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Effects of Altitude

on psychrometric calculations and fan selections

For this EN we're pulling from the archives to address a subject that still causes confusion within the industry and continues to be the subject of frequently asked questions. This EN investigates the effects of altitude on psychrometric calculations and fan selections.

"Standard Air"

As altitude increases, the average barometric pressure drops and air density decreases.

"Standard air" has historically been defined by ASHRAE as having a density of 0.075 lb/ft^3, which equates to air density at sea level (barometric pressure of 29.92 in. Hg). The 2009 *ASHRAE Handbook of Fundamentals* (page 18.13) states that this condition is represented by either saturated air at 60°F dry bulb or dry air at 69°F dry bulb.

Since the performance of heating, cooling, and air-moving equipment is commonly rated at "standard air" conditions, cataloged performance data cannot be used directly for higher altitude applications. For instance, at a barometric pressure of 24 in. Hg (approximately 6000 ft altitude), cataloged data may be off by as much as 20 to 40 percent.

While areas above 6000 ft are statistically limited, a number of states and cities have barometric pressures in the range of 29 to 27 in. Hg. In this range, cataloged ratings may differ from actual conditions by 3 to 20 percent.

Psychrometric Calculations

The equations used in psychrometric calculations remain the same for all altitudes. However, some of the factors used in these equations are affected by altitude.

The sensible heat gain (Q_S) equation is often displayed as follows:

$$Q_S = 1.085 \times \text{cfm} \times \Delta T$$

However, the 1.085 in this equation is not a constant. Rather, it is the product of the density (ρ) and specific heat (C_p) of the air at "standard air" conditions, and the conversion factor of 60 minutes per hour.

$$Q_S = (\rho \times C_p \times 60 \text{ min/hr}) \times \text{cfm} \times \Delta T$$

The specific heat for 69°F dry air at sea level is 0.241 Btu/lb°F. Therefore, at "standard air" conditions, these properties result in the value 1.085.

$$0.075 \text{ lb/ft}^3 \times 0.241 \text{ Btu/lb°F} \times 60 \text{ min/hr} = 1.085$$

The latent heat gain (Q_L) equation is often displayed as follows:

$$Q_L = 0.69 \times cfm \times \Delta W \text{ (gr/lb)}$$

However, the 0.69 in this equation is not a constant. Rather, it is the product of the density and latent heat of vaporization (Δh_{vap}) of the air at "standard air" conditions, and the conversion factors of 60 minutes per hour and 7000 grains/lb.

$$Q_L = (\rho \times \Delta h_{vap} \times 60 \text{ min/hr} / 7000 \text{ gr/lb}) \times cfm \times \Delta W$$

The latent heat of vaporization for 69°F dry air at sea level is 1076 Btu/lb. Therefore, at "standard air" conditions, these properties result in the value 0.69.

$$(0.075 \text{ lb/ft}^3 \times 1076 \text{ Btu/lb} \times 60 \text{ min/hr}) / 7000 \text{ gr/lb} = 0.69$$

The total heat gain (Q_T) equation is often displayed as follows:

$$Q_T = 4.5 \times cfm \times \Delta h$$

However, the 4.5 in this equation is not a constant. Rather, it is the product of the density of the air at "standard air" conditions and the conversion factor of 60 minutes per hour.

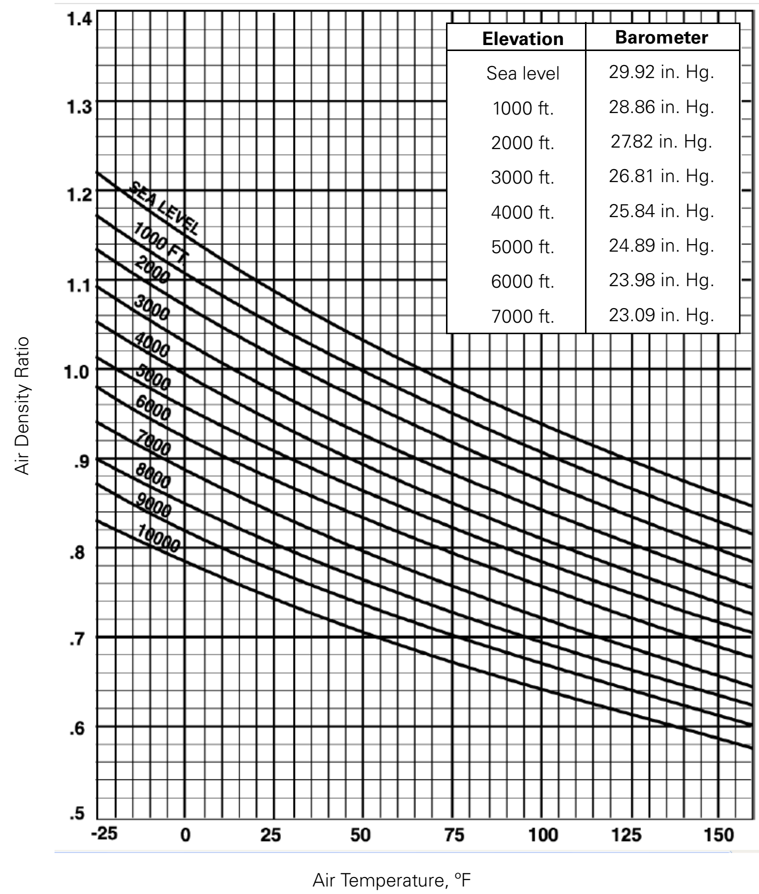
$$Q_T = (\rho \times 60 \text{ min/hr}) \times cfm \times \Delta h$$

For "standard air" density, the result is the value 4.5.

$$0.075 \text{ lb/ft}^3 \times 60 \text{ min/hr} = 4.5$$

Air at other conditions and other altitudes will cause these factors to change.

Figure 1. Air density ratios



Elevation	Barometer
Sea level	29.92 in. Hg.
1000 ft.	28.86 in. Hg.
2000 ft.	27.82 in. Hg.
3000 ft.	26.81 in. Hg.
4000 ft.	25.84 in. Hg.
5000 ft.	24.89 in. Hg.
6000 ft.	23.98 in. Hg.
7000 ft.	23.09 in. Hg.

Fans

Fans are considered to be constant-volume devices. That is, a given fan will deliver a specific volumetric flow rate (cfm) at a specific fan rotational speed (rpm). The mass of air that the fan moves at a given speed will vary based on the density of the air being moved. Air density also changes the static pressure that the fan will develop and the horsepower needed to drive it.

Fan and air handler manufacturers typically catalog fan performance data at "standard air" conditions. If the airflow requirement for a given application is stated at non-standard conditions, a density correction must be made prior to selecting a fan.

The procedure for selecting a fan at actual altitude (or temperatures) is outlined in the following steps:

1 Determine the actual air density and calculate the air density ratio, which is the density at actual conditions divided by density at standard conditions. Figure 1 provides a useful chart for determining the air density ratio based on altitude and air temperature.

$$\textbf{Air Density Ratio} = \frac{\textbf{Density}_{\textbf{actual}}}{\textbf{Density}_{\textbf{standard}}}$$

2 Divide the design static pressure at actual conditions by the air density ratio determined in Step 1.

$$\textbf{SP}_{\textbf{standard}} = \frac{\textbf{SP}_{\textbf{actual}}}{\textbf{Air Density Ratio}}$$

3 Use the actual design airflow (cfm) and the static pressure corrected for standard conditions (see Step 2) to select the fan from the performance tables/charts and to determine the speed (rpm) and horsepower requirement of the fan at standard conditions.

4 The fan speed (rpm) is the same at both actual and standard conditions.

$$\textbf{RPM}_{\textbf{actual}} = \textbf{RPM}_{\textbf{standard}}$$

5 Multiply the input power requirement by the air density ratio to determine the actual input power required.

$$\textbf{Power}_{\textbf{actual}} = \textbf{Air Density Ratio X Power}_{\textbf{standard}}$$

It is important to note that most pressure-loss charts for other system components (such as ducts, filters, coils, and dampers) are also based on standard air conditions.

Summary

Although the wide-scale use of computer software to select HVAC equipment has made the process of correcting for altitude simpler, a fundamental understanding is still important to prevent mistakes and troubleshoot problems.

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