

## Cooling Solution

Since heat dissipation is often not a solution, we will limit our choices to protective vs. fresh air cooling.

Use the environmental and electronic system criteria in the table below to determine whether protective or fresh air cooling is most appropriate for your application.

### Protective vs. Fresh Air Cooling

Specifying protective cooling that keeps your electronics components sealed from the outside environment versus using fresh air cooling to remove damaging heat depends on the following profile of your system application (check one side or the other for each of the six choices):

	FRESH		PROTECTIVE	
Clean Air / Some Dust / Dripping Water	<input type="checkbox"/>	<b>SYSTEM OPERATING ENVIRONMENT</b>	<input type="checkbox"/>	Dirty / Wet / Metal Filings / Outdoors / Corrosive Fumes
Moderate to Low (typically under 95 F / 35 C)	<input type="checkbox"/>	<b>TEMPERATURE OUTSIDE OF THE ENCLOSURE</b>	<input type="checkbox"/>	Hot (typically over 95 F / 35 C)
Somewhat to Well-Above Ambient Temperature	<input type="checkbox"/>	<b>TEMPERATURE RATING OF THE ELECTRONICS</b>	<input type="checkbox"/>	Below to Somewhat Above Ambient Temperature
Moderate to Low	<input type="checkbox"/>	<b>HUMIDITY OUTSIDE OF THE ENCLOSURE</b>	<input type="checkbox"/>	High Relative Humidity
Wide	<input type="checkbox"/>	<b>TEMPERATURE RANGE FOR THE ELECTRONICS</b>	<input type="checkbox"/>	Narrow / Precise
Moderate to Low (typically under 3000 Watts)	<input type="checkbox"/>	<b>SYSTEM POWER DRAW / HEAT LOAD</b>	<input type="checkbox"/>	Moderate to High (typically over 3000 Watts)

If most of your assessments fell on the fresh air side, then a filter fan, fan tray, motorized impeller or blower is probably the correct cooling solution for your application. However, if most of your assessments were on the protective side, then an air conditioner or heat exchanger found in the McLean Protective Cooling Catalog is likely the right cooling solution for your electronics system.

## Cooling Solution Choices

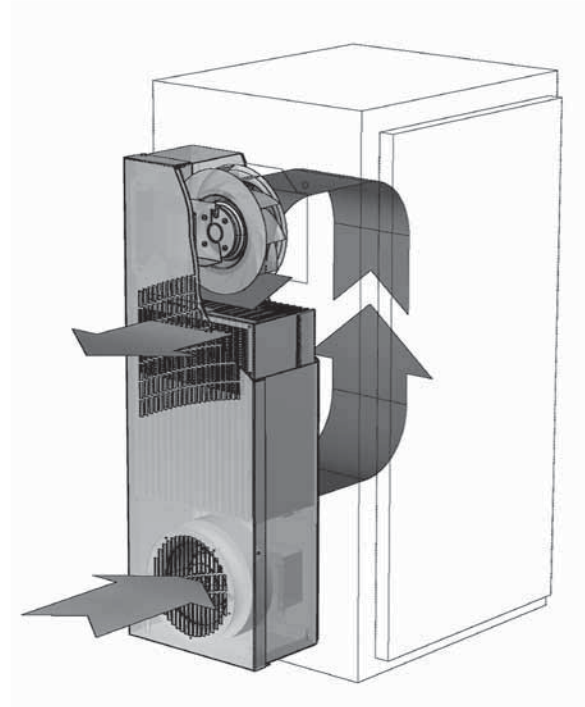
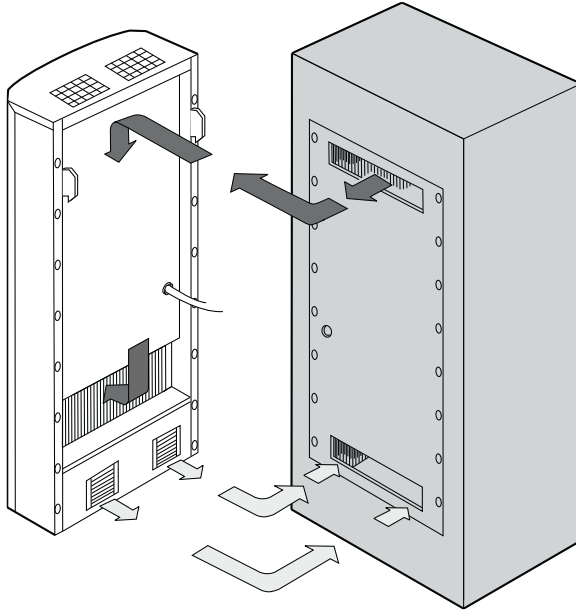
Assuming that protective cooling is needed for the application, there are two basic choices—air conditioners or heat exchangers.

An air conditioner should be specified when:

- The temperature inside the enclosure must be maintained at or below the ambient temperature
- Humidity must be removed
- A moderate to high heat load is being produced by the electronic system

A heat exchanger can be used to transfer heat from inside the enclosure to the outside atmosphere when:

- The electronic components can operate at a temperature above the ambient air temperature
- Humidity is not a factor
- A low to moderate heat load is being produced by the electronic system



## How to Select the Right Cooling Capacity Air Conditioner

### Air Conditioner Cooling Capacity Overview

The cooling capacity of an air conditioner needs to match or exceed the amount of total heat load generated by the electronic system.

Total heat load comes from two sources:

- (a) the electronic components themselves which is called "internal heat load" and
- (b) the ambient heat outside the enclosure which is known as the "heat transfer load."

Most engineers and cooling suppliers determine internal heat load. However, the impact from the heat transfer load is easily overlooked. Heat transfer load can significantly add to the total heat load of the system, especially if the outside air temperature is high and/or the enclosure is located in the sun.

Thus, the **total heat load** to be removed from the electrical enclosure by the air conditioner is the sum of the **internal heat load** and the **heat transfer load**.

$$\text{TOTAL HEAT LOAD} = \text{INTERNAL HEAT LOAD} + \text{HEAT TRANSFER LOAD}$$

### Part A: How to Determine Internal Heat Load

The internal heat load comes from the amount of waste heat generated inside the enclosure by the electronic components and is expressed in Watts (W).

There are several methods to determine internal heat load, depending on data availability.

#### Method 1. Heat Load Data from Each Electronics Component Manufacturer

One way to estimate internal load is to gather heat load data from the manufacturers of the electronics components inside the cabinet. They may know the amount of heat their equipment is generating. If more than one control or other electronics components are inside the enclosure, it will be necessary to add together all the estimates of heat load to determine total internal heat load.

#### Method 2. Component Power – Component Efficiency

A second method is to establish the Watts of power used by each electronic component. Derive Watts of power by multiplying the amp draw of each device by its voltage. Then subtract the efficiency of each component from its estimated power use. Add up the outcomes to get the total internal heat load.

$$\text{INTERNAL HEAT LOAD} = \text{COMPONENT POWER (W)} - \text{COMPONENT EFFICIENCY}$$

(for each electrical device)

Example—

An electronic system uses two components that draw 115 VAC at 15 A. Each has a rated efficiency of 90%. Put another way, 10% of each device is inefficient. Unused power becomes generated heat. Thus the estimated internal heat load is:

$$\begin{aligned} \text{Device Power} &= 115 \times 15 = 1725 \text{ W} \\ \text{Total Power} &= 2 \times 1725 = 3450 \\ \text{Less Efficiency} &= 3450 \times (1 - .90) \\ \text{Total Heat Load} &= 345 \text{ W} \end{aligned}$$

#### Method 3. Incoming – Outgoing Power

A third approach is to estimate the power going into the enclosure and the power coming out of it. The difference becomes the estimated amount of internal heat load. The amps and volts of each electrical line going in are multiplied to determine Watts, then they're added together. The same is done for the electrical line(s) coming out of the application. The outgoing Watts are then subtracted from the incoming Watts.

$$\text{INTERNAL HEAT LOAD} = \text{INCOMING POWER (W)} - \text{OUTGOING POWER (W)}$$

Example—

An enclosure has three input lines of 230 VAC at 11, 6 and 4 A. It has one output control line of 115 VAC at 9 A.

$$\begin{aligned} \text{Incoming Power} &= (230 \times 11) + (230 \times 6) + (230 \times 4) = 4830 \text{ W} \\ \text{Outgoing Power} &= 115 \times 9 = 1035 \text{ W} \\ \text{Total Heat Load} &= 4830 - 1035 = 3795 \text{ W} \end{aligned}$$

#### Method 4. Automated Equipment Horsepower

This fourth method applies only to industrial automation equipment that operates with horsepower (hp) such as variable frequency drives (VFDs). 1 hp = 745.6 W. Thus, the internal heat load from a 3-hp VFD is 2237 W, less its efficiency which is typically 93% - 95%.

Example—

A cabinet has three 5-hp VFDs with 95% efficiency.

$$\begin{aligned} \text{VFD Watts} &= 5 \text{ hp} \times 745.6 \times 3 = 11184 \\ \text{Adjusted Watts} &= 11184 \times (1 - .95) = 559 \\ \text{Total Heat Load} &= 559 \times 1.25 = 699 \text{ W} \end{aligned}$$

*1.25 is an assumed "safety" margin for other minor heat-producing components.*

## How to Select the Right Cooling Capacity Air Conditioner

### Part B: How to Determine Heat Transfer Load Overview

Heat transfer load is the ambient heat outside the enclosure conducting itself through the cabinet walls toward the electronics (heat energy travels from the hottest to coldest location).

When an air conditioner cools the enclosure temperature lower than the ambient air outside, additional heat load is drawn into the cabinet which the air conditioner needs to remove. The higher the ambient temperature and/or the presence of solar heat gain (the "greenhouse effect") on the enclosure, the more cooling capacity is required.

Determining heat transfer load requires that you know the **total surface area** of the cabinet, less any non-conductive surface area such as the enclosure side mounted to a wall. It also requires that you determine  $\Delta T$ , which is the difference between maximum ambient temperature and the maximum temperature rating of the electronics components.

There are two methods for determining heat transfer load—the simple chart method and the equation method.

#### Simple Chart Method

This method is reasonably accurate for most indoor industrial systems where there is no unusual air movement and insulation is not typically used inside the enclosure. The process also provides a ballpark result for outside plant and telecommunications applications, taking into account solar heat gain. However, it does not incorporate the impact of wind or cabinet insulation. If either is present, then the equation method is more precise.

Step A. Determine  $\Delta T$  in °F or °C.

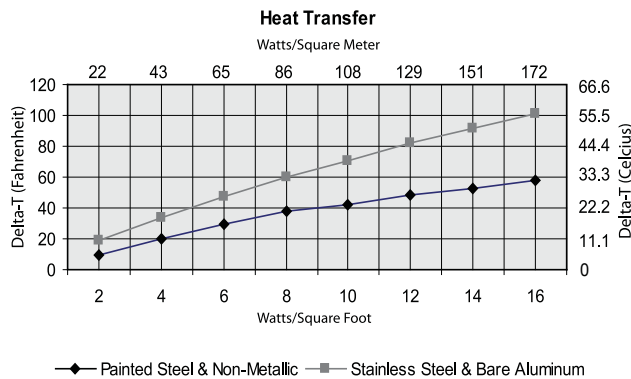
Step B. Find the heat transfer per ft.<sup>2</sup> or m<sup>2</sup> on the chart below, using  $\Delta T$  and the proper cabinet material curve.

Step C. Multiply the heat transfer per ft.<sup>2</sup> or m<sup>2</sup> by the total surface area of the enclosure that will conduct heat. (Remember to exclude surfaces such as a side mounted to a wall.)

$$\text{SURFACE AREA (ft.}^2\text{)} = [2AB \text{ (in.)} + 2BC \text{ (in.)} + 2AC \text{ (in.)}] \div 144$$

$$\text{SURFACE AREA (m}^2\text{)} = [2AB \text{ (mm)} + 2BC \text{ (mm)} + 2AC \text{ (mm)}] \div 1000000$$

$$\text{Total Heat Transfer Load} = \text{Heat Transfer per ft.}^2 \text{ or m}^2 \times \text{Cabinet Surface Area}$$



Example —

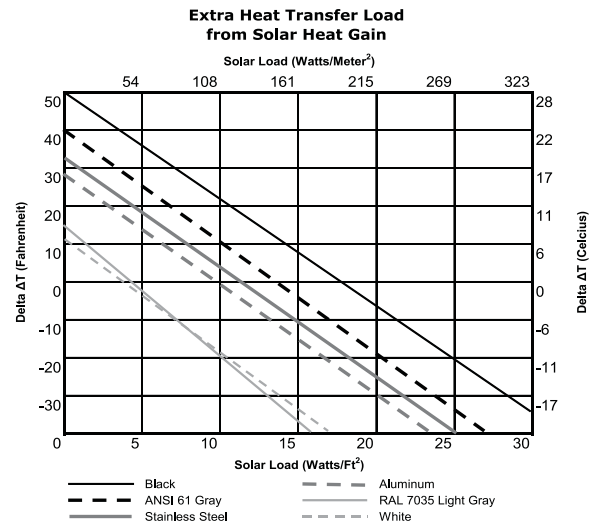
A painted steel cabinet has 80 ft.<sup>2</sup> of surface area and will be located in a maximum ambient temperature of 95 F. The rated temperature of the electronics is 75 F.

$$\Delta T = 95 - 75 = 20 \text{ F}$$

$$\text{Heat Transfer} = 4 \text{ W/ft.}^2 \text{ (from chart)}$$

$$\text{Total Heat Transfer Load} = 80 \times 4 = 320 \text{ W}$$

The estimate for heat transfer load ends here, unless the electronic system will be deployed outdoors. Then solar heat gain needs to be added to the total heat transfer load calculated above. Solar heat gain is determined much the same way as heat transfer per ft.<sup>2</sup> or m<sup>2</sup>, using a similar chart.



Example — The painted cabinet above is in ANSI 61 gray. Thus, 7 W/ft.<sup>2</sup> need to be added to the heat transfer load which is 560 W (7 x 80 ft.<sup>2</sup>). Total Heat Transfer Load consequently becomes 720 W.

*The result does not include insulation which can significantly reduce heat transfer load.*

## How to Select the Right Cooling Capacity Air Conditioner

### Equation Method

Heat transfer load may also be determined by equation. This method should be used when at least one of the following criteria are found in the electronic system:

- Moderate to high airflow within the cabinet
- Outdoor applications that involve breezes or gusty winds
- Insulation used within the cabinet to offset the impact of solar heat gain

The governing equations for heat transfer load are:

English System (°F, inches and feet):

$$q = (T_o - T_i) \div [(1/h_o) + (1/h_i) + R]$$

Metric System (°C, millimeters and meters):

$$q = (T_o - T_i) \div [(1/h_o) + (1/h_i) + R] \times 5.67$$

Definition of Variables—

q = Heat transfer load per unit of surface area

T<sub>o</sub> = Maximum ambient temperature outside the enclosure

T<sub>i</sub> = Maximum rated temperature of the electronics components

h<sub>o</sub> = Convective heat transfer coefficient outside the cabinet

Still air: h = 1.6

Relatively calm day: h = 2.5

Windy day (approx. 15 mph): h = 6.0

h<sub>i</sub> = Convective heat transfer coefficient inside the cabinet

Still air: h = 1.6

Moderate air movement: h = 2.0

Blower (approx. 8 ft./sec.): h = 3.0

R = Value of insulation lining the interior of the enclosure walls

No insulation: R = 0.0

1/2 in. or 12 mm: R = 2.0

1 in. or 25 mm: R = 4.0

1-1/2 in. or 38 mm: R = 6.0

2 in. or 51 mm: R = 8.0

$$q = (125 - 75) \div [(1/6) + (1/2) + 4]$$

$$q = (50) \div (.16 + .5 + 4)$$

$$q = 50 \div 4.66$$

$$q = 10.7 \text{ BTU/hr./ft.}^2$$

#### Total Heat Transfer Load

$$10.7 \times 72 = 770 \text{ BTU/hr. or } 770 \div 3.413 = 226 \text{ W}$$

Since the cabinet is outdoors, and assuming it is painted ANSI 61 gray and located in the sun, extra solar load needs to be added to the outcome above which is 504 Watts (7 W per ft.<sup>2</sup> x 72 ft.<sup>2</sup>).

#### Total Heat Transfer Load with Extra from Solar Heat Gain

$$226 + 504 = 730 \text{ W}$$

### How to Determine Total Heat Load

**Total heat load** to be removed from the electrical enclosure by the air conditioner is the sum of **internal heat load** plus **heat transfer load**.

$$\text{TOTAL HEAT LOAD (C)} = \text{INTERNAL HEAT LOAD (A)} + \text{HEAT TRANSFER LOAD (B)}$$

Thus, one adds together the result from Part A to the outcome from Part B.

Example—

The internal heat load from one of the examples above was 3795 Watts. The heat transfer load from the other example above was 730 W. Therefore, total heat load is 3795 + 730 = 4525 W.

To convert Watts into BTU/hr. to determine air conditioner capacity in the English system, multiply by 3.413. 4525 W is then 15444 BTU/hr.

Power input, protection level and dimensions of the air conditioner also need to fit system requirements.

**Caution!** Do not simply match the nominal cooling capacity of the air conditioner model with the total heat load result above. Be sure to know the maximum ambient temperature outside the enclosure as well as the rated temperature of the electronic components. Apply these temperatures to the performance curves provided by the cooling manufacturer to select an appropriately sized air conditioner. Failure to do so may under-size your air conditioner as much as 20% - 25%, thereby under-cooling the electronics and making the application vulnerable to potential over-heating issues.

## How to Select the Right Cooling Capacity Heat Exchanger

### Heat Exchanger Cooling Capacity Overview

Cooling with an air-to-air heat exchanger assumes the electronic components in your system are able to operate **above** the ambient temperature outside the enclosure. If this is not the case, then an air conditioner must be used.

Selecting a heat exchanger is similar to specifying an air conditioner in that the cooling capacity of the unit must remove the **internal heat load** from the electrical enclosure.

However, since the conductive cooling nature of the cabinet itself removes some of the heat from the system, **heat transfer** should be subtracted from internal heat load (versus added in the case of air conditioners).

Because the cooling capacity of heat exchangers is expressed in terms of Watts/°F or Watts/°C, an extra step is necessary to convert net heat load into a result used to select the appropriate heat exchanger. Divide the net heat load by the **ΔT** which is the difference between the maximum ambient temperature outside the enclosure and the maximum temperature rating of the electronic components.

$$\text{HEAT EXCHANGER CAPACITY (C)} = [\text{INTERNAL HEAT LOAD (A)} - \text{HEAT TRANSFER (B)}] / \Delta T$$

### How to Determine Internal Heat Load

Internal heat load stems from the amount of waste heat generated inside the enclosure by the electronic components and is expressed in Watts.

To determine internal heat load, follow one of the four options outlined in the air conditioner “How to Determine Internal Heat Load” section on page 12.

### How to Determine Heat Transfer

In air-to-air heat exchangers, heat transfer is actually cabinet heat loss because the heat inside the enclosure is conducting itself through the cabinet walls toward the cooler temperature outside the enclosure. That is why heat transfer is subtracted from internal heat load to arrive at total net heat load.

To determine heat transfer you need to know the **total surface area** of the cabinet, less any non-conductive surface area such as the enclosure side mounted to a wall. You must also determine **ΔT** which is the difference between maximum ambient temperature and the maximum temperature rating of the electronic components.

There are two methods to determine heat transfer—the **simple chart method** and the **equation method**. The simple chart method may be used for nearly all indoor heat exchanger applications. The equation method needs to be applied when air movement outside or inside the electrical enclosure is high, or for outdoor applications.

Here are the steps for the simple chart method:

Step A. Determine  $\Delta T$  in °F or °C.

Step B. Find the heat transfer per ft.<sup>2</sup> or m<sup>2</sup> from the Heat Transfer graph on page 13, using  $\Delta T$  and the proper cabinet material curve.

Step C. Multiply the heat transfer per ft.<sup>2</sup> or m<sup>2</sup> by the total surface area of the enclosure that will conduct heat. (Remember to exclude surfaces such as a side mounted to a wall.)

$$\text{SURFACE AREA (ft.}^2\text{)} = [2AB \text{ (in.)} + 2BC \text{ (in.)} + 2AC \text{ (in.)}] \div 144$$

$$\text{SURFACE AREA (m}^2\text{)} = [2AB \text{ (mm)} + 2BC \text{ (mm)} + 2AC \text{ (mm)}] \div 1,000,000$$

$$\text{Heat Transfer (Cabinet Heat Loss)} = \text{Heat Transfer per ft.}^2 \text{ or m}^2 \times \text{Enclosure Surface Area}$$

The estimate for heat transfer ends here, unless the electronic system will be deployed outdoors, or airflow inside or outside the enclosure is high. Then the equation method needs to be used to determine heat transfer (cabinet heat loss).

For the equation method, follow the steps on page 13 in the air conditioner selection section. The result will be a negative number; the negative sign should be ignored when deducting heat transfer from internal heat load.

**Caution!** If the result of the equation method is a positive number, then this means that you want the electronics temperature inside the cabinet to be lower than the temperature outside the enclosure. In this case, an air conditioner should be specified for the electronics system.

## How to Select the Right Cooling Capacity Heat Exchanger

### How to Determine Heat Exchanger Capacity

Air-to-air heat exchanger capacities are not provided in terms of Watts or BTUs/hr. of cooling like air conditioners. Instead, they are expressed in terms of Watts/°F or Watts/°C. Thus, the final step in determining heat exchanger capacity is to divide the total net heat load by  $\Delta T$ . Then select the heat exchanger with the same or higher Watts/°F or Watts/°C as the outcome of this process.

—Indoor Industrial Example—

An electronic system uses two components that draw 230 VAC at 7.5 A. Each has a rated efficiency of 90%. They are protected in a painted steel cabinet that is 60 in. (1524 mm) tall, 36 in. (914 mm) wide and 18 in. (457 mm) deep. The system will be located in a maximum ambient temperature of 80 F (27 C). The rated temperature of the electronics is 95 F (35 C).

$$\text{HEAT EXCHANGER CAPACITY (C)} = \frac{[\text{INTERNAL HEAT LOAD (A)} - \text{HEAT TRANSFER (B)}] \div \Delta T}$$

**Internal heat load (A)** may be determined using the “Component Power – Component Efficiency” method on page 12, given the available information. In this example, the estimated heat load is:

$$\begin{aligned} \text{Device Power} &= 230 \times 7.5 = 1725 \text{ W} \\ \text{Total Power} &= 2 \times 1725 = 3450 \\ \text{Less Efficiency} &= 3450 \times (1 - .90) \\ \text{Internal Heat Load} &= 345 \text{ W} \end{aligned}$$

**Heat transfer (B)** is derived using the simple chart method, since this is an indoor industrial application. Both cabinet surface area and  $\Delta T$  are needed to determine heat transfer. Cabinet surface area is 54 ft.<sup>2</sup> or 5.02 m<sup>2</sup> (from surface area formula on page 13).  $\Delta T$  is 15 F (8 C)—the difference between ambient temperature and the rated temperature of the electronics.

$$\begin{aligned} \text{Heat Transfer (Cabinet Heat Loss)} &= \\ \text{Heat Transfer per ft.}^2 \text{ or m}^2 \times \text{Enclosure Surface Area} & \end{aligned}$$

Using the painted steel curve on the Heat Transfer chart on page 13, heat transfer per ft.<sup>2</sup> or m<sup>2</sup> is 3 W/ft.<sup>2</sup> or 32.5 W/m<sup>2</sup>.  
Heat Transfer = 3 W/ft.<sup>2</sup> x 54 ft.<sup>2</sup> = 162 W

Now that we know internal heat load, heat transfer and  $\Delta T$ , we can determine heat exchanger capacity as follows:

$$\text{HEAT EXCHANGER CAPACITY (C)} = \frac{[345 \text{ WATTS (A)} - 162 \text{ WATTS (B)}] \div 15 \text{ F (or 8 C)}}$$

$$\text{HEAT EXCHANGER CAPACITY (C)} = 12 \text{ W/}^\circ\text{F or } 22 \text{ W/}^\circ\text{C}$$

The result is **minimum** heat exchanger capacity. If no heat exchanger model is similar to the result, choose the next largest size to ensure adequate electronics cooling.

Power input, protection level and dimensions of the heat exchanger also need to fit the system.

—Outdoor Example—

A telecom system draws a total of 5,000 W; its efficiency is 85%. It is protected in a steel cabinet that is 72 ft.<sup>2</sup> (6.69 m<sup>2</sup>) and painted with RAL 7035 light-gray paint. The enclosure walls are lined inside with 1 in. (25 mm) of insulation. The application will be deployed in a maximum ambient outdoor temperature of 104 F (40 C) with occasional winds reaching 15+ mph. The rated temperature of the electronics is 114 F (46 C). Air circulation inside the cabinet is moderate.

$$\text{HEAT EXCHANGER CAPACITY (C)} = \frac{[\text{INTERNAL HEAT LOAD (A)} - \text{HEAT TRANSFER (B)}] \div \text{DELTA } \Delta T}$$

**Internal heat load (A)** is determined using the “Component Power – Component Efficiency” method on page 12. In this example, the estimated heat load is as follows:

$$\begin{aligned} \text{Total System Power} &= 5000 \text{ W} \\ \text{Less Efficiency} &= 5000 \times (1 - .85) \\ \text{Internal Heat Load} &= 750 \text{ W} \end{aligned}$$

**Heat transfer (B)** is derived using the equation method, since this is an outdoor application. For brevity, we will assume the English system (°F, inches and feet).

$$q = (T_o - T_i) \div [(1/h_o) + (1/h_i) + R]$$

“q” is heat transfer per surface area. For an explanation of the other variables, see “Equation Method” on page 14.

$$q = (104 - 114) \div [(1/6) + (1/2) + 4]$$

$$q = -2.14 \text{ W/ft.}^2$$

$$\begin{aligned} \text{Total Heat Transfer} &= 2.14 \times 72 \text{ ft.}^2 = 154 \text{ W} \\ \text{(negative sign is ignored)} & \end{aligned}$$

$\Delta T$  is 10 F — the difference between ambient temperature and the rated temperature of the electronics.

$$\text{HEAT EXCHANGER CAPACITY (C)} = \frac{[750 \text{ W (A)} - 154 \text{ W (B)}] \div 10 \text{ F}}$$

$$\text{HEAT EXCHANGER CAPACITY (C)} = 60 \text{ W/}^\circ\text{F}$$

As in the indoor industrial example, the above result is **minimum** heat exchanger capacity. If no heat exchanger model is similar to the result, choose the next largest size to ensure adequate electronics cooling.

Power input, protection level and dimensions of the heat exchanger also need to fit the system.

**How to Select the Right Cooling Capacity Heat Exchanger****Notes**