Engineering Information

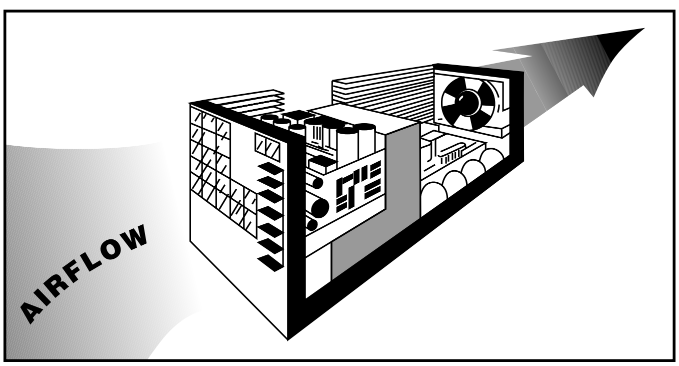
Most densely packaged electronic systems use a fan or blower for forced-air cooling. Smaller systems usually use axial cooling fans where airflow is perpendicular to the fan blades. However, larger systems may require centrifugal blowers to deliver adequate airflow in high static pressure situations.

The need for forced-air cooling should be determined at an early stage in system design. It is important that the design plans for good airflow to heat-generating components and also allows adequate space and power for the cooling fan.

Factors to be considered in fan selection include: required airflow, AC or DC power, voltage, speed, life expectancy, EMI/RFI, heat dissipation, auto-restart and audible noise.

The first stage in designing a forced-air cooling system is to estimate the required airflow. This depends on the heat generated within the enclosure and the maximum temperature rise permitted. AC input power is usually a good approximation of the power dissipated within the enclosure.

In estimating the power dissipated within a system, the possibility of future changes and additions of heat-generating subsystems should be allowed for. Therefore, the power dissipation figure used should be a worst-case estimate for a fully loaded system.



Enclosure with the Cover Removed

The airflow required can be obtained either by calculation or from a graph. The equation for calculation is:

$$Q = \frac{1.76\,W}{T_C}$$

Where:

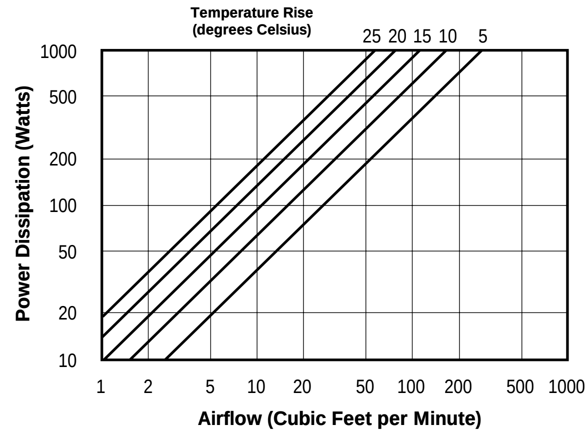
Q = Airflow required in cfm (ft3/min.)

W = Heat dissipated in watts

TC = Temperature rise above inlet temp ° C

For example, 32 cfm of airflow is required for a system that dissipates 200W and allows a 20° temperature rise.

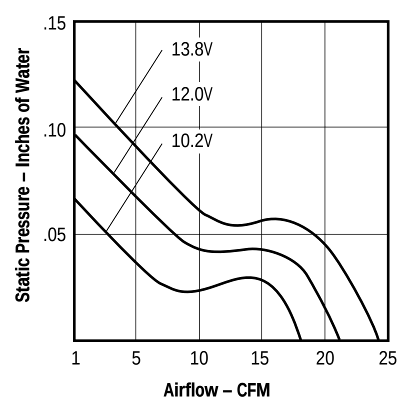
In the following graph, the vertical axis represents the heat to be removed and the horizontal axis represents the airflow; both axes are logarithmic. The sloping lines define the temperature rise in ° C. To use the graph, find the sloping line that represents the permitted temperature rise. Then, find the point on this line that corresponds to the heat to be removed. The horizontal position of this point shows the airflow required.



Power Dissipation vs. Airflow for Various Temperature Increases

System Impedance

Determining the actual airflow produced by a fan mounted in an enclosure is much more difficult than calculating the airflow required. Obstructions in the airflow path cause static pressure within the enclosure. The figure below shows the nonlinear relationship between airflow and static pressure for a typical fan. To achieve maximum airflow, obstructions should be minimized. However, obstructions in the form of baffles may be necessary to direct the airflow over the components that need cooling. Of course, the system components themselves also obstruct the airflow.



Typical Relationship between Airflow and Static Pressure for an Axial Cooling Fan

The experimental method of finding airflow through an enclosure is very accurate, but costly, time-consuming, and cumbersome. Also, it may be close to impossible to find a large enough airflow chamber in which to make measurements.

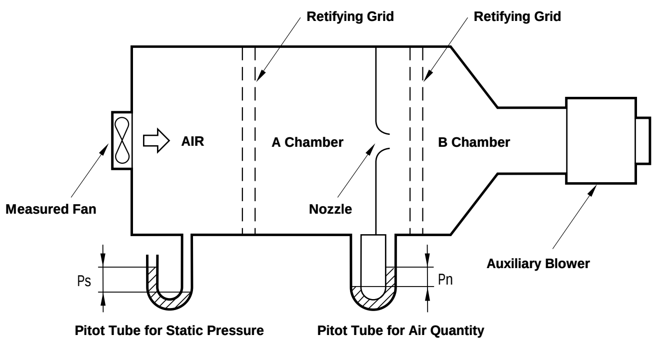
In practice, empirical methods are normally used to estimate airflow resistance. Experience shows that:

- An empty enclosure usually reduces airflow by 5 to 20%.
- A densely packed enclosure reduces airflow by 60% or more.
- Most electronic enclosures have a static pressure of between 0.05 and 0.15 in. H_2O.

Assuming a dense package, the fan in the previous example should be capable of delivering 80cfm in free air, instead of 32cfm.

Measuring Airflow and Static Pressure

An AMCA Standard 210 double chamber is used to accurately measure air volume and static pressure.



List of Equations and Variables

Q : Air Volume $= 60 \cdot C \cdot \frac{\pi}{4} \cdot D^2 = M2g/r \cdot Pn$ (m^3/min)

C : Coefficient of nozzle air volume

D : Diameter of nozzle (m)

r : Air Density $= 1.293 \times \frac{273}{273+T} \times \frac{P}{760}$ (kg/m^3)

T : Temperature (° C)

P : Air Pressure (mm Hg)

Pn: Differential pressure of air volume (mm Aq)

Ps : Static Pressure (mm Aq)

g : 9.8 m/sec^2

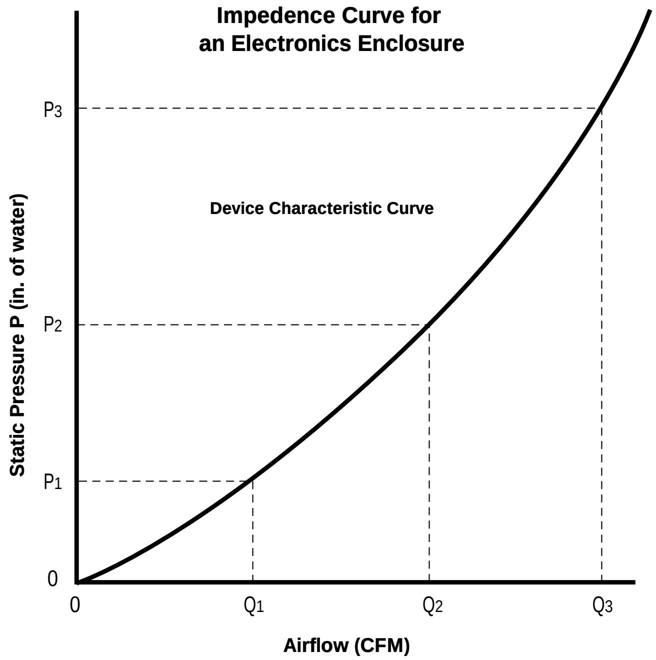
Maximum static pressure and maximum air volume measurements must be taken separately.

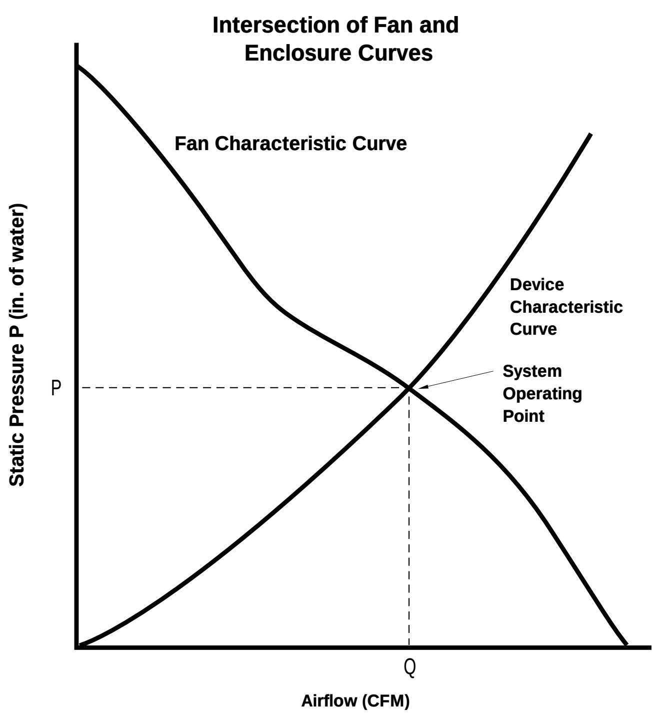
Maximum Static Pressure Measurement: When the nozzle is closed, the pressure in chamber A will reach a maximum. The pressure difference Ps represents the maximum static pressure achievable by the fan.

Maximum Air Volume Measurement: The nozzle is opened and the auxiliary blower is used to lower the pressure in chamber A to Ps = 0. The maximum air volume can then be calculated using Pn, D and the air volume equation above. Q represents the maximum achievable airflow with the fan in free air.

System Operating Point & Ducting Recommendations

The performance of a fan in a specific application is determined by the intersection of the Device Characteristic Curve and the Fan Characteristic Curve. The Fan Characteristic Curve is explained in the MEASURING AIRFLOW AND STATIC PRESSURE section. The Device Characteristic Curve is a property inherent to an individual electronics enclosure. It describes how air will flow through the enclosure given its particular obstacles and internal resistance. Resistance can be turns in the airflow or chambers that the air must flow through. The flow resistance is roughly proportional to the square of the volumetric flow rate. As a result, the graph of static pressure vs. airflow is parabolic for the enclosure. This curve can easily be generated experimentally, by testing the enclosure pressure at various airflow rates.

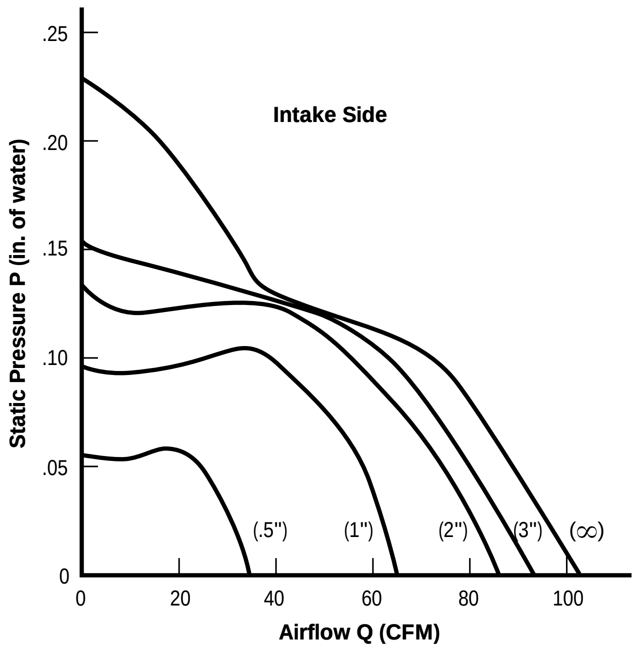


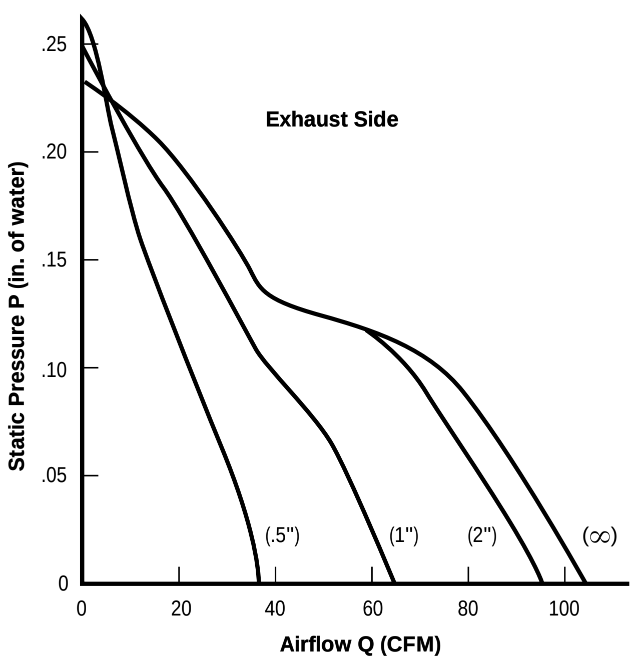


The full potential of the fan is only realized with optimal fan positioning and ducting. Otherwise, the Fan Characteristic Curve is suppressed resulting in reduced airflow. Following is a list of recommendations for fan ducting to minimize losses. These calculations are made for a 4715 series fan; but, the principles apply to other size fans. The preceding graphs show the suppression of the Fan Characteristic Curve caused by an obstruction near the fan inlet or exhaust. X is the distance in inches from the fan to the obstruction.

Finger guards typically have small losses and, if placed on the exhaust side, result in small noise increases. Obstructions placed near the fan intake raise the noise level more than obstructions on the exhaust side of the fan.

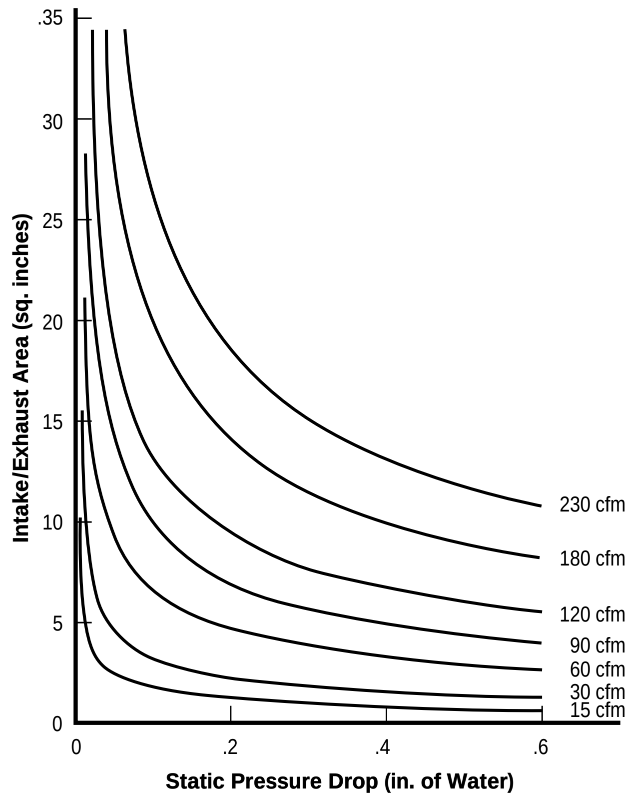
Suppression of the Fan Characteristic Curve with an Obstruction (X) inches Away





The following graph shows the recommended intake or exhaust area for minimized pressure losses.

Recommended Intake/Exhaust Area



Selecting A Fan

By knowing the required airflow, you can select a specific fan. First, consider whether the fan should use AC or DC power. In the past, the higher cost of DC fans led to the almost exclusive use of AC fans. Now that this price differential has disappeared, the many advantages of DC fans make them the best choice. One advantage of DC fans is longer life. Another is almost 60% less power consumption than AC fans. According to industry experts, a 10° C increase in fan temperature can reduce its life by as much as 20,000 hours.

Another selection factor is that the speed of a DC fan is directly proportional to voltage, so it can run at the speed required for adequate cooling. However, usually the fan runs at less than maximum speed, creating less noise, and using less power.

Among other DC fan advantages are lower levels of EMI and RFI than with AC fans. Also, with an AC fan the designer has to deal with various electricity supply voltages and frequencies used around the world. These problems disappear when using a DC fan. Finally, it is simpler to provide alarm capabilities for DC fans rather than for AC fans.

Most DC fans are available in 12 and 24V versions. The higher voltage is preferable because it results in lower current and lower power dissipation.

The frequency and magnitude of the noise generated by a fan increase with rotational speed. Where a choice is available, select a low-speed motor to minimize noise.

Having estimated the enclosures airflow requirement and static pressure, the manufacturer's airflow curves can be consulted to select a fan that will provide adequate cooling. These curves should be used with caution. It's not always clear from the manufacturer's catalog whether the curves are nominal or worst-case. Performance of a specific fan may vary as much as 10% from that shown in a nominal curve.

Sometimes the mistake is made of comparing fans by their free air performance figures. However, free air does not exist in a real enclosure. It is more realistic to compare fans by the airflow they produce between pressures of 0.05 and 0.15 in. of H_2O.

Noise has no effect on cooling, but is very important to the system end user. The quietest fan possible should be selected and techniques to minimize audible noise should be used.

One way to minimize noise is to use the largest fan possible. For a specific airflow, a larger fan runs at a slower speed and therefore creates less noise.

As mentioned above, DC fans create considerably less EMI and RFI than AC fans. For normal applications the EMI and RFI generated by a fan is not a problem. It may be a concern, though, where equipment is sensitive to interference or operates in an interference-sensitive environment.

Fan Life

Bearing wear is the primary factor in fan life. Most fan manufacturers use similar bearings, so there is little to differentiate one fan from another. Most manufacturers quote a life of 50,000 hours; for a 40-hour week, this is equivalent to 25 years. Therefore, it is likely that the fan will outlive the equipment it cools. As previously stated, the life of a fan decreases dramatically as its temperature rises.

UL mandates that fans must be able to withstand a locked rotor for 72 hours (15 days for AC fans) without causing any damage and without overheating. Fans must also restart and run normally after removing the cause of the locked rotor.

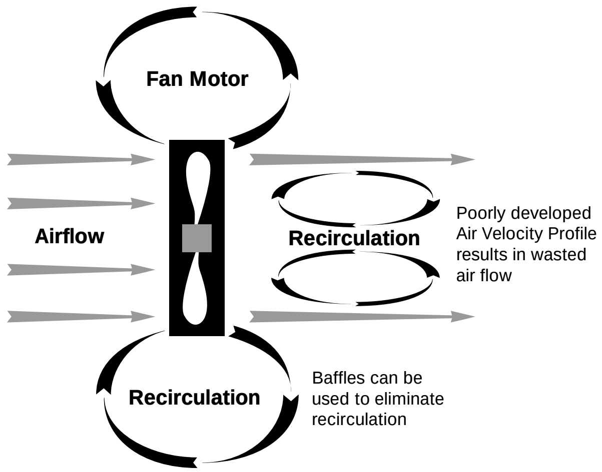
Impedance limits current in the windings of a stalled AC fan, but DC fans require electronic locked-rotor protection to limit current during a stall. Several types of protection are in use, however, not all provide automatic restart. System designers should carefully evaluate the type of protection to ensure that a DC fan restarts automatically after removal of an obstruction. They should also be sure that the protection system operates satisfactorily during intermittent power interruption.

Intake Or Exhaust?

Designers have the choice of mounting a fan to exhaust warm air from, or blow cool air into, an enclosure. Theoretically, the same volume of air is used to dissipate heat. However in real applications, each arrangement has advantages and disadvantages. Air that is drawn into the fan flows laminarly. Laminar flow allows for a uniformly distributed airflow velocity in the enclosure. This is important in eliminating stagnant air and hot spots. Air exhausted from the fan is turbulent. Heat dissipation in a turbulent airflow can be up to double that of a laminar flow with the same volumetric flow rate. But, the turbulent airflow region near a fan exhaust is limited. Developing a well defined airflow path through the whole enclosure is essential. Vents should be at least 50 percent larger in area than the fan opening. Care must be taken to eliminate air recirculation in a fan. Ninety percent, or more, of the airflow can be lost because of recirculation problems. Baffles may be used to eliminate recirculation of the same air. The airflow path will always take the path of least resistance.

Subassemblies and components within the enclosure should be positioned to direct the airflow to places that require cooling; and placement should always take advantage of natural convection. Place warm components above cool components. Avoid placing large components so that they shield smaller components from the flow of air. Use baffles, where necessary, to direct the airflow.

Recirculating Air Problems



An exhaust fan has the disadvantage of reducing the pressure within the enclosure, so airborne dust is drawn in through all the vents and cracks in the enclosure.

If exclusion of dust is a requirement, it is usually better to use a fan that pulls air into the enclosure. In this configuration, a filter at the fan inlet can remove dust from the incoming air. A further benefit is that the enclosure is slightly pressurized; so that dust is not drawn into the enclosure from the surrounding environment. Filters must be changed on a regular basis to eliminate dust accumulation. Dust accumulation can severely restrict airflow, causing elevated temperatures in an enclosure. The dust itself may be less of a problem than the overheating caused by a poorly maintained clogged filter.

A disadvantage of a fan that pressurizes the system is that the heat dissipated by the fan motor slightly warms the incoming air. This can reduce the air's cooling effect. For similar reasons, components that have the most critical cooling requirements should be placed close to the air inlets. High temperature components should be placed closed to the air outlets.

In many applications, using an intake fan, rather than an exhaust fan, can double or triple the life of the fan. The heated air passing over an exhaust fan stresses the fan's bearings much more than the 25° C air flowing over an intake fan. This reduction in temperature has a dramatic result on fan life, as seen in NMB's Fan Warranty Statement and Fan Life De-rating Curve.

Audible Noise

Most designs require minimal fan noise to satisfy users' demands for quiet systems. Compounding this challenge is the desire for smaller enclosures and higher system performance, both of which increase the need for airflow which, in turn, increases noise.

Audible noise originates from several sources, some of which can be controlled by the enclosure designer, whereas the fan manufacturer designs others in. Aerodynamic noise is a result of turbulence caused by the fan blades. The predominant component of this noise is at the blade-passing frequency, the frequency at which blades pass the struts that connect the motor to the fan's outer casing. This relationship might seem to imply that the motor speed, number of blades, and number of struts should be minimized. Unfortunately, the fan requires a certain speed and number of blades to produce the required airflow. Also, the fan needs a certain number of struts to provide rigidity without which mechanical vibration contributes to noise.

Mechanical noise can be caused by bearings or unbalanced rotating elements that cause vibration. If this vibration is at a frequency that matches any resonant frequencies of the enclosure, it can be amplified to an intolerable, or even destructive, level. The motor can contribute to the noise; but this is a very small part of the total noise generated by the cooling system.

All these noise components are inherent in the design of the fan and are almost entirely out of the enclosure designer's control. However, there are some details to which the enclosure designer should pay attention to minimize noise:

- Avoid placing obstructions in high air-velocity areas close to the fan.
- Use vibration isolators to eliminate transfer of mechanical noise from the fan to the enclosure.
- Use structural reinforcements to control enclosure resonant frequencies.
- Mount the fan on an interior surface of the enclosure rather than on an exterior surface.
- Obstructions placed near the fan intake raise the noise level more than obstruction on the exhaust side of the fan.

Designers should be very cautious when comparing noise specifications from different fan manufacturers. Although a standard method of measuring noise has been proposed, it has not been accepted by all fan manufacturers and users. This method is the ANSI 12.11 method. NMB provides this testing on all DC fan motors. It uses TOTAL Sound Power measurements for varying flow rates and impedance. Noise power levels, NPEL, are listed in Bels. This is the best universal method of comparing the noise generated by various fans in an electronics enclosure. It is the next best thing to testing fans in the actual enclosure.

Multiple Fan Use

Despite your best efforts, circumstances may arise that call for additional cooling after a design is finalized. To prepare for this, you should initially select a low-to-medium airflow fan in a specific size. Then, if more cooling air is needed, it is easy to replace the existing fan with one having the same mounting dimensions but with higher capacity.

In contrast, if the fan originally selected is the highest capacity in its size, increased cooling becomes a major redesign project.

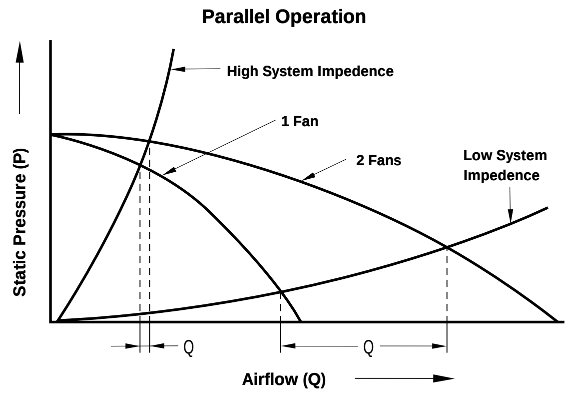
When additional cooling is required and cannot be provided by using a higher capacity fan of the same size, four possible solutions exist:

- Improve airflow within the enclosure.
- Redesign the enclosure to use a larger fan.
- Modify the enclosure to use two or more fans in parallel.
- Modify the enclosure to use two or more fans in series.

Often it is possible to provide sufficient additional cooling just by improving the airflow within the enclosure or by modifying the position or size of vents. If you cannot make the improvement by modifying the airflow, the preferred solution is to modify the enclosure to accept a larger fan. This allows selection of a fan matched to the enclosure requirements. There are times, though, when this choice is not possible. A fan with adequate performance may not be available or dimensional restrictions may prohibit the use of a larger fan. These cases require one or more additional fans.

In some situations, additional fans are used to increase the dispersion of air within the enclosure. Also, redundant fans may be used to increase system reliability.

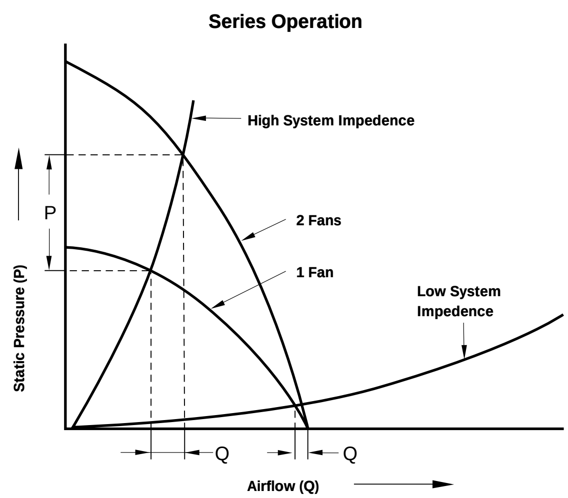
An additional fan can create problems. It doubles the cost, doubles the noise, doubles the heat generated by fans, and may provide only a minimal improvement to the cooling.



Ideal Performance of Two Fans in Parallel

Two fans in parallel double the airflow only in the hypothetical free air situation. If the enclosure has a high static pressure, this arrangement provides very little increase in flow. Two fans in series double the static pressure at shut-off (when no air flows), but do not increase the airflow in the free air situation. An additional fan in parallel to the first increases airflow in a low static pressure situation, whereas an additional fan in series increases the airflow in a higher static-pressure enclosure.

The increased heat dissipation incurred by adding a fan must not be ignored. In some extreme situations, the heat from an additional fan might be greater than the extra cooling it provides.



Ideal Performance of Two Fans in Series

Contact NMB Technologies for assistance in determining your fan requirements and for design recommendations to meet your system specifications.