FAN ENGINEERING

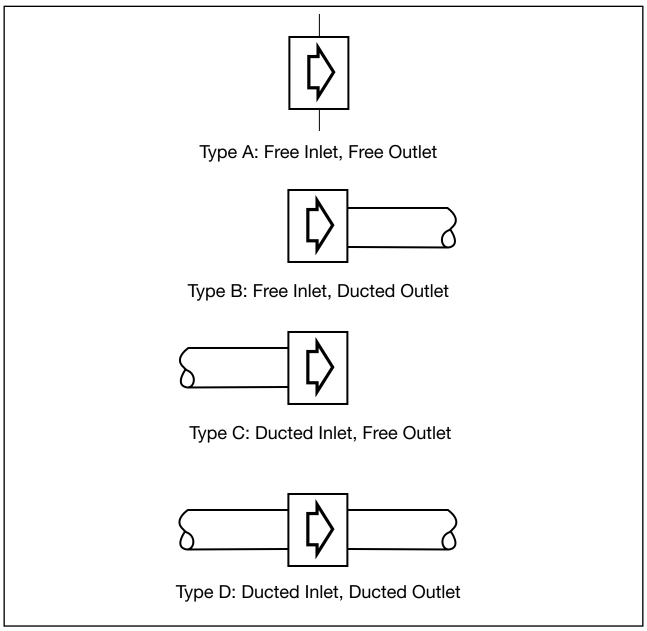
Information and Recommendations for the Engineer FE-1600 Metric

Temperature & Altitude Effects on Fans

Introduction

Fans are tested in laboratories with test setups that simulate installations that are typical for that type of fan. Usually they are tested and rated as one of four standard installation types as designated in AMCA Standard 210. These standard installation types are shown in Figure 1.

Figure 1. Standard Fan Installation Types



Products that are rated and certified by AMCA must illustrate that they have been rated by one of the installation types shown above.

In addition to listing the test type, the ratings must also be published at a standard air inlet density. The fan industry has adopted a standard density of 1.2 kg/m^3 at 21°C at sea level and at a barometric pressure of 101.32 kPa. All manufacturers' ratings are made at, or adjusted to, this standard. Whenever a fan is operated in a system where any or all of these conditions vary, corrections must be made in order to obtain accurate results.

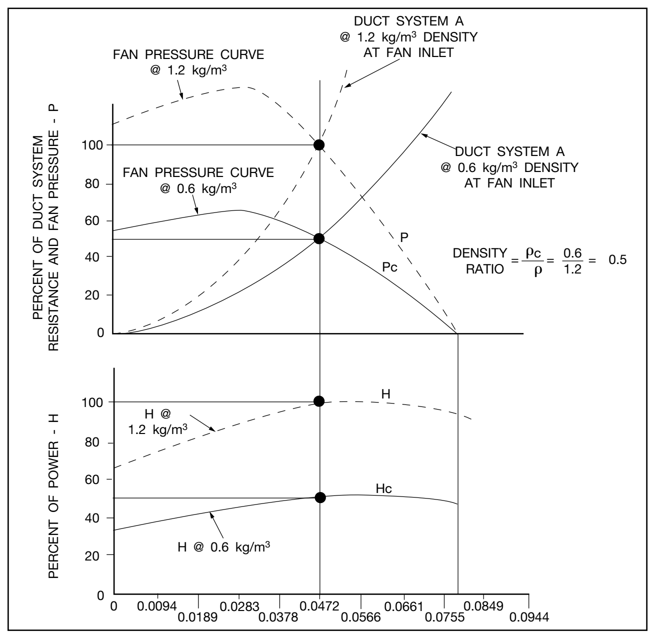
It's not enough to make fan performance adjustments based on density corrections. The designer must also consider what effect the variables that are influencing the fan air density might have on the structural components of the fan. Temperatures other than 21°C can cause an alloy to become too pliable or brittle. Speed adjustments can exceed the limits of the wheel, shaft and bearings. Gases, other than air, that change the inlet density may also be corrosive to vital structural components. All these variables must be considered when making fan inlet density adjustments.

Temperature Effect

Any temperature other than 21°C affects the air/gas density. Fan pressure (P) and power (H) vary directly with the ratio of the air/gas density at the fan inlet to the standard density; however, fan air volume (flow) is not affected by the air density. Fans are constant volume machines that, when operating at constant speed will deliver the same flow at 1.2 kg/m^3 density air as they will with lower density air or higher density air.

For example, Figure 2 illustrates the effect on the fan performance of a density variation from the standard value created by a change in fan inlet temperature.

Figure 2. Percent of Duct/Fan System Airflow – Q



This density ratio must always be considered when selecting a fan from a manufacturer's catalogs or curves.

The dashed curve is representative of cataloged fan performance at 21°C at sea level with a barometric pressure of 101.32 kPa (standard air). The solid curve is representative of the fan's performance with an inlet temperature of 315.6°C at the same altitude and barometric pressure.

The fan laws, with the size and speed remaining constant, that apply here are as follows:

$Qc = Q$

$Pc = P\ (\rho c/\rho)$

$Hc = H\ (\rho c/\rho)$

$\rho c/\rho$ = density ratio

Where: Q = Flow (cubic meters of air per second)
P = pressure (kPa)
H = fan power (kW)
ρ = air density (kg/m^3)
subscript c = converted value

So how do we determine the air density for temperatures other than 21°C? One way would be to calculate it using absolute temperatures, absolute pressures and barometric pressure, or we could simply refer to Table 1 where it's been conveniently worked out for a range of temperatures at sea level.

Table 1. Corrections for Temperature at Sea Level

AIR TEMPERATURE (°C)	FACTOR	AIR TEMPERATURE (°C)	FACTOR
–45.6	0.77	135.0	1.39
–31.7	0.82	148.9	1.43
–17.8	0.87	162.7	1.48
–6.6	0.91	176.7	1.53
4.4	0.94	190.6	1.58
15.6	0.98	204.4	1.62
21.1	1.00	232.2	1.72
26.7	1.02	260.0	1.81
37.8	1.06	287.8	1.91
48.9	1.09	315.6	2.00
60.0	1.13	343.3	2.09
71.1	1.17	371.1	2.19
82.2	1.21	398.9	2.28
93.3	1.25	426.7	2.38
107.2	1.29	482.2	2.56
121.1	1.34	537.8	2.76

Actually, these factors are used directly to determine the corrected fan performance. The factor is equal to the fan's rating density (standard air) divided by the actual air density at the fan inlet.

$$\text{Factor} = \frac{1.2\ \text{kg/m}^3}{\rho}$$

So if the dry air density corresponding to an air temperature other than 21°C is desired, it can be calculated by simply dividing 1.2 by the factor.

Fan densities may vary from standard for reasons other than temperature and altitude. Moisture, gas, or a mixture of gases other than air are a few possibilities. For these cases it will be necessary to obtain the actual density of the inlet gas stream by some other reference material. The factor can then be obtained by substituting the new density for ρ.

Example 1: A fan is required to deliver 7.08 m^3/s against 0.75 kPa SP (static pressure). The fan is to operate at 176.7°C. This fan would be selected from a manufacturer's standard rating table or curve for 7.08 m^3/s at 0.75 kPa SP at 21°C and would operate at 1,621 RPM and require 9.13 kW.

To determine the fan's performance at 176.7°C, simply divide the SP and power by the factor from Table 1. The factor for 176.7°C is 1.53; therefore the operating static pressure and power demand would be as follows:

$$\frac{0.75\ \text{kPa SP}}{1.53} = 0.49\ \text{kPa} \quad \text{SP} \quad \frac{9.13\ \text{kW}}{1.53} = 5.97\ \text{kW}$$

Although the fan RPM is within the speed range specified in the performance tables, the impeller safe speed needs to be verified for operation at the elevated temperature. Most fan manufacturers will list safe speed factors for operation at elevated temperatures in the fan catalog and in their selection software.

Caution is required when selecting the motor. From the power demand calculation it appears that either a 5.5 or a 7.5 kW motor could be used. But perhaps the motor selection should be based on a cold start of 9.13 kW, to allow the fan to start before the air warms up. In this case the fan would require a 11.5 kW motor. An alternative to a larger motor, depending on the fan's power demand characteristics, could be a shutoff damper that would not open until the air is up to temperature. For this particular fan, the shutoff power requirement is 4.47 kW at standard conditions.

Example 2: Let us look at Example 1 another way. Suppose the request is for a fan to deliver 7.08 m^3/s against 0.75 kPa SP at 176.7°C. In this case the designer is asking for a fan to develop the 0.75 kPa SP at 176.7°C inlet temperature. In order to select the fan from the 21°F standard performance tables, we must first convert the static pressure at 176.7°C to 21°C. We accomplish this by the factor established in Example 1.

$$0.75\ \text{kPa SP} \times 1.53 = 1.15\ \text{kPa SP}$$

So for this example, if we select the same fan model, our new requirements are for 7.08 m^3/s at 1.15 kPa SP at 21°C. The fan would operate at 1,742 RPM and require 12.07 kW. It then follows that the operating conditions at 176.7°C would be as follows:

$$\frac{1.15\ \text{kPa SP}}{1.53} = 0.75\ \text{kPa SP} \quad \text{and} \quad \frac{12.07\ \text{kW}}{1.53} = 7.89\ \text{kW}$$

Flow and RPM would not change. And again, check the maximum speed limitations of the impeller and proper motor size for the cold starts.

Also, keep the following in mind when using temperature correction factors:

1. At temperatures higher than standard air (21°C) the air density is less (lighter air); therefore both the pressure and power demand will be less.
2. At temperatures lower than standard air the air density is greater (heavier air); therefore both the pressure and power demand will be more.

Altitude Effect

Fans operating at some altitude above sea level are similar to fans operating above 21°C. The higher the altitude the less dense (lighter) the air. Altitude correction factors for 21°C air are listed in Table 2. Note that these corrections correspond to average barometric pressure at the stated altitude. Actual conditions will vary with the weather.

Table 2. Corrections for Altitude at 21°C Air

ALTITUDE (M)	FACTOR	ALTITUDE (M)	FACTOR
0.0	1.00	1,524.0	1.20
152.4	1.02	1,676.4	1.22
304.8	1.04	1,828.8	1.25
457.2	1.06	1,981.2	1.27
609.6	1.08	2,133.6	1.30
762.0	1.10	2,286.0	1.32
914.4	1.12	2,438.4	1.35
1,066.8	1.14	2,590.8	1.37
1,219.2	1.16	2,743.2	1.40
1,371.6	1.18	3,048.0	1.45

Example 3: Select a fan to deliver 4.01 m^3/s at 0.62 kPa SP at 1,676.4 m elevation. Since no temperature is given it will be assumed to be 21°C. From Table 2, the factor for 1,676.4 m elevation is 1.22. Converting the static pressure to sea level to use the manufacturer's performance tables results in: SP = 1.22 x 0.62 kPa SP = 0.76 kPa SP at sea level and 21°C. Selecting a fan for 4.01 m3/s at 0.76 kPa SP results in an RPM of 1,173 and 3.94 kW at sea level with 21°C entering air temperature. At the operating conditions of 1,676.4 m elevation the SP and power demand would be corrected to:

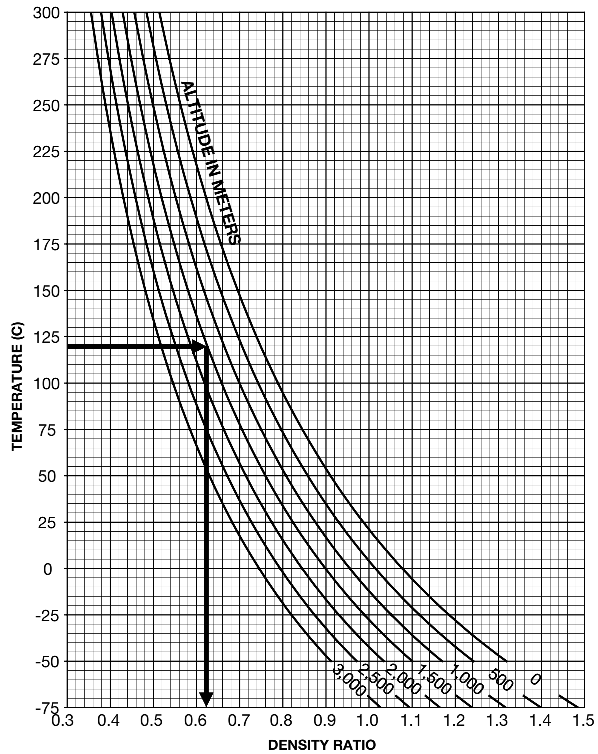
$$\frac{0.76\ \text{kPa SP}}{1.22} = 0.62\ \text{kPa SP} \quad \frac{3.94\ \text{kW}}{1.22} = 3.23\ \text{kW}$$

Flow and RPM would not change. Confirm that the RPM is within published speed limits. The motor power should be okay because the temperature does not vary and the elevation cannot change.

Temperature and Altitude Effect

When both temperature and elevation changes are present, the air density must be modified by a factor from both Tables 1 and 2. An alternative to this would be to use a single density ratio number such as can be found in Figure 3.

Figure 3. Air Density Ratios at Various Altitudes and Temperatures



Example 4: Select a fan to deliver 4.01 m^3/s at 0.62 kPa SP at 1,676.4 m elevation at 121.1°C. From Table 1 the factor for 121.1°C is 1.34 and from Table 2 the factor for 1,676.4 m elevation is 1.22. The overall factor is obtained by multiplying these factors: 1.34 x 1.22 = 1.63. To use a fan manufacturer's performance tables, convert the SP to standard air:

0.62 kPa SP x 1.63 factor = 1.01 kPa SP

The fan will be selected for 4.01 m^3/s at 1.01 kPa SP and will operate at 1,287 RPM, 5.19 kW. Converting to operating conditions results in:

$$\frac{1.01 \text{ kPa SP}}{1.63} = 0.62 \text{ kPa SP} \qquad \frac{5.19 \text{ kW}}{1.63} = 3.18 \text{ kW}$$

And again, flow and RPM will not change. Also, if the fan is to start cold, it will still be at 1,676.4 m elevation. Therefore, to obtain the "cold" power demand, divide the standard air power demand by the altitude factor only.

$$\frac{5.19 \text{ kW}}{1.22} = 4.25 \text{ kW}$$

Identical results can also be achieved by using Figure 3. Locate the temperature on the left-hand scale and proceed horizontally to the intersect of the altitude curve, and then follow it vertically down to the density ratio at the bottom of the graph. For a temperature of 121.1°C and an elevation of 1,676.4 m, we read a density ratio of 0.613. The density ratio is simply the reciprocal of the factor.

$$\frac{1}{1.63 \text{ factor}} = 0.613 \text{ density ratio (DR)}$$

Actual Cubic Meters per Second vs Normal Cubic Meters per Second

These two terms are commonly used in design work, and they should not be confused as this greatly influences the fan selection.

Actual cubic meters per second — Represents the volume of gas flowing anywhere in the system independent of its density. Cubic meters per second is the value that is used when selecting a fan.

Normal cubic meters per second — Air volume corrected to standard density conditions. This term is commonly used when a given weight rate of flow is required. For example, to determine the normal cubic meters per second of a fan delivering 4.72 m^3/s at 315.6°C, we would multiply the m^3/s by the density ratio or divide it by the factor.

$$4.72 \text{ m}^3/\text{s} \times \frac{0.60 \text{ kg/m}^3}{1.20 \text{ kg/m}^3} = 2.36 \text{ Nm}^3/\text{s}$$

Selecting a fan when normal flow (Nm^3/s) is specified requires us to calculate the actual flow (m^3/s). If the fan was specified for 4.72 m^3/s at 315.6°C, then an equivalent weight rate of flow is desired at 315.6°C.

$$4.72 \text{ m}^3/\text{s} \times \frac{1.20 \text{ kg/m}^3}{0.60 \text{ kg/m}^3} = 9.44 \text{ kg/m}^3$$

Select the fan for 9.44 m^3/s.

Inlet Suction Effect

A common influence on density, especially on exhaust systems, is suction. When system resistance is placed on a fan's inlet, the suction creates a partial vacuum at the inlet. This negative inlet pressure (partial vacuum) lowers the barometric pressure at the inlet and therefore the inlet density. This correction is rarely accounted for unless the suction pressure exceeds 2.49 kPa SP. In any event, this negative inlet pressure effect can be accounted for in the following manner:

Inlet density (kg/m^3) =

$$\text{Gas density (kg/m}^3\text{)} \times \frac{\text{Atm. Press. (kPa)} + \text{Inlet SP (kPa)}}{\text{Atm. Press. (kPa)}}$$

— or —

$$\text{DR (inlet)} = \text{DR (gas)} \times \frac{\text{Atm. Press. (kPa)} + \text{Inlet SP (kPa)}}{\text{Atm. Press. (kPa)}}$$

Where: Atm. Press. = atmospheric pressure = 101.32 kPa (at other than sea level divide 101.32 by the altitude factor to get the atmospheric pressure)
Density of standard air = 1.2 kg/m^3
Density ratio (DR) of standard air = 1.00
Inlet SP is normally a negative number.

Example 5: A fan is to deliver 5.07 m^3/s at 5.47 kPa SP. 4.97 kPa of this pressure is at the fan inlet.

$$\text{DR (inlet)} = 1.00 \times \frac{101.32 + (-4.97)}{101.32} = 0.951$$

$$\text{SP} = 5.47 \text{ kPa} \div 0.951 = 5.75 \text{ kPa SP at } 21°\text{C}$$

Therefore, a fan is selected for 5.07 m^3/s at 5.75 kPa SP which results in an RPM of 1,873 and a power demand of 47.58 kW. The corrected power demand would then equal 47.58 x 0.951 or 43.30 kW.

Example 6: If conditions were at 93.3°C instead of standard air, then:

$$DR\ (inlet) = 0.80 \times \frac{101.32 + (-4.97)}{101.32} = 0.761$$

SP = 5.47 kPa ÷ 0.761 = 7.19 kPa SP at 93.3°C

The fan would now be selected for 5.07 m^3/s at 7.19 kPa SP resulting in a speed of 2,073 RPM and a power demand of 59.39 kW. The corrected power demand would then equal 59.39 kW x 0.761 or 45.20 kW.

Both selections could be operated with a 45 kW motor; however, if the 93.3°C fan were to be subjected to cold starts without a shutoff damper, then a 75 kW motor would be required.

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