FANS AND BLOWERS

1. INTRODUCTION

This section describes the main features of fans and blowers.

1.1 What are fans and blowers?

Most manufacturing plants use fans and blowers for ventilation and for industrial processes that need an air flow. Fan systems are essential to keep manufacturing processes working, and consist of a fan, an electric motor, a drive system, ducts or piping, flow control devices, and air conditioning equipment (filters, cooling coils, heat exchangers, etc.). An example system is illustrated in Figure 1. The US Department of Energy estimates that 15 percent of electricity in the US manufacturing industry is used by motors. Similarly, in the commercial sector, electricity needed to operate fan motors composes a large portion of the energy costs for space conditioning (US DOE, 1989).

Fans, blowers and compressors are differentiated by the method used to move the air, and by the system pressure they must operate against. The American Society of Mechanical Engineers (ASME) uses the specific ratio, which is the ratio of the discharge pressure over the suction pressure, to define fans, blowers and compressors (see Table 1).

Table 1: Difference between Fans, Blowers and Compressors (Ganasean)

Equipment	Specific Ratio	Pressure rise (mmWg)
Fans	up to 1.11	1136
Blowers	1.11 to 1.20	1136 –2066
Compressors	more than 1.20	-

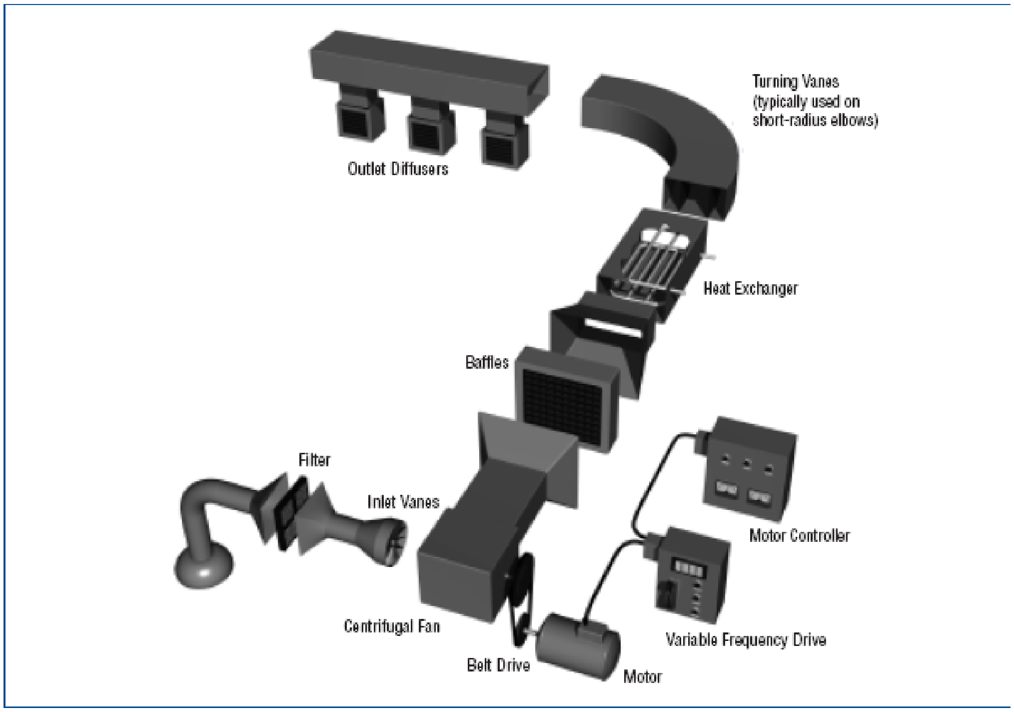


Figure 1: Typical Fan System Components (US DOE, 1989)

1.2 Important terms and definitions

Before types of fans and blowers are described it is important to first understand terms and definitions.[1]

1.2.1 System characteristics

The term "system resistance" is used when referring to the static pressure. The system resistance is the sum of static pressure losses in the system. The system resistance is a function of the configuration of ducts, pickups, elbows and the pressure drops across equipment, for example bag filter or cyclone. The system resistance varies with the square of the volume of air flowing through the system. For a given volume of air, the fan in a system with narrow ducts and multiple short radius elbows is going to have to work harder to overcome a greater system resistance than it would in a system with larger ducts and a minimum number of long radius turns. Long narrow ducts with many bends and twists will require more energy to pull the air through them. Consequently, for a given fan speed, the fan will be able to pull less air through this system than through a short system with no elbows. Thus, the system resistance increases substantially as the volume of air flowing through the system increases; square of air flow.

Conversely, resistance decreases as flow decreases. To determine what volume the fan will produce, it is therefore necessary to know the system resistance characteristics. In existing systems, the system resistance can be measured. In systems that have been designed, but not built, the system resistance must be calculated. Typically a system resistance curve (see

[1] Except for Figure 2, Section 1.2 is taken (with edits) from *Energy Efficiency Guide Book* (2004), Chapter 5, p 93-112, with permission from the Bureau of Energy Efficiency, Government of India.

Figure 2) is generated with for various flow rates on the x-axis and the associated resistance on the y-axis.

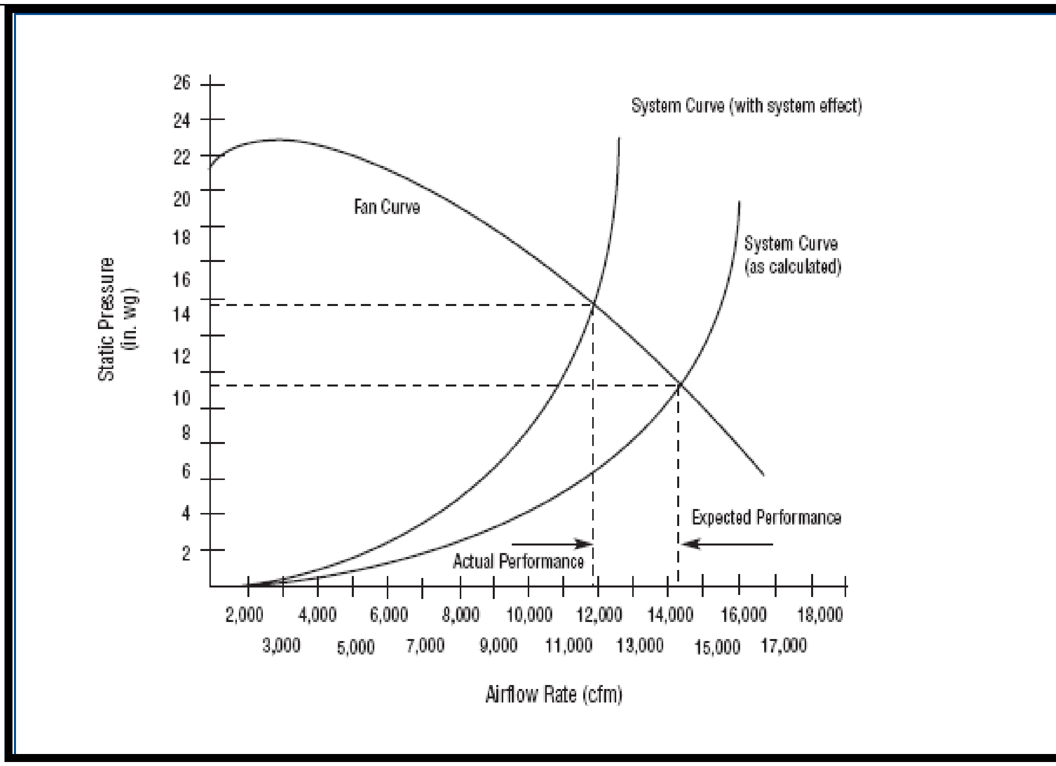


Figure 2. System Curve of a Fan and Effect of System Resistance (US DOE, 1989)

1.2.2 Fan characteristics

Fan characteristics can be represented in form of fan curve(s). The fan curve is a performance curve for the particular fan under a specific set of conditions. The fan curve is a graphical representation of a number of inter-related parameters. Typically a curve will be developed for a given set of conditions usually including: fan volume, system static pressure, fan speed, and brake horsepower required to drive the fan under the stated conditions. Some fan curves will also include an efficiency curve so that a system designer will know where on that curve the fan will be operating under the chosen conditions (see Figure 3). Of the many curves shown in the figure, the curve static pressure (SP) versus flow is especially important.

The intersection of the system curve and the static pressure curve defines the operating point. When the system resistance changes, the operating point also changes. Once the operating point is fixed, the power required can be determined by following a vertical line that passes through the operating point to an intersection with the power (BHP) curve. A horizontal line drawn through the intersection with the power curve will lead to the required power on the right vertical axis. In the depicted curves, the fan efficiency curve is also presented.

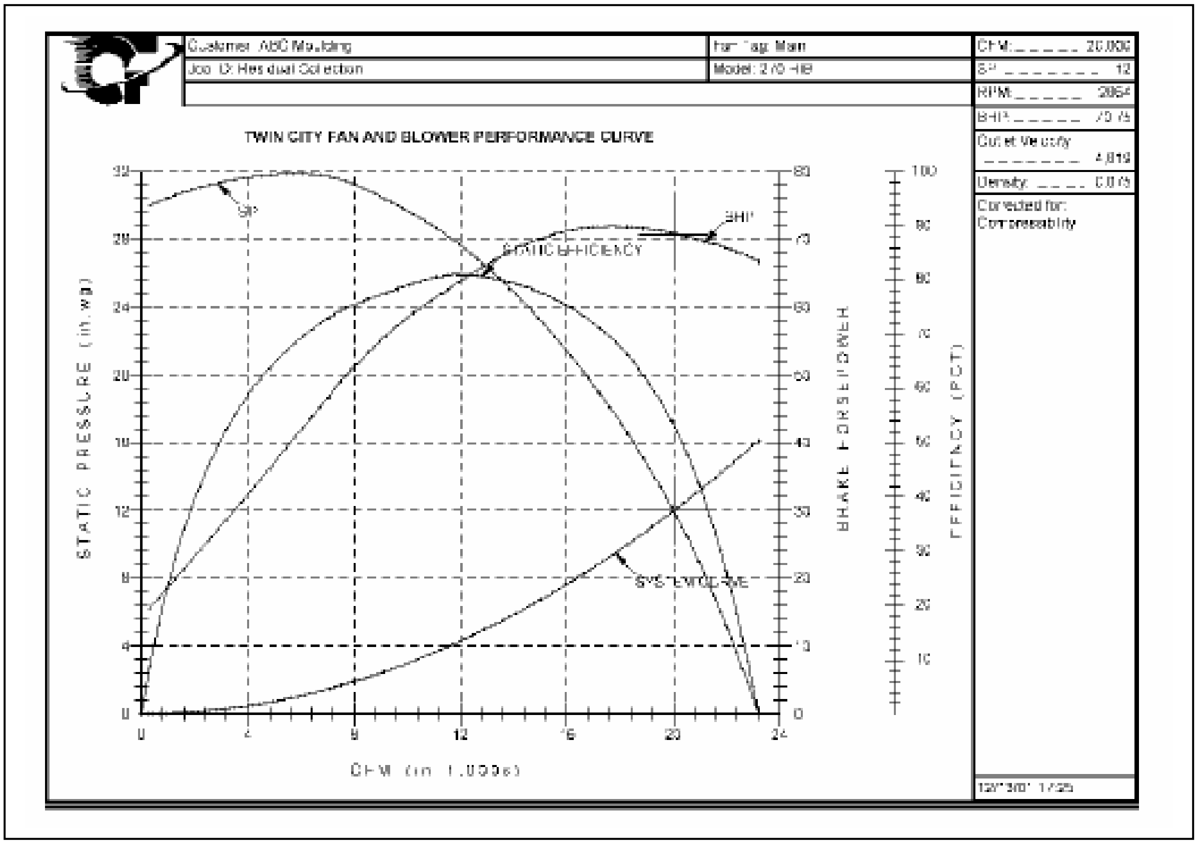


Figure 3. Typical Fan Efficiency Curve (BEE India, 2004)

1.2.3 System characteristics and fan curves

In any fan system, the resistance to air flow (pressure) increases when the flow of air is increased. As mentioned before, it varies as the square of the flow. The pressure required by a system over a range of flows can be determined and a "system performance curve" can be developed (shown as SC) (see Figure 4).

This system curve can then be plotted on the fan curve to show the fan's actual operating point at "A" where the two curves (N_1 and SC_1) intersect. This operating point is at air flow Q_1 delivered against pressure P_1. A fan operates at a performance given by the manufacturer for a particular fan speed. (The fan performance chart shows performance curves for a series of fan speeds.) At fan speed N_1, the fan will operate along the N_1 performance curve as shown in Figure 4. The fan's actual operating point on this curve will depend on the system resistance; fan's operating point at "A" is flow (Q_1) against pressure (P_1).

Two methods can be used to reduce air flow from Q_1 to Q_2:

- The first method is to restrict the air flow by partially closing a damper in the system. This action causes a new system performance curve (SC_2) where the required pressure is greater for any given air flow. The fan will now operate at "B" to provide the reduced air flow Q_2 against higher pressure P_2.
- The second method to reduce air flow is by reducing the speed from N_1 to N_2, keeping the damper fully open. The fan would operate at "C" to provide the same Q_2 air flow, but at a lower pressure P_3. Thus, reducing the fan speed is a much more efficient method to decrease airflow since less power is required and less energy is consumed.

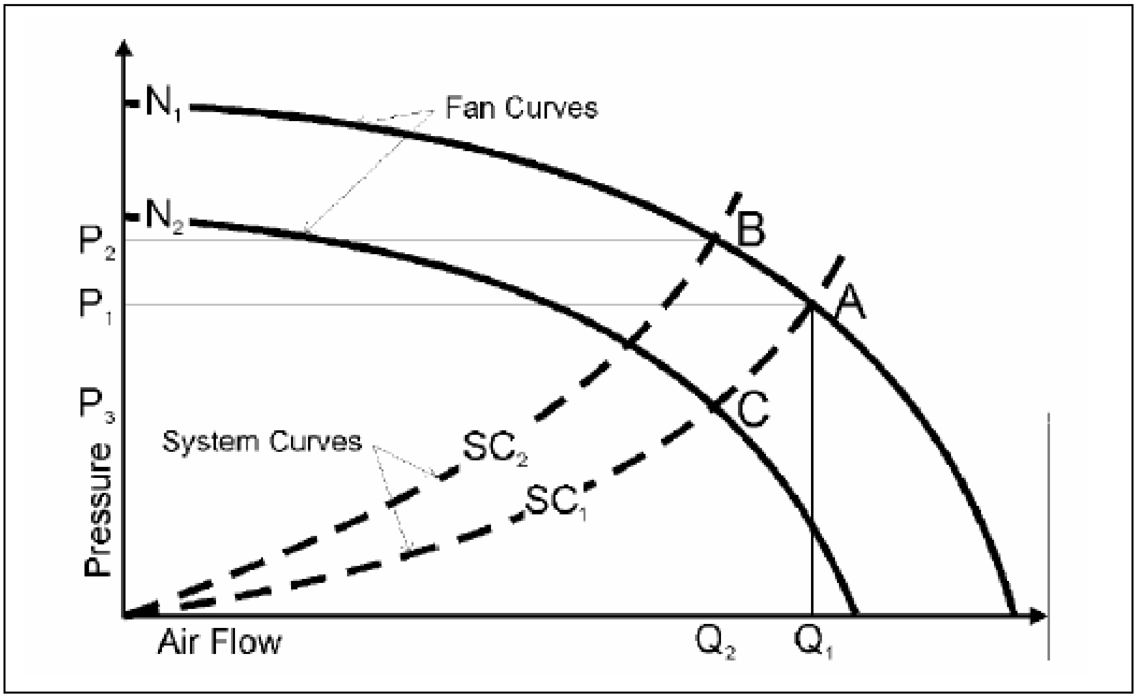
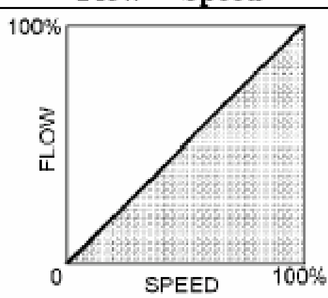
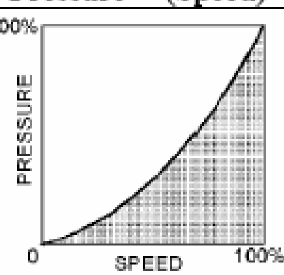
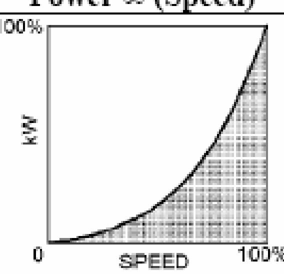


Figure 4. Fan performance curve (BEE India, 2004)

1.2.4 Fan laws

The fans operate under a predictable set of laws concerning speed, power and pressure. A change in speed (revolutions per minute or RPM) of any fan will predictably change the pressure rise and power necessary to operate it at the new RPM. This is shown in Figure 5.

Flow ∞ Speed	Pressure ∞ (Speed)^2	Power ∞ (Speed)^3
		
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{SP_1}{SP_2} = \left(\frac{N_1}{N_2}\right)^2$	$\frac{kW_1}{kW_2} = \left(\frac{N_1}{N_2}\right)^3$
Varying the RPM by 10% decreases or increases air delivery by 10%.	*Reducing the RPM by 10% decreases the static pressure by 19% and an increase in RPM by 10% increases the static pressure by 21%.*	*Reducing the RPM by 10% decreases the power requirement by 27% and an increase in RPM by 10% increases the power requirement by 33%.*

Where Q – flow, SP – Static Pressure, kW – Power and N – speed (RPM)

Figure 5. Speed, pressure and power of fans (BEE India, 2004)

2. Type of fans and blowers

This section briefly describes different types of fans and blowers.

2.1 Types of fans

There exist two main fan types. Centrifugal fans used a rotating impeller to move the air stream. Axial fans move the air stream along the axis of the fan.

2.1.1 Centrifugal fans

Centrifugal fans (Figure 6) increase the speed of an air stream with a rotating impeller. The speed increases as the reaches the ends of the blades and is then converted to pressure. These fans are able to produce high pressures, which makes them suitable for harsh operating conditions, such as systems with high temperatures, moist or dirty air streams, and material handling. Centrifugal fans are categorized by their blade shapes as summarized in Table 2.

Table 2. Characteristics of Different Centrifugal Fans (adapted from US DOE, 1989)

Type of fan and blade	**Advantages**	**Disadvantages**
Radial fans, with flat blades (Figure 7)	▪ Suitable for high static pressures (up to 1400 mmWC) and high temperatures ▪ Simple design allows custom build units for special applications ▪ Can operate at low air flows without vibration problems ▪ High durability ▪ Efficiencies up to 75% ▪ Have large running clearances, which is useful for airborne-solids (dust, wood chips and metal scraps) handling services	▪ Only suitable for low-medium airflow rates
Forward curved fans, with forward curved blades (Figure 8)	▪ Can move large air volumes against relatively low pressure ▪ Relative small size ▪ Low noise level (due to low speed) and well suited for residential heating, ventilation, and air conditioning (HVAC) applications	▪ Only suitable for clean service applications but not for high pressure and harsh services ▪ Fan output is difficult to adjust accurately ▪ Driver must be selected carefully to avoid motor overload because power curve increases steadily with airflow ▪ Relatively low energy efficiency (55-65%)
Backward inclined fan, with blades that tilt away from the direction of rotation: flat, curved, and airfoil (Figure 9)	▪ Can operate with changing static pressure (as this does not overload the motor) ▪ Suitable when system behavior at high air flow is uncertain ▪ Suitable for forced-draft services ▪ Flat bladed fans are more robust ▪ Curved blades fans are more efficient (exceeding 85%) ▪ Thin air-foil blades fans are most efficient	▪ Not suitable for dirty air streams (as fan shape promotes accumulation of dust) ▪ Airfoil blades fans are less stable because of staff as they rely on the lift created by each blade ▪ Thin airfoil blades fans subject to erosion

Figure 6. Centrifugal Fan
(FanAir Company)

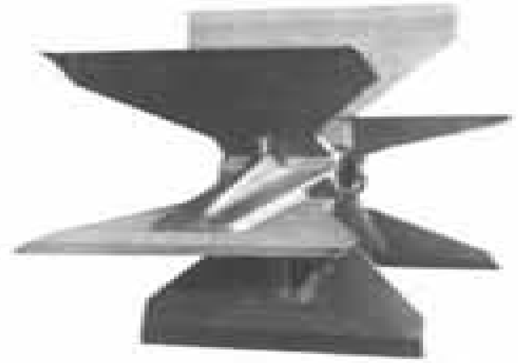


Figure 7. Radial Blade Centrifugal Fan (Canadian Blower)

Figure 8. Forward-Curved Fan
(Canadian Blower)

Figure 9. Backward Inclined Fan
(Canadian Blower)

2.1.2 Axial fans

Axial fans (Figure 10) move an air stream along the axis of the fan. The way these fans work can be compared to a propeller on an airplane: the fan blades generate an aerodynamic lift that pressurizes the air. They are popular with industry because they are inexpensive, compact and light. The main types of axial flow fans (propeller, tube-axial and vane-axial) are summarized in Table 3.

Table 3. Characteristics of Different Axial Fans (adapted from US DOE, 1989)

Type of fan	Advantages	Disadvantages
Propeller fan (Figure 11)	▪ Generate high airflow rates at low pressures ▪ Not combined with extensive ductwork (because the generate little pressure) ▪ Inexpensive because of their simple construction ▪ Achieve maximum efficiency, near-free delivery, and are often used in rooftop ventilation applications ▪ Can generate flow in reverse direction, which is helpful in ventilation applications	▪ Relative low energy efficiency ▪ Comparatively noisy
Tube-axial fan, essentially a propeller fan	▪ Higher pressures and better operating efficiencies than propeller fans ▪ Suited for medium-pressure, high airflow rate	▪ Relatively expensive ▪ Moderate

Type of fan	**Advantages**	**Disadvantages**
placed inside a cylinder (Figure 12)	applications, e.g. ducted HVAC installations ▪ Can quickly accelerate to rated speed (because of their low rotating mass) and generate flow in reverse direction, which is useful in many ventilation applications ▪ Create sufficient pressure to overcome duct losses and are relatively space efficient, which is useful for exhaust applications	airflow noise ▪ Relatively low energy efficiency (65%)
Vane-axial fan (Figure 13)	▪ Suited for medium- to high-pressure applications (up to 500 mmWC), such as induced draft service for a boiler exhaust ▪ Can quickly accelerate to rated speech (because of their low rotating mass) and generate flow in reverse directions, which is useful in many ventilation applications ▪ Suited for direct connection to motor shafts ▪ Most energy efficient (up to 85% if equipped with airfoil fans and small clearances)	▪ Relatively expensive compared to propeller fans

Figure 10. Axial Fan (NISCO)

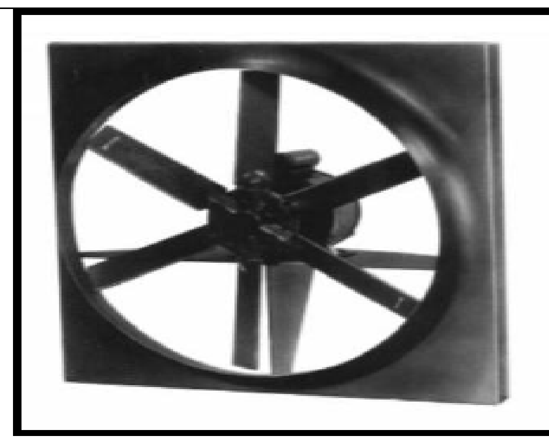


Figure 11. Propeller Fans (FanAir Company)

Figure 12. Tube Axial Fan (NISCO)

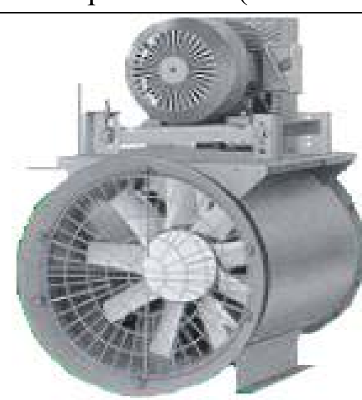


Figure 13. Vane-axial Fan (NISCO)

2.2 Types of blowers

Blowers can achieve much higher pressures than fans, as high as 1.20 kg/cm^2. They are also used to produce negative pressures for industrial vacuum systems. The centrifugal blower and the positive displacement blower are two main types of blowers, which are described below.[2]

2.2.1 Centrifugal blowers

Centrifugal blowers look more like centrifugal pumps than fans. The impeller is typically gear-driven and rotates as fast as 15,000 rpm. In multi-stage blowers, air is accelerated as it passes through each impeller. In single-stage blower, air does not take many turns, and hence it is more efficient.

Centrifugal blowers typically operate against pressures of 0.35 to 0.70 kg/cm^2, but can achieve higher pressures. One characteristic is that airflow tends to drop drastically as system pressure increases, which can be a disadvantage in material conveying systems that depend on a steady air volume. Because of this, they are most often used in applications that are not prone to clogging.

Figure 14. Centrifugal Blower (FanAir Company)

2.2.2 Positive-displacement blowers

Positive displacement blowers have rotors, which "trap" air and push it through housing. These blowers provide a constant volume of air even if the system pressure varies. They are especially suitable for applications prone to clogging, since they can produce enough pressure (typically up to 1.25 kg/cm^2) to blow clogged materials free. They turn much slower than centrifugal blowers (e.g. 3,600 rpm) and are often belt driven to facilitate speed changes.

[2] Section 2.2 is based on *Energy Efficiency Guide Book* (2004), Chapter 5, p 93-112, with permission from the Bureau of Energy Efficiency, Government of India

3. ASSESSMENT OF FANS AND BLOWERS

This section describes how to evaluate the performance of fans, but it is also applicable to blowers.[3]

3.1 What is fan efficiency / performance?

Fan efficiency is the ratio between the power transferred to the air stream and the power delivered by the motor to the fan. The power of the airflow is the product of the pressure and the flow, corrected for unit consistency.

Another term for efficiency that is often used with fans is static efficiency, which uses static pressure instead of total pressure in estimating the efficiency. When evaluating fan performance, it is important to know which efficiency term is being used.

The fan efficiency depends on the type of fan and impeller. As the flow rate increases, the efficiency increases to certain height ("peak efficiency") and then decreases with further increasing flow rate (see Figure 15). The peak efficiency ranges for different types of centrifugal and axial fans are given in Table 2.

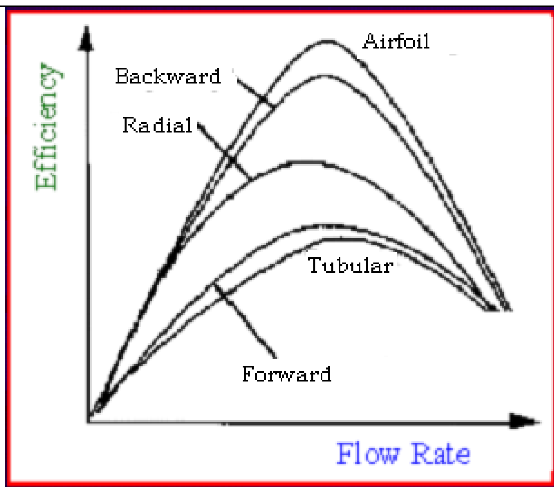


Figure 14. Efficiency versus Flowrate
(BEE India, 2004)

Type of fan	Peak Efficiency Range
Centrifugal Fan	
Airfoil, backward curved/inclined	79-83
Modified radial	72-79
Radial	69-75
Pressure blower	58-68
Forward curved	60-65
Axial fan	
Vanaxial	78-85
Tubeaxial	67-72
Propeller	45-50

Table 4. Efficiency of Various Fans
(BEE India, 2004)

Fan performance is typically estimated by using a graph that shows the different pressures developed by the fan and the corresponding required power. The manufacturers normally provide these fan performance curves. Understanding this relationship is essential to designing, sourcing, and operating a fan system and is the key to optimum fan selection.

[3] Section 3 is based on *Energy Efficiency Guide Book* (2004), Chapter 5, p 93-112, with permission from the Bureau of Energy Efficiency, Government of India

3.2 Methodology of fan performance assessment

Before the fan efficiency can be calculated, a number of operating parameters must be measured, including air velocity, pressure head, temperature of air stream on the fan side and electrical motor kW input. In order to obtain correct operating figures it should be ensured that:

- Fan and its associated components are operating properly at its rated speed
- Operations are at stable condition i.e. steady temperature, densities, system resistance etc.

The calculation of fan efficiency is explained in 5 steps.

Step 1: calculate the gas density

The first step is to calculate the air or gas density using the following equation:

$$\text{Gas density } (y) = \frac{273 \times 1.293}{273 + t\,^{o}C}$$

Where, t ^{o}C = Temperature of air or gas at site condition

Step 2: measure the air velocity and calculate average air velocity

The air velocity can be measured with a pitot tube and a manometer, or a flow sensor (differential pressure instrument), or an accurate anemometer. Figure 15 shows how the velocity pressure is measured using a pitot tube and a manometer. The total pressure is measured using the inner tube of pitot tube and static pressure is measured using the outer tube of pitot tube. When the inner and outer tube ends are connected to a manometer, we get the velocity pressure (i.e. the difference between total pressure and static pressure). For measuring low velocities, it is preferable to use an inclined tube manometer instead of U-tube manometer. See the chapter on Monitoring Equipment for a explanation of manometers.

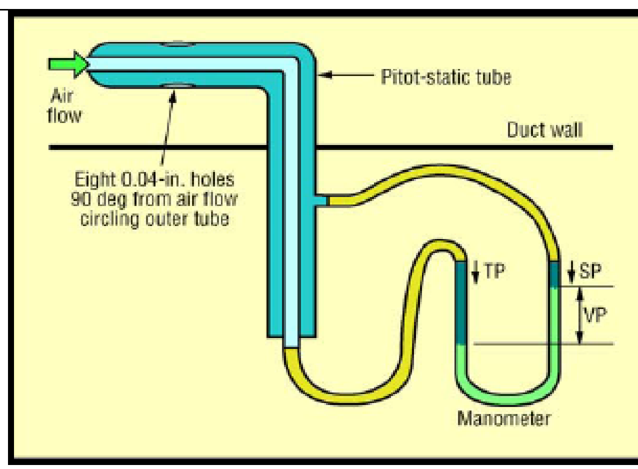


Figure 16. Velocity Pressure Measurement using Pilot Tube
(BEE India, 2004)

Calculate the average air velocity by taking number of velocity pressure readings across the cross-section of the duct using the following equation (note: do not average the velocity pressure, but average the velocities!):

$$\text{Velocity v, m/s} = \frac{C_p \text{ x } \sqrt{2 \times 9.81 \times \Delta p \times \gamma}}{\gamma}$$

Where:

C_p = Pitot tube constant, 0.85 (or) as given by the manufacturer

Δp = Average differential pressure measured by pitot tube by taking measurement at number of points over the entire cross section of the duct.

γ = Density of air or gas at test condition

Step 3: calculate the volumetric flow

The third step is to calculate the volumetric flow as follows:

- Take the duct diameter (or the circumference from which the diameter can be estimated).
- Calculate the volume of air/gas in the duct by following relation

$$Volumetric\ flow(Q), m^3/\sec = Velocity, V\ (m/\sec)\ x\ Area\ (m^2)$$

Step 4: measure the power of the drive motor

The power of the drive motor (kW) can be measured by a load analyzer. This kW multiplied by motor efficiency gives the shaft power to the fan.

Step 5: calculate the fan efficiency

Now the fan's mechanical and static efficiencies can be calculated as follows:

a). Mechanical efficiency:

$$Fan\ Mechanical\ Efficiency\ (\eta_{mechanical}), \% = \frac{Volume\ in\ m^3/\sec * \Delta p\ (total\ pressure)\ in\ mmWC}{102 * power\ input\ to\ fan\ shaft\ in\ kW}\ x\ 100$$

b) Static efficiency, which is the same except that the outlet velocity pressure is not added to the fan static pressure:

$$Fan\ Static\ Efficiency\ (\eta_{static}), \% = \frac{Volume\ in\ m^3/\sec * \Delta p\ (static\ pressure)\ in\ mmWC}{102 * power\ input\ to\ fan\ shaft\ in\ kW}\ x\ 100$$

3.3 Difficulties in assessing the performance of fans and blowers

In practice certain difficulties have to be faced when assessing the fan and blower performance, some of which are explained below:

- ***Non-availability of fan specification data*****:** Fan specification data (see Worksheet 1) are essential to assess the fan performance. Most of the industries do not keep these data systematically or have none of these data available at all. In these cases, the percentage of fan loading with respect to flow or pressure can not be estimated satisfactorily. Fan specification data should be collected from the original equipment manufacturer (OEM) and kept on record.
- ***Difficulty in velocity measurement*****:** Actual velocity measurement becomes a difficult task in fan performance assessment. In most cases the location of duct makes it difficult to take measurements and in other cases it becomes impossible to traverse the duct in both directions. If this is the case, then the velocity pressure can be measured in the center of the duct and corrected by multiplying it with a factor 0.9.
- ***Improper calibration of the pitot tube, manometer, anemometer & measuring instruments***: All instruments and other power measuring instruments should be calibrated correctly to avoid an incorrect assessment of fans and blowers. Assessments should not be carried out by applying correction factors to compensate for this.
- ***Variation of process parameters during tests****:* If there is a large variation of process parameters measured during test periods, then the performance assessment becomes unreliable.

4. ENERGY EFFICIENCY OPPORTUNITIES

This section describes the most important energy efficiency opportunities for fans and blowers.

4.1 Choose the right fan

Important considerations when selecting a fan are (US DOE, 1989):
- Noise
- Rotational speed
- Air stream characteristics
- Temperature range
- Variations in operating conditions
- Space constraints and system layout
- Purchase costs, operating costs (determined by efficiency and maintenance), and operating life

But as a general rule it is important to know that to effectively improve the performance of fan systems, designers and operators must understand how other system components function as well. The "systems approach" requires knowing the interaction between fans, the equipment that supports fan operation, and the components that are served by fans. The use of a "systems approach" in the fan selection process will result in a quieter, more efficient, and more reliable system.

A common problem is that companies purchase oversized fans for their service requirements. They will not operate at their best efficiency point (BEP) and in extreme cases these fans may operate in an unstable manner because of the point of operation on the fan airflow-pressure curve. Oversized fans generate excess flow energy, resulting in high airflow noise and increased stress on the fan and the system. Consequently, oversized fans not only cost more to purchase and to operate, they create avoidable system performance problems. Possible solutions include, amongst other replacing the fan, replacing the motor, or introducing a variable speed drive motor.

4.2 Reduce the system resistance

The system resistance curve and the fan curve were explained in section 1.2. The fan operates at a point where the system resistance curve and the fan curve intersects. The system resistance has a major role in determining the performance and efficiency of a fan. The system resistance also changes depending on the process. For example, the formation of the coatings / erosion of the lining in the ducts, changes the system resistance marginally. In some cases, the change of equipment, duct modifications, drastically shift the operating point, resulting in lower efficiency (See Figure 2). In such cases, to maintain the efficiency as before, the fan has to be changed.

Hence, the system resistance has to be periodically checked, more so when modifications are introduced and action taken accordingly, for efficient operation of the fan.

4.3 Operate close to BEP

It is earlier described that the fan efficiency increases as the flow increases to certain point and thereafter it decreases. The point at which maximum efficiency is obtained is called the peak efficiency or "Best Efficiency Point" (BEP). Normally it is closer to the rated capacity of the fan at a particular designed speed and system resistance. Deviation from the BEP will result in increased loss and inefficiency.

4.4 Maintain fans regularly

Regular maintenance of fans is important to maintain their performance levels. Maintenance activities include (US DOE, 1989):

- Periodic inspection of all system components
- Bearing lubrication and replacement
- Belt tightening and replacement
- Motor repair or replacement
- Fan cleaning

4.5 Control the fan air flow

Normally, an installed fan operates at a constant speed. But some situations may require a speed change, for example more airflow may be needed from the fan when a new run of duct is added, or less air flow may be needed if the fan is oversized. There are several ways to reduce or control the airflow of fans. These are summarized in Table 5 and a comparison of full load power against percentage full flow by different flow control is given in Figure 17.

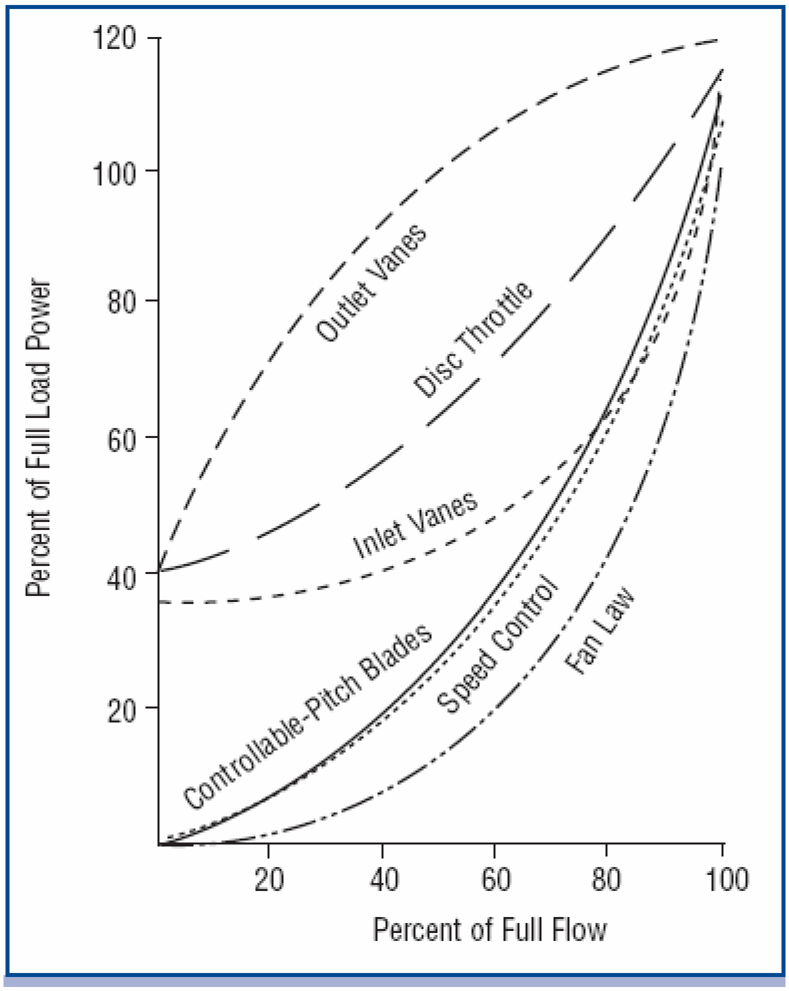


Figure 17. Relative Power Consumption among Flow Control Options (US DOE, 1989)

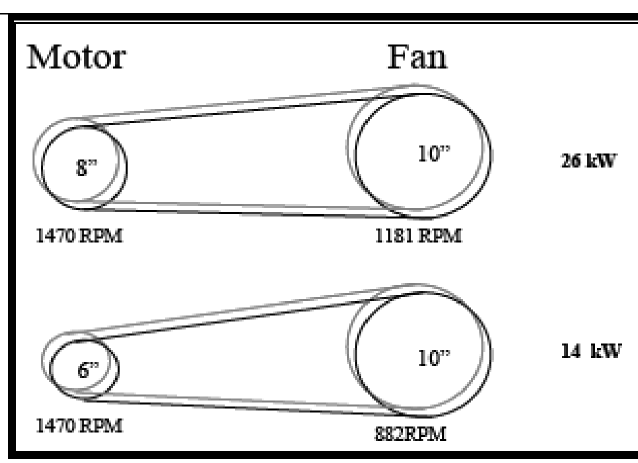


Figure 18. Pulley Dimension Change (BEE India, 2004)

Table 5. Comparison of Different Ways to Control Fan Flow (adapted from US DOE, 1989, and BEE, 2004)

Type of flow control	Advantages	Disadvantages
Pulley change: reduces the motor / drive pulley size	▪ Permanent speed decrease ▪ Real energy reduction (see Figure 18: a 2 inch reduction in pulley results in 12 kW savings)	▪ Fan must be able to handle capacity change ▪ Fan must be driven by V-belt system or motor
Dampers: reduce the amount of flow and increases the upstream pressure, which reduces fan output	▪ Inexpensive ▪ Easy to install	▪ Provide a limited amount of adjustment ▪ Reduce the flow but not the energy consumption ▪ Higher operating and maintenance costs
Inlet guide vanes: create swirls in the fan direction thereby lessening the angle between incoming air and fan blades, and thus lowering fan load, pressure and airflow	▪ Improve fan efficiency because both fan load and delivered airflow are reduced ▪ Cost effective at airflows between 80-100% of full flow	▪ Less efficient at airflows lower than 80% of full flow
Variable pitch fans: change the angle between incoming airflow and the blade by tilting the fan blades, thereby reducing both the motor load and airflow	▪ Can keep fan efficiency high over a range of operating conditions. ▪ Avoid resonance problems as normal operating speed is maintained ▪ Can operate from a no-flow to a full-flow condition without stall problems	▪ Applicable to some axial fan types only ▪ Fouling problems if contaminants accumulate in the mechanical actuator that controls the blades ▪ Operating at low loads for long periods reduces the power factor and motor efficiency, thus loosing efficiency advantages and risking low power factor charge from the utility
Variable Speed Drive (VSD): reducing the speed of motor of the fan to meet reduced flow requirements ▪ Mechanical VSDs: hydraulic clutches, fluid couplings, and adjustable belts and pulleys ▪ Electrical VSDs: eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs: change motor's rotational speed by adjusting electrical frequency of power supplied)	▪ Most improved and efficient flow control ▪ Allow fan speed adjustments over a continuous range For VFDs specifically: ▪ Effective and easy flow control ▪ Improve fan operating efficiency over a wide range of operating conditions ▪ Can be retrofitted to existing motors Compactness ▪ No fouling problems ▪ Reduce energy losses and costs by lowering overall system flow	▪ Mechanical VSDs have fouling problems ▪ Investment costs can be a barrier

Type of flow control	Advantages	Disadvantages
Multiple speed pump	▪ Efficient control of flow ▪ Suitable if only two fixed speeds are required	▪ Need to jump from speed to speed ▪ Investment costs can be a barrier
Disc throttle: a sliding throttle that changes the width of the impeller that is exposed to the air stream	▪ Simple design	▪ Feasible in some applications only
Operate fans in parallel: two or more fans in parallel instead of one large one	▪ High efficiencies across wide variations in system demand ▪ Redundancy to mitigate the risk of downtime because of failure or unexpected maintenance ▪ Two smaller fans are less expensive and offer better performance than one relatively large one ▪ Can be equipped with other flow controls to increase flexibility and reliability	▪ Should only be used when the fans can operate in a low resistance almost in a free delivery condition (see Figure 19)
Operate fans in series: using multiple fans in a push-pull arrangement	▪ Lower average duct pressure ▪ Lower noise generation ▪ Lower structural and electrical support requirements ▪ Suited for systems with long ducts, large pressure drops across system components, or high resistances	▪ Not suited for low resistance systems (see Figure 19)

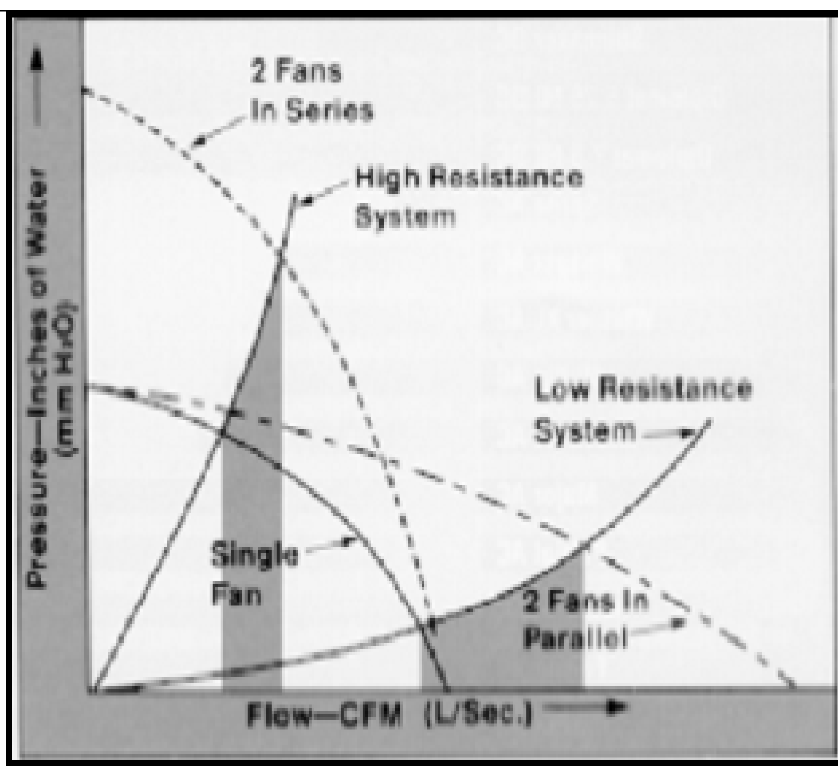


Figure 19. Fans Operating in Series and in Parallel (BEE India, 2004)

5. OPTION CHECKLIST

This section lists the most important energy efficiency options.

- Use smooth, well-rounded air inlet cones for fan air intake
- Avoid poor flow distribution at the fan inlet
- Minimize fan inlet and outlet obstructions
- Clean screens, filters and fan blades regularly
- Minimize fan speed
- Use low slip or flat belts for power transmission
- Check belt tension regularly
- Eliminate variable pitch pulleys
- Use variable speed drives for large variable fan loads
- Use energy-efficient motors for continuous or near continuous operation
- Eliminate leaks in duct works
- Minimize bends in duct works
- Turn fans and blowers off when not needed
- Reduce the fan speed by pulley diameter modifications incase of oversized motors
- Adopt inlet guide vanes in place of discharge damper control
- Change metallic / Glass reinforced plastic (GRP) impeller by more energy efficient hollow FRP impeller with aerofoil design
- Try to operate the fan near its best operating point (BEP)
- Reduce transmission losses by using energy efficient flat belts or cogged raw-edged V-belts instead of conventional V-belt systems
- Minimizing system resistance and pressure drops by improving the duct system
- Ensure proper alignment between drive and driven system
- Ensure proper power supply quality to the motor drive
- Regularly check for vibration trend to predict any incipient failures like bearing damage, misalignments, unbalance, foundation looseness etc.

6. WORKSHEETS

This section includes following worksheets:

- Fans and Blowers Specification Data
- Fans and Blowers Efficiency Calculation

Worksheet #1: FANS AND BLOWERS SPECIFICATION DATA

No.	**Parameter**	**Units**	**Fan/Blower number**		
			1	**2**	**3**
1	Make				
2	Type (Axial/Centrifugal)				
3	Discharge Flow	m^3/hr			
4	Head Developed	mmWC			
5	Fluid Handlled				
6	Density of Fluid	kg/m^3			
7	Dust Concentration	kg/m^3			
8	Temperature of Fluid	^{0}C			
9	Flow Control Type				
10	Flow Control Range	%			
11	Fan Input Power	kW			
12	Fan Speed	RPM			
13	Fan Rated Efficiency	%			
14	Specific Power Consumption	kW/(m^3/hr)			
15	Fan Motor				
	Rated Power	kW			
	Full Load Current	Amp			
	Rated Speed	RPM			
	Supply Voltage	Volts			
	Rated Efficiency	%			
	Rated Power Factor				
	Supply Frequency	Hz			
16	Bearing Type				
	Fan (Driving End)				
	Fan (Non-Driving End)				
	Motor (Driving End)				
	Motor (Non-Driving End)				
17	Lubricant Grade				

Worksheet 2: FANS AND BLOWERS EFFICIENCY CALCULATION

No.	Parameter	Units	Fan/Blower reference		
			1	2	3
1	Fluid (medium) flow (Q) (measured using pitot tube at fan discharge)	m^3/sec			
2	For suction pressure (measured at fan inlet using U-tube manometer)	mmWC			
3	For discharge pressure (measured at fan discharge using U-tube manometer)	mmWC			
4	Total Static Pressure (ΔP) [3–4]	mmWC			
5	Total Differential Pressure (dP) (measured by pitot tube by taking measurement at number of points over the duct cross section)	mmWC			
6	Pitot tube constant (Cp)				
7	Duct Cross sectional Area (A)	m^2			
8	Temperature of fluid medium (measured at fan inlet using a thermometer)	^{0}C			
9	Density of fluid medium handled (r) (taken from standard data and corrected to operating temperature/pressure conditions)	kg/m^3			
10	Motor input power (P) (measured at motor terminals or switchgear using panel or portable energy meter/power analyzer)	kW			
11	Power input to shaft (P1) (P x motor efficiency X transmission efficiency)	%			
12	Supply frequency	Hz			
13	Pump input power	kW			
14	Air/Gas velocity (V) [= (Cpx√(2x9.81xdPxr)]/r	m/sec			
15	Flow rate (Q) (= V x A)	m^3/sec			
16	Fan mechanical efficiency (ηF) (QxΔP)/(102xP1) x 100	%			
17	Specific Power Consumption (P/Q)	kW/(m^3/sec)			
18	% Motor loading with respect to power	%			
19	% Fan loading with respect to flow	%			
20	% Fan loading with respect to total static pressure	%			

7. REFERENCES

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