Establishing Cooling Requirements: Air Flow vs Pressure

Establishing Cooling Requirements

Before a fan can be specified, the airflow required to dissipate the heat generated has to be approximated. Both the amount of heat to be dissipated and the density of the air must be known.

The basic heat transfer equation is: **q= Cp x W x DT**

where:

- **q** = amount of heat transferred
- **Cp** = specific heat of air
- **DT** = temperature rise within the cabinet
- **W** = mass flow

Mass flow is defined as:

W = CFM x Density

By incorporating conversion factors and specific heat and density for sea level are, the heat dissipation equation is arrived at:

CFM = 3.16 x Watts / DT (°F)

This yields a rough estimate of the airflow needed to dissipate a given amount of heat at sea level. It should be noted that the mass of air, not its volume, governs the amount of cooling.

Determining System Impedance

After the airflow has been determined, the amount of resistance to it must be found. This resistance to flow is referred to as system impedance and is expressed in static pressure as a function of flow in CFM. A typical system impedance curve, in most electronic equipment, follows what is called the "square law," which means that static pressure changes as a square function of changes in the CFM. Figure 1 describes typical impedance curves. For most forced air cooling application, the system curve is calculated by:

$P = KrQ^n$

where:

- **P** = static pressure
- **K** = load factor
- **r** = Fluid Density
- **Q** = Flow
- **n** = constant; Let n=2; approximating a turbulent system.

Static pressure through complex systems cannot be easily arrived at by calculation. In any system, measurement of the static pressure will provide the most accurate result. Comair Rotron makes this type of testing available. Please contact Application Engineering for more information

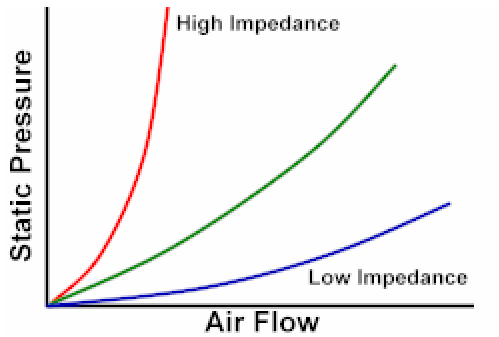

Figure 1: System Impedance Curves

System Flow

Once the volume of air and the static pressure of the system to be cooled are known, it is possible to specify a fan. The governing principle in fan selection is that any given fan can only deliver one flow at one pressure in a given system.

Figure 2 shows a typical fan pressure versus flow curve along with what is considered the normal operating range of the fan. The fan, in any given system, can only deliver as much air as the system will pass for a given pressure. Thus, before increasing the number of fans in a systems, or attempting to increase the air volume using a larger fan, the system should be analyzed for possible reduction in the overall resistance to airflow. Other considerations, such as available space and power, noise, reliability and operating environment should also be brought to bear on fan choice.

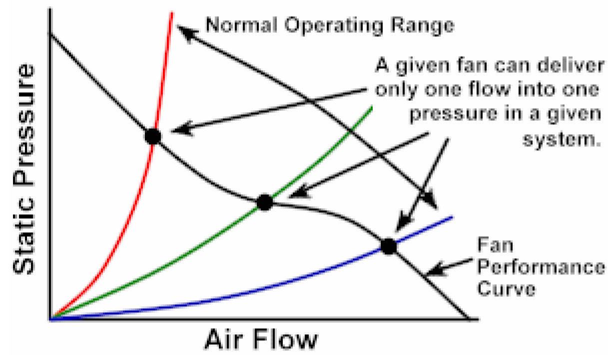

Figure 2: Fan Flow over Operating Range

Impact of Varying System Impedance

To demonstrate the impact of system resistance on fan performance, figure 3 shows three typical fans used in the computer industry. A is a 120 CFM fan, B is a 100 CFM fan and C is a 70CFM fan. Line D represents a system impedance within a given designed system. If 50 CFM of air are needed, fan A will meet the need. However, fan A is a high performance, higher noise fan that will likely draw more power and be more costly. If the system impedance could be improved to curve E, then fan B would meet the 50 CFM requirement, with a probable reduction in cost, noise and power draw. And if the system impedance could be optimized to where curve F were representative, then fan C would meet the airflow requirement, at a dramatically lower power, noise and cost level. This would be considered a well-designed system from a forced convection cooling viewpoint. Keeping in mind that a given fan can only deliver a single airflow into a given system impedance, the importance of system design on fan selection is critical. Comair Rotron urges engineers to minimize system impedance where practical, for best performance, noise, power and cost characteristics.

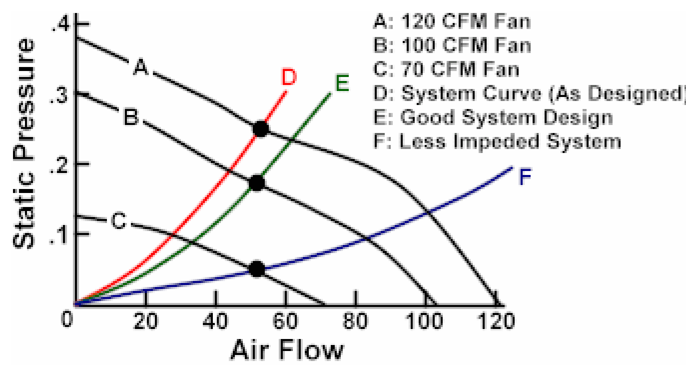

Figure 3: System Impedance Impact

Series and Parallel Operation

Combining fans in series of parallel can achieve the desired airflow without greatly increasing the system package size or fan diameter. Parallel operation is defined as having two or more fans blowing together side by side. The performance of two fans in parallel will result in doubling the volume flow, but only at free delivery. As figure 4 shows, when a system curve is overlaid on the parallel performance curves, the higher the system resistance, the less increase in flow results with parallel fan operation. Thus, this type of application should only be used when the fans can operate in a low impedance near free delivery.

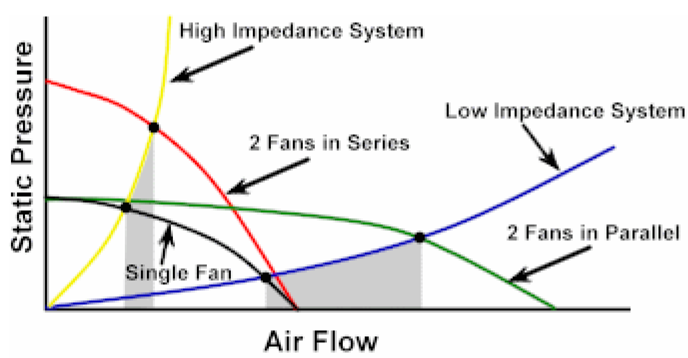

Figure 4: Series vs Parallel Performance

Series operation can be defined as using multiple fans in a push-pull arrangement. By staging two fans in series, the static pressure capability at a given airflow can be increased, but again, not doubled at every flow point, as Figure 5 displays. In series operation, the best results are achieved in systems with high impedance.

In both series and parallel operation, particularly with multiple fans (5, 6, 7, etc.) certain areas of the combined performance curve will be unstable and should be avoided. This instability is unpredictable and is a function of the fan and motor construction and the operating point. For multiple fan installations, Comair Rotron strongly recommends laboratory testing of the system.

Speed and Density Changes

By using dimensional analysis and fluid dynamic equations, basic fan laws can be derived giving a relationship between airflow, static pressure, horsepower, speed, density and noise. The table below shows the most useful of these fan laws.

Basic Fan Laws		
Variable	When Speed Changes	When Density Changes
Air Flow	Varies directly with speed ratio: $CFM_2 = CFM_1 (RPM_2 / RPM_1)$	Varies directly with density ratio: $CFM_2 = CFM_1 (r_2 / r_1)$
Pressure	Varies with square of speed ratio: $P_2 = P_1 (RPM_2 / RPM_1)^2$	Varies directly with density ratio: $P_2 = P_1 (r_2 / r_1)$
Power	Varies with cube of speed ratio: $HP_2 = HP_1 (RPM_2 / RPM_1)^3$	Varies directly with density ratio: $HP_2 = HP_1 (r_2 / r_1)$
Noise	$N_2 = N_1 + 50 \log_{10}(RPM_2 / RPM_1)$	$N_2 = N_1 + 20 \log_{10}(r_2 / r_1)$

As an example of the interaction of the fan laws, assume we want to increase airflow out of a fan by 10%. By increasing the fan speed 10%, we will achieve the increased airflow. However, this will require 33% more horsepower from the fan motor. Usually, the fan motor is being fully used and has no extra horsepower capability. Other solutions will have to be considered. The fan laws can be extremely useful in predicting the effect on fan performance and specification when certain operating parameters are changed.

Density Effects on Fan Performance

Since a fan is a constant volume machine, it will move the same CFM of air no matter what density of the air as seen in figure 5. However, a fan is not a constant mass flow machine. Therefore, mass flow changes as the density changes. This becomes important when equipment must operate at various altitudes. The mass flow is directly proportional to density change, while the volume flow (CFM) remains constant. As air density decreased, mass flow decreases and the effective cooling will diminish proportionately. Therefore, equivalent mass flow is needed for equivalent cooling, or the volume flow (CFM) required at altitude (low density) will be greater than what required at sea level to obtain equivalent heat dissipation.

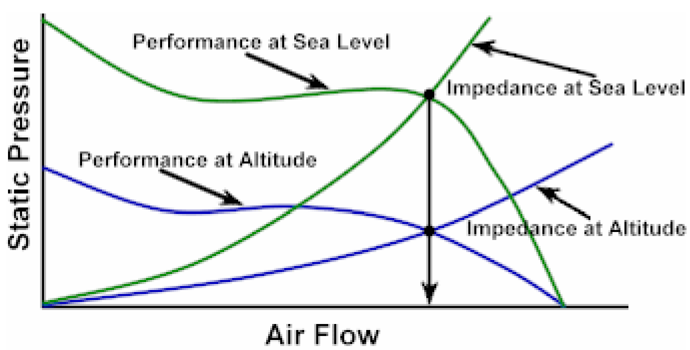

Figure 5: Density Effects on Fan Performance