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▶ **WHITE PAPER:** **Industrial Enclosure Cooling** **Applications - Filter Fans**



ENCLOSURES

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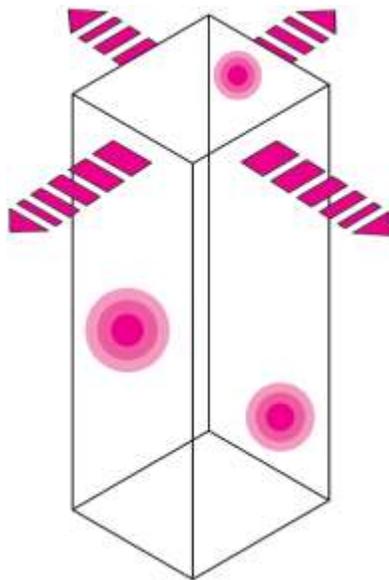
Executive Summary

Improved efficiencies for electronic components have been outpaced by a market demand to make those components smaller. The result is higher density systems that require active cooling solutions. Industrial enclosure climate control systems such as fans, air-to-air heat exchangers, air-to-water heat exchangers, and air conditioners are used to ensure continued operation and to prolong electrical equipment life.

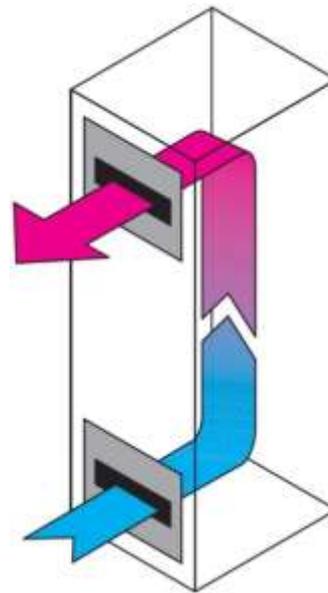
What follows is an examination of the simplest enclosure climate control system, the filter fan. First, however, it will help to understand the different ways in which heat is transferred and why climate control of electrical systems is critical. The reasons why one climate control system is chosen over another is also explored. Then sample calculations are shown for heat transfer using forced air. Finally, a review of how the application of filter fans affects cooling performance is given.

How Heat is Transferred

Heat is transferred through 3 different methods – convection, conduction, and radiation. Conduction occurs in all phases of matter – solids, liquids, gasses, and plasmas. Thermal radiation can occur even in the absence of a medium. Convection is the transfer of heat via a fluid (liquid or gas). More specifically, convection can be broken down into two major types – natural and forced. Natural convection as the name implies describes the flow of a fluid caused by buoyancy forces resulting from density changes (due to temperature changes) of that fluid. Forced convection describes the flow of a fluid caused by some external means such as a fan or pump.



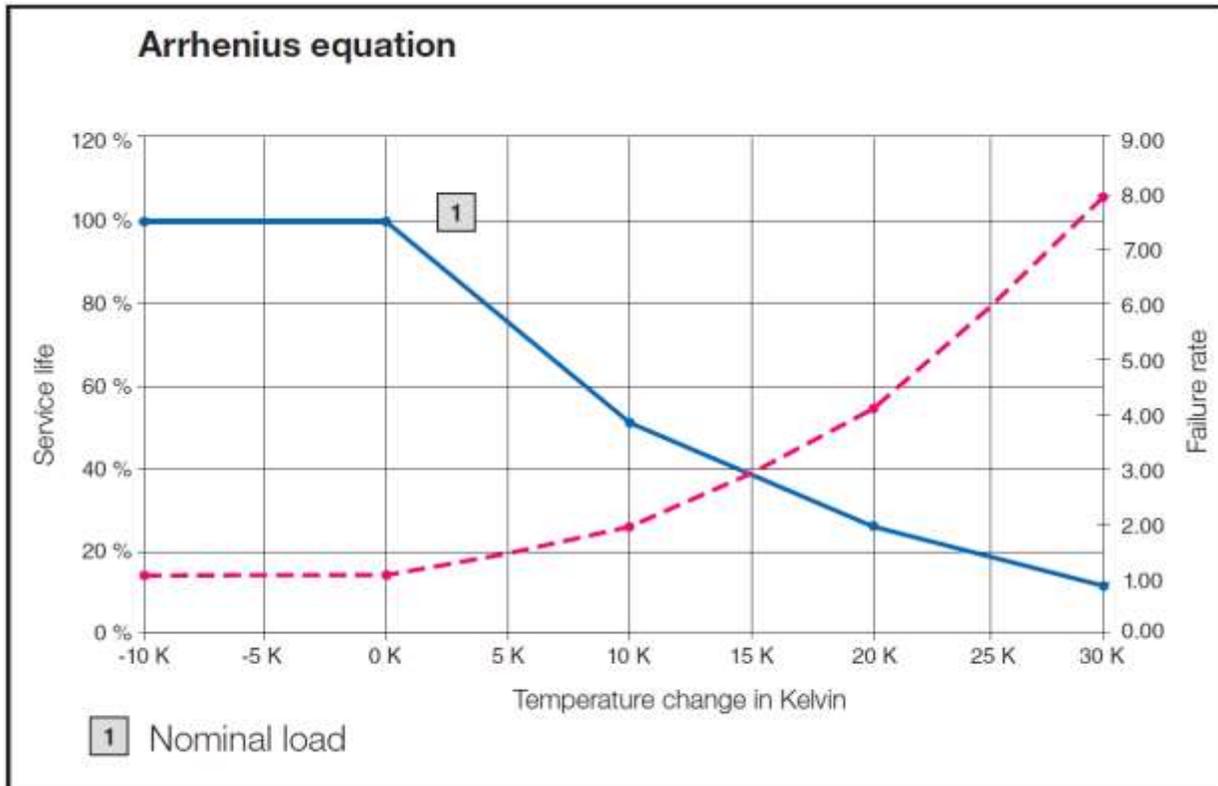
Natural Convection



Forced Convection

Why Climate Control is Needed

Electronics fail for many reasons including contamination by airborne particulates such as oil and dust; however, the main reason for failure is heat. As such, careful scrutiny of climate control methods is critical to achieving long-term operational effectiveness of these systems. Using the Arrhenius principle, the service life of components can be estimated to be halved for every 10 °C ($\Delta 10\text{ }^\circ\text{K} = \Delta 10\text{ }^\circ\text{C}$) increase in temperature above the recommended maximum.

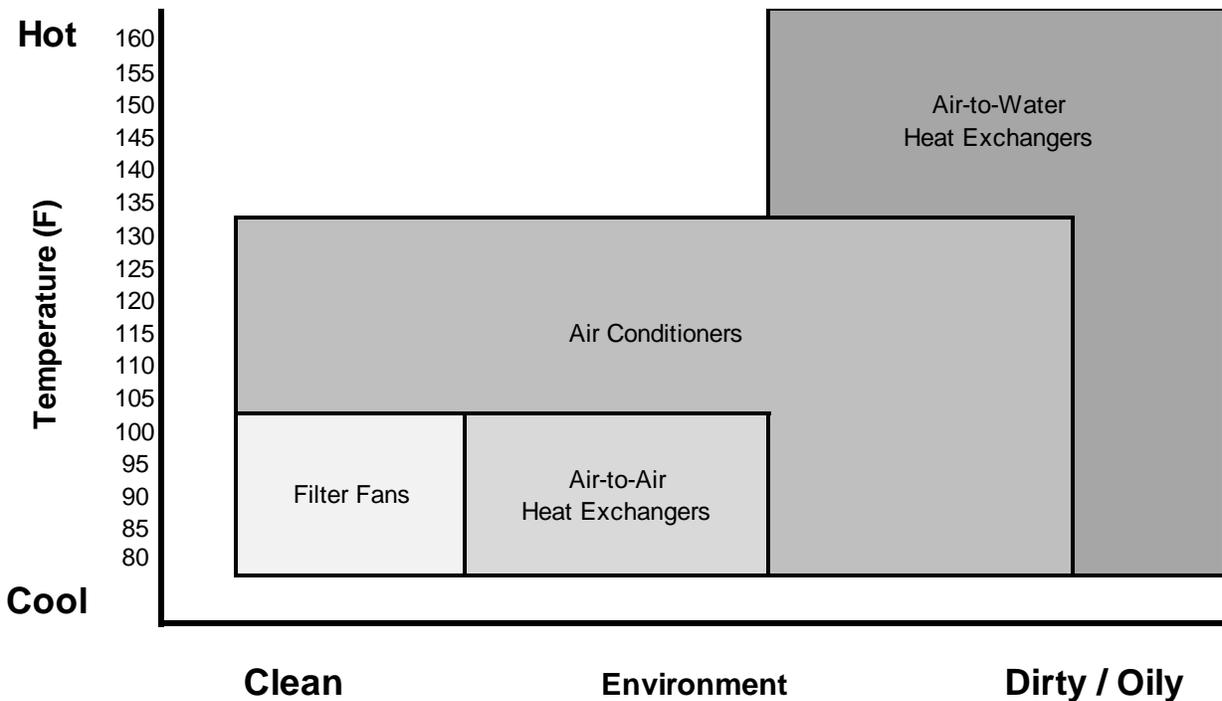


When to Use a Filter Fan

Filter fans are the most desirable active enclosure cooling method due to the ease of installation and cost effectiveness, both in acquisition cost and operating cost. To better explain when the use of a filter fan is optimal it is necessary to understand where filter fans fit within the climate control solution spectrum.

The choice of which climate control product will work with a given application is dependent on two main factors: temperature and the cleanliness of the environment. The following chart plots the ideal scenarios for each of the major climate control protection methods.

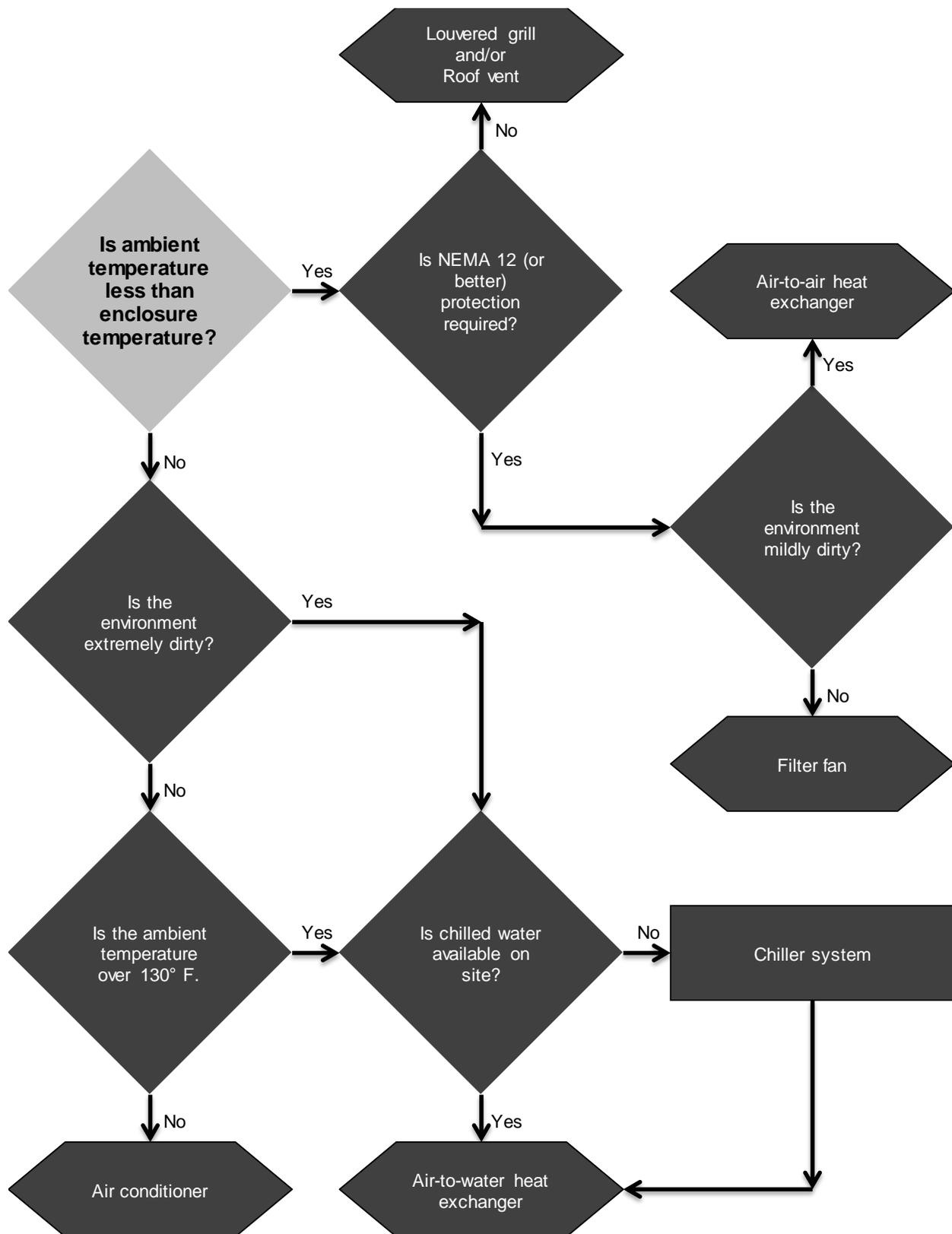
Industrial Enclosure Cooling Applications – Filter Fans



The estimations made here have no reflection on the overall usefulness or suitability of the product. In other words, don't be misled by the scale of the chart. At first glance filter fans may seem to have a narrow window of applications but the fact is there are many instances where filter fans are successfully deployed as the primary climate control option.

In addition to the temperature and cleanliness of the environment, the selection of climate control is also dependent on the type rating of the enclosure and the availability of chilled water. The flow chart on the next page provides a general outline of this selection process.

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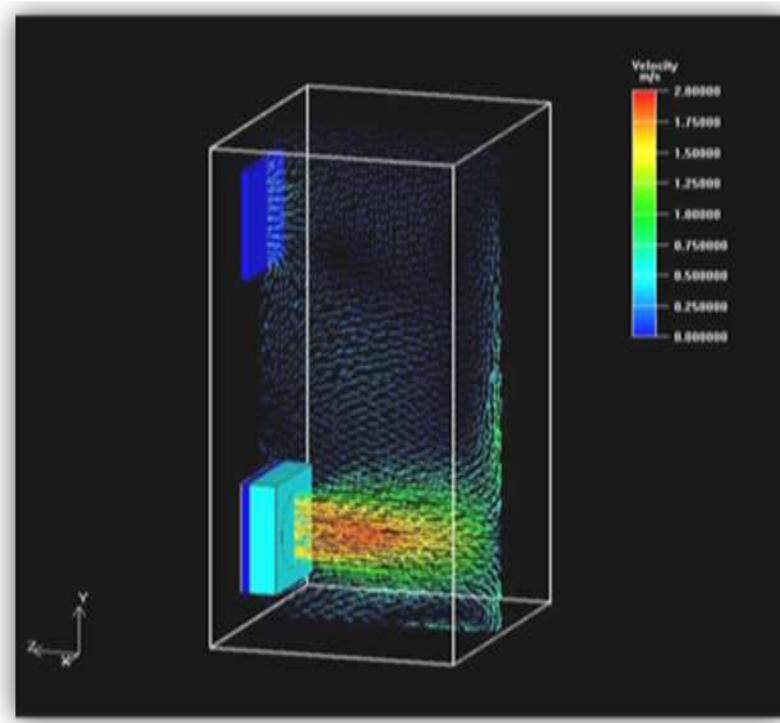


Determining Required Airflow

Given a set of parameters it is possible to determine the required airflow necessary to meet cooling expectations. This airflow is volumetric and given in units of cubic meters per hour ($\text{m}^3/\text{hr.}$) or cubic feet per minute (cfm). There are three main methods for determining this volumetric airflow: Computational Fluid Dynamic (CFD) analysis, manual calculations, and general sizing software.

Computational Fluid Dynamic Analysis

The first method to determine the amount of airflow needed for a forced air application is to use CFD software. Given the input of control variables, CFD uses numerical methods and algorithms to calculate the interaction of liquids and gases. Specifically CFD can provide a visual representation of these airflows for analysis.



CFD software is expensive and requires some expertise to correctly set up input variables as well as to properly analyze the output. It is useful for determining how air will flow for a given fan and filter combination however is overkill for simple selection of a fan given certain heat loads.

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Manual Method

The assumption that air within the enclosure is a uniform temperature (hot spots are quickly dissipated into the surrounding air of the internal enclosure) allows for a manual method that can also be used to determine the required airflow for a given application. With the input of several variables, (enclosure surface area, internal enclosure temperature, ambient temperature, and heat load generated by installed components) it only takes a few formulas and known coefficients to calculate what size fan is needed. Specific values for coefficients and other attributes mentioned below can be found within various engineering websites and heat transfer or thermodynamic textbooks.

Enclosure Surface Area

Enclosure size plays a significant role in climate control applications. An enclosure with more surface area will dissipate a greater amount of heat than an enclosure with less surface area. The installation orientation is also a contributing factor. Fully unobstructed surface areas will dissipate a greater amount of heat than those areas which are facing a wall. The formulas for calculating effective enclosure surface area (A) are specified in DIN 57 660 part 500.

Enclosure installation type to IEC 890		
<input type="checkbox"/>	Single enclosure, free-standing on all sides	<input type="checkbox"/>
<input type="checkbox"/>	Single enclosure for wall mounting	<input type="checkbox"/>
<input type="checkbox"/>	First or last enclosure in a suite, free-standing	<input type="checkbox"/>
<input type="checkbox"/>	First or last enclosure in a suite, for wall-mounting	<input type="checkbox"/>
<input type="checkbox"/>	Enclosure within a suite, free-standing	<input type="checkbox"/>
<input type="checkbox"/>	Enclosure within a suite, for wall-mounting	<input type="checkbox"/>
<input checked="" type="checkbox"/>	Enclosure within a suite, for wall-mounting, covered roof surface	
Installation type to IEC 890	Formula for calculating A [ft ²]	
<input type="checkbox"/>	A = 1.8 x H x (W + D)	+ 1.4 x W x D
<input type="checkbox"/>	A = 1.4 x W x (H + D)	+ 1.8 x D x H
<input type="checkbox"/>	A = 1.4 x D x (H + W)	+ 1.8 x W x H
<input type="checkbox"/>	A = 1.4 x H x (W + D)	+ 1.4 x W x D
<input type="checkbox"/>	A = 1.8 x W x H	+ 1.4 x W x D + D x H
<input type="checkbox"/>	A = 1.4 x W x (H + D)	+ D x H
<input checked="" type="checkbox"/>	A = 1.4 x W x H	+ 0.7 x W x D + D x H
A = Effective enclosure surface area W = Enclosure width [ft] H = Enclosure height [ft] D = Enclosure depth [ft]		

Internal Enclosure Temperature

The internal enclosure temperature (T_i) is the desired maximum temperature of the enclosure when the system is operating at full load.

Ambient Temperature

The ambient temperature (T_a) is the maximum temperature of the air surrounding the enclosure. Remember, for a filter fan application this temperature must be less than the internal enclosure temperature.

Heat Load Generated by Internal Components

The heat load generated by internal components (Q_c) can be formulated in a few ways. The most common method is done early during system engineering. Simply add the total heat loss

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of all components (drives, starters, circuit breakers, etc.) using information supplied by the component manufacturers. The other method is done after a system has been installed. Using a thermometer, the temperatures of the inside (T_{mi}) of the enclosure and the outside (T_{ma}) air are measured. Knowing these temperatures allows for the calculation of the heat being generated within the enclosure, all of which is passing through the enclosure walls and into the ambient air. The following equation is used.

$$\dot{Q}_v = U \cdot A \cdot \Delta T_m$$

Where:

\dot{Q}_v = Heat loss installed in the enclosure (W)

U = Overall heat transfer coefficient $\left(\frac{W}{m^2 \cdot ^\circ K}\right)$

A = Effective enclosure surface area (m^2)

ΔT_m = Measured temperature difference of internal and ambient air ($T_{mi} - T_{ma}, ^\circ K$)

Note, the overall heat transfer coefficient (U) is dependent on the individual heat transfer coefficients of the hot internal air and cool external air as well as the thermal conductivity and thickness of the enclosure material (generally steel). The calculation of this value is not difficult but is beyond the scope of this paper.

Heat Loss via Enclosure Surface

At the desired enclosure temperature, most of the heat will be cooled by the fan but a portion of that heat is still lost through the enclosure surface. Therefore the same equation may be used to determine the amount of heat lost to the surrounding air, but this time the desired internal enclosure temperature and ambient temperature are used.

$$\dot{Q}_s = U \cdot A \cdot \Delta T$$

Where:

\dot{Q}_s = Heat loss via enclosure surface (W)

U = Overall heat transfer coefficient $\left(\frac{W}{m^2 \cdot ^\circ K}\right)$

A = Effective enclosure surface area (m^2)

ΔT = Temperature difference of internal and ambient air ($T_i - T_a, ^\circ K$)

Required Cooling Output

Now, the required cooling output can be calculated. This is the total heat minus the heat lost via enclosure surface.

$$\dot{Q}_e = \dot{Q}_v - \dot{Q}_s$$

Where:

\dot{Q}_e = Required cooling output (W)

\dot{Q}_v = Heat loss installed in the enclosure (W)

\dot{Q}_s = Heat loss via enclosure surface (W)

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Required Volumetric Flow of Filter Fan

The required volumetric flow needed to cool the remaining heat in the enclosure is calculated using the equation for sensible heat.

$$\dot{Q}_e = \dot{M} \cdot c_p \cdot \Delta T$$

Where:

\dot{Q}_e = Required cooling output (W = J/s)

\dot{M} = Mass flow of the air being cooled (kg/s)

c_p = Specific heat of the air $\left(\frac{J}{kg \cdot ^\circ K}\right)$

ΔT = Temperature difference of internal and ambient air ($T_i - T_a, ^\circ K$)

This equation may be used with any fluid, but in this case the fluid is air. Mass flow can be converted into volume flow if the density is known. Note, both the specific heat and density of air will change with both temperature and elevation (pressure) and each should be taken into account. To coincide with most fan manufacturers published data, units of flow per second need changed to flow per hour as well.

$$\dot{M} \text{ (kg/s)} = \frac{\dot{V} \text{ (m}^3\text{/hr)} \cdot \rho \text{ (kg/m}^3\text{)}}{3600 \text{ (s/hr)}}$$

Substituting for M in the first equation gives:

$$\dot{Q}_e = \frac{\dot{V} \cdot \rho}{3600} \cdot c_p \cdot \Delta T$$

Rearranging for V gives the final equation which can be solved to obtain the required volumetric airflow necessary to cool the enclosure to the desired temperature.

$$\dot{V} = \frac{3600 \cdot \dot{Q}_e}{\rho \cdot c_p \cdot \Delta T}$$

Where:

\dot{V} = Volumetric flow of the air being cooled (m³/hr)

\dot{Q}_e = Required cooling output (W = J/s)

ρ = Density of air (kg/m³)

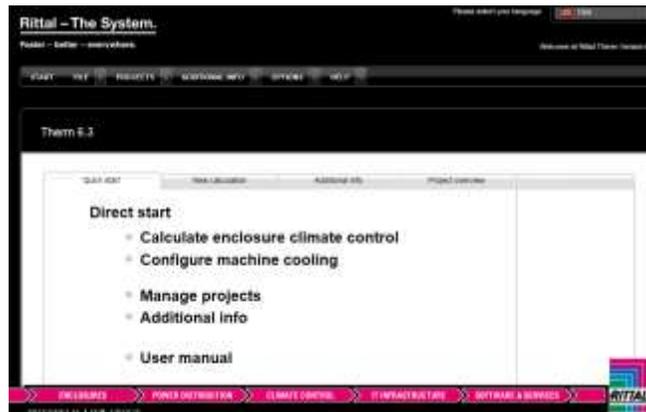
c_p = Specific heat of the air $\left(\frac{J}{kg \cdot ^\circ K}\right)$

ΔT = Temperature difference of internal and ambient air ($T_i - T_a, ^\circ K$)

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General Sizing Software

In review, the CFD method is expensive, requires analysis, and is generally overkill while the manual method involves several equations and takes time to solve. Fortunately there is a third way. The variables used in the manual method can be input into a general sizing program such as Rittal Therm 6.3. Therm makes two assumptions to the manual method equations. Although it can be changed, Therm uses a default value of 5.5 W/m²K for the overall heat transfer coefficient of a steel enclosure. Also Therm only varies the specific heat and density of air based on elevation, not temperature. These are sound assumptions since the overall heat transfer coefficient, specific heat, and density of air are not very different within the small range of temperatures used in most real world enclosure cooling applications.



Therm 6.3 is available for download [here](#). Mobile versions are also available.

Filter Fan Specifications

Below is a typical specifications table for filter fans.

Model No.	Packs of	3237.100	3237.110	3237.124	3238.100	3238.110	3238.124
Rated operating voltage V, -, Hz		230, 1-, 50/60	115, 1-, 50/60	24 (DC)	230, 1-, 50/60	115, 1-, 50/60	24 (DC)
Air throughput (unimpeded air flow) cfm (m ³ /h)		12/15 (20/25)	12/15 (20/25)	12 (20)	32/39 (55/66)	32/39 (55/66)	32 (55)
Rated current A		0.065/0.052	0.12/0.1	0.125	0.12/0.11	0.24/0.22	0.24
Pre-fuse A		2	2	2	2	2	2
Motor circuit-breaker		-	-	-	-	-	-
Power consumption W		11/9	11/9	3	19/18	19/18	5.5
Height (H) inches (mm)		5 (116.5)	5 (116.5)	5 (116.5)	6 (148.5)	6 (148.5)	6 (148.5)
Width (B) inches (mm)		5 (116.5)	5 (116.5)	5 (116.5)	6 (148.5)	6 (148.5)	6 (148.5)
Depth (T1) inches (mm)		1 (16)	1 (16)	1 (16)	1 (16)	1 (16)	1 (16)
Maximum installation depth (T2) inches (mm)		2 (43)	2 (43)	2 (43)	2 (58.5)	2 (58.5)	2 (58.5)
Required mounting cut-out (HxW) inches (mm)		4 x 4 (92 x 92)	4 x 4 (92 x 92)	4 x 4 (92 x 92)	5 x 5 (124 x 124)	5 x 5 (124 x 124)	5 x 5 (124 x 124)
Fan		Axial, self-starting shaded pole motor	Axial, self-starting shaded pole motor	Axial, DC motor	Diagonal, self-starting shaded pole motor	Diagonal, self-starting shaded pole motor	Diagonal, DC motor
Operating temperature range		+5°F...+131°F	+5°F...+131°F	+5°F...+131°F	+5°F...+131°F	+5°F...+131°F	+5°F...+131°F
Storage temperature range		-22°F...+158°F	-22°F...+158°F	-22°F...+158°F	-22°F...+158°F	-22°F...+158°F	-22°F...+158°F
Noise pressure level dB (A)		38/43	38/43	38	46/49	46/49	46
Accessories							
Outlet Filters	1 pc(s).	3237.200	3237.200	3237.200	3238.200	3238.200	3238.200

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This table has valuable information necessary to select filter fans. Along with the required airflow calculated in the previous section, power requirements must also be taken into consideration. The choice between AC or DC voltages will result in different airflows. The operating frequency (50 Hz or 60 Hz) also is a factor. Lastly, the physical dimensions of the fan are listed such that compatibility with the enclosure can be determined.

Most importantly the volumetric airflow is listed as “air throughput (unimpeded airflow)”. To better understand what this means, a review of the factors that affect airflow is necessary.

Filter Fan Performance

The primary components composing a filter fan assembly are the housing, fan motor, and the fan blades. As the fan blades rotate, air is being directed (pushed) and this movement of air creates pressure.

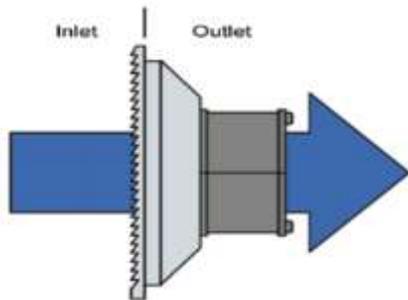


Figure 1

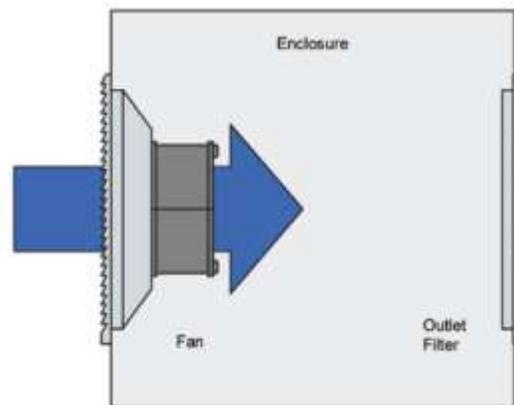


Figure 2

In *Figure 1* above, the airflow passes from the inlet to outlet side of the fan. The inlet side includes the louvers and filter mat while the outlet side is through the motor and blade assembly. This illustrates the “unimpeded airflow” mentioned in the chart above. Please note not all filter fan manufactures list unimpeded airflow this way. Some use the motor and fan blade assembly only and give higher values due to the absence of resistance introduced with the louver and filter mat assembly.

An unimpeded fan operates at zero static pressure and provides maximum air flow. When fitting a filter fan and outlet filter onto an enclosure (*Figure 2*) the fan must overcome resistance that impedes the airflow. This resistance comes in the form of a pressure drop due to the internal components installed within the enclosure (densely populated enclosures provide physical obstructions) and more importantly the outlet filter. The fan counters this pressure loss by increasing pressure which in turn decreases airflow.

Using part number 3237.110 in the specifications table on the previous page as an example, this fan operates on single phase current, 115 V at 50 or 60 Hz. The unimpeded airflow is 12 cfm (20 m³/hr) at 50 Hz and 15 cfm (25 m³/hr) at 60 Hz. To understand how the fan will perform under the real world scenario depicted in *Figure 2*, it is necessary to review the fan's

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performance chart, sometimes referred to as a “fan curve”. This chart shows how a particular fan performs under different pressure measurements.

Figure 3 shows an actual performance chart for Rittal filter fan 3237.110 (60 Hz). The blue curve represents the airflow of filter fan 3237.110 with a standard filter mat and the solid black curve represents the impedance for outlet filter 3237.200. The point where these 2 curves intersect is the actual airflow. So filter fan 3237.110 installed on an enclosure with outlet filter 3237.200 will have an actual airflow of about 10.6 cfm (18 m³/hr). This is the value which should be used when choosing a filter fan for a specific application, not the 15 cfm (25 m³/hr) unimpeded rating. Note, any physical obstructions within the enclosure are considered minimal and are ignored but actual results may vary.

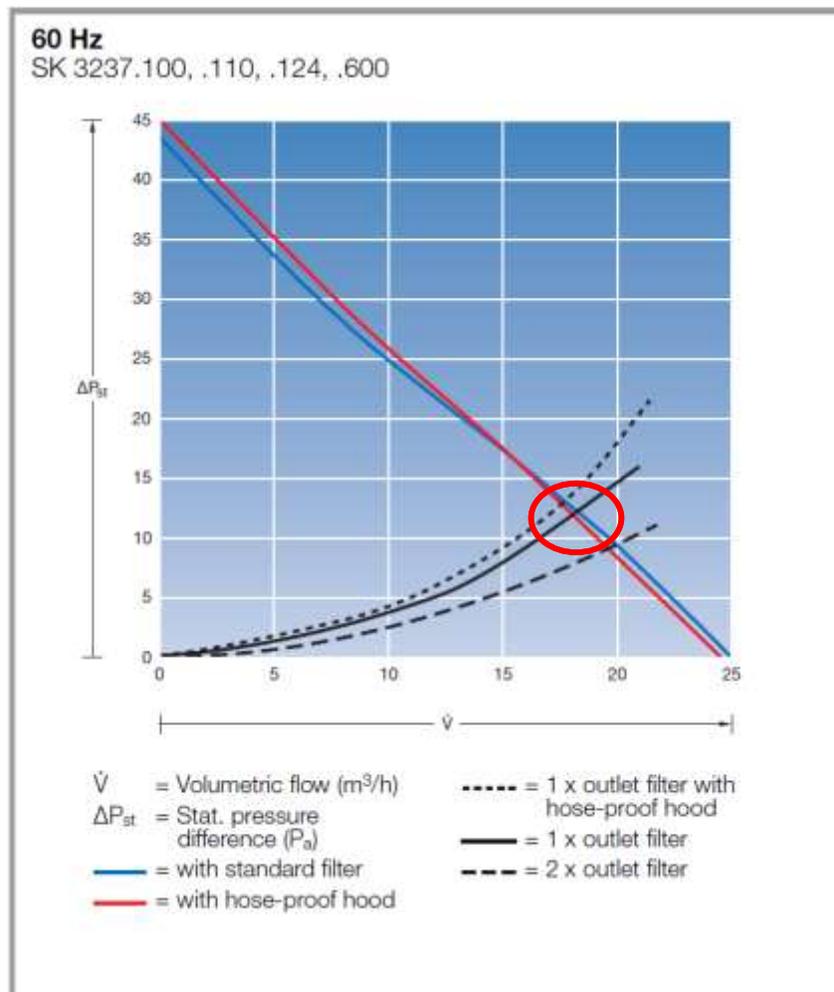


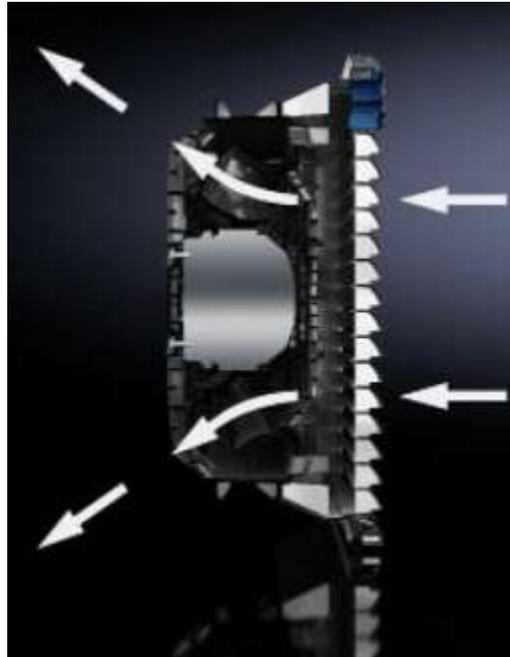
Figure 3 - Rittal filter fan 3237.110 performance chart

Fan Design

Fans can be axial, centrifugal (radial), or a mix of the two. Propeller shaped axial fans direct air from inlet to outlet along a line parallel to the rotation of axis. Axial fans are the most commonly used method to cool individual electronic components. Blade designs are optimized to work at

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specific speeds resulting in very quiet operation; however, axial fans do not handle higher pressures so efficiency drops dramatically beyond their optimized speed. With a centrifugal fan the air flows in a conical manner on the inlet side and is released perpendicular to the rotation of axis on the outlet side. A centrifugal fan will operate at a higher pressure, but at lower airflows. Hybrid fans offer advantages of both axial and centrifugal fan types. The intake is axial while the exhaust is diagonal, resulting in a fan that can be used at higher pressures but still deliver high airflow. For industrial enclosure cooling applications the diagonal fan provides greater pressure stability resulting in a more constant airflow, even with a contaminated filter mat. The diagonal airflow also promotes a more even air airflow distribution throughout the enclosure.



Airflow pattern for a diagonal fan

EC Fans

A typical filter fan with an AC induction motor is usually controlled by a separate bi-metal thermostat that turns the fan on and off based on the temperature within the enclosure. When turned on, the fan runs at a steady speed determined by the design of the motor and voltage applied to it. The temperature difference between when the thermostat switches on and then back off is known as the hysteresis. This hysteresis is a product of the bi-metallic design of the thermostat and prevents short cycling of the fan; however, the trade-off is the fan will run longer than needed. Also, filter fans are typically sized for a worst case scenario which means they are generally oversized for their most common use, leading to more energy inefficiency.

Tighter temperature control may be achieved through the use of another fan type, the EC fan. A fan with EC (electrically commutated) technology is one that utilizes a brushless DC motor and external electronics to power the fan. The precise electronically controlled current produces a more energy efficient fan; however, the largest energy gains come from the ability to easily control the speed. A separate controller with an integral electronic thermostat can send variable

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inputs to the electrical commutation circuit allowing the fan to speed up and slow down as needed. This eliminates the superfluous energy use caused by a thermostat with a hysteresis.

Push vs. Pull

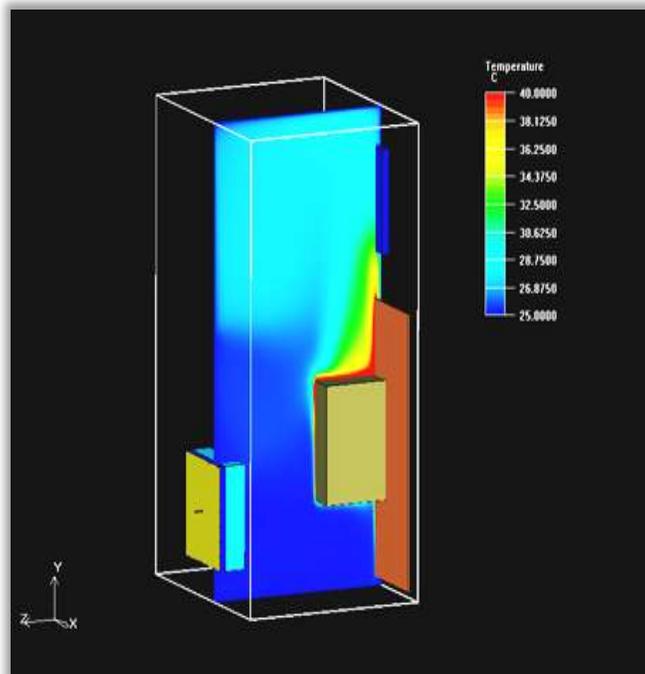
Most modern filter fans for industrial enclosure applications can be set up to blow air into or blow out of the enclosure. The orientation of the airflow has an effect on cooling performance and more. A diagonal fan blowing air into an enclosure will result in a more desirable turbulent airflow which promotes an even distribution throughout the enclosure and reduces the chance for hot spots. Reversing the diagonal fan to blow out will result in a more laminar flow, thereby nullifying this advantage. Another advantage to blowing air in is that it will positively pressurize the enclosure with all air entering through the filter mat. Pulling the air out of the enclosure will result in a negatively pressurized enclosure giving rise to the possibility that air (and with it dust) could leak into the enclosure from sources other than the filter.

Configurations

Different fan and filter configurations will produce different airflows. A fan manufacturer may only show performance curves for a few of these combinations but assumptions can be made to estimate others.

Standard configuration

The standard installation configuration involves a single filter fan and exhaust outlet filter. Fan manufacturers will generally provide performance curves showing at least this one combination. The CFD output below shows an example of this standard configuration.



CFD temperature distribution: single fan + filter

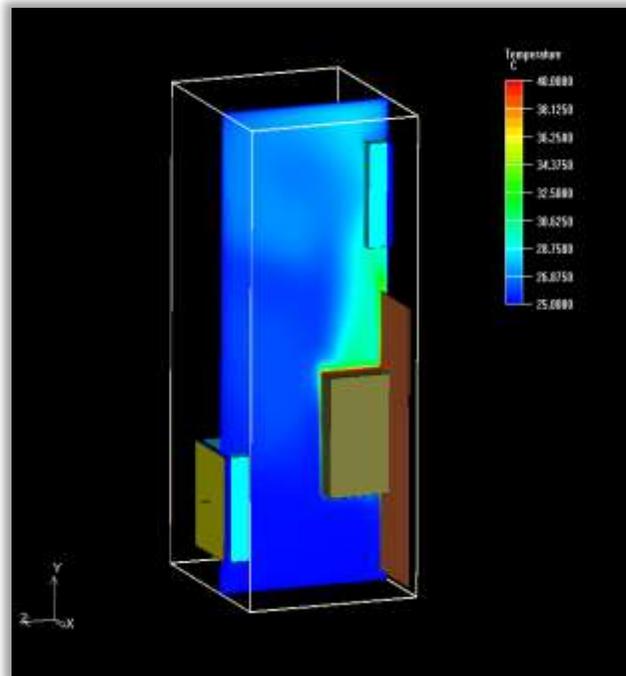
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Larger outlet filters

The addition of an outlet filter to a system results in a pressure drop that the fan must overcome. Doubling the surface area of the outlet filter will generally result in a pressure drop reduction of at least 50% and often much more for higher flow fans. This reduced pressure drop lessens the burden of the fan to increase pressure however the overall effect is small since a pressure increase of four times is needed to double the airflow. Looking at *Figure 3* again, there is an impedance curve for two outlet filters, which results in an airflow of around 11.7 cfm (20 m³/hr); only a 10% increase over the 10.6 cfm (18 m³/hr) for one outlet filter. Larger filter fans will exhibit a greater increase but generally never more than a 20% improvement.

Fans in series (push-pull)

Replacing the outlet filter of a system with an equal size fan will decrease the static pressure inside the enclosure; however, a fan can never go beyond its unimpeded rating. CFD analysis suggests the result of this configuration is equal to the unimpeded rating of the fan minus 2.5-3% but a more conservative value of 4-5% is commonly used. Looking at *Figure 3* again, the unimpeded rating is 14.7 cfm (25 m³/hr). If the outlet filter is replaced with another 3237.110 fan, the output would increase from 10.6 cfm (18 m³/hr) to ~14.1 cfm (24 m³/hr) - unimpeded rating of 25 m³/hr minus 4%. This technique is most beneficial for enclosures with high system impedance.

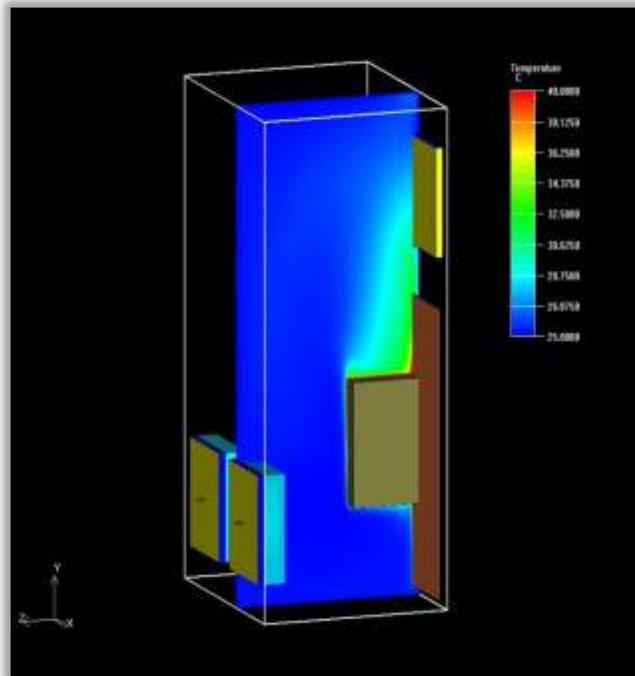


CFD temperature distribution: fans in series

Fans in parallel

The final way fans may be configured is in parallel, two or more fans side-by-side installed along with two or more exhaust filters. In this scenario the airflow is nearly doubled and has the best temperature distribution, although systems with higher impedance will exhibit less improvement.

Industrial Enclosure Cooling Applications – Filter Fans



CFD temperature distribution: fans + filters in parallel

Certifications

One key advantage of filter fans over passive ventilation is the ability to maintain NEMA (National Electrical Manufacturers Association) or UL (Underwriters Laboratories) environmental Type ratings. With filter mats installed, the fan and filter combination provides a dust tight UL Type 12 barrier. The addition of fan hoods makes it possible to achieve Type 3R rain tight and Type 4/4X outdoor ratings. Configurations utilizing these hose-proof-hoods will require the fans to operate at increased pressure, which in turn reduces airflow. This slight reduction can be seen in *Figure 3* above.

UL certification of filter fans is achieved after testing the individual product features such as housing (QMFZ2: Plastics - Component), gasket (JMST2: Gasket Materials - Component), fan (GPWV2: Fans, Electric - Component), and others including motor, and terminal block. The entire assembly is generally UL recognized to NITW2: Industrial Control Panel Equipment Component, but may also be UL listed to FTTA – Environmental-rated Accessories for Enclosures. It is important to note those fans recognized to NITW2 should not be considered inferior to the listed FTTA versions because filter fans are not required to be “procedure described”, a process in which an integrator must pay a fee to have recognized components added to their UL files. Instead UL 508A Table SA1.1 Section 26.2.3 states a fan kit recognized to NITW2 only needs to be “installed according to manufacturer instructions”.

Conclusion

Heat is a deadly enemy of electronics. It only takes an increase of 18°F ($\Delta T=10^{\circ}\text{C}$) to reduce the life expectancy of electronic components by 50%, making the removal of heat the main priority to ensure continued operation of electronic systems. The filter fan has long been the traditional front line defender keeping heat at bay. While filter fans can't be used for every application, they are the most desirable active enclosure cooling method due to the ease of installation and overall cost effectiveness.

Although filter fan selection may seem trivial, the costs associated with a system failure due to heat more than justifies a close review of cooling needs. In addition to the cooling requirement, other factors that play a role in the selection of filter fans are the environmental type rating of the enclosure and power (voltage and frequency) requirements of the system. It is recommended to utilize general sizing software to determine if filter fans are the proper choice for a given application. If after sizing there are no apparent standard solutions, estimations can be made for special configurations such as fans in series. If all else fails, there are other climate control solutions which may work such as air conditioners or heat exchangers.

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