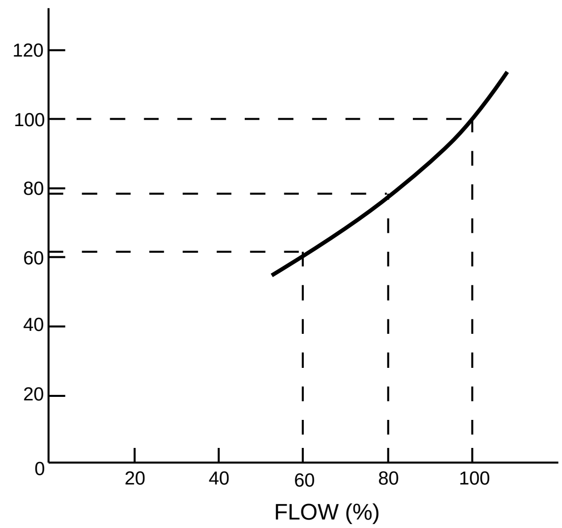


Figure 16. Power Requirements vs Flow for Inlet Vanes Settings

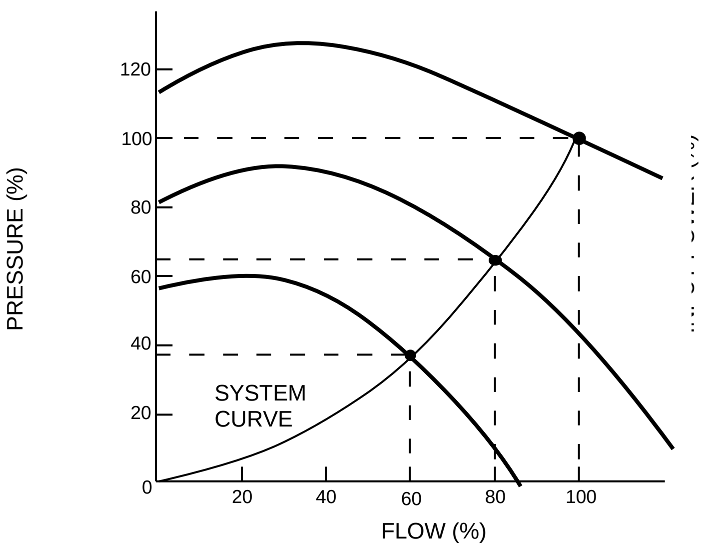


Figure 17. Typical System Curve and Fan Curves for Adjustable Speed Fan Drive

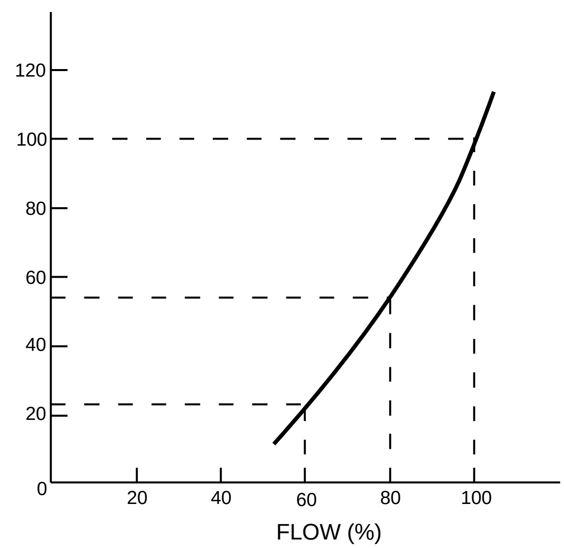


Figure 18. Power Requirements vs Flow for Adjustable Speed Fan Drive

VAV (variable air volume) air conditioning systems, as shown in Figures 10 and 11, control the blower capacity modulation through a duct static pressure sensor and controller. This controller can function with any of the capacity modulation means: a discharge damper, bypass damper, inlet guide vane, or motor speed control.

The controller has a minimum static pressure point (as indicated in Figure 19) which causes the "system curve" to be modified to the curve labeled "actual system curve", which no longer passes through the zero pressure point. This is analogous to static head in pump applications and has a similar effect on potential energy savings, since the fan capacity can not be reduced below the requirement of the minimum static pressure setting.

This minimum static pressure setting is required to meet the requirements of the VAV terminal units and their flow controllers. It should be considered when evaluating the energy savings potential of VAV air conditioning systems.

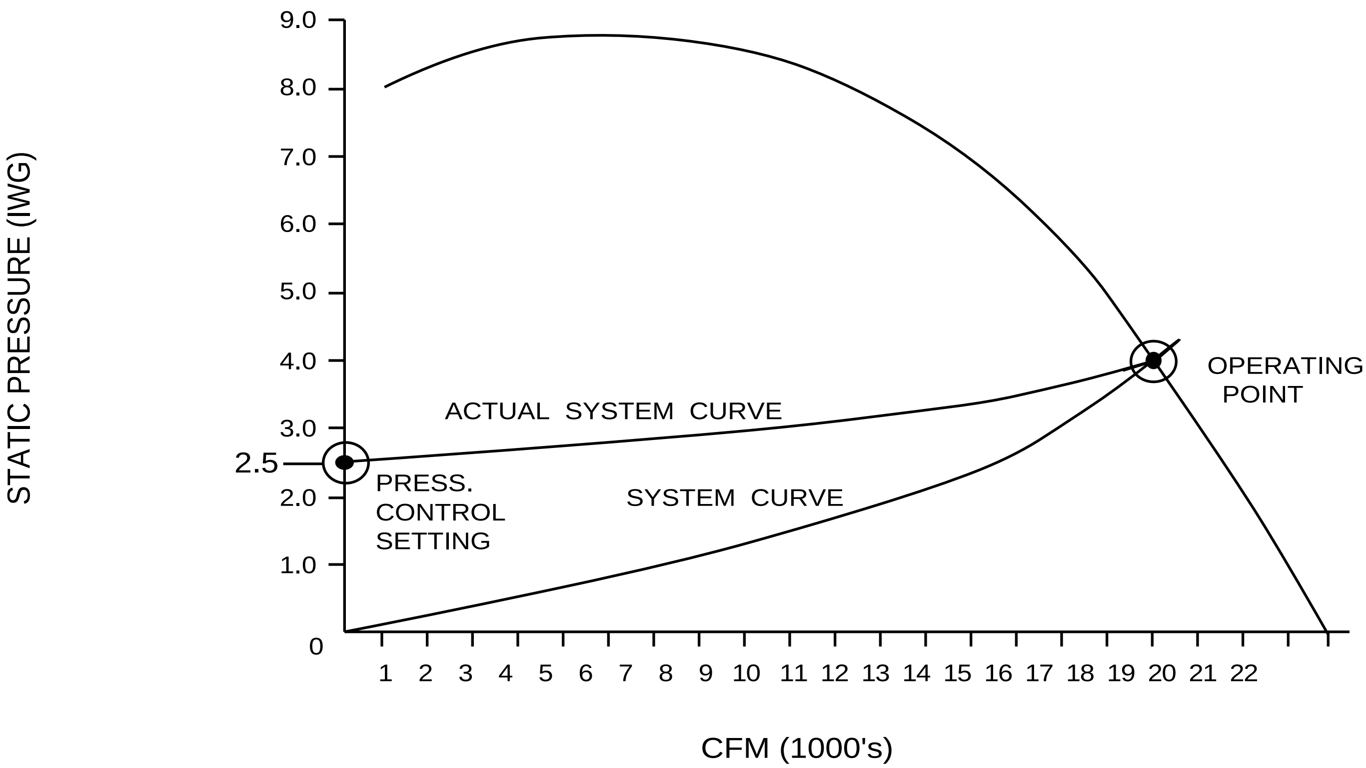


Figure 19. Variable Air Volume (VAV) Air Conditioning Application With Static Pressure Control Example

Terminology and Formulas

A. Fans and Blowers

$$HP = \frac{CFM \times PSF}{33{,}000 \times \text{Efficiency of Fan}}$$

$$HP = \frac{CFM \times IWG}{6356 \times \text{Efficiency of Fan}}$$

$$HP = \frac{CFM \times PSI}{299 \times \text{Efficiency of Fan}}$$

Where

CFM	=	Cubic feet per minute
PSF	=	Pounds per square foot
IWG	=	Inches of water gauge
PSI	=	Pounds per square inch
Efficiency of Fan	=	% / 100

B. Pumps

Head – Measurement of pressure, usually in feet of water. A 30 ft head is the pressure equivalent to the pressure found at the base of a column of water 30 feet high.

Static Head – Pressure required to overcome an elevation change, also expressed in feet of water.

Dynamic Head (or Friction Head) – Pressure losses within the pipe system due to flow. To get water to flow at a particular volume may require overcoming a 10 ft static head plus a 1 ft dynamic head. The dynamic head of a system usually increases proportional to the square of the flow rate.

System Head – Curve of the head required to satisfy both the static head and the dynamic head for a range of flows in a given system.

Pump Head – Pressure the pump produces at its outlet. Centrifugal pump head can vary depending on the flow through the pump and is also determined by the impeller speed and diameter.

Pump Curve – Characteristic curve of a pump showing the head-flow relationship.

Operating Point – Intersection of the pump curve and system curve.

Water Horsepower – Energy output of the pump derived directly from the output parameters

$$\text{Water HP} = \frac{Q \times H \times S}{3960}$$

Where

Q	=	Flow rate (gpm)
H	=	Pressure head (feet of water)
S	=	Specific gravity (water is 1.0)

Brake Horsepower – Horsepower required to operate the pump at a specific point, and equals the water horsepower divided by the pump efficiency.

Affinity Laws – A set of formulas used to evaluate the operation of a centrifugal pump at any operating point based on the original pump characteristics:

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

Where:

N	=	Pump speed (rpm)
Q	=	Flow (gpm)
H	=	Pressure head (feet of water)
P	=	Power (HP)

C. Variable torque Loadf

With this type of load, the torque is directly proportional to some mathematical power of speed, usually speed squared ($Speed^2$). Mathematically:

$$\text{Torque} = \text{Constant} \times \text{Speed}^2$$

Horsepower is typically proportional to speed cubed ($Speed^3$). Figure 19 shows the variable torque and variable horsepower demanded by the load.

Examples of loads that exhibit variable load torque characteristics are centrifugal fans, pumps and blowers. This type of load requires much lower torque at low speeds than at high speeds.

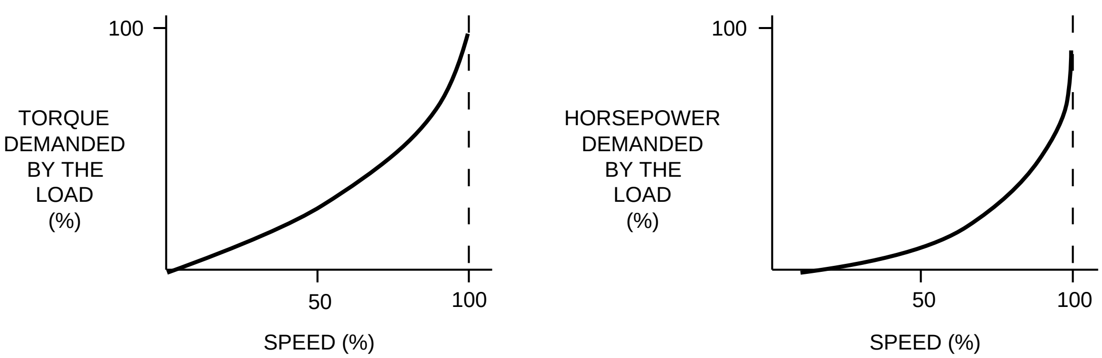


Figure 20. Variable Torque Load