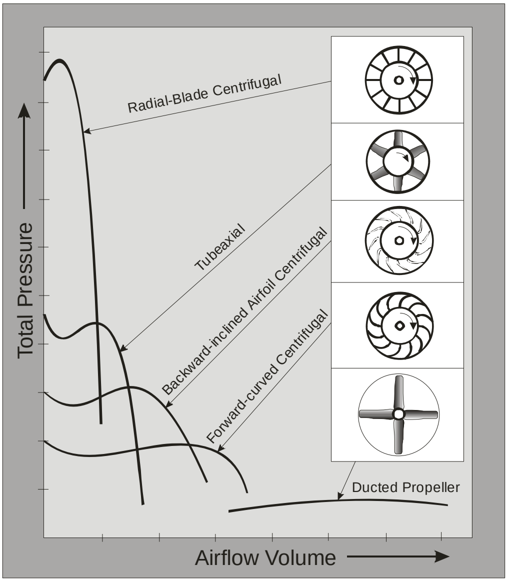
FANS & BLOWERS

Energy Efficiency Reference Guide



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The use of certified practitioners for the application of the information contained herein is strongly recommended.

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Appreciation to Ontario Hydro, Ontario Power Generation and others who have contributed material that has been used in preparing this guide.

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1 PURPOSE OF THIS GUIDE

This guidebook is intended to provide the fundamental information required to make informed and educated decisions about the use and energy efficient operation of fan and blower systems.

Over the lifetime of a typical fan or blower, the value of electricity used can exceed the initial cost by as much as tenfold. Performance optimization of fans and blowers offers tremendous potential for energy savings in the industrial, commercial and institutional sectors. By understanding the relationship between energy and functionality, readers can make informed decisions about the procurement, installation, maintenance and operations of fan and blower systems.

a. Guide Organization

The guide is organized into standalone and related modules. It is expected and recognized that individual readers of this guide have different levels of knowledge and experience with fans, blowers and associated components.

The main themes of the guide are:

Fan and Blower System Fundamentals

- For readers who may not be familiar with the essentials of fan and blower systems, the first section provides a brief discussion of terms, relationships and important system design considerations.

- The main factors for equipment selection and system design are provided, while giving an overview of different types of fans and blowers and their general applications. Energy efficiency concepts are introduced, including a component related to the "affinity laws."

Performance Optimization Opportunity Strategies

- Optimizing the energy performance of fans and blowers, in most cases, requires that a "systems approach" be taken.

- The guide addresses the main components of a fan or blower system and opportunities to improve the overall system performance.

- Short modules address some of the most common design and operations parameters.

- The guide also addresses the key factors and issues in determining the overall lifetime cost of procuring and operating fan and blower systems.

Resources and References

- The guide also has publication and internet references with hyperlinks for many useful sources of assistance that can help readers to learn more about fan and blower systems.

This guide has been written with you in mind. We have adapted the material to accommodate:

- Learning styles that require short bursts of relevant information to assimilate knowledge;
- Expectations that many readers need to have practical knowledge in addition to the theoretical knowledge they may or may not already have;
- Using the Internet or online tools for learning new skills or acquiring knowledge; and,
- Reinforcing key messages and "take away" points.

Key Points

Key points are highlighted in a solid box.

Caution: As with any electrical or rotating equipment, always use proper safety procedures and lockout procedures before operating, testing or servicing fan system equipment.

2 INTRODUCTION

This guide is designed to provide fan[1] system users with a reference outlining opportunities to improve the performance of existing fan systems, or systems being refurbished or expanded. It is not intended to be a comprehensive technical text on designing fan systems. This guide is rather a document that makes users aware of opportunities that may exist to improve performance and efficiency improvements and provides practical guidelines, as well as details where to find more help.

- Fans are widely used in industrial and commercial applications such as ventilation, material handling, boilers, refrigeration, dust collection, cooling applications and others.
- The performance of fans can have a significant impact on plant production. The importance of fan reliability often causes system designers to over-design fan systems to avoid under-performing systems.
- This practice of oversizing fan systems creates problems that can increase system operating costs while decreasing fan reliability.

Fans that are oversized for their service requirements do not operate at their best efficiency points.

[1] In order to simplify the language in this Reference Guide, the term "fan" is used to refer to both "fans" and "blowers."

2 Introduction

In industrial applications fans are commonly used to supply ventilation or combustion air, to circulated air or other gases through equipment and to exhaust air or other vapours from equipment. This guide uses the term “airflow” to mean the flow of air or any other gaseous substance.

Under certain conditions, these fans may operate in an unstable manner because of an unfavourable point of operation on the fan airflow-pressure curve. Oversized fans generate excess flow, resulting in high airflow noise, increased stress on the fan and the system and excessive energy consumption. Consequently, oversized fans not only cost more to purchase and to operate, they create avoidable system performance problems.

The use of a “systems approach” in the fan selection process will typically yield a quieter, more efficient and more reliable system.

3 SELECTION & APPLICATION OF FANS & BLOWERS

Air handling systems are normally designed to deliver a certain amount of air under specific operating conditions.

- In some cases, the air requirements are constant.
- In other cases, the air requirements may vary up or down or may even be zero at times.
- A variety of fan types is available to the system designer, as well as various types of motors and drive systems that provide flow control in an efficient manner.

The system to carry the air through a building's duct system or an industrial process can also be designed with features that reduce the "friction" or the backpressure of the flowing air and which minimize air leakage.

Once built, making changes to the ductwork or piping can become costly. For this reason, when duct systems are expanded or refurbished, it pays to review the various features that could be incorporated into the design to further reduce pressure losses and leaks and thus reduce the amount of energy required to drive the process.

Finally, keen observation of the performance and behaviour of the system along with proper maintenance can reduce energy and maintenance costs, and can increase reliability and service life.

4 HOW TO RECOGNIZE FAN & BLOWER TYPES

There are two primary types of fans:

- Centrifugal fans, and
- Axial fans.

These types are characterized by the path of the airflow through the fan.

Centrifugal fans use a rotating impeller to move air first radially outwards by centrifugal action, and then tangentially away from the blade tips.

- Incoming air moves parallel to the impeller hub and it turns radially outwards towards the perimeter of the impeller and blade tips.

- As the air moves from the impeller hub to the blade tips, it gains kinetic energy. This kinetic energy is then converted to a static pressure increase as the air slows before entering the tangential discharge path.

- Centrifugal fans are capable of generating relatively high pressures. They are frequently used in “dirty” airstreams (high moisture and particulate content), in material handling applications and in systems operated at higher temperatures.

Axial fans - as the name implies, these fans move the airstream along the axis or shaft of the fan.

- The air is pressurized by the aerodynamic lift generated by the fan blades, much like a propeller or an airplane wing.

- Although they can sometimes be used interchangeably with centrifugal fans, axial fans are commonly used in "clean air," low-pressure, high-volume applications.

- Axial fans have less rotating mass and are more compact than centrifugal fans of comparable capacity.

- Additionally, axial fans tend to require higher rotational speeds and are somewhat noisier than in-line centrifugal fans of similar capacity.

a. Centrifugal Fans

Centrifugal fans are rugged, are capable of generating high pressures with high efficiencies and can be manufactured to accommodate harsh operating conditions. These are the most commonly used types of industrial fans.

Centrifugal fans have several types of blade shapes, including:

- Backward-inclined curved blade;
- Backward-inclined, airfoil blade;
- Backward-inclined, flat blade;
- Forward curved;
- Radial-blade; and
- Radial-tip.

Figure 1 summarizes the characteristics and applications of each type.

Figure 1: Typical Characteristics and Applications of Centrifugal Fans

Type	Characteristics	Applications
Forward curved (See Fig. 2)	- blades curve in the direction of rotation - compared to other types, have low efficiency (between 55 and 65 percent) - small size relative to other fan types - low speed, does not require high-strength design - relatively quiet - limited to clean service applications - fan output is difficult to adjust accurately (note how the fan curve is somewhat horizontal), and these fans are not used where airflow must be closely controlled. - the power curve increases steadily with airflow as the back-pressure drops	- applications that require low to medium air volumes at low pressure - well suited for residential heating, ventilation and air conditioning (HVAC) applications - careful driver selection is required to avoid overloading the fan motor. - the dip in the performance curve represents a potential stall region that can create operating problems at low airflow rates.
Radial-blade, (See Fig. 3)	- suitable for low to medium airflow rates at high pressures - capable of handling high-particulate airstreams, including dust, wood chips and metal scrap because the flat blade shape limits material build-up - blades can be coated with protective compounds to add resistance to erosion and corrosion - even in stall situations where vibrations can be a problem, large clearances between the blades also allow this fan to operate safely and quietly	- many rugged industrial applications - “workhorse” of industry

Type	Characteristics	Applications
Radial-tip, (See Fig. 3)	- fills the gap between clean-air fans and the more rugged radial-blade fans. This type is more efficient than forward curved and radial blade fans because of reduced turbulence resulting from the low angle of attack between the blades and the incoming air. - well-suited for use with airstreams that have small particulates at moderate concentrations and airstreams with high moisture content - efficiencies up to 75 percent	- used in airborne solids - handling services because they have large running clearances.
Backward-inclined, flat (See Fig. 4)	- flat blades are inclined in the direction opposite to the rotation - considered more robust than other types - the low angle of contact with the airstream facilitates the accumulation of deposits on the fan blades - performance drops off at high airflow rates	- suitable for forced-draft service. (Fan is exposed to the relatively clean airstream on the upstream side of the process.) - unsuitable for airstreams with airborne particulates. - "safe" choice because of its non-overloading motor characteristic - often selected when system behavior at high airflow rates is uncertain
Backward-inclined, curved (See Fig. 4)	- curved blades inclined away from the direction of rotation - more efficient than flat blades - low angle of contact with the airstream promotes the accumulation of deposits on the fan blades - performance drops off at high airflow rates	- suitable for forced-draft service. (Fan is exposed to the relatively clean airstream on the upstream side of the process) - because of its non-overloading motor characteristic, this fan type is often selected when system behavior at high airflow rates is uncertain

Type	Characteristics	Applications
Backward-inclined, airfoil (See Fig. 4)	- airfoil blades tilt away from the direction of rotation - most efficient with thin blades (~85%), but most unstable because of stall - low angle of impingement with the airstream promotes the accumulation of deposits on the fan blades as well as erosion. - performance drops off at high airflow rates	- suitable for forced-draft service. (Fan is exposed to the relatively clean airstream on the upstream side of the process.) - because of its non-overloading motor characteristic, this fan type is often selected when system behavior at high airflow rates is uncertain

Radial blade centrifugal fans are capable of serving widely varying operating conditions, which can be a significant advantage in industry.

Figure 2: Forward-Curved Centrifugal Fan

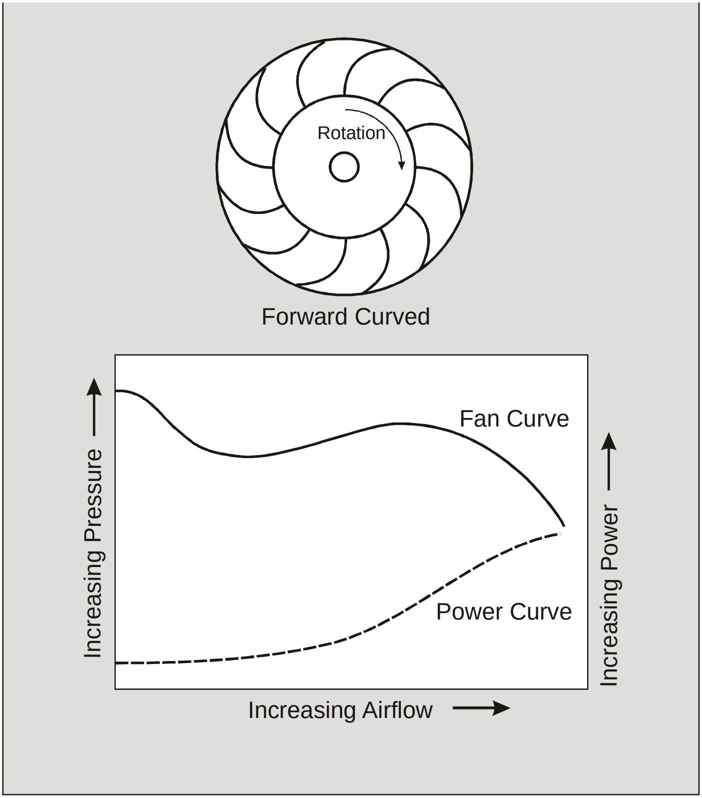


Figure 3: Radial-Blade and Radial-Tip Centrifugal Fans

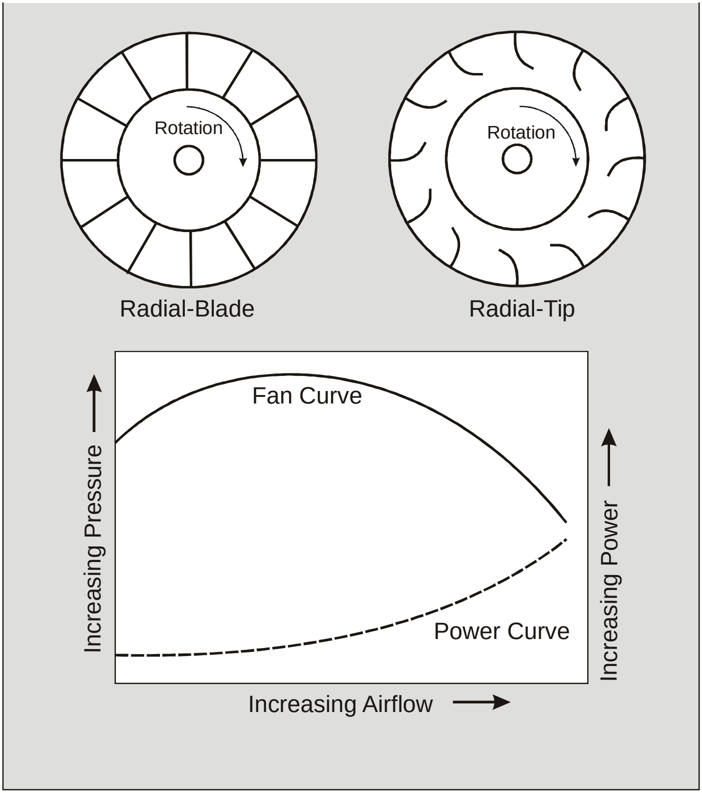


Figure 4: Backward-Inclined Centrifugal Fans

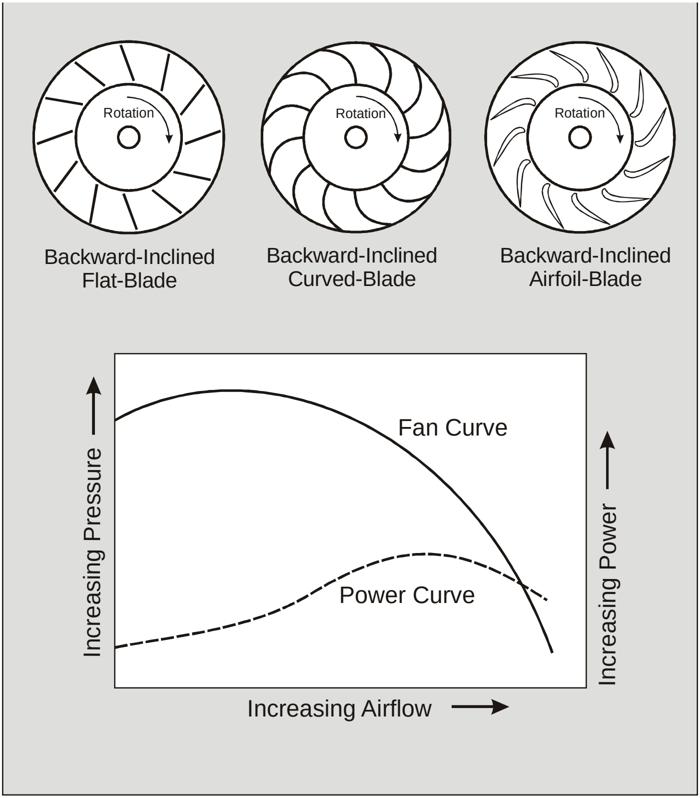
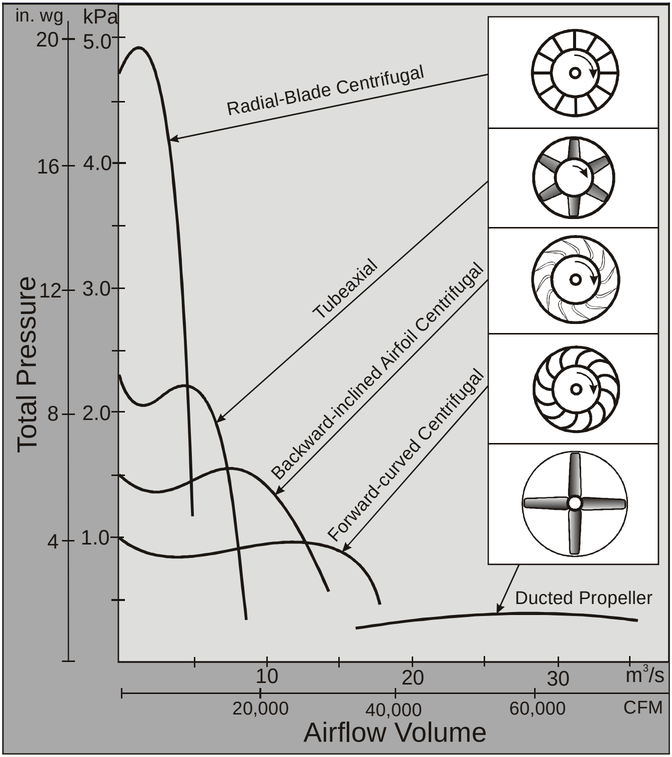


Figure 5 shows a comparative diagram of various fan characteristics including the relationship between pressure and flow.

Figure 5: Comparative Fan Designs at an Equal Power Consumption



b. Axial Fans

Axial airflow fans have a number of advantages over other types including:

- Compactness;
- Light weight;
- Low cost;
- Direct-drive units operating near the synchronous speed of the induction motor; and
- Belt-drive units offering flexibility in fan speed selection.

Usual applications for axial fans are:

- Exhausting contaminated air or supplying fresh air;
- Unidirectional or reversible air-flow applications;
- Exhaust applications where airborne particulate size is small, such as dust streams, smoke and steam.

Disadvantages

- Axial fans have an undesirable characteristic that can cause problems in situations where the air flow must vary considerably; these fans have a stall region in the lower airflow range that makes them unsuitable for systems operating under widely varying air flow conditions.

- There are anti-stall devices available that can be installed to alter the airflow patterns around the fan blades and virtually eliminate the problem of stall.

- The problem of stall can be avoided by selecting a fan type with a stable fan operation over the entire range of airflow and pressure.

- To achieve the same airflow capacity as centrifugal fans, axial fans must rotate at a higher speed. For this reason, axial fans are generally noisier than comparable centrifugal fans.

- Access to the motor is restricted by the location of the blades and supports.

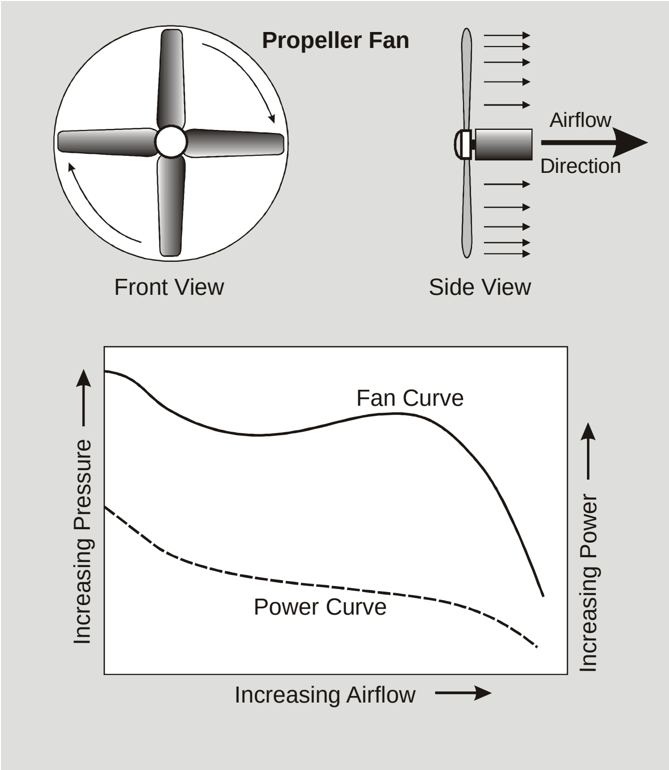
There are three types of axial fans; their characteristics and common applications are described in more detail in Figure 6.

Figure 6: Types of Axial Fans

Type	Characteristics	Applications
Propeller Fans (see Fig 7)	- develop high airflow rates and low pressures - not suitable for extensive ductwork - relatively low efficiencies - inexpensive - comparatively noisy - power requirements of propeller fans decrease with increasing airflow - maximum efficiency at lowest delivery pressure	- often used in rooftop ventilation applications
Tubeaxial Fans (see Fig 8)	- achieve higher pressures and better operating efficiencies than propeller fans - applied in medium-pressure, high air flow rate applications - the airflow downstream of the fan is uneven, with a large rotational component - generates moderate airflow noise - because of low rotating mass, they can quickly accelerate to rated speed - because of the high operating speeds of 2-, 4-, and 6-pole induction motors, most tubeaxial fans use belt drives to achieve fan speeds below 1,100 revolutions per minute	- well-suited for ducted HVAC installations - ventilation applications
Vaneaxial Fans (see Fig 9)	- a vaneaxial fan is essentially a tubeaxial fan with outlet vanes to straighten the airflow, converting the airstream's kinetic energy to static pressure - the airflow profile is uniform - when equipped with variable pitch blades, can be adjusted to change the angle of attack to the incoming air stream and air delivery rate - have unstable regions to the left of the peak pressure - highly efficient: when equipped with airfoil blades and built with small clearances, efficiencies up to 85 percent are achievable - usually directly attached to the motor shaft	- typically used in medium- to high-pressure applications, such as induced draft service for a boiler exhaust - low rotating mass, which allows them to achieve operating speed relatively quickly - emergency ventilation - reversal of air flow direction

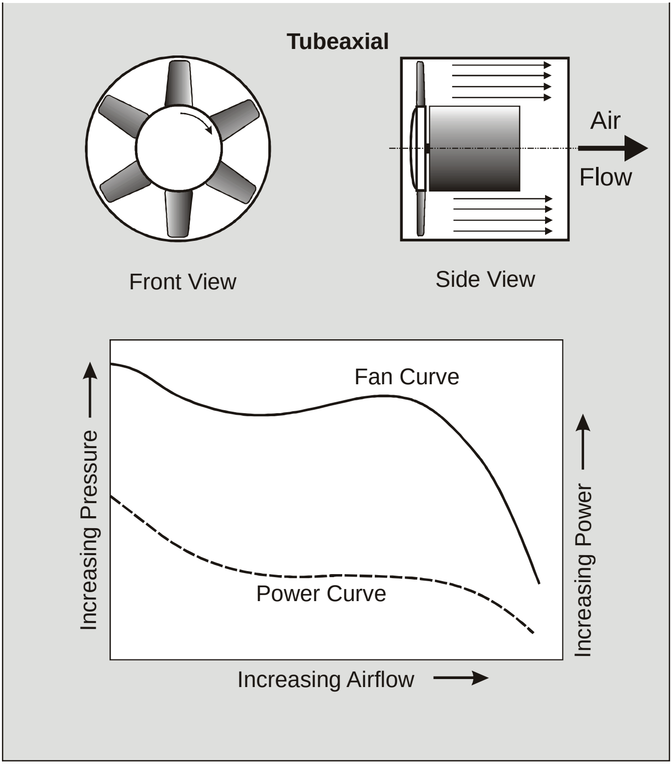
The performance curve for propeller fans is shown in Figure 7.

Figure 7: Propeller Fan



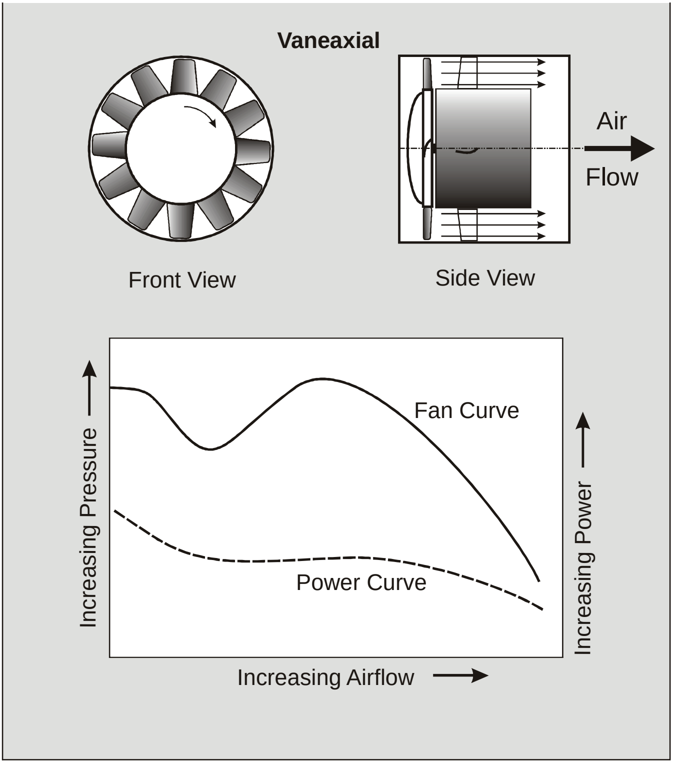
The performance curve for tubeaxial fans is shown in Figure 8.

Figure 8: Tubeaxial Fan



Vaneaxial fans, a refinement over the axial fan involving flow straightening vanes, have a characteristic curve as shown in Figure 9.

Figure 9: Vaneaxial Fan



All three types of axial fans exhibit the stalling characteristic (where the pressure drops as the flow increases to the left of the peak pressure region) so care must be exercised in their application.

c. Special Fan Designs

Bifurcated Fans

- In industrial processes that require the extraction of sticky, corrosive or volatile fumes, specially designed direct drive axial fans can be used.

- The motor of the axial fan is equipped with a unique protective casing that allows the motor to be removed from the airstream while maintaining a direct-drive arrangement. The casing protection is normally made from plastic or coated metal.

- The mating flanges at each end of the casing are identical. The casing diameter however is increased in barrel fashion around the casing to permit smooth passage of a similar cross-section of air concentric with the motor enclosure.

Centrifugal Inline Fans

Centrifugal fans are used in commercial applications where high efficiency, low sound levels and space are the main considerations.

- They have a direct-drive or belt-driven airfoil or backward inclined impellers, mounted perpendicular in a rectangular or tubular casing with ample clearance around the blade tips.

- The air is discharged radially from the blade tips and must turn 90 degrees to pass through the fan exit, which is in line with the impeller inlet. This fan produces what is called "mixed flow."

Centrifugal Roof Exhausters

- These specialized fans are designed as a package together with their housing. They are designed to exhaust air to the outdoors.

- The down-discharge configuration is used for exhausting relatively clean air. The up-blast configuration is used for exhausting hot or contaminated air.

- They are usually direct-driven or belt-driven airfoil or backward inclined impellers in a multi-component housing.

- The housing is comprised of a curb cap with an integral inlet venturi, a shroud with drive-mounting support and a weatherproof motor hood.

- The impeller has an inlet cone that allows mixed flow through the impeller blade passages and air exits radially from the blade tips through a concentric discharge passage. The shroud redirects the air, either down or up.

Utility Fans

- Packaged utility fans, complete with the motor (direct or belt driven), are available for commercial and industrial ventilation applications requiring low to medium air volumes and pressures. These fans are usually equipped with forward curved or backwards inclined blades.

5 UNDERSTANDING THE THEORY

The overall system energy efficiency for an existing system can be expressed in terms of the specific fan power (**SFP**). The science of SFP evolved in Europe and is gaining acceptance in North America.

The SFP is defined as the installed motor power of all the fans in the air distribution system divided by the design air flow rate.

SFP is expressed in terms of kW per 1000 CFM or in kW per (m^3/s):

- An efficient system has a low SFP of usually under 0.7 kW/1000 CFM [1.5 kW/(m^3/s)];
- A medium efficiency system has an SFP in the range of 0.7 to 1.9 kW/1000 CFM [1.5 to 4.0 kW/(m^3/s)]; and,
- A low efficiency system has an SFP above 1.9 kW/1000 CFM [4.0 kW/(m^3/s)].

Although the original design of a ventilation system will determine to a large extent the specific fan power value (based on the selected fan and motor characteristics, loading, duct system configuration and design properties, vents, filters), the SFP will be determined by the actual operating conditions.

The efficiency of operation can be increased by modifying the ductwork to reduce pressure drop, by proper selection and maintenance of filters, by selecting the most appropriate fan-motor combination, by shutting down the fans when air flow is not required and by avoiding over-ventilation.

Using SFP can help identify opportunities to increase fan system efficiency.

a. Principles of Operation

- Systems that require air flow are normally supplied by one or more fans of various types, driven by a motor.

- The motor rotates the fan which delivers air to the system as it develops a pressure in the ductwork (or air pathways) that causes the air to move through the system.

- Moving air in a streamline has energy due to the fact that it is moving and it is under pressure.

In terms of air movement, Bernoulli's theorem states that static pressure plus velocity pressure as measured at a point upstream in the direction of airflow is equal to the static pressure plus velocity pressure as measured at a point downstream in the direction of airflow plus the friction and dynamic losses between the two measuring points.

- The motor imparts energy to the fan, which in turn transfers energy to the moving air.

- The duct system contains and transports the air. This process causes some losses in static pressure due to friction with the walls and changes in the direction of flow (due to elbows and other fittings), as well as air losses through unintentional leaks.

b. Fan Laws

Rotational Speed: Fan rotational speed is measured in revolutions per minute (**RPM**). Fan rotational speed affects fan performance, as shown by the following fan laws.

Airflow rates vary in direct proportion to the rotational speed of the fan:

$$Airflow_{final} = Airflow_{initial} \times \frac{RPM_{final}}{RPM_{initial}}$$

Pressure built up by the fan varies as the square of the rotational speed of the fan:

$$pressure_{final} = pressure_{initial} \times \left(\frac{RPM_{final}}{RPM_{initial}} \right)^2$$

Power required by the fan varies with the cube power of the rotational speed of the fan:

$$Power_{final} = Power_{initial} \times \left(\frac{RPM_{final}}{RPM_{initial}} \right)^3$$

Care needs to be taken when using the fan laws to calculate the effects of changes in fan speed, since these laws apply to a specific density of gaseous medium. When fan speed changes are accompanied by significant changes in other parameters such as gas composition, moisture content and temperature, the fan laws will need to be adjusted accordingly to compensate for the resulting change in medium density.

Rotational speed must be considered concurrently with other issues, such as:

- Air stream density (pressure, temperature, moisture content, gas composition);
- Ambient noise;
- Mechanical strength of the fan; and,
- Variations in the fan load.

To avoid overloading the motor, some types of fans must be sized appropriately for the air flow rate and pressure requirement. In particular, forward-curved blade centrifugal fans, which are capable of generating high airflow at relatively low speeds, can readily provide excessive airflow and pressure and overload the motor if operated at too high a speed for the application. Moreover, operating the fan below the required speed can cause insufficient air flow through the system.

Air stream temperature has an important impact on fan-speed limits because of the effect of heat on the mechanical strength of most materials.

For high temperature applications, low speed fan types provide the advantage of lower forces on shafts, bearings and blades, all of which have lower yield strengths at these temperatures.

(Dynamic stresses on these components are proportional to the square of the rotational speed).

c. Fan Characteristics

Fan Performance Curve

The fan performance curve expresses the power required over the range of airflow rates. Individual points on a fan performance curve are determined by plotting the developed pressure against the air flow rates. This curve is essential in the design of the system, in the selection of the equipment and in the operation of the system.

The ***Fan Characteristics*** section describes the various types of fans available, along with their pressure-flow characteristics.

When the actual air flow in a system cannot be predicted with some accuracy, or the air flow is expected to vary considerably, it is very important to select the type of fan, motor and control system that will prevent equipment overloads.

Fan Efficiency

Fan efficiency is defined as the ratio of power transferred to the airstream to the power delivered to the shaft of the fan.

- The power of the airflow stream is the product of the pressure and the flow, corrected for consistency of units.

The fan efficiency can be expressed in terms of *total pressure* (Total Efficiency) or in terms of *static pressure* (Static Efficiency).

Total Efficiency is the ratio of power of the airflow stream (using total pressure) divided by power delivered to the fan shaft in consistent units, or

$$Total\ Efficiency = \frac{Total\ pressure\ \times airflow}{bhp \times 6362}$$

Where:

- Total Pressure is in inches of water (in. WG)
- Airflow is in cubic feet per minute (cfm)
- bhp is brake horsepower
- 6,362 is the unit consistency factor

Static Efficiency is the ratio of power of the airflow stream (using static pressure) divided by power delivered to the fan shaft in consistent units, or

$$Static\ Efficiency = \frac{Static\ pressure\ \times airflow}{bhp \times 6362}$$

Where:

- Static Pressure is in inches of water (in. WG)
- Airflow is in cubic feet per minute (cfm)
- bhp is brake horsepower
- 6,362 is the unit consistency factor

Since the two defined efficiencies are quite distinct and different from each other, one must be clear to identify the type of efficiency referred to when comparing performance values.

Best Efficiency Point

- The best efficiency point (**BEP**) is a point on the operating characteristics of the fan where a fan operates most efficiently and cost-effectively in terms of both energy use and cost of maintenance/replacement.

- Operation of a fan near its BEP results in high efficiency and reduced wear and tear on the equipment. Operation far away from the BEP results in lower fan efficiency, increased bearing loads and higher noise levels.

Region of Instability

- For most types of fans, the characteristic curve arcs downward to the right from the zero flow condition, indicating that as the backpressure on the fan is reduced, airflow increases.

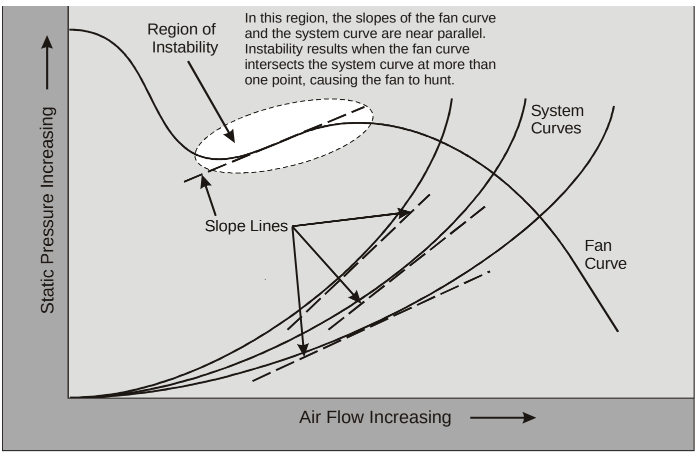
- For all systems, the system resistance curve increases as the airflow increases.

- A fan operating in a typical system will normally settle at a pressure-flow point where the fan characteristic curve and the system resistance curve intersect.

- A fan operating in the region where the slope of the characteristic curve is in the same direction as the system curve can have unstable operation (see Figure 10), because of the fan's interaction with the system: as the fan attempts to generate more airflow, the system pressure increases, reducing the airflow. Then, as the airflow decreases, the system pressure also decreases, and the fan's response is to generate more airflow. This cyclic behavior results in a cyclic increase and decrease in fan power requirement creating a reciprocating sound similar to "breathing." This unstable operating condition results in reduced fan efficiency and increased wear on the fan components and may contribute to worker fatigue.

The following types of fans have an operating region in which their performance curve reverses direction so that it slopes in the same direction as the system resistance curve: tubeaxial, vaneaxial, propeller and forward-curved centrifugal fans. This creates a region of instability which should be avoided.

Figure 10: Fan Curve with Instability Zone



d. Control Systems

For many ventilation and air-moving requirements, it is necessary to be able to adjust the air flow from slight to significant amounts. For these situations, there are several ways of providing the necessary control. While dampers that increase pressure drop and reduce flow may be an inexpensive solution to implement on a system, they are not recommended because they represent the least efficient method of control, which results in an increase in power requirement and increased operating cost. More attractive options for controlling the air flow are:

- Motor controllers for motors with multiple speed windings that can be switched (e.g. 2, 4, or 6-pole devices) to make step changes in speed from full to 1/2 speed or 1/3 speed.

- Belt drives with various combinations of pulleys (sheaves) on the motor and the fan to vary the fan speed when driven by a single-speed motor.

- Variable pitch fan blades that can be adjusted to various angles of attack to change the amount of air flow at a nearly constant rotational speed.

- Adjustable speed drives for motors that change the speed of the fan from zero to greater than full motor speed in very small increments to provide the greatest amount of air flow variation.

Motor Controllers

An important component of the prime mover is the motor controller.

Motor controllers are switching mechanisms that receive a signal from a low power circuit, such as an on/off switch, low-medium-high/start selector switch, and are wired to relays that configure and energize the motor windings to drive the multiple speed motor at the selected speed.

Motors are built to operate at different speeds in two principal ways:

1. As a consequent pole motor: with a single set of windings equipped with a switch that energizes either a two pole configuration or a four pole configuration (to provide full speed and half speed as needed);

2. As a multiple speed motor: with the use of multiple windings and appropriate switching between 2- 4- 6- or 8-poles, to provide full-, half-, third- or quarter speed.

Although multiple speed motors cost more and are less efficient than single-speed motors, they do provide effective and efficient speed and air flow control for many fan applications.

Belt Drives

A convenient way of reducing the rotational speed of fans (usually designed to operate under 1,800 rpm) is by making use of a belt drive between the motor and the fan using an appropriate ratio of sheave to pulley diameter to achieve the required fan speed reduction. The belt transfers the power from the motor to the fan, and changes the fan speed relative to the motor speed according to the desired pulley ratio. Since all the power from the motor is transferred to the fan entirely by the belt, the operating condition of the belt and its relationship with the sheave and pulley determine the efficiency and effectiveness of the power transfer and speed change. There are several types of belts, each one with its own set of advantages/disadvantages.

Types of Belt Drives

The four principal types of belts are:

- Flat belts;
- V-belts;
- Cogged V-belts; and,
- Synchronous belts.

The descriptions, advantages and disadvantages of each type are summarized in Figure 11.

Belt slippage reduces the fan rotational speed and causes an energy loss between the belt and the pulley, as well as reduced air delivery, and contributes to accelerated wear and deterioration of the belt and pulleys

At the other extreme, over-tightening a fanbelt can result in early bearing (motor or fan) failure as well as early belt failure. When belt life becomes a frequent problem affecting the reliability of the system, it is necessary to review the factors outlined in the following sections that affect the operation and life of the drive system: Belt Size, Fanbelt Maintenance Practices, Maximum Practical Speed Ratio for Fanbelts, Alignment of Pulleys, Variable Pitch Fan Blades and Adjustable Speed Drives.

Figure 11: Descriptions of Types of Drive Belts, Advantages and Disadvantages

Type	Description	Advantages	Disadvantages
Flat	- Uniform cross-section - Power transmission via friction contact with flat pulley surfaces	Simple, inexpensive	Can slip easily
V-belts	- Wedge cross-section - Wedging action on pulley supplements friction contact for improved power transfer		Reduced slip characteristic
Cogged V-belts	- Wedge cross-section - Notched belt adds belt flexibility - Permits the use of smaller pulley diameters - Same advantages as V-belts	Slightly more efficient than conventional V-belts	
Synchronous	- Belts have teeth that engage with grooves in the sheave/pulley - Most efficient type of belt	- They do not contribute to loss of efficiency through slip - They tolerate lower belt tension than conventional belts - They reduce the radial load on motor and fan bearings and extending their operating lives - They maintain efficiency as they wear	- Very noisy - They transfer torque very quickly - Can cause problems in applications with rapid load changes - Although all belts should be properly aligned synchronous belts require more precise alignment than other belts

Belt Size

Four separate factors need to be considered in the selection of the belt size: the horsepower required by the driven load, the site operating temperature, the service factor and the actual arc of contact between the belt and the sheave or pulley.

The size of belt required is determined first by the horsepower being transmitted. However, because temperature also affects the mechanical strength of a belt, it is necessary to carefully size the belt to meet the highest torque required at the highest normal operating temperature. However, since rubber contracts at higher temperatures, belts with high rubber content increase their tension and stress on bearings as the operating temperature increases.

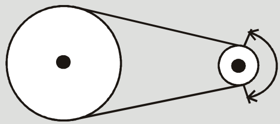
The increase in stress of a belt drive during start-ups and changes in loads is often between 20 to 40 %. This increase in stress effectively increases the load on the belt drive and must be considered while sizing a belt. This increase, commonly known as the service factor, can vary between 1.2 to 1.4.

Since belt drives rely on friction between the surface of the pulleys and the surface of the belt, the horsepower that can be transmitted by a belt-pulley combination (at a given tightness level) depends on the arc-of-contact with the smallest pulley. As shown in Figure 12 the horsepower rating of a V-belt declines as the arc-of-contact declines from 180° of the pulley circumference. At an arc-of-contact of 120°, the horsepower rating of a V-belt drive will decline by about 17% of its nominal rating. Different types of belt and pulley combinations will have different service factors.

Figure 12: Effect of Arc-of-Contact on V-belt Horsepower Rating

Correction Factor for horsepower rating of V-Belts

Degrees of Contact	Correction Factor
180	1.00
170	0.98
160	0.95
150	0.92
140	0.89
130	0.86
120	0.83
110	0.79
100	0.74
90	0.69



The role of the belt is to deliver power to the fan. Since power to the fan is related to the cube of fan speed, a relatively small rise in fan speed can result in a significant increase in transmitted power and stress on the belt, and vice-versa. For this reason, small changes in the slip speed of induction motors, or replacement of induction motors with (higher speed) synchronous motors, can have a significant effect on belt power requirements.

Although flow rate is linearly proportional to fan speed, the driving power required is proportional to the cube of the fan speed.

Establishing the right fan speed to operate the system efficiently determines the required belt power requirement. Underestimates of fan speed require reviews of the power rating requirement of the belt drive system

Many manufacturers recommend that fan-belt speeds should be kept below 6,500 feet per minute (ft/min.). This limit minimizes bearing loads, resulting in increased reliability.

Fanbelt Maintenance Practices

In order to maximize the reliability of fan systems, the following practices are recommended:

1. Checking belt tension and pulley alignment periodically.

   Belt drives should be tightened to the lowest level where the belt does not slip at peak load.

2. Avoiding the use of belt dressings (which are claimed to increase friction between the belt and pulley surfaces).

   Dressings mask and temporarily reduce the effects of belt slippage; a more permanent solution is to clean the drive system and adjust the belt tension to the proper level.

3. Some belts are often designed and tagged with a preferred direction of rotation. Others can be operated in either direction; however, when manufacturers test these, they test in one direction and indicate this direction when packaged. To maximize belt life, install according to manufacturer's directions.

4. Condition new belt drives for operation at high temperatures.

For belt drives that operate at high temperatures, it is recommended that new belts be operated at low load conditions at the elevated temperature for a reasonable period of time to increase the creep strength of the belt material.

Maximum Practical Speed Ratio for Fanbelts

- Most industrial fanbelt drive applications are limited to speed ratios below 4:1 (the motor speed is 4 times faster that the fan speed). The reasoning is that for higher speed ratios, the area of contact between the belt and the sheave declines very quickly, reducing the amount of frictional force between the belt and the sheave. Increasing tension to overcome the lower friction is not an option because it adds too much mechanical stress to the bearings and to the belt itself. However, for small horsepower applications (less than 1 hp), this ratio can be as high as 10:1 because the forces involved are low enough and available friction between the sheave and belt is high enough to drive the fan without overstressing the belt and bearings.

- The limiting factors on speed ratios are the practical size of the pulleys, the arc of contact between the belt and the drive pulley, belt speed and force on the bearings.

Alignment of Pulleys

- All belts wear out in time, but proper belt installation (direction), alignment of pulleys (to minimize side wear) and proper tension ensure longevity and reliable service.

- Belt tightness can also be checked while running, by checking the slack side for excessive looseness on the slack side.

- Inadequate belt tightness shortens the life of the belt, promotes belt slippage (which reduces air flow) and can result in polishing the sheave surface, as well as wearing out the contact surface of the belt.

- A polished sheave surface has a lower than normal level of friction and reduces the belt's ability to transfer power. As a consequence the air-delivery rate drops. As the belt wears it releases tension, further reducing the transmitted power and airflow rate.

Variable Pitch Fan Blades

- Processes that require changing airflow conditions can make use of variable pitch fans, which can efficiently change the amount of energy delivered to the air. Certain types of axial fans have a capability that allows the adjustment of the pitch of the blades. Operating at a constant speed, the variable pitch feature causes the angle of attack between the incoming air and the blade to change, as well as the power imparted to the air to vary from almost zero flow to full flow.

- Reducing the angle of attack of the fan blades reduces the rate of airflow, the load on the motor and the motor consumption over time.

- Although variable pitch fans cost more than fixed blade fans, they offer a very efficient operation. In addition, since variable pitch fans can be operated at a nearly constant speed, resonance problems can be avoided.

- A very important benefit of variable pitch fans for controlling air flow rates is that this type of fan does not experience a "stall" problem as the flow is varied from no-flow to full-flow conditions. A secondary benefit of this type of fan is that it can be started unloaded at very low torque to reduce the starting torque on the motor.

- Variable pitch blades have mechanical actuators that are exposed to the air stream and, depending on the application, they have the potential of fouling by the accumulation of contaminants.

- If a process requires partial or reduced air flows for a significant portion of the day, every day, the variable pitch fan may not be the best option, since motor efficiency drops and power factor increases for motor loads below 50 percent. Operating at low loads for long periods may not provide efficiency advantages and will result in a low power factor for the motor. It may actually be more economical in the long-run to consider multiple fans or other air flow rate control options.

Adjustable Speed Drives

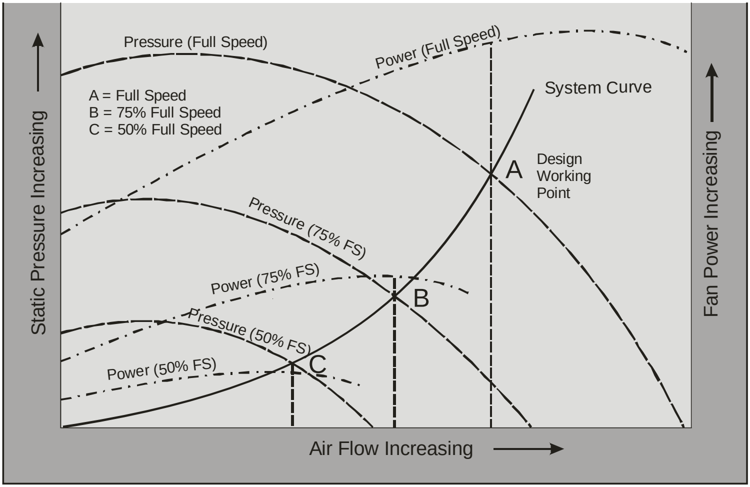
- The operating speed of electric motors can be controlled with adjustable speed drives (ASDs). These electronic or mechanical devices allow the user to adjust the speed of operation of motors efficiently and continuously from virtually zero to full speed.

- There are various types of electronic variable frequency drives available including ac and dc motor drives and wound rotor motors. These drives regulate the power flowing to the motor, thus there would not be a concern with regards to power factor penalties for operation at low motor power levels.

- There are various types of mechanical ASDs including adjustable belts and pulleys as mentioned earlier, hydraulic clutches, fluid couplings and eddy current clutches.

A fan driven by a motor controlled by an electronic adjustable speed drive operates efficiently over most of the speed range. The point of operation on the fan's characteristic is unchanged as the speed varies and the duct pressure changes (as the square of air speed). This has the advantage of maintaining the fan's efficiency, resulting in a corresponding maximum reduction in power consumption and fan noise level as the speed is reduced (see Figure 13).

Figure 13: Flow Control by Speed Regulation



Word of Caution:

Tubeaxial, vaneaxial, propeller and forward-curved centrifugal fans may become unstable when operating over a speed range where the slope of the fan characteristic is parallel to the slope of the system curve and the intersection between both characteristic curves becomes indeterminate, causing a cyclic loading and unloading which causes annoying noise and excessive wear.

Although ASDs offer one of the most efficient methods of controlling the performance of a fans one must be very careful about the type of fan being controlled, the relationship between the system curve and fan characteristic curve and the speed range of control.

e. Energy Saving Checklist

The list of questions in Figure 14 can be used to identify potential opportunities for improving the efficiency of fan systems. Also listed are the approximate savings resulting from the implementation of each efficiency measure.

Figure 14: Energy-Saving Checklist for Fan Systems

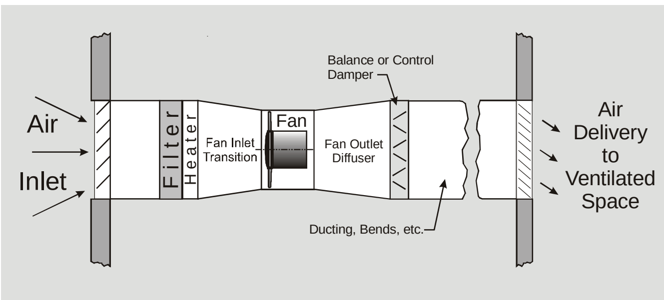
Area	Question	Improvement	Typical Energy Savings
Process	Is the system doing useful work continuously or periodically?	Shut down when not required	10-50%
	Have the exact requirements for the process been determined or re-evaluated for an older system?	Oversizing leads to inefficiency	10-50%
Location of Fan	Does the location of the fan minimize the system resistance?	Relocate the fan to reduce length of runs, straighten bends	5-30%
Variation in airflow demand	How is the supply of air to the system controlled and varied?	VSD, variable pitch axial fans, multi-speed motor	5-30%
Fan type and application	What type of fan is installed and is the impeller facing in the right direction?	Replace with an impeller with the required characteristics and facing in the right direction	depends
	Is it a centrifugal fan producing too much or too little air flow?	Change the impeller to reduce/ increase the amount of air flow and optimize energy consumption	depends
	Incorrect type of fan for required pressure/flow characteristics?	Savings can be achieved if a more efficient fan is available to provide a closer match to system demand	5-30%
Fan Inlet Ductwork (See Ductwork section)	What are the entry conditions like? (Is there a swirl in the opposite direction to the fan blade at the inlet of an axial fan?)	An entry swirl in the opposite direction to fan rotation can cause a motor overload; Install fixed blades to straighten the flow	5-15%
	Is there a sharp bend near the entry point of the air into the fan inlet?	Install turning vanes to even out the flow of air into the fan inlet	5-15%
	Is there a transition piece where duct size is reduced or increased?	Install a transition piece	5-15%
	Are flexible connections fitted with no offset or slack?	Inspect and adjust	Up to 30% on low pressure axial fans

Area	Question	Improvement	Typical Energy Savings
Fan outlet ductwork (See Ductwork section)	Are there bends in the ductwork near the fan outlet?	Try to avoid bends near the outlet. If unavoidable, use turning vanes to direct and distribute the air flow evenly	depends
	For axial or propeller fans, is there a set of straightening guide vanes to recover pressure?	Guide vanes should be considered for pressures above 750 Pa (3-in WG)	depends
Motor	Is the motor oversized?	If loaded at or below 50% for extended periods, consider downsizing or installing multiple fans	5-10%
	Is the motor operating on all 3 phases?	Check for faulty wiring and fuses	0-15%
	Is an ac motor running below normal speed?	Problem can be with a winding or with the starter circuit	0-10%
	Is the motor a high efficiency type?	Except for low duty motors, high efficiency motors are economically worthwhile	2-5%
System ducting	What shape is the duct cross-section?	Tubular ducting (rather than rectangular) results in the least amount of material, lowest pressure drop, lowest velocity, and lowest losses	7%
System performance	If dampers are used for balancing, is the pressure as low as it can be?	Good design should ensure that all legs have equal pressure losses. Re-balance to minimize pressure drop	7%
	Has a measurement of absorbed power (pressure-drop x velocity) been made?	This measurement can be used to detect changes in energy consumption on the air moving side of the system	

6 SYSTEM & OPERATIONAL CONSIDERATIONS

A fan system usually consists of a fan near the inlet or the outlet connected to a duct system. The duct system can have various components installed within the air pathway such as air control dampers, heat exchangers, filters on the inlets or outlets, diffusers and noise attenuators (see Figure 15). The fan drives the air stream to overcome resistance caused by the ductwork and other components. The ducting directs the air flow to the required locations and also acts as a support or housing for the other components used in the particular process.

Figure 15: A Fan within a System



a. System Curve

The ***system curve*** is defined as the static pressure versus flow rate characteristic curve for the entire system. The static pressure is the sum of the individual pressure losses along the system attributed to each component such as:

- Ducts;
- Dampers;
- Baffles;
- Filters;
- Grills;
- Connections and diversions (tees, wyes, elbows);
- Louvers; and,
- Intrusions, obstacles, within the system.

The static pressure drop is proportional to air velocity squared. The equation that relates pressure drop across a component is:

$$\Delta p = C \times \left(\frac{V}{1097} \right)^2 \times \rho$$

Where:

Δp = pressure loss in inches of water gage (in. wg)
C = loss coefficient for the component
V = velocity in feet per minute
ρ = density of the airstream (0.075 pounds per cubic foot at standard conditions)

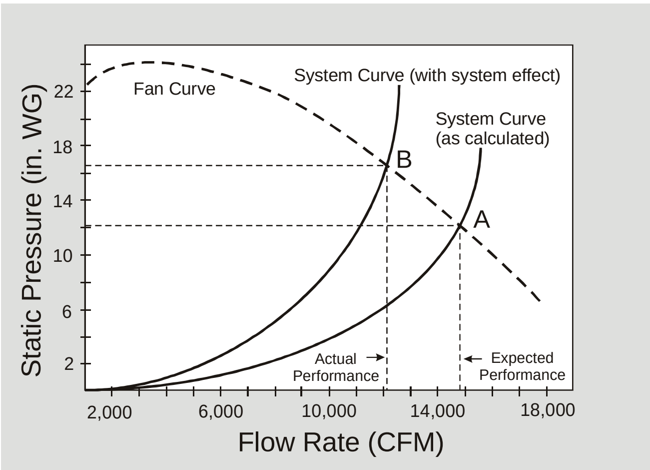
When all the components are in series, the total system pressure drop Δp is the sum of the individual pressure drops. If ***Static Pressure Drop*** is plotted versus air ***Velocity***, the resulting curve will be parabolic in shape, as shown in Figure 16. This curve now represents the theoretical ***system curve*** (based on the assumptions made about the pressure loss characteristic of each component being additive when in series). In reality, however airflow is usually non-uniform because the airstream develops swirls, and vortices and uneven flow distributions caused by interference with system components. The net result is that actual total pressure drops (losses) are higher than the theoretical loss would indicate. In effect, these added losses tilt the system curve up, as shown Figure 16. This tilt upwards of the system curve is called the ***system effect.*** Systems that have a lot of obstacles, corners and changes in directions tend to have a higher systems effect. Systems that are composed of straight, open paths are conducive to low (pressure drop) losses and a much lower system effect.

The condition at which the system operates is called the ***balance point***. The balance point corresponds to the intersection of the system curve and the fan characteristic point, as shown on a plot of system pressure vs. flow in Figure 16. This figure plots the theoretical system curve and the modified system curve including the system effect. These two curves intersect the fan characteristic curve at two points: the theoretical balance point (A) and the actual balance point (B).

By comparing the values of pressure and flow at each intersection point, one notes that the expected performance according to the theoretical system curve (point A) is considerably different (lower pressure drop and higher flow rate) than the actual performance at point B (higher pressure and lower flow, requiring more fan power). Since it is difficult to accurately predict the magnitude of the system effect, system designers specify a certain amount of fan overcapacity to reduce the risk of not meeting the flow and pressure requirements of the process. However, over-design of fan systems results in having to adjust the flow to meet the system requirements, and depending on how this is done, the adjustment can have a significant impact on energy consumption.

The system effect can be kept very small by configuring the system for as uniform and unidirectional flow as possible. By doing this, the fan selection would be closer to the theoretical requirement and overcapacity would be unnecessary.

Figure 16: System Effect for a Typical Fan and System



Since the operation of a fan is affected by system components, it is necessary to look at the entire system in order to optimize the operation of a fan and reduce its energy consumption. This is called the “systems approach.”

b. Systems Approach

The systems approach looks at the operation of the entire system by considering the characteristics of each component as well as the interactions among the components over all operating conditions. The factors and considerations to be taken into account when selecting a fan and/or fan system that is efficient both in terms of its performance and its energy consumption include:

1. Selecting the most appropriate fan for a particular application.

2. Selecting the correct type and rating of the motor used to drive the fan.

3. Control systems for fans, and the factors that need to be taken into account when deciding which type to use.

4. Determining the air velocity as part of the design process.

5. Minimizing pressure drop through the entire system.

6. Correct installation in terms of fan inlet and outlet conditions and mounting.

7. Regular maintenance of the fan and fan system.

8. Conducting an annual system review to ensure that the maximum energy savings are maintained.

Striking the right balance between these competing costs requires effort; however, using a systems approach during the design phase can minimize system life-cycle costs.

These factors are described in more detail below:

1. The efficiency curve of fans is far from constant and there can be a difference of 30% between peak and low efficiency in the fan's working range. In addition, the energy use of similar fans from different manufacturers performing the same duty can vary by up to 30%. It is therefore important to select a fan that is operating as near its peak efficiency as possible in the normal operating range. Fan specifications should stipulate the use of a high efficiency fan.

2. Select high efficiency rather than standard efficiency motors to achieve maximum energy savings during the operational life of the equipment (these can save, on average, 3% of energy consumption compared to standard motors). Sizing the motor correctly is also very important, as it can significantly reduce both the capital and running costs of electric motors. Motors are often rated well above the power levels at which they operate. Modern motors are designed for maximum efficiency at 75% of full load, although there is minimal variation in efficiency between 50% and 100% load. Significant reductions in efficiency occur at 25% load or less. Oversized, under-loaded motors operate at lower efficiency levels, and may contribute towards the need to add power factor correction capacitors.

3. Most systems require some type of air flow rate adjustment. The rate may be required to be adjusted once only to compensate for initial errors in calculation, intermittently to give, for example, a summer and winter condition, or continuously to maintain an environment or

to supply a variable process. Control can be achieved either by changing the effective resistance of the system or by altering the performance characteristic of the fan. The method chosen will strike some balance between savings in absorbed (wasted) power at reduced flow rates and the initial cost of the flow control method used.

Although dampers offer the simplest means of adjusting air flow, closing the damper increases the resistance to flow and the quantity of air falls as determined by the fan characteristic. The pressure loss across a damper is a waste of energy may create noise and should be avoided. A more efficient method of controlling air flow rate is to adjust the performance of the fan itself by changing the fan speed or by other means as described in the ***Control Systems Section***.

4. Air velocity is the first choice to be made when designing a fan system. Low velocity systems should be used where possible, because they produce low pressure losses and require the lowest fan power level, thus minimizing energy use. However, this also means designing ductwork with the largest cross-sectional area, requiring more materials and space.

5. While minimizing pressure drop through the entire system will automatically reduce the energy requirements to operate the system, for practical reasons such as limited space, smaller duct systems may have to be selected, implying higher air velocities and pressure drops. The advantages and disadvantages of low, medium and high velocity systems are outlined in Figure 17.

Figure 17: Advantages & Disadvantages of Low, Medium & High-velocity Systems

System Velocity			Advantages	Disadvantages
	Typical filter & coil face velocities (m/s)	Typical main duct velocity (m/s)		
Low	<2	5	Low fan power Low noise	Higher capital cost More space
Medium	2-3	8	Lower capital cost Requires less space	More fan power Increased noise
High	>3	≥12	Least capital cost Least space	High fan power High noise

6. The fan inlet and outlet conditions and mounting can have a significant effect on system performance. The three most common causes of poor fan performance due to installation effects are: non-uniform inlet velocity, swirl at the inlet and improper outlet conditions such as uneven airflow distribution and immediate change in direction. In each case, the performance of the fan is hampered by the inlet and outlet conditions, causing a shortfall in delivery capacity compared to the published level. Because the magnitude of this effect is often unknown, contingencies may have to be added to the calculated system curve to allow for shortfall in fan performance due to the inlet and outlet conditions. This can result in increased capital and running costs, and a system that is not operating at its designed condition. The fan inlet and outlet conditions can be improved by preventing sharp bends in the ductwork in both the inlet and outlet, using turning vanes or flow straightening vanes as required to prevent

recirculating flow and counter rotating flow at the inlet and non-uniformity in the outgoing air flow stream.

7. Regular maintenance of the fan and fan system is essential to ensure it continues to operate at maximum efficiency and hence minimum energy use. Maintenance items include: checking fastenings on the fan and motor, checking impeller, balance, flexible connections to the ductwork, shaft bearings (lubricate or replace), sheaves and pulleys, belts, filters and other elements (check, replace).

8. An annual system review of the performance of the system will ensure that the maximum energy savings are maintained. The system performance should be checked to ensure that it meets the current production requirements and ties in well with the results of the original commissioning. If the system is not meeting requirements, it is prudent to investigate and identify the cause(s). Examples of changes that can be considered for improving performance by changing air flow rate include:

    - Changing the pitch angle of an axial impeller;
    - Changing the pulley ratios on a belt drive;
    - Changing the impeller to increase or decrease the volume flow within the limitations of the existing motor power (only in extreme cases); and,
    - Contacting the original equipment supplier for technical advice.

The following sections present more details on the adjustments and alterations that can be made to system components to adjust and improve the overall system performance.

Type of Fan and Effect of Blade Angle Change

- Once a system is operational and its use pattern established, a comparison of pressure-flow system requirements and fan characteristics can be made to determine whether the fan is operating according to expectations and specifications (remember to take into account the system effect).

- If adjustments need to be made because of mismatch between fan characteristics and system requirements, a different type of fan or a different angle blade can be considered.

- Failing this, other options include a different drive speed (sheave and pulley ratio) or different type of drive system such as a variable frequency drive if wide changes in air flows are also required.

Effect of Belt Condition

Belt drives are frequently the most maintenance intensive component of a fan motor assembly, and typical factors include:

- Belt wear;
- Noise;
- Rupture;
- Belt tension;
- Uneven belt tension;
- Contaminants buildup on the belt;
- Slippage;
- Wear on the sheaves; and,

- Misalignment.

Over-tightening belts can result in the shortened life of the belt itself as well as the bearings and, in extreme cases, structural problems with the motor-fan assembly.

Loose belts result in wear and polishing of the of the sheave and pulley running surfaces, encouraging more slippage and belt wear, as well as heating of the belt and reduced air flow.

Process Equipment Cleaning Economics

Air-moving systems include components that interact with and impede the flow of air such as heat exchangers used to condition the airstream to achieve a particular temperature or to remove moisture, filters (cyclone types or mesh types) to remove unwanted particles or gases and flow diverters that inherently create pressure drops, adding to the overall pressure drop of the system.

- Mesh-type filters create increasingly large pressure drops as they accumulate particles. In many systems, poor performance and increased operating cost are a direct result of inadequate attention to filter cleanliness.

- Regular filter inspection and maintenance should be a priority item.

- Simple instrumentation or alarms can be installed to monitor pressure drops across heat exchangers and filters to warn of fouling and to optimize the maintenance schedule while minimizing fan energy use.

System Interface

- When considering a replacement fan one must be careful to take into account the effects that the fan inlet conditions and outlet conditions can have on fan performance.

- Normally, when fans are rated, the inlet is open and the outlet has a straight duct attached to ensure uniform airflow into the fan and efficient recovery of static pressure at the outlet.

Restricting the inlet or outlet in any way will cause a change in performance that reduces the flow or increases the pressure across the fan.

- Often, a spin of the inlet air is established. Depending on the direction of the spin, the fan power (flow and pressure) will be affected as follows: a spin in the same direction as the impeller rotation will slightly reduce fan pressure and flow; a spin counter-rotating with the impeller will slightly increase flow and pressure and significantly increase fan power requirement. The spin can be avoided by changing the entry angle of incoming air appropriately and re-distributing the inlet air stream velocity more uniformly.

- The most common cause of reduced fan performance is non-uniform air flow to the inlet of the fan.

Parallel Fan Selection

- Systems that require variable air flow rates are sometimes supplied by parallel arrangement of similar fans, in such a way that one or more fans may be energized to supply the needed air flow (see ***Assessing Fan System Needs*** Section).

The advantage of parallel fan operation is that the number of fans operating can be selected to target a total flow rate that causes the system pressure to fall within each fan's BEP.

- The number of fans operating can be selected manually or with an automatic programmer that adjusts the number of fans that are energized according to the target system pressure. Care must be taken to eliminate too frequent cycling of fan motors, and ensure that all fans are sharing the load equally in the long-run.

Fan Noise

- In industrial ventilation applications, noise can be a significant concern because it promotes worker fatigue.

Gradually increasing noise can be an indication of increased airflow resistance, excessive leakage, deterioration of fan blades, clogging of filters and increased motor load.

- The noise generated by a fan depends on fan type, speed, airflow rate and pressure. Inefficient fan operation is often indicated by a comparatively high noise level for a particular fan type.

- In situations where corrosive gases or abrasive particles degrade fan blades to the point that the airflow over the surfaces becomes disrupted, the fan will impart energy less efficiently to the air stream. To re-establish flow, higher speeds may be required, producing more noise. Many fan manufacturers have developed materials and coatings that solve this problem.

Noise can also be caused by bearing problems. Bearings should be the principal maintenance item, since these can cause unplanned downtime if neglected.

- Both radial and thrust bearings should be checked; axial fans typically require thrust bearings, which are comparatively more expensive. Vibration analysis tools can improve confidence in determining bearing condition and planning bearing work.

Once the maintenance is completed on the drive system and on the filters, if excessive noise persists, noise reduction can be accomplished by several methods:

- Insulating the duct;
- Mounting the fan on a suitable spring isolator as required to limit the amount of transmitted vibration energy; or
- Installing sound damping material inside or outside the ducts or external baffles to absorb noise energy.

Duty Cycle

- Tracking the required and actual duty cycle of a system may reveal opportunities to save energy by turning down or turning off fans.

- Where two different levels of air movement are required, a multiple fan arrangement (in parallel) may be appropriate, where a lower flow fan may be operated alone during the turn down periods thus reducing the energy consumption.

Motors, Controllers and Drive Systems

Motors

- Most industrial fans are driven by alternating current (AC) electric motors. Most are induction motors supplied with three-phase, 240-, 480- or 600-volt power. In recent years, the efficiency of general-purpose motors has significantly improved through better designs and materials.

- The cost of these more efficient motors is 10 to 20 percent higher than the average motor. For high run-time applications, investment in high efficiency motors results in very attractive paybacks through lower operating costs.

Almost all motors are now available in energy efficient versions ranging from 2 to 6% higher efficiency.

- For large motors with high duty cycles, these differences in efficiency result in very short payback periods for the more efficient motors.

- Induction motors have a characteristic slip (a drop in revolutions per minute) depending on the load or torque on the shaft.

- Consequently, in most fans, actual operating speeds are usually around 2 or 3 percent less than their nominal speeds.

- For example, a theoretical four-pole induction motor with no slip would rotate at 1,800 rpm with a 60-hertz power supply; however, rated operating speeds for this motor are usually around 1,750 rpm, indicating that slip rates are a little over 2.7 percent at rated load.

Fans that are driven by synchronous motors, on the other hand, operate at the system frequency with no slip.

A word of caution: lower efficiency motors tend to operate at higher levels of slip than more energy efficient motors.

- Upgrading to a new motor can reduce operating costs, because of improved motor efficiency, while offering slightly improved fan performance.

- However, since higher efficiency motors operate with less slip, fans driven by these motors will rotate at slightly higher speeds and consequently at higher outputs (output varies as the cube of fan speed).

- For applications that can effectively use this additional output, this higher efficiency motor or synchronous motor can be attractive. However, if the additional output is not useful, the added power consumption increases operating costs.

Motor Service Conditions

The conditions under which motors operate can impact on the reliability and life of the motor. High-temperatures, contaminants, erosive or corrosive properties and moisture in the air stream can preclude the exposure of motors to the air stream.

- Motors can be sealed for protection against the harmful effects of some airstreams; however, these motors are more expensive and sometimes require external cooling services.

Motor performance is closely linked to its operating temperature. High ambient temperature and/or blockage of air flow through the motor will increase winding temperature, which will reduce efficiency and shorten motor life.

- High winding temperatures decrease motor efficiency and accelerate the degradation of winding insulation, shortening motor life. In most severe system environments, belt drives are used to allow the motor to operate outside of the harmful service conditions.

- Access to a motor for maintenance and repairs in a direct-drive fan assembly can be a problem when it disrupts production.

- Because many direct-drive applications are selected for space-saving reasons, these motors are often located in tight spaces, complicating tasks such as lubricating and replacing bearings.

Controllers and Drive Systems

The motor drive system often offers substantial opportunities to improve energy efficiency and to lower overall system operating costs.

The principal types of drive systems are:

Direct Drive: fan is attached to the motor shaft

- Simple, efficient system;
- Less flexible with respect to speed adjustments;
- Operating speed is limited to within a few percent below the synchronous motor speeds (most commonly 1,200, 1,800, and 3,600 rpm);
- Disadvantage - due to the sensitivity of a fan's output to its operating speed differences between the design and actual performance requirements can result in a direct-drive fan system that operates inefficiently;
- Adding an adjustable speed drive (ASD) to a direct-drive system is one way to add rotational speed flexibility; By allowing a range of shaft speeds, ASDs are quite practical for systems that have varying demand and can provide a highly efficient system for

fans that operate over a range of conditions that require variable speeds;

- Direct-drive fans are very appropriate for applications with low temperatures and clean system air because the motor mounts directly behind the fan and can be cooled by the airstream.

Belt Drive

- Fan rotational speed adjustments can be made by altering pulley diameters;

- Belt drives keep the motor out of the airstream, which can be an advantage in high temperature applications or in dirty or corrosive environments.

There are several different types of belt drives, including standard belts, V-belts, cogged V-belts and synchronous belts. There are different cost and operating advantages to each type:

- In general, synchronous belts are the most efficient, while V-belts are the most commonly used. Synchronous belts are highly efficient because they use a mesh type contact that limits slippage and can lower operating costs. However, switching to synchronous belts must be done with caution.

- Synchronous belts usually generate much more noise than other belts. They also transfer shock loads through the drive train without allowing slip. These sudden load changes can be problematic for both motors and fans. Another problem with synchronous belts is the limited availability of pulley sizes. Because the pulleys have a mesh pattern, machining them alters the pitch diameter, which interferes with engagement.

- Consequently, pulleys are available in discrete sizes, which preclude an important advantage of belt drives: the ability to alter operating rotational speeds by adjusting sheave diameters. Because of these factors, synchronous belts are not as widely used as V-belts in fan applications.

- In contrast, V-belts are widely used because of their efficiency, flexibility and robust operation.

V-belts have a long history in industrial applications, which means there is a lot of industry knowledge about them. An important advantage to V-belts is their protection of the drive train during sudden load changes because of the limited slip they allow.

- Service conditions that experience sudden drive train accelerations cause accelerated wear or sudden failure. While synchronous belts tend to transfer these shock loads directly to the shafts and motors, V-belts can slip, affording some protection.

- Although they are less efficient than synchronous belts, V-belts offer many advantages such as low cost, reliable operation and operating flexibility. In applications that use standard belts, upgrades to V-belts should be considered.

Gear Drive

Gear systems offer some advantages over belt systems. Gear systems tend to be much more expensive than belt drive alternatives; however, gears tend to require less frequent inspection and maintenance than belts and are preferable in applications with severely limited access.

- Gears also offer several motor/fan configurations, including in-line drives, parallel offset drives, and 90-degree drives, each of which may provide an attractive advantage in some applications.

- Gear-system efficiency depends largely on the speed ratio and on the number of stages. In general, spur or helical gearing efficiency is about 97% per stage, with additional losses from bearings and circulation of lubricant, which can reduce the efficiency further to 92% per stage for fractional horsepower motors and to somewhat higher efficiencies for larger motors.

- Because gears require lubrication, gearbox lubricant must be periodically inspected and changed. In addition, because gears, like synchronous belts, do not allow slip, shock loads are transferred directly across the drive train.

7 ENERGY SAVINGS AND ECONOMICS

Because fan systems often directly support production processes, many fans operate continuously. These long run times translate into significant energy consumption and substantial annual operating costs.

The operating costs of large fans are often high enough that improving fan system efficiency can offer a quick payback.

- In spite of this, facility personnel often do not know the annual operating costs of an industrial fan, or how much money could be saved by improving fan system performance.

- Operating costs of fan systems primarily include electricity and maintenance costs. Of these two components, electricity costs can be determined with simple measurements. In contrast, maintenance costs are highly dependent on service conditions and need to be evaluated case-by-case. A particularly useful method of estimating these costs is to review the maintenance histories of similar equipment in similar applications.

- The cost of operating a fan system is affected by the amount of time and the percentage of full capacity [load factor] at which the fan motor operates. Because the fan system does not usually operate at rated full load all the time, an estimate of its average load factor must be made.

a. Determination of the Load Factor

The load factor of a fan system can be determined by listing the number of operating hours at each level of output over a typical plant cycle like one week.

By multiplying the number of hours by the level of output, adding the results and dividing by the total number of hours in the entire period, one obtains the average load factor of the fan system.

b. Calculating Electricity Consumption

Electricity consumption can be determined by several methods, including:

- Using motor nameplate data;
- Using direct electrical measurements; or
- Using fan performance curve data.

With any of these methods, the data's usefulness is limited by how representative it is of the average system operating conditions.

- In systems with widely varying operating conditions, simply taking data once will probably not provide a true indication of fan energy consumption. It is better to use data for several operating points and use a weighted average based on hours of operation at each point.

Using Motor Nameplate Data

This is the quickest but often the least accurate way to determine energy costs, as in many applications, the fan/motor assembly is oversized and the motor operates well below its full-load nameplate data.

- By using the nameplate data in combination with the load factor, motor efficiency and power factor estimates, the fan's annual operating cost can be calculated.
- Other necessary data include the annual hours of operation (hours/year) and the average annual unit cost of electricity ($/kilowatt-hour [kWh]).
- Annual electricity costs can be calculated by inserting this information into the equation below, which is followed by a sample calculation.

Annual electricity costs = *Motor full load bhp x 0.746*
÷ (motor efficiency)
x (annual hours of operation)
x (avg. elect. cost in $/kWh)
x (motor load factor)

The numerical example uses the following assumptions:

- Cost of electricity = \$0.10/kWh
- Load factor = 70 %
- Motor efficiency = 94 %
- Motor full-load bhp = 150 hp
- Annual hours of operation = 8,760 hours (3-shift, continuous operation)

Annual electricity costs = (150 hp) x (0.746 kW/hp) ÷ (0.94) x (8,760 hours) x (\$0.10/kWh) x (0.70)

= \$72,997

The motors used on most fans have a 1.15 continuous service factor. This means that a motor with a nominal nameplate rating of 150 brake horsepower (bhp) may be operated continuously up to 172.5 bhp, although motor efficiency drops slightly above the rated load. Using nameplate data to calculate energy costs on motors that operate above their rated loads will understate actual costs.

Direct Measurement

A more accurate way to determine electricity consumption requires taking electrical measurements of motor current, voltage and power factor over a range of operating conditions.

- Motor full-load bhp and efficiency are not required for this calculation. The power factor should be measured with a power meter; however, if this measurement is not feasible, then an estimate may be obtained from the motor manufacturer's data.

- Wattmeters, in general, are more difficult to use because they require two simultaneous inputs, voltage and current; many motor installations do not offer convenient access to both.

- However, if the use of a wattmeter is practical, then it would provide a more accurate indication of actual power consumption.

"Hot" measurement of motor voltage exposes workers to risk and may not be feasible in some industrial environments because of exposure of the power connections to moisture or contaminants. Only properly trained personnel should take such readings.

Examples of Direct Measurement Calculations:

Option A: Using a Voltmeter and an Ammeter

The formula for calculating the annual electricity cost using measured voltage and current is:

Annual electricity costs = *Operating current reading x supply voltage reading x 1.732 (for 3-phase power) x (power factor) ÷ (1000) x (annual hours of operation) x (avg. elect. cost in $/kWh) x (motor load factor)*

Option B: Using a Wattmeter

The formula for calculating the annual electricity cost using measured Watts is:

Annual electricity costs = *Wattmeter reading (using a 3-phase setting; in kW) x (annual hours of operation) x (avg. elect. cost in $/kWh) x (motor load factor)*

For example, using voltage and current readings (i.e. Option A)

Assumptions and measurements:

- Cost of electricity = $0.10/kWh
- Load factor = 70 %
- Motor efficiency = 94 %
- Power factor = 0.85 (estimated)
- Measured motor current = 135 amps
- Measured supply voltage = 600 volts
- Annual hours of operation = 8,760 hours (3-shift, continuous operation)

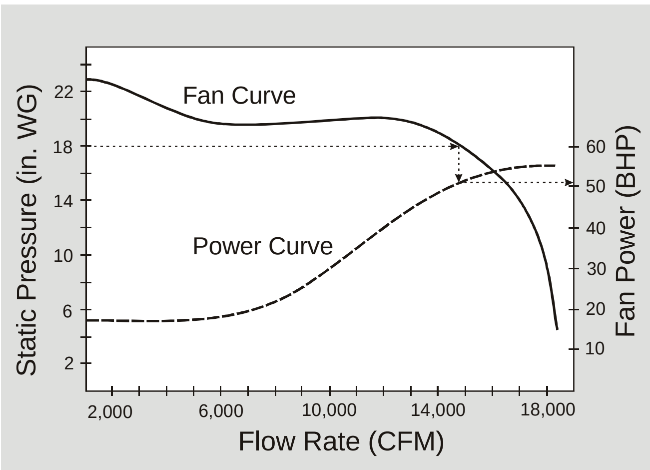
Annual electricity costs = (135 amps) x (600 volts) x (1.732 for 3-ph power) x (0.85) ÷ (1000) x (8,760 hours) x ($0.10/kWh) x (0.70)

= $73,123

Use of Fan Curves

Fan power consumption can be estimated from pressure measurements of the air stream by using the fan's performance curve. For a given static pressure, the corresponding flow rate can be determined. One can also determine the corresponding shaft power required by the fan by reading the power curve value at the same flow rate (refer to Figure 18). By dividing the fan power by the efficiency of the motor, one can obtain an estimate of the expected electrical power input to the motor.

Figure 18: Use of Fan Curve to Determine Power Consumption



Care must be taken using this method because:

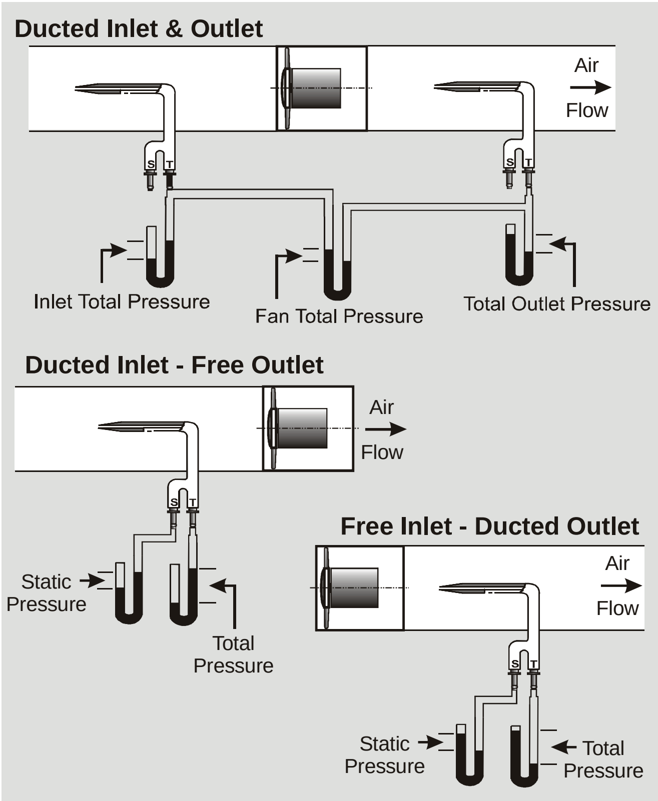
- The correct method of measuring fan pressure depends on how the fan is configured in the system.

- Total pressure consists of static pressure plus velocity pressure and must be measured both upstream and downstream of the fan. Figure 19 shows the proper method for a ducted inlet and outlet, for a ducted outlet only and for a ducted inlet only.

- Once the fan operating pressure is known, the corresponding fan flow rate can be determined from the fan characteristic curve as shown in Figure 18.

- Next, looking at the power curve and the same flow rate, the corresponding brake horsepower requirement can be determined.

Figure 19: Alternative Methods of Measuring Fan Pressure



The following sample **Calculation with Fan Curves** shows how to estimate annual energy cost.

Sample Calculation with Fan Curves

Annual electricity costs = (Fan bhp) x 0.746 kW/hp
÷ (motor efficiency)
x (annual hours of operation)
x (electricity cost in $/kWh)
x (motor load factor)

Assumptions:

- Fan discharge pressure is known
- Motor efficiency = 90 %
- Load factor = 70 %
- $0.10/kWh unit electricity cost

For example:

- Fan discharge pressure = 18 in. wg
- Reading from the power curve in Figure 18, fan bhp = 51 hp

Annual electricity costs = (51 bhp) x (0.746 kW/hp)
÷ (0.9) x (8,760 hrs) x ($0.10/kWh) x (0.70)

= $25,922

The fan has an expected annual operating cost of approximately $26,000.

8 HOW TO IDENTIFY INEFFICIENT FANS & BLOWERS

There are a number of clues that may reveal fans and blowers that are not operating efficiently:

- High operating cost;
- High maintenance cost;
- High level of noise;
- High air leakage in ducting or system;
- Inadequate air flow through certain branches; or
- Inability to adjust flow rates according to production needs.

High operating costs are often caused by inefficient fan operation, possibly a result of improper fan selection (usually oversizing for the application), operation in the wrong pressure range for the fan, poor system design, wasteful air flow control choices and operation when not needed.

High maintenance costs can be associated with the motor or with the driven fan or blower. Belt alignment and adjustment can have a very significant effect on fan operation reliability and life.

Belt slippage is not only wasteful of energy, but also results in excessive wear and early failure of the belt and pulleys.

- Belt over-tightening results in higher energy consumption, excessive wear on the bearings and early belt and bearing failure.

- Frequent start-ups of large motor loads can add significant stress to an electrical system. The in-rush current and the starting current for motors can cause the motor to run hot for several minutes.

Soft starters can extend fan motor life by keeping the motor temperature lower.

Variable frequency drives (VFDs) are also commonly used to soft start fans by gradually bringing fan speed up to operating conditions.

High level of noise is often associated with oversized fans, or with the wrong type of fan for the application.

- An effective way of minimizing maintenance and operating costs is to keep a fan operating within a reasonable range of its best efficiency point (BEP); however, this practice is often difficult to apply in systems that have changing demands.

High air leakage from ducts or system components can result from poorly designed or maintained ducting or equipment, stuck dampers or other reasons. The result is more fan power being required to provide the necessary process air flows through the system.

- In severe cases, many centrifugal fan motors will overload if operated against little or no backpressure. If not corrected, an overloaded motor will typically shut itself down with a thermal or an over-current safety cutout switch.

Inadequate air flow through certain branches can be caused by inadequate balancing and by duct configurations that introduce airflow resistance or leakage, both of which are usually overcome by providing more fan power at additional operating cost.

Inability to adjust flow rates according to production needs; systems that require variable air flow rates need to have a means of adjusting the air flow efficiently.

- As system airflow requirements change, the fan may move far away from its BEP and perhaps enter the unstable region of the performance curve due to excessive back pressure, possibly causing surging.

The use of dampers to block or by-pass air flow is very inefficient and causes more power to be drawn by the fan.

9 ASSESSING FAN SYSTEM NEEDS

Fans are usually sized to handle the largest expected operating or design condition. Because normal operating conditions are often well below these extreme design conditions, air-moving equipment is often oversized and is operating below its best efficiency point (BEP) for extended periods of time. As a result, these fans may cause high system pressures, excessive noise and high energy costs.

- In systems with high particulate airborne content, erosion of impeller and casing surfaces can occur prematurely.

- In situations where oversized equipment is used over extended periods of time, there is a need for efficient flow control in order to reduce energy consumption and extend fan and motor life.

- Often, the existing flow control devices (e.g. dampers) are inefficient, yet the costs associated with their inefficiency are not recognized.

- To diagnose the problem, one can take simple pressure and flow measurements, along with observations of duration of operations well below design conditions and note excessive noise, hunting and records of early failure of motor, bearings, and belts. These observations can be used to identify equipment application problems and opportunities to save energy.

a. Options to Optimize Fans and Blowers

When air flow requirements change with time, a single fan may be forced to operate far away from the BEP over long periods of time, reducing the fan efficiency. If a single fan cannot be found with the right pressure-flow characteristics, there are a number of options available including:

- Multiple fans in series or parallel;
- Replacing fans with a more appropriate type for the load;
- Better matching of fans/blowers to motors; or
- Other options.

Multiple Fans in Series or Parallel

Multiple fans can be combined in series or in parallel as an alternative to a single fan. In many cases, two smaller fans are less expensive and offer better performance than one relatively large one. However, the installation and operation of a parallel or series fan arrangement requires special precautions, care and special operating arrangements.

- Fans can be installed in series close to each other to increase pressure locally or far apart to increase pressure in different parts of the ductwork. They may be installed in parallel for single or dual operation for varying the air flow rate, depending on system requirements. Each arrangement and fan location has its own pre-requisites and merits.

- Fans configured in series (with some distance between them) tend to be appropriate for systems that have long ducts or large pressure drops across system components.

- Fans used in series in an induced-draft/forced-draft configuration can minimize the amount of pressurization in a duct or an enclosure.

Advantages of fans in series include:

- Lower average duct pressure and less leakage;
- Lower noise generation; and,
- Lower structural and electrical support requirements.

In situations where wide variations in system air flow demand are expected, multiple fans installed to operate in parallel may be appropriate. This arrangement allows units to be energized one at a time or together to efficiently meet the various air flow demands of the system.

- Under varying flow conditions, a single (constant speed) fan would not likely operate consistently near its best efficiency point (BEP) and would result in higher operating and maintenance costs than a dual-parallel fan arrangement.

By energizing or de-energizing individual fans installed in parallel to meet demand changes, each fan can be operated near its BEP, or be turned off, resulting in more efficient overall operation.

- Multiple parallel fan arrangements require that each fan be equipped with a back-draft damper to prevent backflow through the fan when not in use.

Advantages of fans placed in parallel include:

- High efficiencies across wide variations in system air flow demand;
- Lower noise generation;
- Redundancy to mitigate the risk of downtime because of failure or unexpected maintenance of one fan;
- Parallel configurations may be feasible for systems with large changes in air-moving requirements; and,
- Parallel fan configurations may offer safety benefits over single fan systems, where failure in such applications as ventilation of mines, underground parking garages and hazardous work environments could impact on personnel safety.

As shown in Figure 20, placing the series-configurations fans along different points in a system minimizes the average static pressure in a duct.

- Ideally, all fans operating in parallel should be the same type and size and ducted in a manner that minimizes the differences in backpressure to ensure that one fan does not dominate another.

In the parallel fan arrangement there is the possibility that one fan will force another fan to operate far away from its BEP and cause instability in the form of alternate load sharing that can occur below certain airflow rates (hunting).

- Alternate load sharing can lead to noise and increased wear on fans due to repeated acceleration and deceleration. This problem is especially applicable to fans with unstable operating regions (axial fans, forward-curved centrifugal fans and airfoil fans).

The system airflow should be kept to the right of Point 1, shown in Figure 21.

Figure 20: Low Duct Pressure with Fans Operating in Series

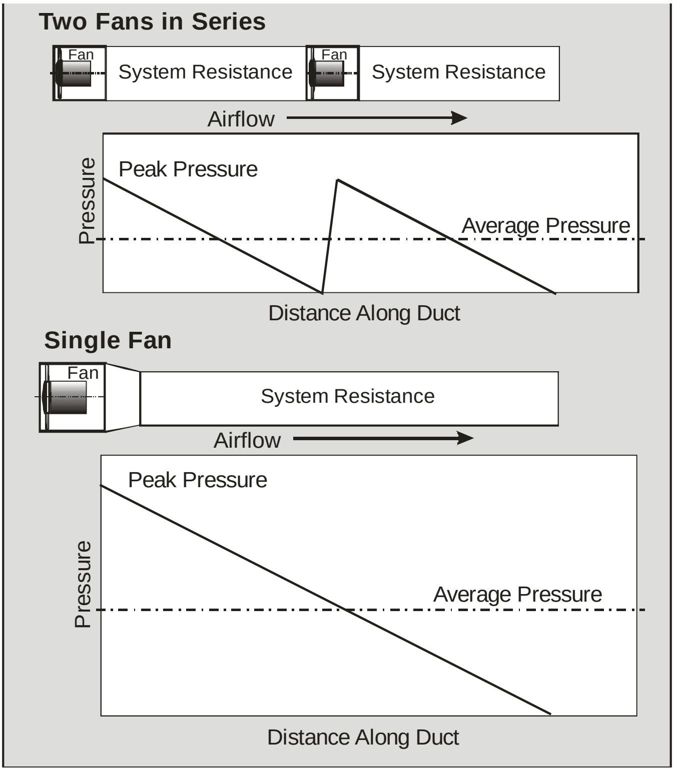
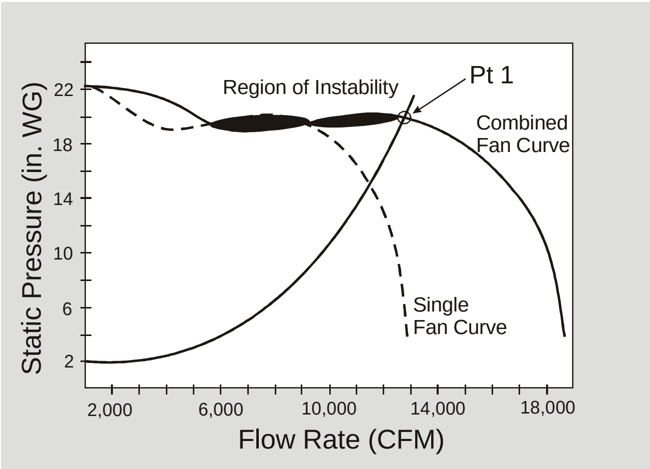


Figure 21: Instability Region with Identical Fans in Parallel Operation



b. Replacement Fans

An option that may provide an attractive payback in high run-time applications is the replacement an existing fan with a different, more appropriate model.

- Selecting a new fan, larger, smaller or of different type, requires consideration of the same factors that are involved in any initial fan selection. If an existing fan requires extensive refurbishment and does not have the required air flow properties, replacement with a new fan, more efficient for the purpose, may be more economically attractive in the long-run than refurbishing the existing one.

- Consideration must be given to the system effect factors that can significantly reduce the air flow of the fan because of specific inlet and outlet conditions once the fan is installed into the system (see ***Systems Approach*** Section).

c. Matching Fans/Blowers to Motor

Fans are usually selected to match the maximum pressure and flow requirement of the system. Although the system may not be required to operate at the maximum conditions all the time, the fan-motor combination must be capable of delivering the required air flow when needed.

- The motor selected for the drive system must be capable of supplying the fan with the required driving power.

- Fans are typically driven by alternating current (AC) motors. In industrial fan applications, the most common motor type is the squirrel-cage induction motor, selected for its durability, low cost, reliability and low maintenance requirements. These motors are commonly available with 2 or 4 poles which, on a 60-hertz system, translate to nominal operating speeds of 3,600 revolutions per minute (rpm) and 1,800 rpm, respectively.

- Although motors with 6 poles or more are used in slower fan systems, they are relatively expensive. The most common class of motors for fan applications is NEMA Design B. Motors can operate safely over long periods of time above the rated output or with a "service factor" above 1. Service factors range from 1.1 to 1.15, meaning that the motors can safely operate at loads between 110 to 115 percent of their output power rating.

- When a continuous range of speed variation is required, variable frequency drives (VFDs) can be used to efficiently vary the speed of the motor driving the fan. These controls can be used to accurately match fan output (flow and pressure) to the requirements of the system. VFDs provide the motor with a variable frequency supply by means of solid-state switching. One must be aware of the fact that these drives generate harmonic currents that contribute towards extra heating of the motor, likely affecting the temperature of the motor windings and possibly accelerating the degradation rate of the electrical insulation in the motor windings.

- A classification of motors known as "inverter-duty" has been developed to improve the matching of VFDs to motors. Conventional motors usually must be de-rated by 5 to 10 percent when used with VFDs in order to account for the added heating of the winding.

- In some applications where the loading on motors is not high, the anticipated savings from VFDs may not materialize because of the impact of the losses associated with the VFD controller.

- Although at full capacity VFDs can achieve efficiencies of 98 percent, their efficiency at part-loads is often much lower. When considering VFDs, test data from the manufacturer should be evaluated for the efficiencies at the actual load levels of the application.

- VFDs offer an attractive opportunity to reduce energy consumption in many applications; however, all of these considerations should be included in any feasibility study.

- Care must be taken in situations where increased air flow causes an overload on the motor (forward curved centrifugal fan, unplanned high air flow) or where increased system pressure, such as could be caused by clogged air filters, causes an overload on the motor (axial fan, unplanned increase in pressure).

d. Other Options

There are a number of ways of adjusting air flows to match the system requirements:

- Multiple-speed motors to drive fans *(with separate windings for each speed, such as low, medium and high)*;

- Variable frequency drives (VFDs) *(adjust fan speed over a continuous range by changing the frequency of the power supplied to the motor)*;

- Inlet vanes (*these control fan output by creating a swirl in the airflow before it reaches the fan blades, thus changing the angle of attack; they are less* *efficient Than speed adjustment, but offer a relatively simple and inexpensive option that is widely used)*;

- Controllable-pitch axial fan blades *(by changing the angle of attack to the incoming air, the amount of airflow generated and the load on the motor can be controlled; this flow control option is relatively efficient and offers several advantages that are discussed in more detail in the* ***Control Systems*** *Section)*; or

- Air flow dampers *(offer another alternative that is commonly used, but is not energy efficient, as explained below).*

Although dampers have the ability to reduce air flow by adding a restriction in the path of an air stream, they have a detrimental effect on energy consumption and on fan life.

- As dampers close, they reduce the amount of flow and increase pressure on their upstream side.

By increasing system resistance, dampers force fans to operate against higher backpressure, which reduces their output. As a fan works against higher backpressure, its operating point shifts to the left along its performance curve.

- Fans operating away from their best efficiency points cause increased operating and maintenance costs.

e. Examples

Dust Collection System Example

A typical dust collection system uses ductwork, fans and hoods to capture and transport the contaminants. Depending on the application, they may also incorporate some form of air cleaner or dust collector. Since the cost of operating and maintaining these systems can be considerable, it is wise to minimize dust/fume production and to ensure efficient capture of the contaminants so that the amount of exhausted air is minimized. Under certain conditions, flammable powders can be explosive, and measures have to be taken to avoid the hazardous concentrations and ignition sources.

Dust collection systems are rather specialized since heavier particles require certain precautions and should be caught in their trajectory. Exhaust hoods must be located in the path of the particles to assure capture and removal. The following measures can help reduce the total energy consumption for dust collection:

- Use both blowing as well as exhaust openings in a so-called ‘push-pull’ system for more effective and efficient collection.

- Use outside air for blowing. This measure results in less exhaust of building air and thus decreases the number of air changes in the building and reduces the space heating load during the heating season.

- Exhausted air can be re-circulated into occupied spaces, but only if the dust or fume is non-toxic, the collection efficiency is high and there are no small particles that elude collection.

- Use a heavier duct wall thickness to avoid damage and leaks in the ductwork.

- Use ducts with a smooth inside surface and with gaskets and flanges finished flush with the duct interior to avoid lips.

- All bends should be of a sufficient diameter to minimize pressure loss.

- Ducts should generally be not less than 100 mm in diameter to prevent clogging.

- Air tightness is another important issue; higher-pressure losses mean that in-leakage may be quite large, thus 'robbing' the furthest sections of the system.

- If dampers must be used, then the slide type (coming from the top of the duct) is recommended so that no dust build-up occurs.

- Sweep-up points should be self-closing and airtight. It is not normal to allow for a large quantity of air flowing through them, as they are open only for short periods.

- Electrical continuity should be arranged across flanged sections; otherwise the build-up of static electricity would lead to sparking across gaskets and potential ignition of the air-powder mixture.

Mechanical Ventilation (MV) System Example

MV systems consume energy through the operation of fan motors. The amount of energy used depends on the pressure in the system as well as on the volume of air transported. Energy can be saved if:

- The pressure drop can be reduced;
- An efficient fan is selected; and/or,
- Excess supply of air is avoided.

Mechanical ventilation systems consist of the following components:

- An air handling unit containing the supply fan, heaters, heat exchangers and filters;
- Ductwork leading to the conditioned space;
- Ductwork drawing air from the outdoors;
- An extraction fan with a duct system from the conditioned space to the outdoors; and,
- An optional heat recovery system between the supply and exhaust ducts.

Ductwork

Several factors can contribute towards the requirement of higher fan power: the resistance to the flow of air caused by the ducts themselves, by changes in airflow direction, by filters and by the leaks in the ducts.

Ductwork that distributes air throughout the building or process usually contributes 40 to 50% of the losses.

Duct losses can be reduced by:

- Increasing the duct diameter;
- Modifying the geometry of the ductwork ;
- Improving the fan inlet conditions; and,
- Improving the fan outlet conditions.

A brief description of the ways to reduce each of the above loss components follows:

Duct Diameter

Friction between the airstream and the duct surfaces accounts for most of the energy consumed by the fan. The resistance of airflow through a duct is a function of the square of the velocity, as indicated in the pressure loss formula:

$$\Delta p = f \times \frac{L}{D} \times \left(\frac{V}{1097} \right)^2 \times \rho$$

Where:

Δp = pressure loss in inches of water gage (in. wg)
f = non-dimensional coefficient of friction for the duct
L = duct length (in ft)
D = duct diameter (in ft)
V = velocity (in feet per minute)
ρ = density of the airstream (0.075 pounds/cu ft at standard conditions)

- The formula indicates that the pressure drop across a duct is proportional to the length and inversely proportional to the diameter of the duct.

- The friction coefficient (f) depends on the duct surface finish, duct diameter and the level of turbulence in the airstream.

- For a given delivery volume, increasing duct diameter decreases both the velocity <u>and</u> the friction loss per duct length. For example, for a certain required air flow rate, increasing the duct diameter by 10% would result in a drop in duct velocity of more than 17%.

- The lower velocity, combined with the lower friction coefficient would result in a reduction in pressure drop across the duct of about 38%. The reduced pressure drop would reflect as a lower amount of power requirement from the fan and motor.

Consequently, larger ducts create lower friction losses and lower operating costs. Offsetting the lower operating costs associated with large ducts are higher initial costs, both in terms of duct material, added structural requirements and more space required.

Caution must be exercised in certain material handling applications that require a certain minimum air velocity to ensure proper entrainment, such as in dust collection, where a suitable duct diameter must be selected for the required airflow rate.

Geometry

- Avoiding changes in direction of air flow;
- Replacing right angle bends with radius bends;
- Replacing T-junctions with Y-junctions;
- Adding turning vanes to restore uniform, rather than uneven, air flow across the duct cross-section; and,
- Using round ducts or aspect ratios close to 1 for rectangular ducts.

Fan Inlet Conditions

The direction of the incoming air flow relative to the fan inlet area as well as the uniformity of air flow across the inlet of the fan has a direct and pronounced impact on the effectiveness and efficiency with which the fan imparts energy to the airstream:

- Placing a bend too close to a fan inlet can cause the airflow to be highly non-uniform, entering the fan unevenly, resulting in inefficient energy transfer from the fan blade to the air and fan vibrations. To significantly reduce this problem one must provide a straight duct length of at least 3 times the duct diameter just prior to the fan inlet.
- Alternatively, when space does not permit long duct runs to straighten airflow, an airflow straightener such as a set of turning vanes can be used to improve the uniformity of the incoming air flow velocity and thus improve fan performance.

- Depending on the duct geometry, swirls can become established at the fan inlet. When in the same direction as fan rotation, the swirl can effectively decrease the pressure and flow of air from the fan, reducing the load on the fan and shifting its performance curve downwards and to the left. This swirl is so effective at reducing the load on the fan that, in some applications, flow diverters are deliberately installed to cause controlled swirls to unload fans and reduce air flows.

- A swirl at the fan inlet in the direction opposite to the fan rotation creates an additional load on the impeller. Although this swirl tends to shift a fan's performance curve upwards, a counter-rotating swirl is an inefficient method of increasing fan pressure.

Fan Outlet Conditions

Poor outlet conditions as described below also contribute to under-performance of fan systems:

- Swirls and vortices sometimes form in the outlet air stream and end up increasing the pressure drops of elbows and other duct fittings;
- The elbows and fittings closest to the fan outlet are affected the most by swirls and vortices;
- The orientation of fans that oppose rather than match the eventual direction of air flow through elbows or turns unnecessarily increase the duct resistance;
- Undersized outlet duct; and,
- Oversized outlet duct without proper transition.

The following guidelines can be used to improve fan outlet conditions:

- Avoid swirls and vortices in the fan's outgoing air by careful design of the outlet ductwork and fittings and obstructions;
- Place tees and other fittings far enough downstream of a fan for the airflow to become uniform;
- Orient fans so that the airflow profile out of a fan matches, rather than opposes, the airflow behavior created by fittings such as an elbow;
- Install turning vanes to improve the uniformity of air flow around corners and thus reduce pressure drop; and,
- Install air flow straighteners and splitters where there is insufficient duct distance to allow uniform flow to become established.

Repairing leaks by securing, tightening and taping also reduces fan power required.

Filters

Filtration also contributes to some pressure drop and consequently some additional losses. There are three types of filters, each one with its own pressure loss characteristic. The more efficient the filter, the higher is the pressure drop across it. The three types are:

- Low efficiency roughing filter - This category includes disposable panel filters, filter pads, washable filters and automatic roll filters.

- Medium/high-efficiency (secondary) - this type includes bag filters, electrostatic filters and deep pleated filters.
- Very-high-efficiency - these include high efficiency particulate air (HEPA) filters and ultra-low-penetration air (ULPA) filters.

Efficient Fan

Using the specified flow and static pressure requirements to select various fan types, the most efficient fan (lowest specified driving shaft power) that meets these requirements should be selected. A margin, known as the contingency, (usually 10%) is added to the calculated pressure drop to account for unforeseen duct runs and dirty filters, otherwise known as the system effect, as described in the ***System Curve*** Section.

- The application of the contingency can lead to a higher than expected flow if the actual pressure drop is lower than estimated, as is often the case. To minimize the system effect on the fan, it is necessary to ensure that the flow is laminar at the fan inlet/outlet, ideally by allowing 4-5 diameters of ductwork on either side of the fan before changing direction or duct diameter.
- It is more efficient to select a fan with an adjustable performance, rather than to use dampers to limit the flow. A variable frequency drive (VFD) on direct drive fans can assist in balancing the system, but unless a variable flow is required, it may not be economic or efficient to use a VFD.

- Direct drive motors avoid pulley and belt losses and are therefore more efficient. When fan selection is left to the designer of the system, make sure to specify high efficiency fan models.
- For example, backward-bladed centrifugal fans are generally more efficient and should be used in preference to forward-curved above flow rates of 2 m^3/s (4,000 CFM).

Excess Supply of Air

Since mechanical ventilation systems are key elements of a building energy management system, it is very important that these be operated efficiently to start with.

- Sometimes balancing needs result in having to supply excess air to other parts of the system. This is wasteful and should be avoided by more careful and judicious balancing.

- Excess supply is also associated with excessive noise, and this can result in occupant complaints as well as increased cost of operation.

Plugged air filters or the wrong type of filter can also result in decreased ventilation rates and the need for higher fan power which is also wasteful.

10 CODES, STANDARDS & REGULATIONS

a. Fan Standards

ISO/IEC

The fan standard, *ISO5801:1997, Fans for General Purposes, Part 1 – Performance Testing using Standardized Airways,* explains in detail how to measure the fan parameters. The revision of ISO5801 published in 2007 has an Appendix E, electrical input power consumed by a fan, and gives a good explanation of the losses within a fan system.

The Air Movement and Control Association (AMCA)

This international industry association offers a number of fan application publications and fan standards through its website: http://cart.amca.org/publications/default.asp?Page=2

The standards are related to test methods for fan measurements and installation practices, for example:

AMCA 203/N - Field Performance Measurement of Fan Systems Air Movement and Control Association / 01-Jan-1990 / 147 pages.

ANSI/AMCA 210/N - Laboratory Methods of Testing Fans for Aerodynamic Performance Rating, Air Movement and Control Association / 02-Dec-1999 / 67 pages.

AMCA Publication 211/N – Certified Ratings Program – Product Rating Manual for Fan Air Performance

In the European Union, the EC conducted a market study of fans[2] in the interest of improving their efficiency. The 2002 report provides a brief summary of the fan efficiency standards for fans primarily used in building ventilation in the UK, Switzerland, Germany, Sweden, Denmark and the Netherlands. The codes focus on the performance of the fans and the duct systems for residential and commercial building ventilation. Some countries specify maximum specific fan power levels for new and old buildings, others specify maximum duct air velocities and others specify maximum watts input per cubic meter per hour.

[2] Market Study for improving the Energy Efficiency of Fans, Project XVII/4.1031/Z/99/313 under the SAVE Program, 2002 (http://www.google.ca/search?hl=en&q=AMCA+Publication+202-98.+Troubleshooting&btnG=Google+Search&meta=)

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3. *Improving Fan System Performance - a sourcebook for industry*, U.S. Department of Energy Efficiency and Renewable Energy

4. Software: *Fan Assessment Tool*, downloadable from the following website: http://www1.eere.energy.gov/industry/bestpractices/SoftwareToolDownload.asp

5. FMA guidance note 4, *Fan Efficiency Guidance,* from the Fan Manufacturers Association (UK) Website: http://www.feta.co.uk/fma/index.htm

6. FMA Guidance Note 2, *Fan Installation Effects – A guide to installed fan acoustics,* from the Fan Manufacturers' Association. (UK) Website: http://www.feta.co.uk/fma/index.htm

7. *Good Practice Guide 257 – Energy Efficient Mechanical Ventilation Action Energy*, from the Carbon Trust website (Register at www.carbontrust.co.uk to download): http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=GPG257&metaNoCache=1

8. *Good Practice Guide 383 - Energy Savings in Fans and Fan Systems – Action Energy,* from the Carbon Trust website (Register at www.carbontrust.co.uk to download): http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=GPG383&metaNoCache=1

9. Frank P., *Fan Handbook: Selection, Application, and Design – Edition 1,* McGraw-Hill Professional / 01-Sep-1997 / 640 pages, ISBN: 0070059330. *(A comprehensive guide to all aspects of modern fan technology. The book goes through the design, selection, maintenance, and repair of fans used in a wide range of applications; It also contains information on fan codes, standards, and specifications plus complete details on fan testing, physical laws affecting fan performance, ventilation requirements, and symbols and conversions)*

10. Norton, Robert L., *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines, Edition 3*, McGraw-Hill Professional / 2004 / 880 pages, ISBN 0071214968.
(includes information on gear efficiency)

12 GLOSSARY OF TERMS

ACFM – actual cubic feet per minute; the quantity or volume of a gas flowing at any point in a system. Fans are rated and selected on the basis of ACFM, as a fan handles the same volume of air regardless of density. Also see “CFM” and “SCFM.”

Adjustable speed drive – A mechanical, hydraulic or electrical system used to match motor speed to changes in process load requirements.

Air-handling unit – factory-made encased assembly consisting of a fan or fans and other equipment to circulate, clean, heat, cool, humidify, dehumidify or mix air.

Anemometer – a device that reads air velocity, such as a wind vane. In fan applications, it is usually a spinning-vane-type instrument used to read low velocities at registers or grills.

Apparent Power – in an AC circuit, the product of Volts x Amperes supplying a single-phase motor, or 1.732 x Volts x Amperes supplying a 3-phase motor; expressed in either volt-amps (VA) or kilovolt-amps (kVA), where 1000 VA = 1 kVA. See also “Real Power” and “Power Factor.”

Atmospheric pressure – one atmosphere is approximately 14.7 psi, 408" water gauge at sea level. Airflow is the result of a difference in pressure (above or below atmospheric) between two points.

Axial fan – fan where the airflow through the impeller is mainly parallel to the axis of rotation. The impeller is contained in a cylindrical housing.

Axial flow – in-line air movement parallel to the fan or motor shaft.

Backward-inclined fan – a group of centrifugal fans with blades that angle back from the direction of fan rotation. These fans can have flat, curved or airfoil blade shapes. Airfoil blades are among the most efficient fan types.

Balancing – the process of adding (or removing) weight on a rotor in order to move the center of gravity toward the axis of rotation; see also "balancing air flows."

Balancing air flows – the process of adjusting the flow resistances in parallel branches of an air distribution system that is supplied from a common fan in order to achieve the desired air flows in each branch.

Barometric pressure – a measurement of the pressure of the atmosphere; standard atmospheric pressure is 29.92 in-Hg at sea level.

Best efficiency point (BEP) – the operating condition at which a fan transfers energy to an airstream most efficiently. In general, this is a point on a fan pressure-flow curve to the right of peak pressure.

Blower – A fan with a discharge pressure from 2 psig (55" WG) to 36 psig (915" WG).

Brake horsepower (bhp) – a measure of the rate of energy expended. One bhp is equivalent to mechanical energy consumed at a rate of 33,000 ft-lbs per minute, also equal to 0.746 kilowatts.

Brake horsepower can be calculated by: *bhp = torque (ft-lbs) x RPM / 5,250*

Butterfly damper – a type of damper where adjacent blades rotate in the opposite direction; also called an "opposed-blade damper."

Centrifugal fan – a fan design in which air is discharged perpendicular to the impeller's rotational axis.

CFM – cubic feet per minute; the volume of flow for a given fan or system. See also "ACFM" and "SCFM."

Curve, fan performance – a graphic representation of static or total pressure and fan bhp requirements over an airflow volume range.

Curve, system – a graphic representation of the pressure versus flow characteristics of a given system.

Damper - an accessory to be installed at a fan inlet or outlet for air-volume modulation.

Density – the measure of unit mass equal to its weight divided by its volume (lbs/cu-ft.); standard air density is 0.075 lb/cu-ft.

Design Point – A point of operation generally based on a duty that is slightly larger than the highest duty ever expected for the application. This point represents a specific set of criteria used to select the fan or blower.

Dust collector – an air-cleaning device used to remove heavy-particulate loadings from exhaust systems prior to discharge.

Duty – For a fan, the inlet volume flowrate at the rated fan pressure.

Fan – a power-driven machine that moves a continuous volume of air by converting rotational mechanical energy to an increase in the total pressure of the moving air.

Fan capacity – performance requirement for which a fan is selected to meet specific system calculations given in terms of ACFM at the fan inlet.

Fan laws – theoretical constant relationships between cfm, rpm, static pressure (sp) and bhp for a given fan used in a given fixed system:

$$\text{cfm} \sim \text{rpm}; \quad \text{sp} \sim (\text{rpm})^2; \quad \text{bhp} \sim (\text{rpm})^3$$

Foot-pound (ft-lb) – torque rating or requirement; equivalent to the force required to raise a 1-pound mass one vertical foot in height; equal to 12 in-lbs.

Forced draft – how air is provided in a process, such as a combustion process; when air is blown or forced into a process, it is known as a “forced-draft” system. See also “Induced Draft.”

Forward-curved blade fan – a fan type with blades that angle toward the direction of rotation. This fan type generates relatively high pressure at low operating speeds and is used frequently in residential furnace applications

FPM – feet per minute; commonly defines air velocity (to determine velocity pressure or suitability for material conveying), shaft/bearing speeds (used to determine lubrication requirements) and impeller tip speeds.

Frame size – a set of physical dimensions of motors as established by National Electrical Manufacturers Association (NEMA) for interchangeability between manufacturers. Dimensions include shaft diameter, shaft height and motor-mounting footprint.

Frequency – any cyclic event, whether vibration, alternating current or rotational speed. Usually expressed in cycles per second (cps) or just "cycles."

Friction loss – resistance to airflow through any duct or fitting, given in terms of static pressure.

Full-load speed – the speed at which the rated horsepower of an induction motor is developed. This speed is less than synchronous speed and varies with motor type and manufacturer.

Full-load torque – the torque developed by the motor to produce the rated horsepower at the full-load speed.

Gauge pressure – the static pressure differential between atmospheric pressure and the pressure at the point of interest.

Heat exchanger – a device, such as a coil or radiator, which is used to transfer heating or cooling between two physically separated fluids.

HEPA filter – high-efficiency particulate air filters, commonly called absolute filters.

Hertz (Hz) – frequency measured in cycles per second.

Hg – symbol for mercury. Pressure is often measured in inches of mercury (1 inch Hg = 13.64 inches wg).

Horsepower (hp) – (as applied to motors) an index of the amount of work the machine can perform in a period of time. One hp equals 33,000 ft-lbs of work per minute, also equal to 0.746 kilowatts.

Horsepower can be calculated by: *horsepower = torque (ft-lbs) x RPM / 5,250*

Housing – the casing or shroud of a centrifugal fan.

Impeller – another term for fan "wheel." The rotating portion of the fan designed to increase the energy level of the gas stream.

Inch of water – unit of pressure equal to the pressure exerted by a column of water 1 inch high at a standard density (1 inch of water = 0.036 psig).

Inch-pound (in-lb) – torque equal to one-twelfth foot-pound.

Inclined manometer – a metering device used to obtain pressure measurements.

Induced draft – how air is provided in a process, such as a combustion process, where air is drawn or pulled through a process. See also “Forced Draft.”

Induction – the production of an electric current in a conductor in a changing magnetic field.

Inlet-vane damper – round multi-blade damper mounted to the inlet of a fan to vary the airflow.

Instability – the point of operation at which a fan or system will “hunt” or pulse; common in forward-curved fans and some axial fan types where the point of operation is left of the peak of the static pressure curve

Kilovolt-amperes or kVA – is a measure of apparent power. A kVA is equal to 1000 volt-amps (VA). In an alternating current (AC) circuit; kVA equal the product of Volts x Amperes ÷ 1000 for a single-phase motor; or 1.732 x Volts x Amperes ÷ 1000 for a 3-phase motor. See also “Real Power” and “Power Factor.”

Kilowatt or kW – is a measure of power. A kilowatt (kW) is equal to 1000 Watts (W), which is equal to 1.34 horsepower (hp). In an alternating current (AC) circuit, kilowatts equal the product of Volts x Amperes x Power Factor ÷ 1000 for a single-phase motor; or 1.732 x Volts x Amperes x Power Factor ÷ 1000 for a 3-phase motor. See also “Apparent Power” and “Power Factor.”

Laminar flow – gas or fluid in parallel layers with some sliding motion between the layers.

Load factor – ratio of the average capacity to the rated full capacity, determined by the following relationship:

Load Factor = (Sum of actual load x hours of operation at each operating point) divided by (Rated full load x total hours of operation).

Make-up air – a ventilating term which refers to the replacement of air lost because of exhaust air requirements.

Manometer – instrument for measuring pressure; u-shaped, and partially filled with liquid, either water, light oil or mercury.

Maximum continuous rating – the point at which the fan is expected to operate.

NEMA – the National Electrical Manufacturers Association; the trade association establishing standards of dimensions, ratings, enclosures, insulation and other design criteria for electric motors and other devices.

Opposed-blade damper – a type of damper where adjacent blades rotate in the opposite direction; also called a “butterfly damper.”

Parallel-blade damper – a type of damper where the blades rotate in the same direction.

Parallel fans – two or more fans that draw air from a common source and exhaust into a common duct or plenum. A parallel fan arrangement is generally used to meet volume requirements beyond that of single fans. Two identical fans in parallel will effectively deliver twice the rated flow of any one fan at the same static pressure.

Pitch diameter – the mean diameter or point at which V-belts ride within a sheave. This dimension is necessary for accurate drive calculations.

Pitot tube – a metering device consisting of a double-walled tube with a short right-angle bend; the periphery of the tube has several holes through which static pressure is measured; the bent end of the tube has a hole through which total pressure is measured when pointed upstream in a moving gas stream.

Plenum – a chamber or enclosure within an air-handling system in which two or more branches converge or where system components such as fans, coils, filters or dampers are located.

Poles – the number of magnetic poles established inside an electric motor by the placement and connection of the windings.

Power Factor – in an AC circuit, the power factor or PF is the ratio of "real power" (kW) to "apparent power" (kVA). An induction motors has a power factor less than one, which gets smaller as the motor is unloaded. A resistance load, such as a heater, has a PF equal to one.

Pressure, static – The pressure with respect to a surface at rest in relation to the surrounding fluid.

Pressure, total – The sum of the static pressure and the velocity pressure at the point of measurement.

Pressure, velocity – The pressure at a point in a fluid such as air existing by virtue of its density and its rate of motion, or velocity; also referred to as dynamic pressure.

Propeller fan – an axial fan type that is compact, inexpensive, but relatively inefficient; suitable for low pressure, high flow applications.

psia – pounds per square inch absolute, represents total pressure above a perfect vacuum.

psig – pounds per square inch measured in gauge pressure, represents the difference between psia and atmospheric pressure.

Radial blade – fan impeller design with blades positioned in straight radial direction from the hub.

Radial tip – fan impeller design with shallow blades in which the trailing edge points radially from the axis of rotation.

Real Power – same as Power in an AC circuit; equal to the product of Volts x Amperes x Power Factor for a single-phase motor, or 1.732 x Volts x Amperes x Power Factor for a 3-phase motor; expressed in Watts (W) or kilowatts (kW), where 1000 W = 1 kW. See also “Apparent Power” and “Power Factor.”

Rotor – the rotating part of most alternating current motors.

RPM – rotational speed, measured in revolutions per minute.

Saturated air – air containing the maximum amount of water vapor for a given temperature and pressure.

SCFM – standard cubic feet per minute; a volume of air at 0.075 lbs/cu-ft density; used as an equivalent weight of air.

Scroll – the general shape of a centrifugal fan housing; the formed piece to which housing sides are welded.

Series fans – a combination of fans connected so that the outlet of one fan exhausts into the inlet of another. Fans connected in this manner are capable of higher pressures than a single fan and are used to meet greater pressure requirements than single fans.

Service factor – the number by which the horsepower rating is multiplied to determine the maximum safe load that a motor may be expected to carry continuously.

Slip – the percentage difference between synchronous speed and actual speed.

Static pressure – the pressure with respect to a surface at rest in relation to the surrounding fluid.

Surge limit – that point near the peak of the pressure curve that corresponds to the minimum flow at which the fan medium can be operated without instability.

Specific Fan Power or SFP – is a measure of overall system energy efficiency and is defined as the installed motor power of all fans in an air distribution system divided by the design air flow rate. It is expressed in kW per 1000 CFM or kW per m^3.

Specific gravity – the ratio of the weight or mass of a given volume of any substance to that of an equal volume of some other substance taken as a standard. The ratio of the density of any gas to the density of dry air at the same temperature and pressure is the specific gravity of the gas.

Standard air density – 0.075 lbs per cu. ft, corresponds approximately to dry air at 70°F and 29.92 in. Hg.

Stator – the stationary parts of a magnetic circuit with operating speeds associated windings.

Synchronous speed – of an AC motor, usually expressed in RPM, that is determined by the frequency of the AC supply and the number of poles in the stator winding. Induction motors require a "Slip" in order to operate, and will have an actual operating speed that is lower than synchronous speed. *Synchronous speed (RPM) = 120 x supply frequency (Hz) /(number of poles*).

System curve – graphic presentation of the pressure versus volume flow-rate characteristics of a particular system.

System effect – the difference between the actual flow-pressure characteristics of a fan or a fan system component and the flow-pressure characteristics determined in laboratory tests to obtain performance ratings.

Tachometer – an instrument for measuring speed of rotation; usually in RPM.

Tip speed – fan impeller velocity at a point corresponding to the outside diameter of the impeller blades; normally expressed in feet per minute (circumference times rpm).

Torque – a force that produces rotation; commonly measured in ft-lbs or in-lbs.

Total pressure – the sum of the static pressure and the velocity pressure at the point of measurement.

Tubeaxial fan – axial fan without guide vanes.

Tubular centrifugal fan – fan with a centrifugal impeller within a cylindrical housing that discharges the gas in an axial direction.

Turbulent flow – airflow in which true velocities at a given point vary erratically in speed and direction.

Uniform flow – airflow in which velocities between any two given points are fairly constant.

Vaneaxial fan – axial fan with either inlet or discharge guide vanes or both.

Velocity pressure – the pressure at a point in a fluid such as air existing by virtue of its density and it rate of motion, or velocity; also referred to as dynamic pressure.

Watt – a unit of power measurement; 746 watts are equal to 1 horsepower.

WG – water gauge, used as a pressure measurement. See also "inch of water."

APPENDIX 1 - TROUBLESHOOTING FAN PROBLEMS

Excessive Noise or Vibration

- Belts too loose - worn or oily belts.
- Speed too high.
- Damaged or unbalanced fan rotor.
- Dirt buildup on fan blades.
- Bearings need lubrication or replacement.
- Fan surge.
- Resonance of housing or ductwork.
- Incorrect direction of rotation. Make sure the fan rotates in same direction as the arrows on the motor or belt drive assembly.

Low Air Delivery or Pressure

- Poor fan inlet conditions - There should be a straight clear duct at the inlet.
- Poor fan outlet conditions - modify system to reduce pressure drops.
- Excessive throttling at the fan outlet – check balance or control dampers.
- Excessive system leakage - inspect and repair gaskets, flex connections and duct flanges, etc.

- Improper running clearance resulting in excessive recirculation in fan housing – set proper clearances.
- Incorrect direction of rotation - Make sure the fan rotates in same direction as the arrows on the motor or belt drive assembly.
- Improper wheel alignment.

Overheated Bearings

- Improper bearing lubrication.
- Excessive belt tension.
- Unbalanced fan rotor or dirty fan blades.
- Motor, Fan misalignment.

Overheated Motor

- Motor improperly wired.
- Cooling air diverted or blocked.
- Improper inlet clearance.
- Incorrect fan RPM - adjust pulleys or gearing.
- Motor, Fan misalignment.
- Incorrect direction of rotation - Make sure the fan rotates in same direction as the arrows on the motor or belt drive assembly.
- Incorrect supply voltage.

APPENDIX 2 – WORKSHEETS

a. Fan Audit Data Worksheet

b. Fan Measures and Savings Checklist

FAN AUDIT DATA SHEET

Audit Date:

System Information

System or Location: | Annual Hours of Operation: hrs

System Description:

Fan Information

Fan Manufacturer: | Fan Age: yrs

Fan Model:

Rated Input power: hp or kW (circle one) | Rated Speed: RPM

Actual Flow: (if available) CFM | Actual Pressure: (if available) inches WG

Max. (rated) Flow: CFM | Max. (rated) Pressure: inches WG

Impeller Type: (Circle one) **Forward-curved** **Radial** **Backward-Curved** **Air-Foil**

Other: (specify)

Fan Drive and Controls

Inlet Damper:	% open	control or adjustment: (circle)	**Auto**	**Manual**	**Fixed**
Outlet Damper:	% open		**Auto**	**Manual**	**Fixed**
Inlet Guide Vanes:	% open		**Auto**	**Manual**	**Fixed**

Variable Speed Drive: **No** **Yes** (circle one) | *if yes,* Type: (circle one) **ASD** **Eddy-Current** **Hydraulic coupling** **Wound Rotor** | % speed

Motor-Fan Coupling: (circle one) **Direct Drive** **Belt Drive** | pulley ratio | Adjustable sheaves? **Yes** **No** | **Gear Reducer** | gear ratio

Motor Information

Motor Manufacturer: | Motor Age: yrs

Motor Model:

Nameplate Data: hp | RPM | NEMA | % Efficiency

Volts | FLA

Load Factor and Energy Cost

Average Cost of power $ / kWh

Formula: Three-phase power (kW) = 1.732 x Amps x Volts x Power Factor/1000

Average Annual Operating Cost ($) = Average power (kW) x Annual Operating hours x Average Cost of Power ($/kWh)

Load Duty Cycle

Operating Point	Flow (% or CFM)	Hours per year	Motor Amps	Motor Volts	Damper Setting	Fan Speed (RPM)	Power Factor*	Input Power (kW)	Average Cost ($)
1									-
2									-
3									-
4									-
5									-
Annual Totals		-							-

*** Tip:** Power factor (PF) varies with motor load; estimate the PF at the operating point from manufacturer's data sheets or use typical values

Fan Measures / Savings Checklist

Complete the Fan Audit Worksheets and then focus attention on fan equipment and systems with higher energy usage and better opportunities for efficiency improvements. These will typically have longer operating hours (eg, > 4000 hrs/yr), larger motor sizes and variable air requirements over time (ie, airflow requirements could vary daily, weekly or by season).

Step	Energy Management Actions		
Determine the Need	*NOTE: Much of this step will have been accomplished while completing the Fan Audit Worksheets* • Determine the process requirements for air flow, possibly in as a profile over time • Determine the range of pressures that the fan needs to overcome • Determine if the airflow is fixed or variable; is this different than the process requirements • Determine the duration of the need for flow (eg, hours per day)		
	Housekeeping / No-Cost Items	**Low-Cost Items**	**Retrofit Items**
Match the Need	• Provide and use manual control of fans • Turn fans off when not needed • Eliminate leaks in ductwork (e.g. flex joints, gaskets, flanges, etc.) • Eliminate or reduce throttling as a means of flow control (i.e. only use dampers to balance) For fan systems with a fixed flow requirements, reduce airflow to the requirement by: • reducing fan speeds by sheave changes; shutting off extra/backup fan(s) in multiple fan installations.	• Conduct an air balance with using a qualified contractor • Control operating times of fans by automatic controls (e.g. changes in control software) • Use variable inlet dampers instead of parallel blade or butterfly dampers to trim airflow.	For fan systems with a variable flow requirements, vary flow by: • using a two-speed motor; • using an adjustable speed drive.
Maximize Efficiency	• Provide proper maintenance for fans: o Lubrication o Belts & Pulleys o Fan overhaul and cleaning • Reduce pressure drops / ductwork resistance by: o Maintain air filters o Select filters with lower pressure drop o Clean inside of ductwork, heating/cooling coils, silencers	• Reduce pressure drops / ductwork resistance by: o Streamline duct connections at fan inlet and outlet to reduce losses o Avoid sharp elbows in ductwork where possible; if not, install turning vanes. o Modify system to reduce turbulence and flow obstructions	• Select and install a more efficient fan: o More appropriate design for application; o New equipment / technology. • If motor oversized (e.g. max loading at or below 50% rating), replace with a properly sized motor. • Install a more efficient motor. • Reduce pressure drops /ductwork resistance by: o Increase duct size where possible

APPENDIX 3 – CONVERSION FACTORS

Area:	1 in^2 = 0.6452 x 10^{-} m^2 = 645.2mm^2 1 ft^2 = 0.0929 m^2
Density:	1 oz. = 28.35 g 1 lb/ft^3 = 16.02 kg/m^3
Gravitational Constant	32.2 feet per second per second 9.81 m/ s^2
Length:	1 in = 25.4 mm 1 ft = 0.3048 m
Mass:	1 lb = 0.4536 kg
Power:	1 hp = 0.7457 kW
Pressure:	1 in W.G. = 0.2484 kPa W.G. @ 68°F 1 in Hg = 3.386 kPa, Hg @ 32°F 1 psi = 6.895 kPa 1 kPa = 1000 N/m^2 1 atm = 14.696 psi 1 bar = 14.504 psi 1 in Hg = 13.63 in W.G.
Temperature:	1 °F = 0.556 °C 0 °C Corresponds to 32 °F, 273.2 K and 491.7 R For °F to °C : TC = (TF - 32) x .556 For °F to °R : TR = TF + 459.7 For °C to °K : TK = TC + 273.2
Velocity:	1 fpm = 5.08 x 10^{-3} m/s 1 ft./s = 0.3048 m/s
Volume Flow:	1 CFM = 0.4719 x 10^{-3} m^3/s 1 Imp. GPM = 0.2728 m^3/hr = 4.546 L/min 1 US GPM = 0.2271 m^3/hr = 3.785 L/min
Volume:	1 in^3 = 16.387 ml 1 ft^3 = 0.02832 m^3 1 Imp. Gallon = 4.546 L 1 US Gallon = 3.785 L 1 L = 1 x 10^{-3} m^3 1 US Gallon = 0.13368 ft^3 1 Imp. Gallon = 1.20095 US Gallon

Appendix 3 – Conversion Factors

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Your feedback and comments are appreciated.
Please provide suggestions to:

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Energy Efficiency is Good Business

- Economic Prosperity
- Environmental Performance
- Social Responsibility
- Security