Application of Fans in Commercial HVAC Equipment

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INTRODUCTION

The indoor fan is a critical component in every forced-air, space-conditioning system. The fan is the principal means for delivering conditioned air to a space, and therefore the effectiveness of the fan has a direct impact on system efficiency, perceived comfort level, and air quality in the space. There are a variety of fan types and arrangements, each with unique operating properties that lend themselves to particular applications and design requirements.

This paper explores the differences between fan types and describes their application in air handlers and rooftops. In order to select the best fan arrangement for a system, it is important to understand the operating characteristics and application strengths of different types of fans and drives. The type of fan used in a particular unit is based on the equipment designer's knowledge of fan characteristics and evaluation of the operating requirements. The fan selected is the one that best meets the application.

OVERVIEW OF CENTRIFUGAL FAN TYPES

A typical supply fan or impeller (wheel) can be described by the blade constructions. The distinguishing characteristic is the shape of the individual fan blades and their orientation relative to wheel rotation. The airfoil (AF) fan has contour blades that curve away from the direction of rotation. The backward incline (BI) fan is slightly less efficient but similar to the AF fan; the BI wheel has single thickness blades that also curve away from the direction of rotation. The forward-curved (FC) fan blades curve into the direction of wheel rotation.

This paper will focus on the application of FC and AF fans. See Table A in the Appendix for a comparison summary of these types of fans.

Forward-Curved (FC) Fans

Forward-curved fan blades curve into the direction of wheel rotation, producing an air velocity at the blade tip (VR) which is actually greater than the tip (tangential) velocity itself (V2). See Figure 1. This effectively means that a forward-curved fan can move air at greater velocities while requiring less rotational speed than other fan types.

Forward-curved fans are the most commonly used wheel type in HVAC equipment. Forward-curved fans are typically used in low-pressure applications (under 5.0 in. wg), since they can satisfy airflow requirements at lower rotational speeds (typically 800 to 1200 rpm). As a result of lower operating pressures, the design of the forward-curved fan is usually lightweight when compared to other fans and typically has the lowest cost among fan types.

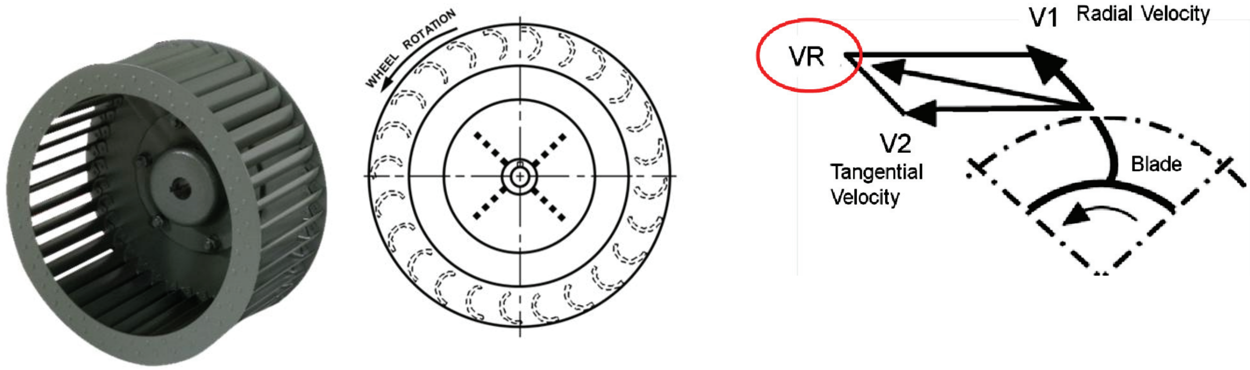

Figure 1 – Forward-Curved Fan Wheel and Rotational Velocities

Airfoil (AF) Fans

Airfoil fans are comprised of individual airfoil blades. Each blade is oriented with the tip pointing opposite to the direction of rotation. This backward orientation results in an air velocity (VR) that is slower than the blade-tip velocity (V2). (See Figure 2.) The result is that the airfoil fan must rotate with higher tip speed than a FC fan in order to move the same amount of air. These higher rotational speeds (1200 to 3000 rpm) and additional stress during operation require a sturdier, more substantial blade cross section and fan structure than that of a slower, forward-curved fan.

Airfoil fans are typically applied in high static applications, ranging from 5 to 10 in. wg or higher. The AF fans are fundamentally more efficient than FC fans due to the ability of the AF fan to produce more of the static pressure rise within the wheel itself. The FC wheel produces little static pressure in the wheel and relies on the scroll of the fan housing to change velocity into static pressure.

Axial Fans

Sometimes referred to as propeller fans, these fans move a great quantity of air, but have very little static pressure capability. In HVAC products, they are almost always used for condenser fans. They may be used for light static exhaust fans.

Figure 3 shows an example of a high-efficiency low noise shrouded outdoor (condenser) fan.

Figure 3 – Axial Condenser Fan

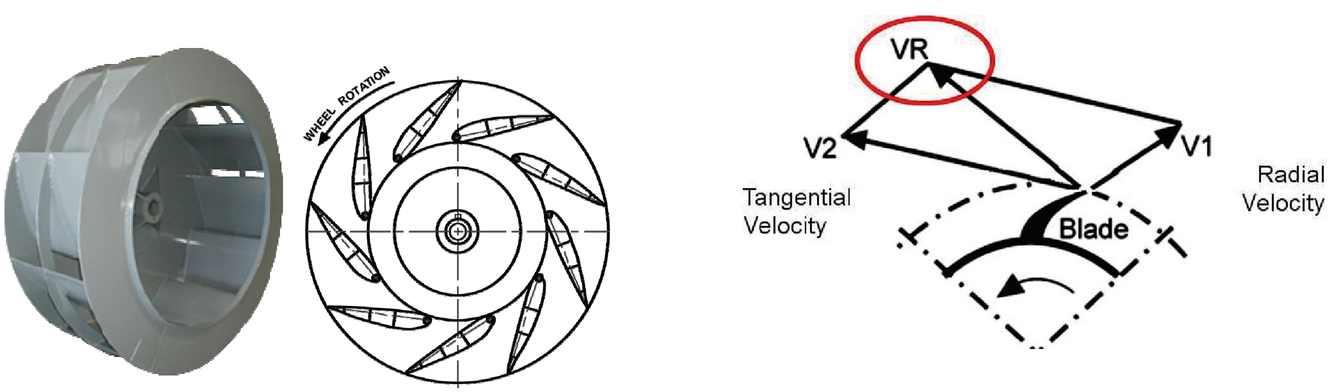

Figure 2 – Airfoil Fan Wheel and Rotational Velocities

Overloading vs Non-Overloading Fans

Another significant difference between FC and AF fans is that, unlike the FC fan, the AF is considered to be a "non-overloading" fan, as it requires relatively constant power input at a given speed, regardless of airflow conditions. As static pressure is lowered at a constant rpm, the fan's bhp remains relatively constant and thus does not "overload."

Forward-curved fans have an overloading horsepower characteristic. In an overloading type fan, as the fan remains at constant rpm and the static pressure is decreased, the brake horsepower requirements of the fan will increase thus "overloading" the fan and motor.

Figure 4 shows the difference between an overloading type fan (FC) and a non-overloading type fan (AF). The FC fan increase in bhp at constant rpm can easily be seen. As the static pressure decreases (shown by the red lines in the graphs below) the rprm lines cross the bhp lines at the points shown by the blue arrows. This increase in bhp may result in over working and damaging the motor. The AF fan has rpm lines and bhp lines that are nearly parallel to one another. Airfoil fans, which have the highest rpm capabilities of all fan choices, may require the highest motor horsepower for those high rpm operating points.

In new construction where ductwork is not complete or when ducting is changed for remodeling, caution should be taken to make sure that the FC fan does not operate in the overloading area. Overall static pressure on the fan must be maintained.

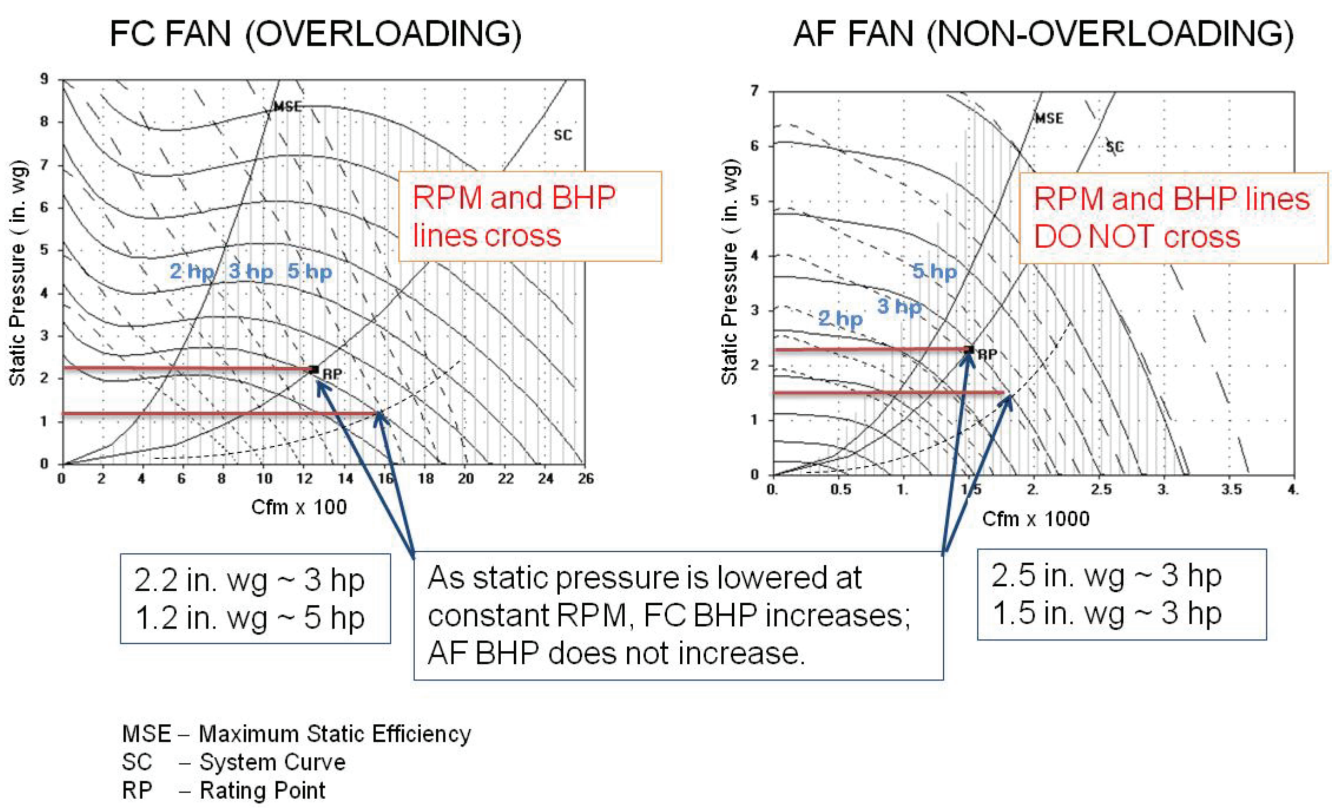

Figure 4 – Overloading (FC) vs Non-Overloading (AF) Type Fans

CENTRIFUGAL FAN ARRANGEMENTS AND APPLICATION CONSIDERATIONS

In addition to blade type, fans are typically organized by arrangement and operating characteristics. For most commercial and industrial applications, fans can usually be grouped into either housed-type fans or plenum-type fans. Each group has particular qualities which lend themselves to preferred or "best suited" applications. In order to understand these key operating characteristics, it is necessary to understand the fundamental differences in arrangements.

Note that although it is important to recognize the operating characteristics of stand-alone fan arrangements, fan efficiency and performance ultimately will depend on the surrounding equipment and intended application. For example, when comparing static efficiency, FC fans have a range of 60 to 80%, AF fans have a range of 75 to 80%, and axial fans have a static efficiency in the range of 70 to 72%. However, the fan selected should be the one that will best satisfy the airflow requirements of an application or fan system, while requiring the least amount of input power. A comparison of housed fan and plenum fan application considerations is given in Table B in the Appendix.

Housed Fan

The most common fan used in the HVAC industry is the housed centrifugal fan. This design is comprised of a blower wheel and the surrounding scroll, often referred to as the fan housing. The fan housing controls the flow of air in a desired path, exiting at a discharge as shown in Figure 5.

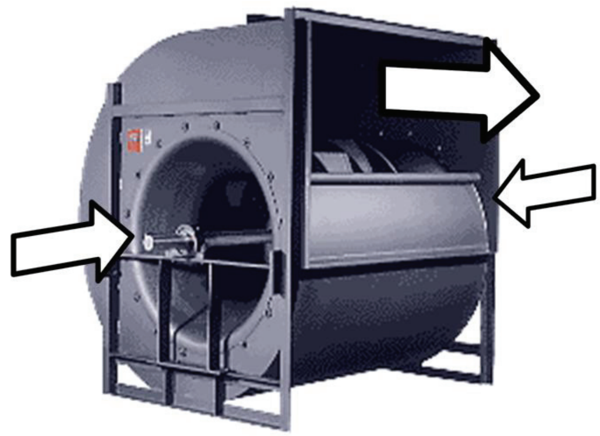

Figure 5 – Housed Fan Showing Direction of Airflow

Housed centrifugal fans utilize either FC or AF type wheels. In larger applications, there is often more than one inlet per wheel in a fan housing. The most common configuration is the double-width, double-inlet (DWDI) construction, which has two wheels side by side sharing a common back plate. (See Figure 6.)

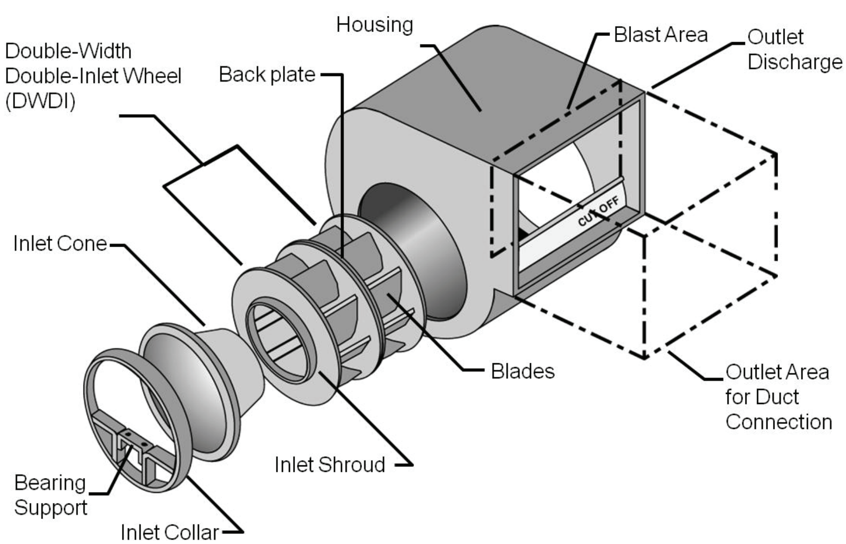

Figure 6 – Double-Width, Double-Inlet Fan Wheel

Housed Fan Application Considerations

When using a housed fan, consideration must be given to the possibility of system effect and the discharge ductwork must be designed appropriately to minimize this effect. Since the velocity profile at the outlet of a housed fan is not uniform, adequate straight duct distance must be allowed for the velocity profile to fully develop. (See Figure 7.) If a turn or bend in the duct takes place before this distance, the fan's external static pressure (ESP) capability will diminish.

With regard to the cooling coil location, the draw-thru configuration offers three advantages. First, the air is evenly drawn through the cooling coil and no dissipation means are necessary. Second, the cool higher density air results in better fan performance. Third, with the most common vertical discharge configurations, the fan discharge is attached to the duct and the velocity profile is dissipated in the duct. No discharge dissipation means are necessary.

In a blow-thru configuration, discharge airflow of a housed fan may also require a means to properly dissipate the discharge air before the air comes in contact with a filter or coil, ensuring the air is spread evenly across the available face area. This dissipation is normally accomplished via a diffuser, which generally adds section airway length to a unit and possibly additional cost.

Plenum Fan

Another fan arrangement used in HVAC equipment is the plenum fan. Plenum fans are fans without housings that discharge freely into a plenum space. They discharge air in all directions rather than having flow directed as with a housed fan. (See Figure 8.) These fans have traditional BI or AF type blades and are almost always of the single-width, single-inlet (SWSI) type. The fans are employed directly in a discharge space, or plenum, and pressurize this plenum during operation. By pressurizing the plenum or cabinet, plenum fans create static pressure at the discharge openings of the plenum, eliminating the requirement for uninterrupted duct run to achieve optimal flow. Typically, these fans have a larger wheel spinning at higher speed to reach a pressure and flow comparable to that of a housed fan.

Plenum Fan Application Considerations

Plenum fans are best suited for applications requiring a high degree of flexibility in the fan discharge connections. Since the fan wheel is open inside the plenum or section, the fan creates static pressure inside the fan cabinet providing a relatively even distribution of airflow. One or multiple

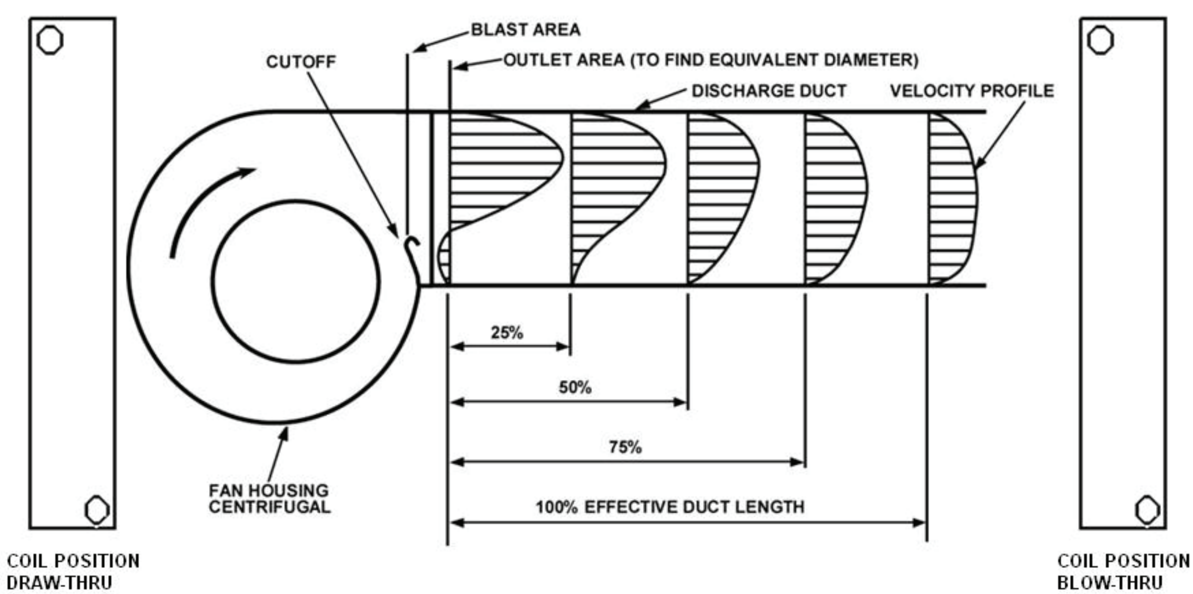

Figure 7 – Housed Fan Discharge Velocity Profile

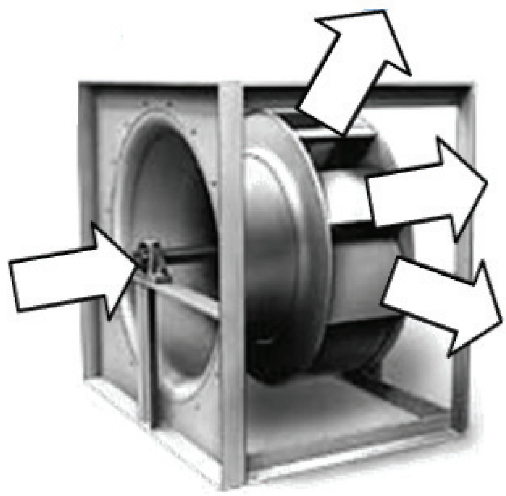

Figure 8 – Plenum Fan Wheel Showing Airflow Direction

discharge connections can be made from the fan section as long as the connections are made downstream of the fan wheel and do not interfere with the integral supports of the fan.

Plenum fans, due to their heavy construction and airfoil type blades, are capable of high static pressures across the fan. While this high pressure capability can be very useful, it comes at a cost. Plenum fans generally operate at higher speeds and often have larger wheels than their housed fan counterparts.

While plenum fan discharge location flexibility makes them more desirable, discharge duct or exit losses must still be considered. (See Figure 9.) Plenum fans, as well as other AHU components, can experience airflow issues if the space immediately upstream of the plenum fan is not properly addressed. The area approximately 24 inches immediately upstream of a plenum fan will not experience uniform full cabinet face area flow. Any component within this area may experience localized high-velocity airflow. This can become an issue for many system components, especially a cooling coil. For example, if a cooling coil were located within 24 inches of the plenum fan inlet, the resulting localized high velocity airflow may cause moisture carryover since the coil face velocity will exceed the recommended 500 to 550 fpm.

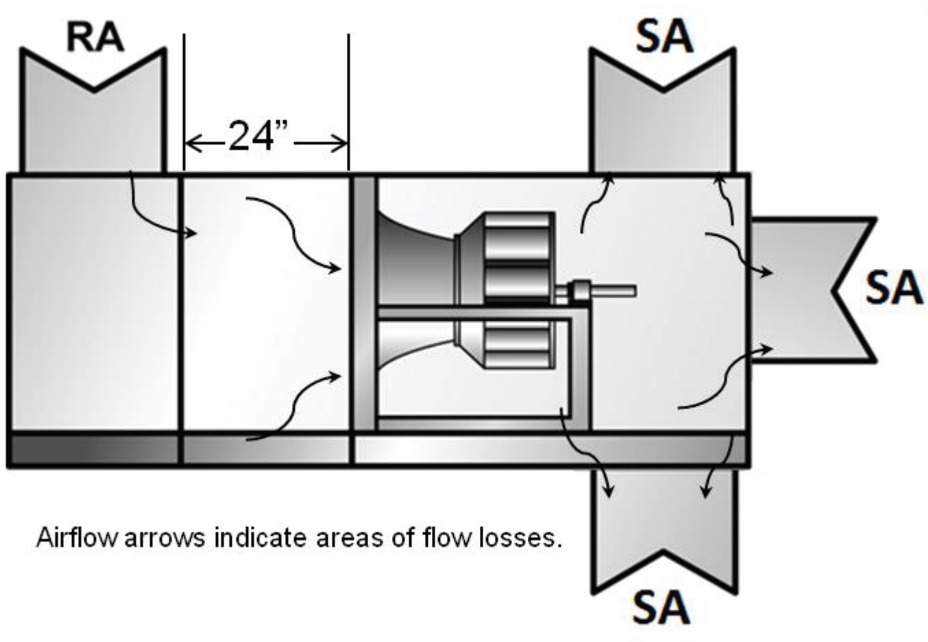

Figure 9 – Discharge Duct Losses in Plenum Fan Arrangement

DRIVE TYPES

Fan drives can be reduced to two basic types: indirect drives (belt drives) and direct drives. Both types have strengths and weaknesses that should be considered carefully during selection. For a summary of the differences between direct and indirect drives, see Table C in the Appendix.

Indirect (Belt) Drives

Indirect drives, or belt drives, are traditionally the most common drive type employed in commercial air-moving equipment. These arrangements generally consist of an intermediary link between a driving motor and a driven fan, usually in the form of a drive belt. In order to facilitate adaptability in application, the motor and fan each have drive pulleys whose pitch may be adjusted to obtain desired fan speeds.

Belt drives have high flexibility in their fan operating speeds, since the fan rpm can be changed easily by adjusting the belts, sheaves and pulleys. Belt drives tend to require much less complex but more frequent maintenance than direct drives, as the maintenance generally pertains to changing belts or lubricating bearings. Indirect drive motors are capable of higher service factors than those of direct drives, since the indirect drive motors operate at their nominal frequencies (where cooling effects are at their highest) while direct drive motors do not.

The main drawback of indirect drives is the drive losses they entail. Generally equal to 3 to 5%, these efficiency losses negatively affect the brake horsepower (bhp) required, demanding higher bhp of the motor than is required by the fan. Indirect drives can also see higher first costs, possibly longer airway lengths, and higher vibration levels than their direct drive counterparts unless optimized as part of overall equipment design.

Direct Drives

Direct drives are simply fans coupled directly to their driving motor. This is usually accomplished by way of a common shaft, or by a mechanical coupling. As a result of the direct coupling, direct drives have no need for belts, sheaves or pulleys between the motor and the fan. This has both advantages and disadvantages.

With larger fans, the additional lateral stresses placed on the motor bearings may require a special motor or for the fan to be mounted on a separate shaft with its own bearings.

First costs and equipment savings may be realized by not requiring belts, pulleys or sheaves. These savings may be offset by the need for ancillary equipment to vary the fan motor speed. Direct-driven fans will rotate at the same shaft speed as their driving motor. In almost all applications, the fan will not be able to provide the project-specific airflow conditions at the motor's nominal speed. The motor's frequency must be altered to achieve the correct fan rpm. This is normally accomplished with a variable frequency drive (VFD).

Variable frequency drives are very commonly used for variable air volume (VAV) applications. Variable speed fans are the preferred choice from a power standpoint, since they take advantage of the the relationship between power and speed, namely, that a reduction in speed will result in an exponential decrease in power consumption. For example, decreasing speed by 10% will decrease horsepower by 33%. Variable frequency drives do have an efficiency cost due to electrical losses of about 2% within the drive.

Serviceability may be a constraint for a direct-driven fan. Service to the driving motor often necessitates removal of the fan assembly, or at least alternate support within the unit. In some units, this may pose a significant problem as the clearances required are not always provided.

SOUND CONSIDERATIONS

The acoustic performance of a unit is of great importance in many applications. A comparison of acoustic performance between fan types is difficult for several reasons. In addition to fan wheel speed varying from one application to the next, fan placement in the unit and unit placement relative to occupied zones varies as well. The whole system must be considered.

For example, a given stand-alone fan may have better acoustic performance than another fan at standard test conditions. However, when applied in an air-moving unit, a variety of factors may affect the amount of sound power developed and transmitted by the fan. The equipment manufacturer's sound performance data should be consulted to understand the projected fan performance for a specific application in a specific piece of equipment.

FAN CONSTRUCTION COMPARISON – AMCA FAN CLASSES

Fans can be grouped into three AMCA (Air Movement and Control Association) classes based on their maximum outlet velocity and the maximum pressure characteristics: Classes I, II, and III. Class I represents lower velocities and static pressure capabilities, while Class III represents the highest. Fan class categories are shown in Figure 10.

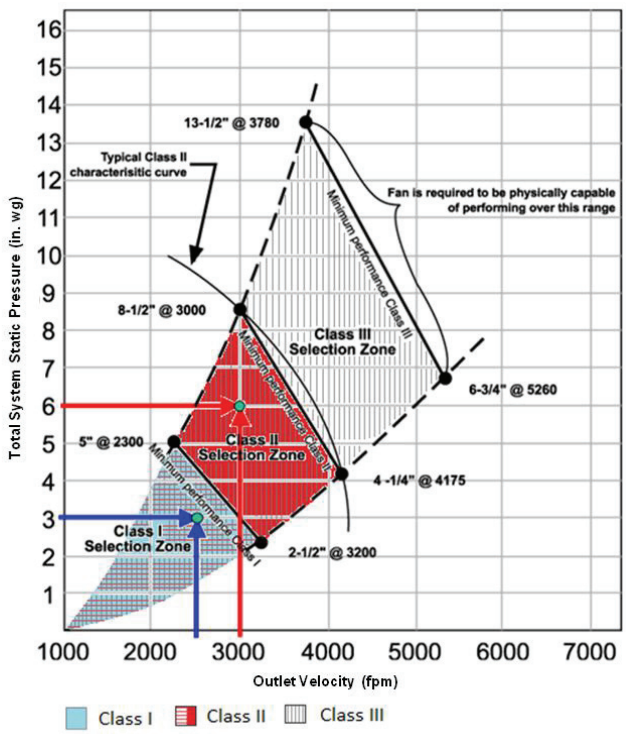

Figure 10 – AMCA Fan Classes

This classification system not only indicates a fan's performance capabilities, but also inherently reflects the physical construction of the fan. Typically, Class II and III fans have blades with thicker cross-sections, reinforced hubs, larger shaft diameters, more rugged keyways, and sturdier cross-bracing to accommodate the higher stresses associated with moving air at higher velocities and against higher pressures. Note that a fan is not simply classified based on its type: a forward-curved fan may be Class I or Class II, while an airfoil wheel may be Class II or Class III. It is also possible to achieve the same performance with two fans of differing classes. In these areas of overlapping capability, the decision between two fans may be reduced to cost and durability. Typically, fans of lower class are lower in cost. Fans designed for lower operating speeds and pressures do not require the additional strengthening material and structure, as well as assembly costs that a higher AMCA Class fan requires. Fans with higher class ratings are often more expensive, with the largest price increase being from a Class II to a Class III fan. In Figure 10, the blue lines show a Class I operating point and the red lines show a Class II point.

COST COMPARISON

Total cost is a significant factor in selecting or specifying a fan and is often the deciding factor when choosing between two fan types or arrangements. While true costs are of course always variable, there are some generalizations that can be made relative to basic fan constructions and applications. For our purposes here, we'll define total cost as a combination of first cost and operating cost. (Operating cost includes the cost of energy and the expense associated with service requirements.)

The first cost of a fan is typically a function of fan size and type. Forward-curved fans tend to be the least expensive fan option since their construction is normally small and light and they usually have the smallest fan wheels. Airfoil fans tend to be the most expensive since their constructions are typically very robust and heavy with larger fan wheels.

Housed fans (especially forward-curved housed fans) generally are less expensive than plenum fans. The particular system design and operating points could require a larger bhp for the housed fan. In cases where the fan discharges directly into duct, the housed fan is typically lower cost.

Direct-driven plenum fans also tend to be less expensive than belt-driven plenum fans. However, direct-driven fans typically require the added cost of variable frequency drives (VFDs) to control their speed.

If the system airflow or static pressure must be changed at installation or during start-up, a belt-driven-fan (forward-curved or airfoil housed fan or belt-driven airfoil plenum fan) can be easily re-balanced and new belts, sheaves and pulleys can be installed to achieve the new desired conditions.

As stated above, these typical first costs must be combined with operating costs, such as required service and energy consumption. While motor horsepower requirements are a function of the fan airflow and static pressure conditions, the lowest motor horsepower requirements are generally seen in a belt-driven airfoil plenum fan. Forward-curved fans and direct-drive airfoil plenum fans tend to require a higher motor hp for the given condition.

Service requirements also contribute to life cycle operating costs. Bearing and coupling maintenance may be present on any of the fan types, dependent on size and usage.

A direct-driven plenum fan does not have belts, sheaves or additional bearings to maintain or replace, which means that the routine servicing of a direct-driven fan is minimal. However, fan adjustments to a direct-driven fan can be very significant and much more extensive than adjustments made to a belt-driven fan, which is why direct-driven plenum fans are usually installed with VFDs. Adjusting a direct-driven fan that has been installed with a VFD will require programming adjustments and could result in motor replacement.

The AMCA Fan Classification provides a good relative-comparison tool: typically, fans of lower class are lower in cost. Fans designed for higher speed operation will usually have a greater blade thickness, as well as incorporate additional/larger hubs and cross-bracing. All of this translates to higher costs for higher class fans.

FAN SELECTION EXAMPLE

An example may be the best way to illustrate the overall effects of fans in commercial HVAC applications. For an air-handling unit (AHU) with filter mixing box and cooling and heating coils, a fan was selected with 25,000 cfm of supply air and a total static pressure of 4.68 in. wg. The cost rankings, along with airway lengths (AWL), fan bhp, and motor hp are given in Table 1 below. Overall, the FC fan section and the AHU containing the FC fan are the lowest cost options. However, the FC fan has the highest fan bhp, which is expected since it has the smallest fan wheel.

The housed fans generally result in a less expensive air handler than plenum fans, especially in draw-thru configurations (as is the case with the current example). This is because of the upstream plenum space requirements (typically 24 in.) that plenum fans require and housed fans do not.

Note the differences between the belt-driven and direct-driven plenum fans. The direct-driven plenum fan (DDPF) requires a larger motor than the belt-driven plenum fan (BDPF), while having a very similar fan bhp. This requirement is due to the reduced service factor that DDPF motors have (1.0 vs 1.2 for motors in belt-driven fans) and the VFD transmission losses experienced by the DDPF motors. While the DDPF motor is more expensive than the BDPF motor, the cost of the total fan section is not. This reduced cost is due to the fact that the DDPF does not need a a belt drive and also because the DDPF fan frames are generally less expensive than their BDPF counterparts.

Table 1 — Cost Ranking of Housed and Plenum Fans (25,000 cfm with 4.68 in. wg TSP)

FAN TYPE	FORWARD CURVED (FC) FAN	AIRFOIL (AF) FAN	BELT-DRIVEN AF PLENUM FAN	DIRECT-DRIVEN AF PLENUM FAN
COST RANKING*				
AHU	1	2	4	3
Total Fan Section	1	2	4	3
Fan Sled	2	3	4	1
Belt Drive	2	2	1	N/A
Motor	2	2	1	4
Fan Section AWL	1	2	2	2
AHU AWL	1	2	3	3
FAN BHP	33.4	32.8	27.4	28
MOTOR HP	40	40	30	40
FAN WHEEL DIAMETER (in.)	27	30	40	40.2
FAN CLASS	II	II	II	II

*1= Lowest Cost/Shortest AWL, 4 = Highest Cost/Longest AWL.

AHU – Air-Handling Unit
AWL – Airway Length
TSP – Total Static Pressure

SUMMARY

Every Carrier product undergoes a rigorous design process, which includes fan selection. There is no single, best solution for all applications or products. Each fan type and configuration lends itself particularly well to a certain design. The “best” fan type is the one that will deliver the best performance for the intended application of the equipment. Consideration of a fan’s fundamental strength is necessary in order to achieve the highest performance possible at a reasonable cost.

The external static pressure of the application or the pressure drop incurred by the supply and return system external to the air-moving unit is usually the most significant factor in selecting a fan. There are a great many applications where fans of either blade type, or of multiple wheel configurations, can supply the required volumetric airflow against a specified external static pressure. For high-static systems, airfoil blade fans are certainly more capable of delivering the required airflow. Forward-curved fans generally lend themselves better to lower static applications. In such a situation, fan selection can be decided by performance at given operating conditions.

If the type of fan you expect to find in a product is not available, it is likely that it is not the best choice for the product.

APPENDIX

Table A - Fan Type Characteristics

FACTOR	FC FANS	AF FANS	AF PLENUM FANS
Typical Application	Best efficiency at low or medium pressure (~0 to 5 in. wg).	Best efficiency in high-capacity and high-pressure applications (4 to 10 in. wg).	Best efficiency in high-capacity and high-pressure applications (4 to 10 in. wg) where discharge flexibility is required. Fan creates static pressure in plenum.
Cost	Less expensive than AF (BI) fans.	Most expensive of centrifugal fans.	More expensive than FC fan. Generally larger than housed fan due to SWSI vs. DWDI.
Operation	Runs at relatively low speed, typically 800 to 1200 rpm. Hp overloads as static pressure increases – "overloading" type fan	Operates at high speeds, typically 1500 to 3000 rpm. About double the speed of FC fan for a given flow. "Non - Overloading" type fan	Operates at high speeds, typically 1500 to 3000 rpm. "Non-Overloading" type fan.
Construction	Blades curve toward direction of rotation. Lightweight construction.	Blades have aerodynamic shape and are backward curved. Heavy-duty construction.	Typically airfoil type blades, backward curved. Heavy duty construction.
Sound	Typically lower sound levels than airfoil or plenum fan.	Typically lower sound levels than plenum fan.	Typically higher sound levels than housed fans. Plenum may aid in sound attenuation.

AF – Airfoil
BI – Backward Incline
FC – Forward Curved
TSP – Total Static Pressure
DWDI – Double-Width, Double-Inlet
SWSI – Single-Width, Single-Inlet

Table B – Application Considerations of Housed and Plenum Fans

FACTOR	HOUSED FAN – FC, BELT-DRIVEN	HOUSED FAN – AF, BELT-DRIVEN	PLENUM FAN – AF, BELT-DRIVEN (BDPF)	PLENUM FAN – AF, DIRECT DRIVEN (DDPF)
First Cost (Assuming a VFD Application)	Low	High	High	Medium to High
Bhp Requirement	Medium to High	Low	Low	Low
Fan Wheel Size	Small	Medium	Large	Large
Effects On AHU AWL	Downstream space needed for diffuser in blow-thru arrangement	Downstream space needed for diffuser in blow-thru arrangement	Upstream space needed to ensure uniform airflow and maintenance accessibility	Upstream space needed to ensure uniform airflow and maintenance accessibility
Discharge Ducting Flexibility	Limited. Consideration must be given to limit system effect	Limited. Consideration must be given to limit system effect	Discharge duct can be cut at nearly any point and at any size in the plenum cabinet downstream of the fan wheel.	Discharge duct can be cut at nearly any point and at any size in the plenum cabinet downstream of the fan wheel.
Required Maintenance	Couplings, belts and bearings	Couplings, belts and bearings	Couplings, belts and bearings	Bearings
Overloading?	Yes	No	No	No
VFD Usage	Recommended for VAV	Recommended for VAV	Recommended for VAV	Required for all applications
System Effect Concerns	Velocity profile leaving the fan discharge must be fully developed before duct transitions.	Velocity profile leaving the fan discharge must be fully developed before duct transitions.	No concerns on discharge as long as plenum discharge opening is downstream of fan wheel and exit losses are considered. Minimal concerns on fan inlet.	No concerns on discharge as long as plenum discharge opening is downstream of fan wheel. Minimal concerns on fan inlet.

AF – Airfoil
AHU – Air-Handling Unit
AWL – Airway Length
BDPF – Belt-Driven Plenum Fan
DDPF – Direct-Driven Plenum Fan
FC – Forward Curved
VFD – Variable Frequency Drive

Table C – Comparison of Direct and Indirect Drives

FACTORS TO BE CONSIDERED	DIRECT DRIVE	INDIRECT (BELT) DRIVE
Transmission Losses	~2% VFD electrical loss	3 to 5% efficiency losses (~2% VFD electrical loss if VFD used)
Downstream Contaminant Concerns	None	Some due to belt residue
Routine Maintenance	Bearings	Belts, sheaves, additional bearings
Maintenance Complexity	Field motor change involves changing integral fan components	Field motor change involves motor, belts and sheaves
First Cost	Often lower than belt drive	Often higher than direct drive
Motor Service Factor	1.0	Up to 1.2
Range of Operating Speeds	Fan cannot operate below recommended motor speed	Changing belts and sheaves can allow fan to operate in low flow applications
Fan Section AWL	Often shorter than belt drive due to direct connection of fan and motor	Often longer than direct drive due to belts, sheaves, etc.
Vibration	Often less than belt drive due to direct connection of fan and motor	Additional spinning elements that could require balancing.

AWL – Airway Length
VFD – Variable Frequency Drive

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