GREENHECK
Fan Application
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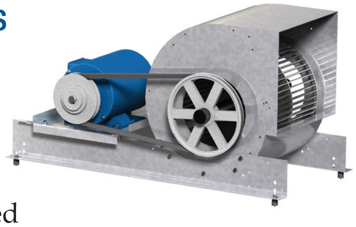
PRODUCT APPLICATION GUIDE
A technical bulletin for engineers, contractors and students in the air movement and control industry.

Comparing Supply Fan Types and Performance in Applied Equipment

Selecting the best supply fan for make-up air (MUA) equipment is extremely important for fan efficiency, maintenance costs and operating cost. The good news is more supply fan options exist today. However, the basis for selecting a fan typically depends more on component costs than performance consideration.

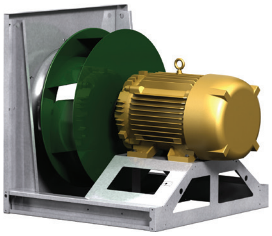
This paper reviews the most common fans used in MUA equipment, explaining the performance and operating cost benefits and deficiencies of each. The paper also covers power transmission loss and maintenance requirements.

Forward-Curved Fans



Forward-curved fans are well suited for handling high flow rates at low pressures. The design is best applied to lower fan speeds and temperatures. The forward-curved fan is inherently overloading, where the horsepower curve rises constantly from shut-off to free delivery. Its design does not offer high efficiency, but familiarity and reliability have made it a very common option. Control of forward-curved fans in MUA equipment allows for the altering the speed of the fan through an adjustable belt sheave or a variable frequency drive (VFD).

Backward-Inclined Plenum Fans

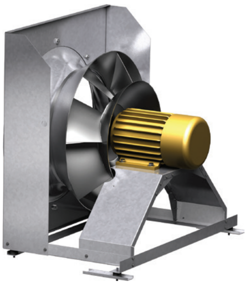


The backward-inclined fan is non-overloading, unlike forward-curved fans. This means that the horsepower curve rises to a peak in between shut-off and free delivery. It is best suited for clean air applications but can handle non-sticky dust-like particles. This design sustains higher pressures compared to a forward-curved fan. Where the forward-curved fans throw air out the discharge of the blower housing, plenum fans positively pressurize the fan compartment, causing air flow when installed in MUA equipment. This use is slightly less efficient when compared to a housed, backward-inclined fan. However, the performance often is better because there is no need for a developed velocity profile like other fans. The backward inclined fan also is typically more efficient than forward-curved fans.

Propeller Fans

Propeller fans have many different designs including various blade shapes and blade quantities. In MUA equipment, these mount in a housing panel and ultimately mounted in a wall, keeping air from re-circulating from the fan discharge back to the inlet. Pressures are normally less than 1 inch of total static pressure with very high flow rate. Because of low operating pressures, the use in MUA equipment is limited.

Mixed-Flow (Plenum) Fans



The mixed flow fan wheel is a hybrid of axial and centrifugal designs. It operates most efficiently in a range between vane axial and centrifugal fans, satisfying applications for moderate flow rates and pressures.

MUA equipment may use mixed flow fans in a plenum or a housing with straightening vanes. These fans can operate between 2 - 3½ inches of water, depending on the design, with some designs beyond 6 inches. The fan's main advantages are its high efficiencies and low sound levels when in MUA equipment. The mixed-flow fan generally operates at 4 - 6 decibels less than a comparable forward-curved fan.

Pre-Shaft Power Losses

Every fan has power input requirements necessary to perform specific airflow at a system static pressure (design duty point). However, many components within a fan assembly reduce efficiency before the fan performs the work at the required duty point, requiring more power to complete the work. Power losses occur from belts, sheaves, bearings, VFDs, and motors. These losses are described below.

Motor Efficiency

Motor efficiency is the ratio of mechanical power out to electrical energy in. Friction in bearings, wire size and magnetic interaction with the stator and armature in motors, all cause inefficiency. Although efficiency increases as nominal motor size increases, other factors that affect motor efficiency include nominal motor RPM, the motor enclosure and the motor design. A motor table from the National Electrical Manufacturers Association (NEMA) for a 7.5 hp motor illustrates the differences in motor efficiencies.

- Standard efficiency motor – 85.5%
- High efficiency motor – 89.5%
- Premium efficiency motor – 91.7%

Belt Losses

Losses in transmission systems are due to friction on surfaces of contact and friction within the belt material. Friction develops heat and requires power as belts contact and come into grip with sheaves. Certain belts have cogs to reduce the amount of belt losses, increasing the overall power transmission efficiency. However, all belt drive power transmissions types consume some power to operate.

The Air Movement and Control Association, International, Inc. (AMCA) has developed a standard—AMCA 207—that contains the following formula to help understand belt transmission efficiency loss for belt drive systems.

NB = 0.968(Hi/(Hi+2.2) ^0.05

Where NB is transmission efficiency

Hi = Fan input power

Typical belt losses are 2% – 10%. Additional losses in a belt drive system not previously mentioned may come from belt sheave misalignment, non-uniform belt wear, improper belt tension and even poor bearing maintenance.

Direct Drive

Before the advent of the VFD and electronically commutated motors, speed control in motors was limited to a few methods. These included 2-speed motors, rheostats for PSC motors and belt drive transmissions. Although 2-speed motors allow for direct-drive applications, control is extremely limited, and the motor cost is expensive. Speed control with rheostats is limited to fractional horsepower motors, and the efficiency of the motor was reduced significantly, as the speed was reduced. Direct-drive with a VFD or EC motor maintains high efficiency at reduced speeds and relieves belt losses as described in the previous section.

VFD Losses

VFDs are a common technology for altering speed of 3-phase induction motors. However, the internal solid-state components that allow frequency and voltage variation also cause some efficiency losses. AMCA 207 takes motor and VFD efficiency into consideration. When the VFD efficiency is considered, the approximate loss is 2% of the required power for the load.

Ease of Startup with Direct Drive Fans

The use of VFD controlled motors and electronically commutated (EC) motors have become more common in MUA equipment. Costs for VFD controlled motors and EC technologies have decreased considerably and are now cost-effective. While extremely useful in variable air volume systems, there are also benefits to using control methods on constant volume systems too. Many contractors and technicians realize the value of VFD controlled motors for accurate air balancing and quick startup. VFD controlled motors and EC motors in MUA equipment make adjusting set points and fan RPM easier, and more accurate compared to a belt drive assembly. A VFD controlled motor has virtually infinite fan motor speed adjustments while adjustable sheaves (pulleys) or fixed sheave sizes have limited speed adjustment capability.

Accurate system external static pressures are extremely difficult to accurately estimate in design and are time-consuming to correct for when balancing building supply or exhaust air flows during commissioning. VFD controlled motors and EC motors allow fan speeds to be adjusted in minutes to compensate for these variations in system design static pressures, regardless of whether the fan has a direct or belt drive.

Maintenance Considerations for Drives

Maintenance requirements for a belt drive fan are very different from those for a direct drive fan. Belt drive fans require belts be checked for wear, adjusted routinely and replaced regularly. The sheaves also require the same regular inspection. Cost to repair and replace vary greatly based on belt size and quantity. Belt drive fans also require more maintenance because of fan shaft bearings. Direct drive fans (AMCA arrangement 4) eliminate shaft bearings, belts and sheaves.

Belt Drive Performance Considerations

Typically, in MUA belt-driven equipment, the driver sheave (motor) and the driven sheave (fan) have different diameters. Because both sheaves have the same linear belt contact over a period, the smaller sheave can wear faster than the larger sheave. This slows the overall belt speed (when the smaller sheave is driven), reducing the fan speed and airflow of the equipment. MUA equipment with direct drive fans do not experience this, and the fan RPM remains constant, providing consistent air flow performance during the life of the unit.

Operating Costs

Different fan types in MUA equipment vary in efficiency and maintenance, directly affecting operational costs. The required system airflow delivered at a static pressure refers to the fan's duty point. As system designs change, a supply fan will operate at different duty points. These duty points depend on the application, tempering options or system features selected. Comparing operating costs of different supply fan and drive arrangements for use in the same piece of equipment is easy. The following examples show the effect different supply fan types have on operational and maintenance costs in make-up air equipment.

Supply Fan Differences in Make-up Air Applications

Table 1 shows the difference in operational cost for a typical large direct gas-fired kitchen make-up air unit using a forward-curved belt-driven supply fan and one using a direct drive mixed flow plenum fan:

Example 1: Direct Fired Kitchen Make-Up Air Application										
Example	Fan Type	Unit Relative Price (%)	Supply Airflow (CFM)	Total Static Pressure (in. wg)	Fan Power (BHP)	Belt Transmission Loss (%)	VFD Loss (%)	Nominal Motor Size (HP)	Motor Efficiency (%)	10 Year Operating Costs
1-A	Forward Curved	1	5000	1.19	3.43	5.57	0	5	90	$22,220
1-B	Mixed Flow	1.02	5000	1.19	1.78	0	2	2	90	$9,420

Table 1 – Direct Fired Kitchen Make-Up Air Application Example

Summary: Make-up Air Application Example #1

The example in Table 1 shows how much more it costs to operate a unit using a belt drive forward-curved fan when compared to a similar unit using a direct drive mixed flow plenum fan. The operational **cost savings of $12,800** are a result of 2 primary factors. A mixed flow direct drive plenum fan offers increased fan efficiency; it eliminates friction losses that are inherent with a belt drive transmission found in the forward-curved belt drive fan and eliminates belt transmission maintenance.

The first cost of equipment in the comparison (example 1-A and 1-B) is nearly identical. The forward-curved fan typically is less expensive than the mixed flow plenum fan. However, it has a larger motor, belts, sheaves, bearings and structural support for the fan assembly the mixed flow plenum fan assembly does not have.

The next example compares the difference in the operating cost of a make-up air application used in a manufacturing facility. It compares a forward-curved belt drive supply fan and a direct drive mixed flow plenum fan.

Summary: 14,000 cfm Direct Gas-fired Make-up Air Application Example #2

The forward-curved fan option in example 2-A **costs $26,340 more** to operate over 10 years versus the mixed flow option in example 2-B.

The operating cost savings of the unit with the direct drive mixed flow plenum fan is attributed to the higher efficiency of the mixed flow plenum fan and the elimination of the belt drive losses.

The first cost in this example gives a very slight edge to the forward-curved fan. However, the important point to consider is the 40% difference in brake horsepower, showing the superior efficiency of the mixed flow fan when running 5 days/week, every week for the life of the MUA unit. The **$26,340 savings in operating cost** quantifies this efficiency.

Both examples demonstrate how using a direct drive mixed flow plenum fan is a better option for the customer in terms of operating and maintenance cost savings. The mixed flow plenum fan allows for a reduction in the nominal motor size. This in turn, also reduces the maximum current protection (MOP) and an additional reduction in, wiring and breaker size used for the project. The result is an overall reduction in installation cost. Specific details and formulas for both examples are available in the appendix to this paper.

Conclusion

New and innovative fan technologies such as the direct drive mixed flow plenum fan using VFDs or an EC motor increase fan efficiency and lower maintenance costs. This has a significant impact on reducing total operating costs for MUA make up air equipment. Additionally, these offer many other advantages. Start-up using direct drive technology when compared to belt-driven adjustments is quick and easy. Maintenance is less with no belts or components to inspect, adjust or replace. Direct drive mixed flow plenum fans for use in MUA equipment where pressures are at or below 2 inches, could reduce power consumption by up to 50%. Consider the mixed-flow fan in applications requiring MUA equipment.

References:

1. VFD Efficiency and Belt Drive Losses: From AMCA 207
2. Motor Efficiency: https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf, Appendix B.

Example 2: Direct Fired General Make-up Air Application

Example	Fan Type	Unit Relative Price (%)	Supply Airflow (CFM)	Total Static Pressure (in. wg)	Fan Power (BHP)	Belt Transmission Loss (%)	VFD Loss (%)	Nominal Motor Size (HP)	Motor Efficiency (%)	10 Year Operating Costs
2-A	Forward Curved	1	14,000	1.13	10.14	4.15	0	15	90	$58,040
2-B	Mixed Flow	1.08	14,000	1.13	6.01	0	2	7.5	90	$31,700

Table 2 – General Make-Up Air Application Example

Appendix –
Application Example Calculations:

Example 1-A:

Direct gas-fired make-up air Installation on a typical kitchen application using a forward-curved belt drive fan.

5,000 cfm @ 1.19” of total static pressure

Utilize belt drive forward-curved fan – 3.43 shaft (brake) horsepower requirement

Consider the following assumptions:

- Operation is 24 hours/day, 5 days/week, 52 weeks/year
- $0.10/kWh for power
- 90% efficient motor
- Belt replacement is $250/year for parts and labor
- Sheave replacement is $100/year for parts and labor (average replacement frequency is every 4 years)

Per AMCA 207 - NB = 0.968(Hi/(Hi+2.2) ^0.05

NB = 0.968(3.43/ (3.43+2.2)^0.05

NB = 0.9443 or 5.57% belt transmission loss

Power requirement:

- 3.43 fan shaft horsepower + (3.43*(1-NB)) belt drive losses = 3.62 motor horsepower required
- 5 horsepower nominal motor
- 3.62 horsepower = 2.7 kW
- 2.7 kW / 90% motor efficiency = 3.0 kW power requirement
- No VFD losses considering speed control with belt drive assembly
- 6240 hours/year * 3.0 kW power requirement * $0.10/kWh = $1,872/year electrical cost
  - $18,720 over 10 years in electrical costs
  - $2,500 over 10 years in belt replacement costs
  - $1,000 over 10 years in sheave replacement costs

Operating costs over 10 year period - $22,220

Example 1-B:

Direct gas-fired make-up air Installation on a typical kitchen application using a mixed flow direct drive fan.

Utilize direct drive mixed flow fan – 1.78 shaft (brake) horsepower requirement

Consider the following assumptions:

- Operation is 24 hours/day, 5 days/week, 52 weeks/year
- $0.10/kWh for power
- 90% efficient motor
- 2% VFD losses
- Belt replacement is not required
- Sheave replacement is not required

Power requirement:

- 1.78 fan shaft horsepower = 1.78 motor horsepower required (no belt loss)
- 2 horsepower nominal motor
- 1.78 horsepower = 1.33 kW
- 1.33 kW / 90% motor efficiency = 1.48 kW + 2% VFD loss = 1.51 kW power requirement
- 6,240 hours/year * 1.51 kW power requirement * $0.10/kWh = $942/year electrical cost
  - $9420 over 10 years in electrical costs
  - $0 over 10 years in belt replacement costs
  - $0 over 10 years in sheave replacement costs

Operating costs over 10 year period - $9,420

Example 2-A:

General direct gas-fired make-up air application using a forward-curved belt drive fan.

14,000 cfm @ 1.13″ of total static pressure

Utilize belt drive forward-curved fan – 10.14 shaft (brake) horsepower requirement

Consider the following assumptions:

- Operation is 24 hours/day, 5 days/week, 52 weeks/year
- $0.10/kWh for power
- 90% efficient motor
- 15 horsepower nominal motor
- Belt replacement is $250/year for parts and labor
- Sheave replacement is $100/year for parts and labor (average replacement frequency is every 4 years)

Per AMCA 207 - NB = 0.968(Hi/(Hi+2.2) ^0.05

NB = 0.968(10.14/ (10.14+2.2)^0.05

NB = 0.9585 or 4.15% belt transmission loss

Power requirement:

- 10.14 fan shaft horsepower + (10.14*(1-NB))belt drive losses = 10.56 motor horsepower required
- 10.56 Horsepower = 7.87 kW
- 7.87 kW / 90%motor efficiency = 8.74 kW power requirement
- 6,240 hours/year * 8.74 kW Power Requirement * $0.10/kWh = $5,454/year electrical cost
  - $54,540 over 10 years in electrical costs
  - $2,500 over 10 years in belt replacement costs
  - $1,000 over 10 years in sheave replacement costs

$58,040 over 10 years in total operating cost

Example 2-B:

General direct gas-fired make-up air application using a mixed flow direct drive fan.

Utilize direct drive mixed flow fan – 6.01 shaft horsepower requirement

Consider the following assumptions:

- Operation is 24 hours/day, 5 days/week, 52 weeks/year
- $0.10/kWh for power
- 90% efficient motor
- 2% VFD losses
- 7.5 horsepower nominal motor
- Belt replacement is not required
- Sheave replacement is not required

Power requirement:

- 6.01 fan shaft horsepower = 6.01 motor horsepower required (no belt loss)
- 6.01 horsepower = 4.48 kW
- 4.48 kW / 90%motor efficiency = 4.98 kW * 2% VFD loss = 5.08 kW power requirement
- 6240 hours/year * 5.08 kW power requirement * $0.10/kWh = $3170/year electrical cost
  - $31,700 over 10 years in electrical costs
  - $0 over 10 years in belt replacement costs
  - $0 over 10 years in sheave replacement costs

$31,700 over 10 years in total operating costs

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