Solving High Altitude Cooling Problems

Introduction

When testing cooling fans and blowers, the tests are typically performed in locations that are at or near sea level. For instance, most cities are no more than 2,500 feet in elevation. When comparing test results to the manufacturer's data, the test results show similar performance. But why do tests performed at elevations greater than 3,000 feet not match the manufacture's data?

The answer is in the density of the air. The density is different at different elevations. The scope of this paper will be to explain how elevation effects the cooling performance of a fan or blower.

CFM vs. Density?

When choosing the right fan or blower for an application, the choices are always specified as being able to supply CFM.

What is CFM?

CFM is Cubic Feet per Minute; a measurement of volume over time. It has no considerations as to what gas it pertains to nor the density of the gas. CFM is strictly a rate of volume measurement. But within that volume of gas, and in our case – air, we can evaluate the quality of the air and its ability to transfer heat. Every molecule of air has a mass, and this mass has the ability to absorb or emit energy; also known as transferring heat. If we count the number molecules for a given volume we obtain the density of the air (mass/volume).

If we pack more molecules of air into a given volume, increasing the density, we have more mass per volume and the ability to transfer heat increases. Consequently, the reverse applies also.

At sea level, the density remains fairly constant and we calculate the CFM using a heat transfer equation:

CFM = Q /(Cp * r * DT)

Where:
- **CFM** = Cubic Feet per Minute
- **Q** = Heat Transferred (kW)
- **Cp** = Specific Heat of Air
- **r** = Density
- **DT** = Change in Temperature

If the specific heat of air and the density are held constant (eg. sea level), the equation then becomes simplified:

CFM = 3160 * Q (kW) / DT (°F)
or
CFM = 1760 * Q (kW)/ DT (°C)

Suppose we want to cool a box at sea level that emits 340 watts of energy and we want to maintain a 15°C temperature differential. From the heat transfer equation, we calculate that 40 CFM is required. See Appendix A1 for derivation of these equations.

Density Change at High Altitude

At sea level, the density of air is .075 lbs/ft^3 (1.19 kg/m^3), see Table 1. This value is created by all of the other molecules in the atmosphere weighing down on the molecules at sea level. As the elevation increases, there are fewer molecules weighing down and the density of the air decreases. For instance, at 5,000 feet, the density is .066 lbs/ft^3 (1.056 kg/m^3). At 25,000 feet, the density is .034 lbs/ft^3 (0.549 kg/m^3). For these altitudes, we need to recalculate our heat transfer equation using the appropriate density for the altitude the fan will operate in. But this time the constant changes in the equation because the density is now a variable.

CFM = 237 * Q (kW) / (r * DT (°F))
or
CFM = 2074 * Q (kW) / (r * DT (°C))

Where the density units are lb/ft^3 for °F and kg/m^3 for °C. See Appendix A2 for derivation of these equations.

Table 1: Air Density Change with Altitude		
Altitude (ft)	Density (lb/ft^3)	Density (kg/m^3)
Sea Level	.075	1.19
5000	.066	1.06
10000	.056	.904
15000	.048	.771
20000	.041	.652
25000	.034	.549
30000	.029	.458
35000	.024	.379

Let's assume a fan will operate at 25,000 feet and will need to cool 340 watts and maintain a 15 °C temperature differential. Using the equation we get:

CFM = 2074 * Q (kW) / (r * DT (°C))
CFM = 2074 (.340 kW)/ (.549 kg/m^3 * 15°C)
CFM = 86 ft^3/min

Where at sea level we only needed 40 CFM.

Pressure Change at High Altitude

At 25,000 feet, we calculated that an 86 CFM fan is needed. This is due to the change in the density of the air molecules; which in turn, is due to fewer molecules above 25,000 feet exerting pressure on them.

So at high altitude, our black box requires more CFM. But in order to get more CFM to flow throughout the black box, we need to apply more pressure to it. To calculate the increase pressure requirement, we use the fan law that states:

$P_{sl} / P_{alt} = (CFM_{sl} / CFM_{alt})^2$

If we continue to use 25,000 feet as an example and .12 inches of water as our P_{fan} at sea level, we get:

$P_{alt} = P_{sl} (CFM_{alt} / CFM_{sl})^2$

$P_{alt} = 0.12 (86/40)^2$

P_{alt} = .55 inches of water

The new fan must have an operating point 86 CFM at .55 inches of water. This is a significant increase considering at sea level, we only needed 40 CFM at .12 inches of water. Instead of using a small Flight 90 (90mm x 25mm) fan, a larger Falcon (172mm x 55mm) fan is required.

Summing Up

To summarize, when calculating CFM; consider the application that the fan will be in. If the system will go in an office environment, you will be safe calculating the CFM and static pressure at sea level. If the system goes on the top of a mountain in Tibet, you should calculate CFM and static pressure based on the density at that altitude.

In these calculations, the temperature was held constant so that we could simplify the equations. If the temperature changes dramatically, you should determine the new values for specific heat and density.

If you have any further questions about this topic, or any other questions pertaining to fan and blower performance, please contact our Application Engineering department.

References

1. Loorents, Otto H. "Primer on Air Moving Devices for use at High Altitude", Rotron, Inc. Dec. 1975.
   Moran, Michael J.; Shapiro, Howard N. "Fundamentals of Engineering Thermodynamics",
   New York, Wiley & Sons, 1988.

Appendix A1 – Solving the Heat Transfer Equation at Sea Level

For DT in °F

CFM = Q/(Cp * r * DT)

Where:

Cp = .240 Btu/(lb*R)
r = .075 lb/ft^3

CFM = Q (kW) / (.240 Btu/(lb*R) * .075 lb/ft^3 * DT (R))

CFM = [Q (kW) / .018 Btu/ft^3] * [3413 Btu/hr / kW] * [1 hr / 60 min] * [1 / DT (°F)]

CFM = [3160 ft^3/min (Q (kW)) / DT (°F)

This requires that the amount of energy to be expelled is in kWatts and the temperature differential between the ambient air and the system air is in °F. The substitution of R (Roentgen) and °F (Fahrenheit) is justified because the units have the same difference in value and we are calculating a difference in temperature.

Appendix A2 – Solving the Heat Transfer Equation at Altitude

For DT in °C

CFM = Q /(Cp * r * DT)

Where:

Cp = 1.021 kJ/(kg*K)
r = 1.19 kg/m^3

CFM = Q (kW) / [1.021 kJ/(kg*K) * 1.19 kg/m^3 * DT (K)]

CFM = [Q (kW) / .823 kJ/m^3] * [kJ/s / kW] * [60 s / min] * [(3.28 ft)^3 / (1m)^3]

CFM = 1760 ft^3/min [Q (kW)] / DT (°C)

This requires that the amount of energy to be expelled is in kWatts, the density is in lb/ft^3, and the temperature differential between the ambient air and the system air is in °C. The substitution of K (Kelvin) and °C (Celsius) is justified because the units have the same difference in value and we are calculating a difference in temperature.