Overview

Electrical and electronic components are continually being reduced in size allowing designers to place more equipment in a smaller space. This concentration of equipment generates higher internal temperatures and makes heat dissipation very important. Overheating causes electrical insulation to deteriorate and shortens the life of electrical and electronic components. As a rule of thumb, for every 18°F (10°C) above room temperature (72°F or 22°C) an electronic device operates, its life expectancy is reduced by 50%

Enclosure Materials

The following information applies to gasketed and unventilated enclosures. Exterior surface finishes significantly influence temperature rise. Fiberglass and painted steel enclosures dissipate heat better than unfinished aluminum or stainless steel enclosures because the fiberglass and painted steel surfaces are more efficient thermal radiators than the unfinished surfaces. In outdoor applications light colored enclosures such as white have a high reflectance which minimizes solar heat gain compared to dark colored enclosures.

Enclosure Surface Area

The total surface area of the enclosure directly influences heat dissipation. The larger the total surface area the lower the temperature rise will be.
To calculate the total internal surface area in sqft use the following equation:

Surface Area = 2[(AxB)+(A*C)+(BxC)] / 144 where the specific enclosure inside dimensions are A x B x C.

This equation uses all six (6) sides of an enclosure. If any particular side is not available for transferring heat (example the back is mounted against a cement wall) that surface area should be subtracted from the total surface area available.
Also note, enclosure volume cannot be substituted for enclosure area.

Enclosure Heat Input

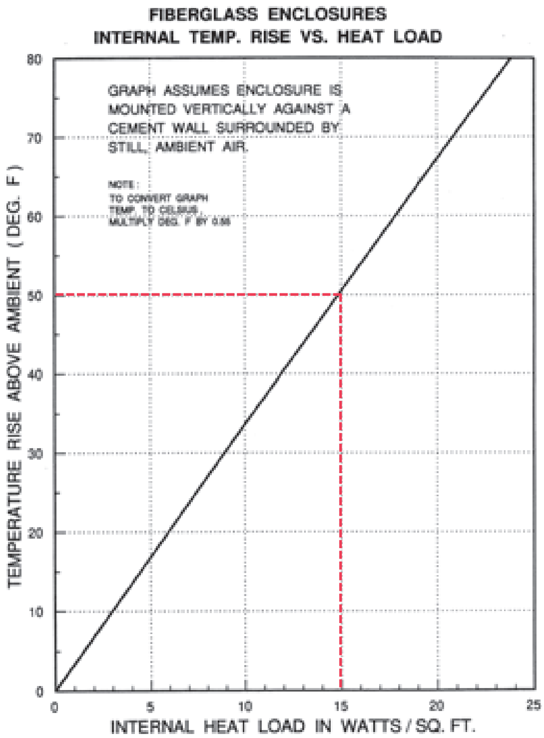
The heat generated in an enclosure varies and depends on the equipment mounted in the enclosure and the application. In order to calculate Temperature Rise, this heat input or power input must be known. This information can be obtained from the component manufacturers of components to be installed in the the enclosure.

Enclosure Temperature Rise (ΔT)

Enclosure temperature rise is the temperature difference between the air inside a non-ventilated or cooled enclosure and the ambient air outside the enclosure. The enclosure temperature rise is independent of the ambient temperature; it is dependent on the heat generated within the enclosure and the actions taken to dissipate that heat. To establish the maximum service temperature, the temperature rise value from the graph in Figure 1, must be added to the maximum ambient temperature surrounding the enclosure.

Example:
Max ambient T = 130°F
Internal Heat Load = 15 watts/sqft or 50°F estimated from Figure 1
Calculated Maximum Service Temperature = (130°F + 50°F) = 180°F

Figure 1. Internal Temperature Rise vs. Heat Load



The temperature graph was developed through empirical testing using several enclosures of various sizes. The temperatures represent an average of one temperature measurement near the bottom of the enclosure and a second measurement near the top. Electric heaters mounted equidistant from the internal surfaces of the enclosure were used as the heat source. Because hot air rises, a significant temperature gradient occurred from top to bottom. Typical of an actual installation, the top was much hotter than the bottom.

Technical Information

Table 1. Approximate Enclosure Internal Surface Areas for Popular Enclosure Sizes

Fiberglass Enclosures					
Cat. No.	Internal Area Sq. Ft.	Cat. No.	Internal Area Sq. Ft.	Cat. No.	Internal Area Sq. Ft.
N16107	5.37	N30247	17.08	J1407	3.27
N20166	7.98	N302410	19.53	J1412	4.24
N20168	8.98	N302412	20.95	J1614	5.36
N201610	9.97	N302414	22.50	J1816	7.77
N201612	10.98	N302416	24.06	J2016	9.39
N201616	12.82	N36308	24.82	CL707	1.51
N24126	8.04	N363012	28.60	CL907	1.81
N241210	10.09	N363016	32.41	CL1109	2.82
N242410	15.72	N483612	39.87	CL1311	3.89
N30208	14.78	N483616	44.57	CL1513	5.11
N302010	16.17	J606	1.16	C2016	8.98
N302012	17.56	J806	1.45	C2412	10.09
N302014	18.95	J1008	2.01	C2424	15.72
		J1210	3.09	C3024	19.53
				C3630	26.71

Influences of Heat Transfer

Convection and thermal radiation are used most often to dissipate heat from enclosures. Because fiberglass is used as a thermal insulator, a common misconception exists that fiberglass enclosures operate at significantly higher temperatures than metal enclosures. To the contrary, performance data reflect that enclosure material has little influence on the operating temperature and confirm that non-metallic and painted metallic enclosure function at nearly the same temperature with the same internal heat load. Based on these observations material thermal conductivity is not a major factor in determining heat transfer for an enclosure.

Even though the thermal conductivity of the composite plastic is much less than aluminum or steel, the heat transfer characteristic of fiberglass and metal enclosures are similar. Other factors such as the high thermal insulation of air contained within the enclosure along with the finish, color and total surface area of the enclosure have more influence on heat transfer than thermal conductivity. In general the finish and color of an enclosure most affect the heat transfer capability, In-door and in out-door applications.

Thermal conductivity is commonly measured in BTU/hr/ft^2/°F/in, the K Value. K units represent the quantity of heat, which can pass through one square foot of material in one hour for every °F in temperature difference across one inch of material thickness. Larger K values indicate better heat conductivity. The K value for fiberglass is 1.68; the K value for steel is 334; and the K value for aluminum is 1050.

The heat transfer factor (Q) is measured in BTU/hr/ft2/°F or watts/ft^2/°F. For the analysis in this section the Q value used for steel enclosures is 1.25 BTU/hr/ ft^2/°F (0.37 watts/ft^2/°F); for fiberglass enclosures the Q value is 0.62 BTU/hr/ft^2/°F (0.2 watts/ft^2/°F). The Q value for sheet metal enclosures will vary between 1 BTU/hr/ft^2/°F (0.29 watts/ft^2/°F) and 5 BTU/hr/ft^2/°F (1.46 watts/ft^2/°F), depending on the amount of enclosure insulation.

Air as an Insulator

If metals have much better thermal conductivity, why does equipment in a fiberglass enclosure operate at nearly the same temperature as in metal enclosures? The air confined within the enclosure has a K value of 0.017, almost 100 times less than fiberglass. The thermal resistance of the air and the enclosure wall material are in series and must be added. Because air is a superior thermal insulator compared to either fiberglass or steel, it is a predominant factor in establishing heat dissipation. This helps explain why equipment operates at the same temperature regardless of which enclosure material is used and also why environmental control systems heat or cool the air to control the internal temperature.

Surface Area as a Factor

Another factor, which directly influences heat dissipation, is surface area. If the enclosure surface area is doubled with a given internal heating load, the temperature rise will only be half as great. It is important to remember that surface area is not necessarily related to enclosure volume, i.e., an enclosure having twice the surface area does not always have twice the volume.

Other Related Issues

Certain applications may require the walls of an enclosure to act as a heat sink. For example, it is not uncommon to locate a high power semiconductor on the wall of a metal enclosure to dissipate heat. Fiberglass will not perform this function efficiently because the compression-molded walls have negligible thermal conductivity. In this application conduction is used to dissipate the heat and a fiberglass enclosure will not function the same as a metal enclosure.

Calculating Temperature Rise

Enclosure temperature rise can be approximated using the following steps and calclulations:

1. Calculate the internal surface area
    a. (some common enclosure sizes and areas are already calculated and can be found in Table 1.
    b. Using the Enclosure Surface Area formula on page 173
2. Determine the Input Power by dividing the expected heat load by the internal surface area
3. Then using Figure 1, estimate the temperature rise by finding where the Internal Heat Load value intersects the line and reading the approximate temperature rise on the left vertical axis of the graph.
    Note these are approximations, safety factors should be considered to minimize uncertainties.

Example

A J1816 enclosure contains a device that generates 120 watts, calculate the internal temperature rise.

Solution

1. Surface Area = 7.77sqft from Table 1 (alternate method for any size use calculation on page 357 for Internal Surface Area)
2. Internal Heat Load = 120 watts / 7.77 sqft = 15.44 Watts/sqft
3. Using Figure 1, Input Power of 15.44 intersects the diagonal line corresponds to a temperature rise of 51`F above ambient.

Additional Cooling Methods

When it has been determined that the heat load is too large for an enclosure to dissipate by radiation and convection, the following supplemental cooling methods are available:

Breather Vents and Louver Vents

Breather Vents and Louver Vents are designed to remove heat from the enclosure by allowing natural air circulation around the heat source and ex-hausting the hot air through slots or louvers. This method is relatively inexpensive and has no operating cost; however, it can only be used to dissipate a limited amount of heat and it is difficult to predict the temperature drop produced by a vent utilizing natural convection.

Circulating Fans

In larger sealed enclosures a fan can be used to circulate the air and reduce localized heat concentrations; however, the applications are limited because a closed system fan only redistributes heat, it does not dissipate the heat generated by the hot spot.

Where an enclosure does not need to be sealed from the outside environment, fans can be used to circulate air through an enclosure and dissipate the heat generated by power supplies, transformers and other heat producing equipment. Fans can provide as much as 10 times the heat transfer rate of natural convection a radiation. Once the heat input in watts/ft2 is determined and temperature rise is established from Figure 1, the following equation can be used to calculate the fan flow rate:

Fan Flow Rate (CFM) = 3.17 x Internal Heat Load (watts)/Temperature Rise

Example
Equipment in an N363012 enclosure generates sufficient heat to require a fan, which will dissipate 300 watts. The maximum ambient temperature in the application environment is 115°F. If the temperature of the other contents in the enclosure cannot exceed 125°F, what size is required?
The allowable temperature rise is 125°F - 115°F = 10°F.
The application requires dissipation of 300 watts.

Solution
To determine the cubic feet per minute (CFM) required in a standard application, use the following equation (if the air density is significantly more that 0.075 lb. per cubic foot, a non-standard application exists and this equation should not be used):

Fan Flow Rate (CFM) = 3.17 x 300 watts/10°F
Fan Flow Rate (CFM) = 95 CFM

This calculation is exact, but adding an additional 25% capacity to the CFM level is standard to provide a safety factor.

1.25 x Fan Flow Rate (CFM) = 1.25 x 95 CFM = 119 CFM

If the air density is non-standard (significantly more than 1.075 lb. per cubic foot), the following equation can be used to calculate the fan capacity:

Fan Flow Rate (CFM) x 0.075 lb. per cubic foot / Non-standard Air Density (lb. per cubic foot)

Fans can be used to draw air through an enclosure insert, exhaust hot air from an enclosure or to draw cool air into an enclosure. An inlet fan offers the following advantages:

- Raises the internal pressure, which helps keep dust and dirt out of an unsealed or frequently open enclosure.
- More turbulent airflow improves heat transfer.
- Longer fan life with cooler incoming air.

The following considerations are important in locating a fan:

- Avoid placing transformers, power supplies or other heat generating devices in front of the fan. Although this cools the device, it increases the heat load on other devices within the enclosure. It is best to place these devices near the exhaust outlet.
- To achieve maximum cooling, the inlet and outlet should be separated by the maximum distance. If the outlet and inlet are adjacent to each other, the hot outlet air will be drawn into the inlet and cooling efficiency will be reduced. In general the inlet should be at the bottom of the enclosure and the outlet at the top.
- Fans should not be used or located in areas where the airflow is restricted. A plenum is recommended to accelerate air velocity and improve fan performance. A plenum is particularly helpful when a filter is used where airborne contaminants are a problem.
- The air outlet area should at least equal the inlet area. For best results the exhaust opening should be 1.5 times the area of the fan opening.
- Air is less dense at high altitudes. For this reason airflow should be increased in high altitude applications.
- All fans used in parallel should be identical.

Heat Exchangers - Cooling

Heat exchangers are a good option when precise control of heat and humidity are not required and the heat transfer requirements are significant. The required heat exchanger capacity can be calculated using the formula,

Heat Exchanger Capacity (watts/°F) = Internal Heat Load/ΔT + 0.22 x Enclosure Surface Area,
Where ΔT = Temperature Rise.

Example

If the internal heat load is 1000 watts in an N603616 Fiberglass enclosure, what is the minimum cooling capacity for the heat exchanger unit? The Maximum ambient temperature is 130°F and the internal equipment will malfunction if the internal enclosure temperature exceeds 105°F.

Solution

Internal Heat Load = 1000 watts
Maximum Temperature Differential = T_i - T_o =105°F-130°F = -25°F = [25°F], use Absolute Value.
Enclosure Surface Area = 53.49 ft^2

Heat Exchanger Capacity =
1000 watts/(25°F) - 0.22 x 53.49 ft^2 = 28.23 watts/°F

In this example the surface area acts to cool the enclosure and is subtracted, the Absolute Temperature Value is used because this is a temperature difference.

Air Conditioning-Cooling

Air conditioning will be required in high ambient temperature locations where precise temperature control and humidity reductions are required in a sealed enclosure. Air conditioning can also be required where neither convection, thermal radiation, louvers, slots nor a circulating fan system provide adequate cooling. Because air conditioners remove moisture from the enclosure, a condensate drain is generally required.

The four-step process to size and select the air conditioner is influenced by the internal heat load, enclosure size and the application environment. The following information is required:

Step 1. Determine the Internal Heat Load

Heat generated by all sources within the enclosure shall be added together to establish the internal heat load in watts. The heat load in watts may be multiplied by 3.413 to convert to BTU/hr.

Internal Heat Load =_______________ watts X 3.413 =_______________ BTU/hr.

Step 2. Calculate the Surface Area of the Enclosure

For an enclosure size not shown in Table 1, the surface area can be calculated by using this formula.

SURFACE AREA = [2(AxB)+2(AxC)+2(BxC)]/144 IN² = AREA IN SQUARE FEET

If the enclosure is mounted on a wall or against another enclosure, the surface area calculation may be modified as identified in
Table 2.

Step 3. Establish the Temperature Differential

The temperature differential (ΔT) is calculated by subtracting the maximum allowable temperature inside the enclosure (T_i) from the maximum ambient temperature outside the enclosure (T_o).

$T_o - T_i = \Delta T =$ ________°F

Step 4. Calculating the Required Air Conditioning Capacity

The values determined in the first three steps are used to calculate the required capacity of the air conditioner according to the following formula,

Cooling Capacity (BTU/hr) = Surface Area x ΔT x Q + Internal Heat Load, where Q = 0.62 BTU/hr/ft²/°F (0.2 watts/hr/ft²/°F) for fiberglass enclosures.

Example
If the internal heat load is 500 watts in an N20168 fiberglass enclosure, which is wall mounted, what is the cooling capacity required for the air conditioning unit? The maximum ambient temperature is 125°F and the internal equipment will malfunction if the internal enclosure temperature exceeds 110°F.

Step 1: Internal Heat Load = 500 watts = 3.413 x 500 watts = 1707 BTU/hr

Step 2: From Table 1, Total Surface Area = 8.98 ft°

Step 3: Temperature Difference:
$T = T_o - T_i$ = 125°F - 110°F = 15°F

Step 4: Air Conditioner Capacity
8.98 ft² x 15°F x 0.62 BTU/hr/fr²/°F + 1707 BTU/hr = 1790.5 BTU/hr

8.98 ft² x 15°F x 0.2 watts/ft² +500 watts = 526.9 watts

Air Conditioning - Heating

Some enclosure systems have minimum as well as maximum operating temperature limitations. When the equipment in an enclosure must be maintained above a minimum temperature at low ambience, these same equations can be modified and used to calculate the supplemental heat required to select and size the heaters. The only differences are that the internal heat load will help heat the enclosure and the temperature difference, ΔT, is calculated by subtracting the minimum ambient temperature (T_o) outside the enclosure from the required temperature (T_i) inside the enclosure. The minimum supplementary heat can be calculated according to one of the following equations:

$\Delta T = T_o - T_i$

Supplementary Heat = [Surface Area x (ΔT - 1)] /4.1
or = Surface Area x ΔT x Q
where Q = 0.2 watts/ft² °F

<u>Example</u>

If the internal heat load in 100 watts in an N20168 Fiberglass enclosure, which is wall mounted, what is the minimum heating capacity for the heating elements? The minimum ambient temperature is 0°F and the internal equipment will malfunction if the internal enclosure temperature drops below 40°F.

$\Delta T = T_o - T_i = 40°F - 0°F = 40°F$

Supplementary

Heat = [8.98 ft² x (40°F -1)] /4.1 = 85.4 watts

- or -

8.98 ft² x 40°F x 0.2 watts/ft² °F = 71.84 watts

Two Commonly used, but different, equations shown above have been used to show the effect of using different heat transfer values.

In addition to heating, supplementary heaters are often used in enclosures to keep the internal enclosure ambient temperature a few degrees above the ambient temperature to prevent condensation on internal equipment.

TABLE 2. CALCULATION OF ENCLOSURE SURFACE AREA DEPENDING ON LOCATION

Enclosure Configuration	Position	Formula for Surface Area	Surface Area of N20168
Single Enclosure, Free Standing	■	[2(AxB) + 2(AxC) + 2(BxC)]/144	8.98 ft²
Single Enclosure, Free Standing*	■	[1.8(AxB) + 1.8(AxC) + 1.4(BxC)]/144	7.66 ft²
Single Enclosure, Against a Wall	▨ ■	[1.4(BxA) + 1.4(BxC) + 1.8(CxA)]/144	6.78 ft²
Side by Side Enclosures; First or Last Enclosure in Bank of Enclosures	■ □ □	[1.4(CxA) + 1.4(BxC) + 1.8(BxA)]/144	7.16 ft²
Side by Side Enclosures; First or Last Enclosure in Bank of Enclosures Against Wall	▨ ■ □ □	[1.4(AxB) + 1.4(AxC) + 1.4(BxC)]/144	6.28 ft²
Side by Side Enclosures Not at the End of Enclosure Bank	□ ■ □	[1.8(AxB) + 1.4(BxC) + (AxC)]/144	6.65 ft²
Side by Side Enclosures within an Enclosure Bank, Bank Against a Wall	▨ □ ■ □	[1.4(AxB) + 1.4(BxC) + (AxC)]/144	5.77 ft²
Side by Side Enclosures within an Enclosure Bank, Bank Against a Wall & Roof Above	▨ □ ■ □ □	[1.4(BxA) + 0.7(BxC) + (CxA)]/144	5.05 ft²

*Depending on the enclosure design, the complete surface area may not be exposed for cooling. This formula and the remaining ones are conservative and account for such differences.