MELCOR

APPLICATION NOTES FOR THERMOELECTRIC DEVICES

Since thermoelectric cooling systems are most often compared to conventional systems, perhaps the best way to show the differences in the in the two refrigeration methods is to describe the systems themselves.

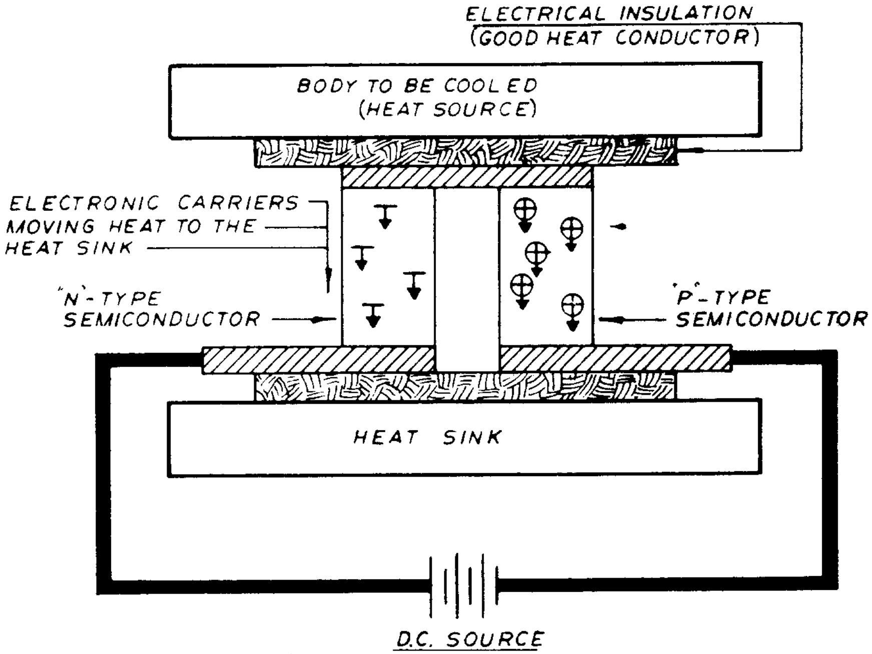
A conventional cooling systems contains three fundamental parts - the evaporator, compressor and condenser. The evaporator or cold section is the part where the pressurized refrigerant is allowed to expand, boil and evaporate. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor acts as the refrigerant pump and recompresses the gas to a liquid. The condenser expels the heat absorbed at the evaporator plus the heat produced during compression, into the environment or ambient.

A thermoelectric has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element(p-type).

Thermoelectric Coolers are heat pumps, solid state heat pumps, heat pumps without moving parts, fluids or gasses. The basic laws of thermodynamics apply to these devices just as they do to conventional heat pumps, absorption refrigerators and other devices involving the transfer of heat energy.

An analogy often used to help comprehend a T.E. cooling system is that of a standard thermocouple used to measure temperature. Thermocouples of this type are made by connecting two wires of dissimilar metal, typically copper/constantan, in such a manner so that two junctions are formed. One junction is kept at some reference temperature, while the other is attached to the object being measured. The system is used when the circuit is opened at some point and the generated voltage is measured. Reversing this train of thought, imagine a pair of fixed junctions into which electrical energy is applied causing one junction to become cold while the other becomes hot.

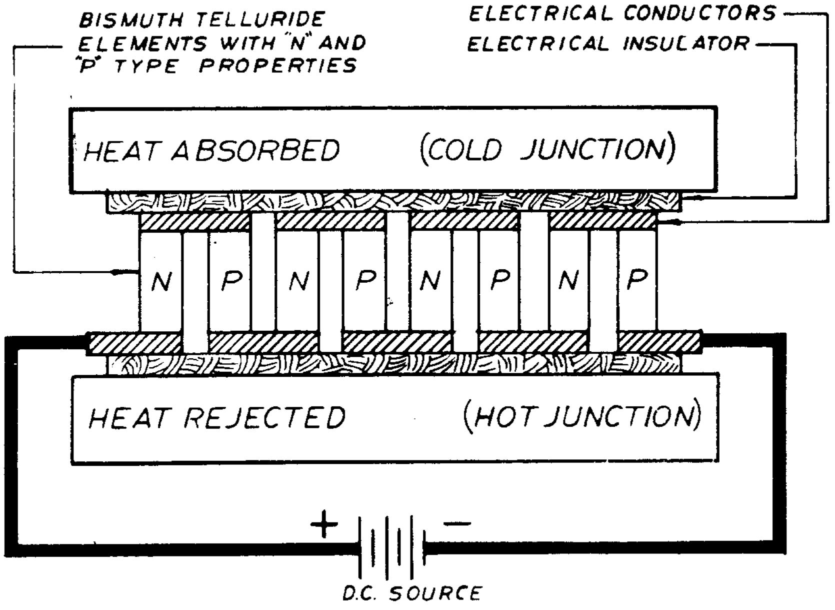
Fig. 1



CROSS SECTION OF TYPICAL THERMOELECTRIC COOLER

Thermoelectric cooling couples (Fig. 1) are made from two elements of semiconductor, primarily Bismuth Telluride, heavily doped to create either an excess (n-type) or deficiency (p-type) of electrons. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to current passing through the circuit and the number of couples.

ig. 2



TYPICAL MODULE ASSEMBLY — ELEMENTS ELECTRICALLY IN SERIES AND THERMALLY IN PARALLEL

In practical use, couples are combined in a module (Fig. 2) where they are connected electrically in series, and thermally in parallel. Normally a module is the smallest component commercially available.

Modules are available in a great variety of sizes, shapes, operating currents, operating voltages and ranges of heat pumping capacity. The present trend, however, is toward a larger number of couples operating at lower currents. The user can select the quantity, size or capacity of the module to fit the exact requirement without paying for excess capacity.

There is usually a "need" to use thermoelectrics instead of other forms of cooling. The "need" may be a special consideration of size, space, weight, reliability and environmental conditions such as operating in a vacuum. If none of these are a requirement, then other forms of cooling should be considered and in fact are probably desirable.

Once it has been decided that thermoelectrics are to be considered, the next problem is to select the thermoelectric(s) that will satisfy the particular set of requirements. Three specific system parameters must be determined before device selection can begin.

These are:	T_c	Cold Surface Temperature
	T_h	Hot Surface temperature
	Q_c	The amount of heat to be absorbed at the Cold Surface of the T.E.

In most cases the cold surface temperature is usually given as part of the problem - that is to say that some object(s) is to be cooled to some temperature. Generally, if the object to be cooled is in direct intimate contact with the cold surface of the thermoelectric, the desired temperature of the object can be considered the temperature of the cold surface of the T.E. (T_c). There are situations where the object to be cooled is not in intimate contact with the cold surface of the T.E., such as volume cooling where a heat exchanger is required on the cold surface of the T.E. When this type of system is employed the cold surface of the T.E. (T_c) may need to be several degrees colder than the ultimate desired object temperature.

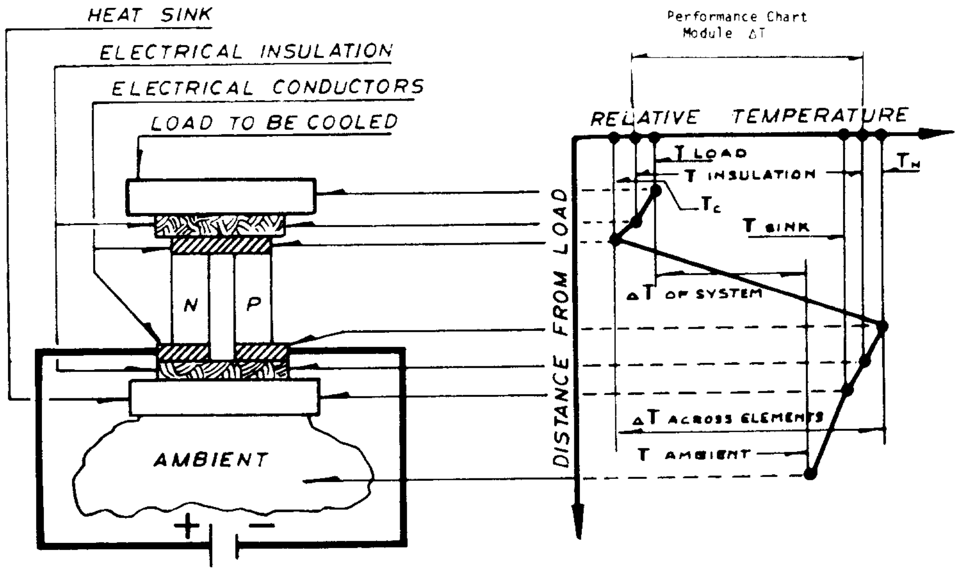
The Hot Surface temperature is defined by two major parameters:

1) The temperature of the ambient environment to which the heat is being rejected.

2) The efficiency of the heat exchanger that is between the hot surface of the T.E. and the ambient.

These two temperatures (T_c & T_h) and the difference between them (ΔT) are very important parameters and therefore must be accurately determined if the design is to operate as desired. Figure 3 represents a typical temperature profile across a thermoelectric system.

Fig. 3



TYPICAL TEMPERATURE RELATIONSHIP IN A THERMOELECTRIC COOLER

The third and often most difficult parameter to accurately quantify is the amount of heat to be removed or absorbed by the cold surface of the T.E. All thermal loads to the T.E. must be considered. These thermal loads include, but are not limited to, the active or I^2R heat load from electronic devices and conduction through any object in contact with both the cold surface and any warmer temperature (i.e. electrical leads, insulation, air or gas surrounding objects, mechanical fasteners, etc.). In some cases radiant heat effects must also be considered.

Single stage thermoelectric devices are capable of producing a "no load" temperature differential of approximately 67°C. Temperature differentials greater than this can be achieved by stacking one thermoelectric on top of another. This practice is often referred to as Cascading. The design of a cascaded device is much more complex than that of a single stage device, and is beyond the scope of these notes. Should a cascaded device be required, design assistance can be provided by MELCOR personnel.

Once the three basic parameters have been quantified, the selection process for a particular module or group of modules may begin. Some common heat transfer equations are attached for help in quantifying Q_c & T_h.

There are many different modules or sets of modules that could be used for any specific application. One addition criteria that is often used to pick the "best" module(s) is Coefficient of Performance (C.O.P.). C.O.P. is defined as the heat absorbed at the cold junction, divided by the input power ($Q_c \div Q_{in}$). The maximum C.O.P. case has the advantages of minimum input power and therefore, minimum total heat to be rejected by the heat exchanger ($Q_h = Q_c + Q_{in}$). These advantages come at a cost, which in this case is the additional or larger T.E. device required to operate at C.O.P. maximum. It naturally follows that the major advantage of the minimum C.O.P. case is the lowest initial cost.

Power supply and temperature control are additional items that must be considered for a successful T.E. system. A thermoelectric device is a D.C. device. Any A.C. component on the D.C. is detrimental. Degradation due to ripple can be approximated by:

$\Delta T/\Delta T_{max} = 1/(1+N^2)$, where N is % current ripple.

MELCOR recommends not more than 10% ripple.

Temperature control can be generally considered in two groups: Open Loop and Closed Loop, or manual and automatic. Regardless of method, the easiest device parameter to detect and measure is temperature. Therefore, the cold junction (or hot junction in heating mode) is used as a basis of control. The controlled temperature is compared to some reference temperature, usually the ambient or opposite face of the T.E.

In the Open Loop method, an operator adjust the power supply to reduce the error to zero. The Closed Loop accomplishes this task electronically. The various control circuits are too numerous, complex and constantly being upgraded to try to discuss in this text. There are several manufacturers of control circuits and systems that are better equipped to give expert counsel in this specific area. Suffice it to say that the degree of control, and consequent cost, varies considerably with the application.

PARAMETERS REQUIRED FOR DEVICE SELECTION

There are certain minimum specifications that anyone must answer before the selection of a T.E. device can begin. Specifically there are three parameters that are required. Two of these parameters are the temperatures that define the gradient across the T.E. device. The third parameter is the total amount of heat that must be pumped by the device.

The gradient across the T.E. device (Actual ΔT) is not the same as the apparent ΔT (System ΔT). The difference between these two ΔT's is often ignored, which results in an under designed system. The magnitude of the difference in ΔT's, is largely dependant on the type of heat exchangers that are utilized on either the hot or cold sides of the system.

Unfortunately, there are no "Hard Rules", that will accurately define these differences. Typical allowances for the hot side of a system are:

(1.) finned forced air: 10 to 15°C
(2.) free convection: 20 to 40 °C
(3.) liquid exchangers: 2 to 5 °C

Since the heat flux densities on the cold side of the system are considerably lower than those on the hot side, an allowance of about 50% of the hot side figures (Assuming similar types of heat exchangers) can be used. It is good practice, to check the outputs of the selection process to reassure that the heat sink design parameters are reasonable.

The third parameter that must be identified for the selection process, is the total heat to be pumped by the T.E. device. This is often the most difficult number to estimate! To reduce the temperature of an object, heat must be removed from it, faster than heat enters it. There are generally two broad classifications of the heat that must be removed from the device. The first is the real, sensible or "active" heat load. This is the load that is representative of what wants to be done. This load could be the I^2R load of an electrical component, the load of dehumidifying air, or the load of cooling objects. The "other" kind of load is often referred to as the parasitic load. This is the load due to the fact that the object is cooler than the surrounding environment. This load can be comprised of conduction and convection of the surrounding gas, "leak" through insulation, conduction through wires, condensation of water, and in some cases formation of ice. Regardless of the source of these parasitic loads they must not be ignored.

There are other things that may be very important to a specific application. Things such as physical dimensions, input power limitations or cost. Even though these are important, they are only secondary.

MELCOR's approach to thermoelectric device selection/recommendation utilizes a computer aided design program which computes an optimized thermoelectric design for the given operating hot side temperature, desired cold side temperature, and the total heat load to be pumped over the Actual ΔT.

We have attached a "check list" to assist you in defining your application's existing conditions. If you should require any further assistance please do not hesitate contacting one of our engineers.

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THERMOELECTRIC (T.E.) MULTISTAGE (CASCADED) DEVICES

A multistage thermoelectric device should be used only where a single stage device does not fill the need. Figure 1, depicts ΔT, vs. C.O.P. MAX, vs. Number of stages. C.O.P. is defined as the amount of heat absorbed (in thermal watts heat pumped) at the cold side of the device, divided by the input power (in electrical watts). This figure should help identify when to consider cascades since it portrays the effective ΔT range of each cascade. A two stage cascade should be thought of, somewhere between a ΔT of 40°C, where the C.O.P. lines of the 1 and 2 stage devices begin to diverge, and 65°C, where a single stage device reaches its maximum ΔT, and also, heat pumping "shutoff", $Q_c=0$. Similar decisions must be made as to the number of stages to be considered at larger ΔT's. The two important factors again are ΔT and C.O.P.

There is another very significant factor that must always be considered and that is the cost. Usually, as the number of stages increase, so does the cost. Certain applications require a trade-off between C.O.P. and cost.

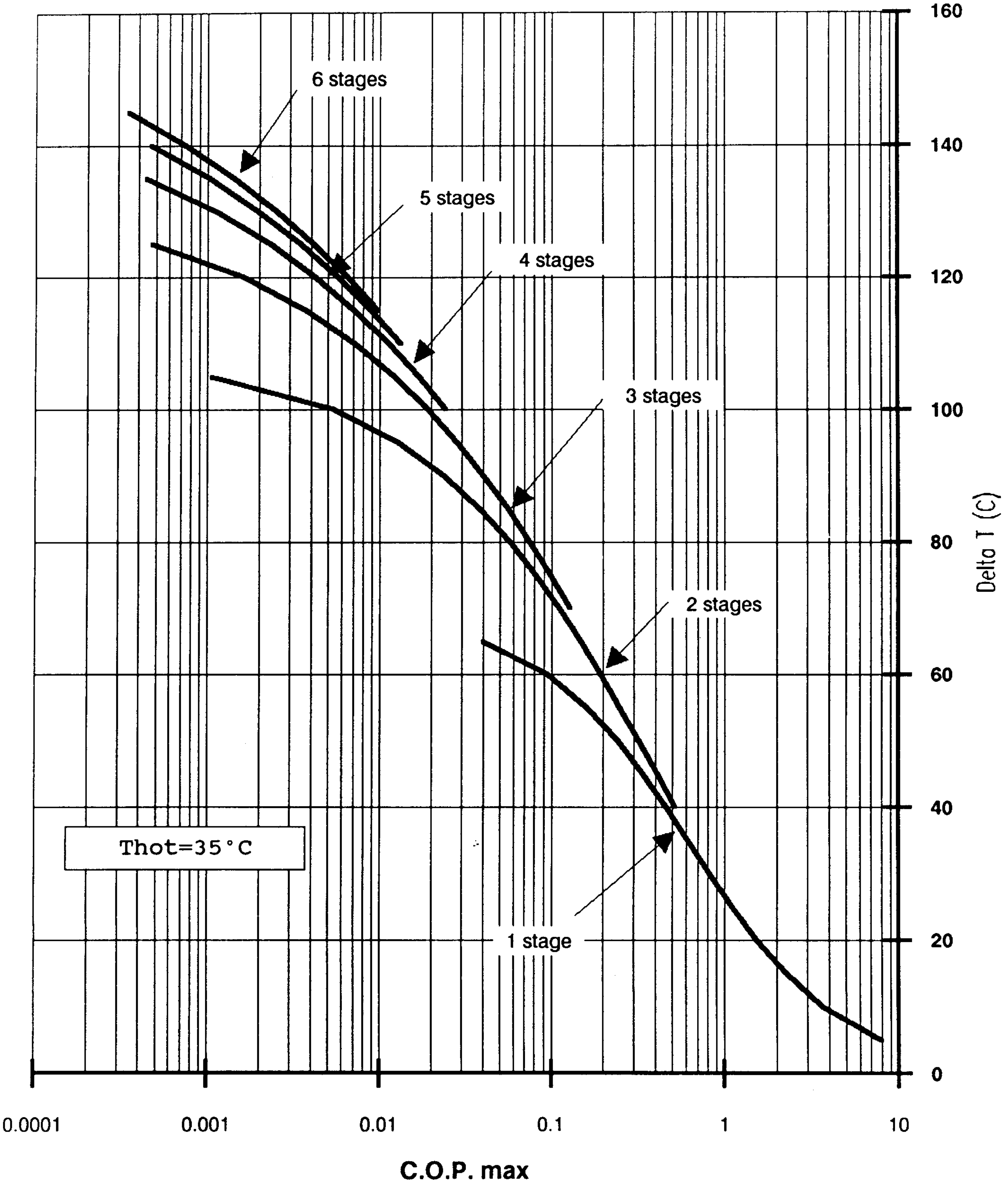
As with any other T.E. system, to begin the selection process requires the definition of at least three parameters.

These are:
T_c ⇒ Cold side temperature
T_h ⇒ Hot side temperature
Q_c ⇒ The amount of heat to be removed (absorbed by the cooled surface of the T.E.

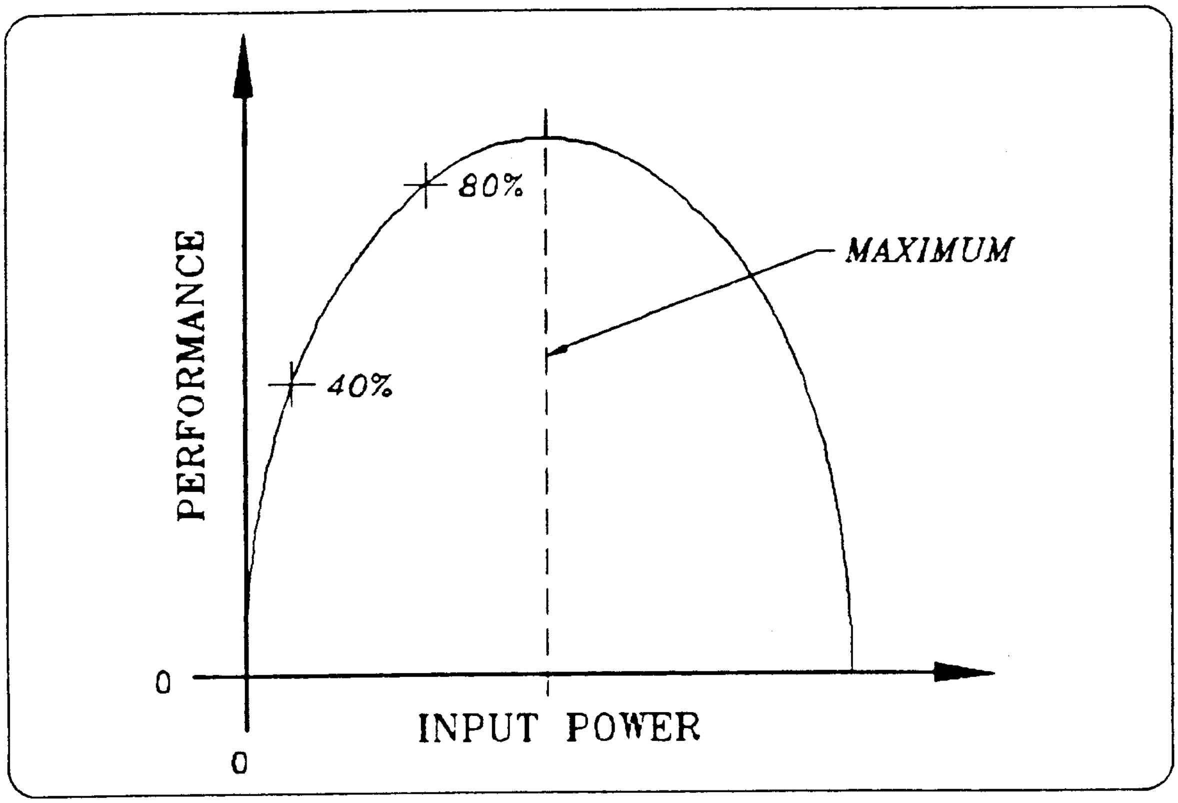
Once ΔT (T_h-T_c) and the heat load have been defined, utilization of Figure 1 will yield the number of stages that may be required. Knowing C.O.P. and Qc, input power can also be estimated. The values listed in Figure 1 are theoretical maximums. Any device that is actually manufactured will rarely achieve these maximums, but should closely approach this value.

MELCOR offers a line of 'Standard Cascades' though there are no 'Standard' applications. Each need for a cascade is unique, so too should be the device selected to fill the need. MELCOR has developed a computer aided design system to help select a device. The three parameters listed above are used as inputs to the programs. Other variables such as physical size, and operating voltage or current can, within limits, be used to make the final selection. Over 40,000 different cascades can be assembled utilizing available ceramic patterns. This allows near custom design, at near 'standard' prices. When the three parameters have been defined, please contact MELCOR for assistance in cascade selection.

Figure 1: C.O.P. MAX as a function of Delta T and # of stages



TYPICAL DEVICE PERFORMANCE



When PERFORMANCE vs. INPUT POWER is plotted for any thermoelectric device, the resultant curve will appear as in the figure above ; an inverted parabola. Performance can be ΔT (T_h - T_c), heat pumped at the cold side (Q_c), or as in most cases, a combination of these two parameters. Input power can be current (I), voltage (V) or the product of IV.

When we refer to the ΔT_{max} or Qc_{max}, we are referring to that point where the curve peaks. The same is true when referring to either I_{max} or V_{max}. Since operating at or very near the peak is relatively inefficient, most devices are operated somewhere between 40% and 80% of Input Power MAX.

As stated, devices are normally operated on the near-linear, upward sloping portion of the curve. When automatic or closed loop temperature control is being used, current or voltage limits should be set below the MAX intercepts.

HOW TO USE THE PERFORMANCE CURVES

The graphs contained in the following section depict typical performance characteristics of the largest modules in each basic group. For smaller modules (with fewer thermocouples), Q and V are directly proportional to the number of couples for any given current and ΔT For example, if a module with 127 couples has a Q_{cmax}. of 50watts and a V_{max} of 15volts, then a module from the same group with 71 couples would have a Q_{cmax} of 28watts and a V_{max} of 8.4volts. T_c, T_h, and ΔT values apply universally to all modules.

The following symbols are used with the performance curves:

T_c = Module cold surface temperature.
T_h = Module hot surface temperature.
$\Delta T = T_h - T_c$, in °C.
Q_c = Heat pumped, in BTU/hr or Watts.
I = Current input, in DC amperes.
V = Voltage input, in DC volts.

The enclosed performance curves include three or more sets of graphs, each for a different value of T_h. The reason for this is that different applications operate with different hot side temperature. For example, the set of graphs based on T_h = 35°C may be used directly in an air-cooled heat sink applications where the ambient air temperatures are 23°C to 29°C. But, if your particular application operates with a different T_h due to different ambient temperatures or for any other reason, then a graph based on a different T_h may be better suited for the your particular thermal assembly.

With T_h, T_c, and Q_c known, the corresponding value of I is determined from the ΔT vs. Q_c graphs. Then, knowing $\Delta T$and I, the value of V can be determined from the ΔT vs. V graphs.

Linear interpolation can be used when finding thermal parameters for applications having T_h values between the ones shown on the graphs.

EXAMPLE:

It is found that a cold plate requires 25 watts of heat pumping to maintain a temperature of 0°C in an ambient temperature of 25°C. It is also found that this design requires a T_c of -5°C, and a T_h of 35°C to allow for temperature gradients across the cold plate and the heat sink. Assuming that a 12 volt power supply is available, try using the performance curves for the CP0.8-127-05L.

1) Using the center graph (T_h = 35°C), locate 40°C on the bottom x-axis (ΔT *(40)* = T_h *(35)* -T_c *(-5)*). From this point, draw a vertical line through the both the ELECTRIC and THERMO sections of the graph.
2) Using the ELECTRIC section, locate 12.0 volts on the y-axis. Draw a horizontal line through the graph. At the intersection of 12.0 volts and ΔT =40°C, read the current required (amps). *Interpolation between currrent lines is required. Intersection is between 1.6amp and 2.1 amp lines. Estimate intersection at 1.9 amps.*
3) Using the THERMO section, locate the intersection of ΔT =40°C and 1.9 amps. *Again, interpolation is required.* At this point, draw a horizontal line through the graph. On the y-axis, read the corresponding Qc value (Qc=8.5 watts of heat pumped), This indicates that the module will pump 8.5 watts under these conditions:
   (T_h = 35°C, T_c = -5°C,V=12 volts, I = 1.9 amps)

Therefore, to pump 25 watts would require using three CP0.8-127-05L modules placed thermally in parallel with each module requiring 1.9 amps of input current (I total = 5.7 amps).

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HEAT TRANSFER FORMULAE

NOTE: Due to the relatively complex nature of heat transfer, results gained from application of these formulae, while useful, must be treated as approximations only. Design safety margins should be considered before final selection of any device.

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1) Heat gained or lost through the walls of an insulated container:

$$\boxed{Q = \frac{A \times \Delta T \times K}{\Delta X}}$$

Where: Q = Heat (*W*)
A = External surface area of container (m^2)
ΔT = Temp. difference (inside vs. outside of container) (*°K*)
K = Thermal conductivity of insulation (*W/m - °K*)
ΔX = Insulation thickness (*m*)

---

2) Time required to change the temperature of an object:

$$\boxed{t = \frac{m \times C_p \times \Delta T}{Q}}$$

Where: t = Time interval (*seconds*)
C_p = Specific heat of material (*J/kg - °K*)
m = weight of the object (*kg*)
ΔT = Temperature change of object (*°K*)
Q = Heat added or removed (*W*)

NOTE: It should be remembered that thermoelectric devices do not add or remove heat at a constant rate when ΔT is changing. An approximation for average Q is:

$$\boxed{\frac{Q(@\Delta T_{\max}) + Q(@\Delta T_{\min})}{2}}$$

---

3) Heat transferred to or from a surface by convection:

$$\boxed{Q = h \times A \times \Delta T}$$

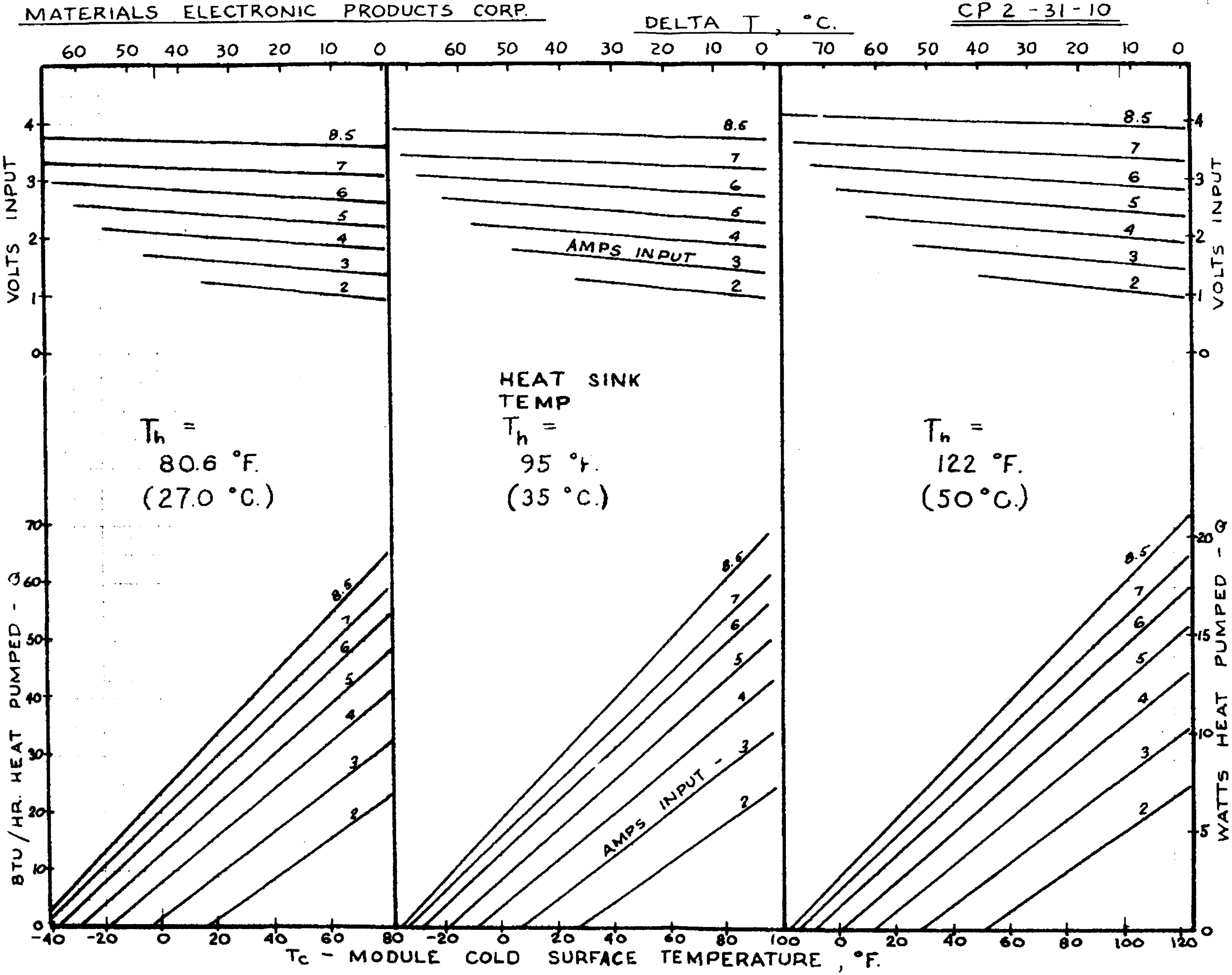
Where: Q = Heat (W)
h = Heat transfer coefficient *(W/m² - °K)*
(1 to 30 = "Free" convection - gases, 10 to 100 = Forced convection - gases)
A = Exposed surface area *(m²)*
ΔT = Surface Temp. - Ambient *(°K)*

Conversions:

Thermal Conductivity	1 BTU/hr-ft °F	=	1.73 W/m-°K
	1 W/m-°K	=	0.578 BTU/hr-ft-°F
Power (heat-flow rate)	1 W	=	3.412 BTU/hr
	1 BTU/hr	=	0.293 W
Area	1 ft^2	=	0.093 m^2
	1 m^2	=	10.76 ft^2
Length	1 ft	=	0.305 m
	1 m	=	3.28 ft
Specific Heat	1 BTU/lb-°F	=	4184 J/kg-°K
	1 J/kg-°K	=	2.39×10^{-4} BTU/lb-°F
Heat Transfer Coefficient	1 BTU/hr-ft^2-°F	=	5.677 W/m^2-°K
	1 W/m^2-°K	=	0.176 BTU/hr-ft^2-°F
Mass	1 lb	=	0.4536 kg
	1 kg	=	2.205 lb

MATERIALS ELECTRONIC PRODUCTS CORP.

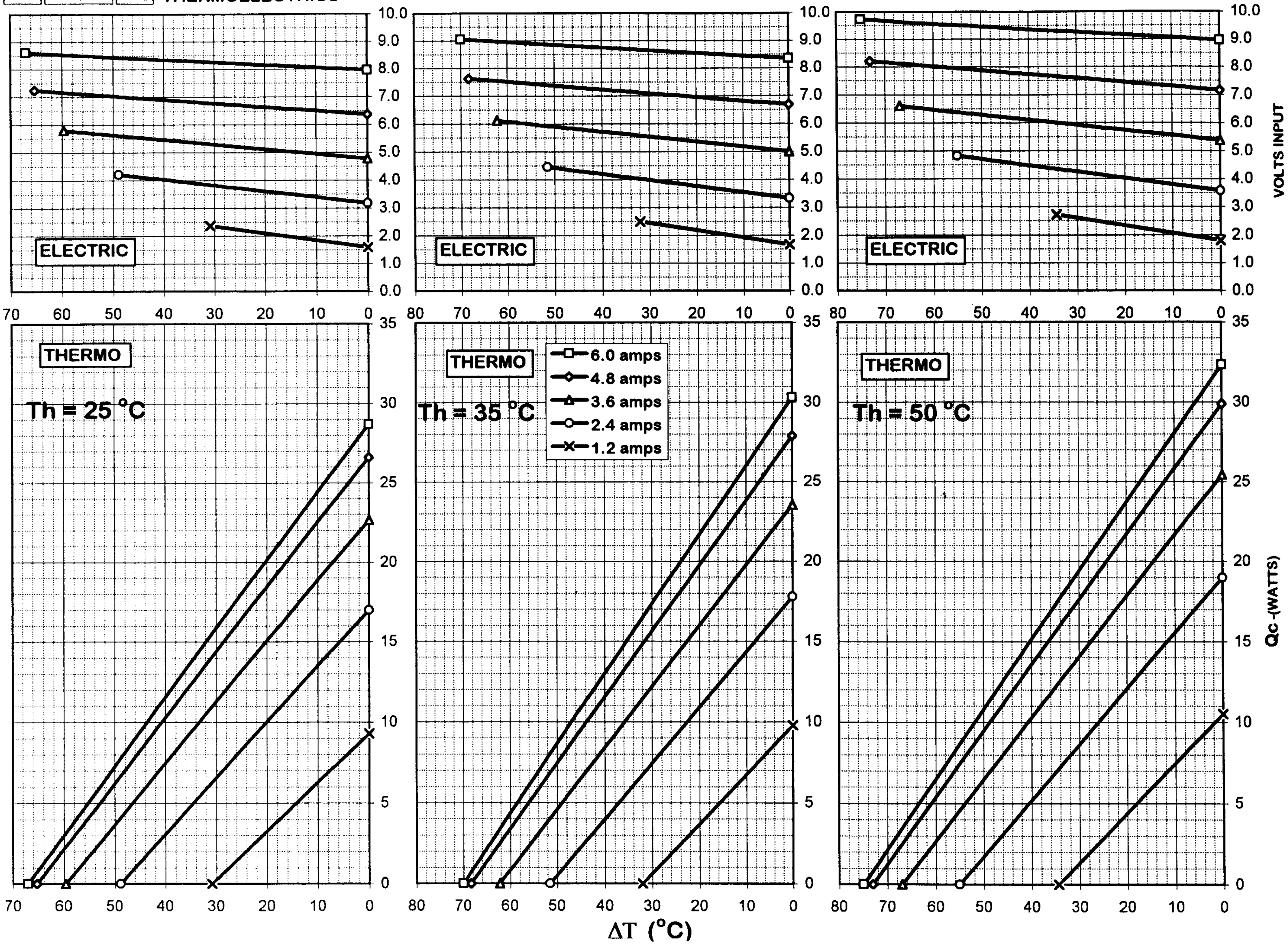
CP 2-31-10



MELCOR THERMOELECTRICS

PERFORMANCE GRAPH

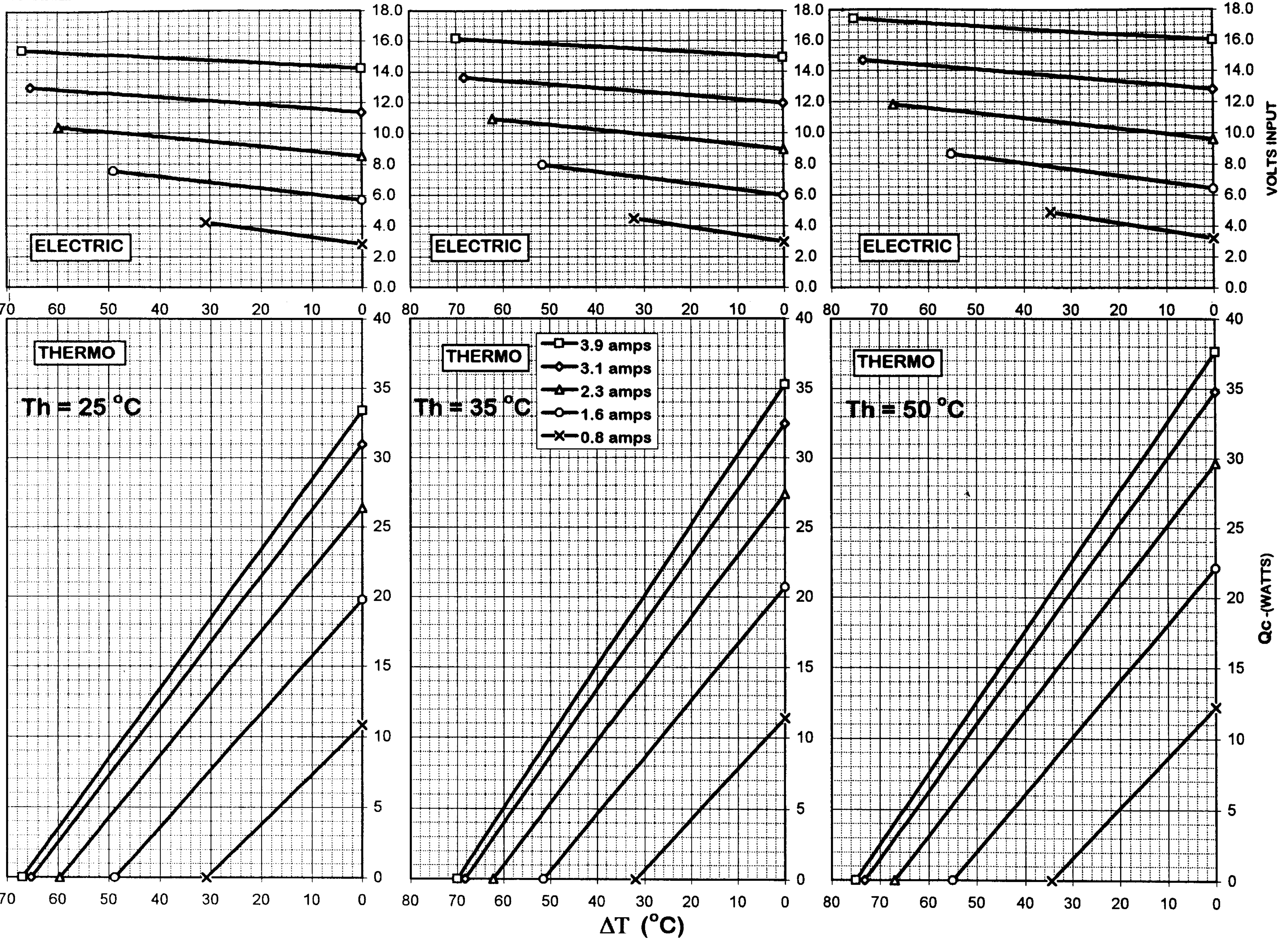
CP 1.4-71-06 L



MELCOR THERMOELECTRICS

PERFORMANCE GRAPH

CP 1.0-127-05 L



MELCOR THERMOELECTRICS

PERFORMANCE GRAPH

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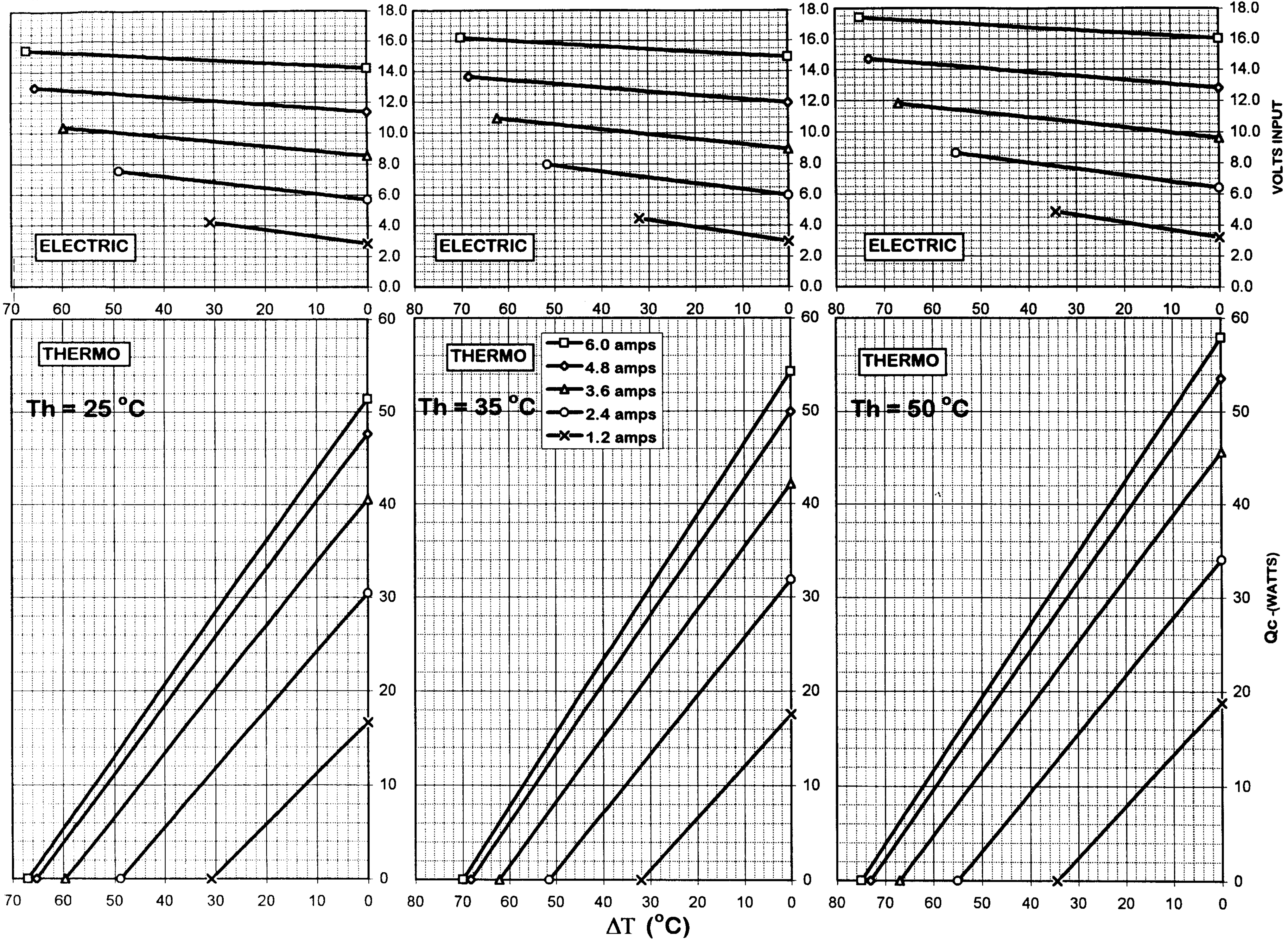
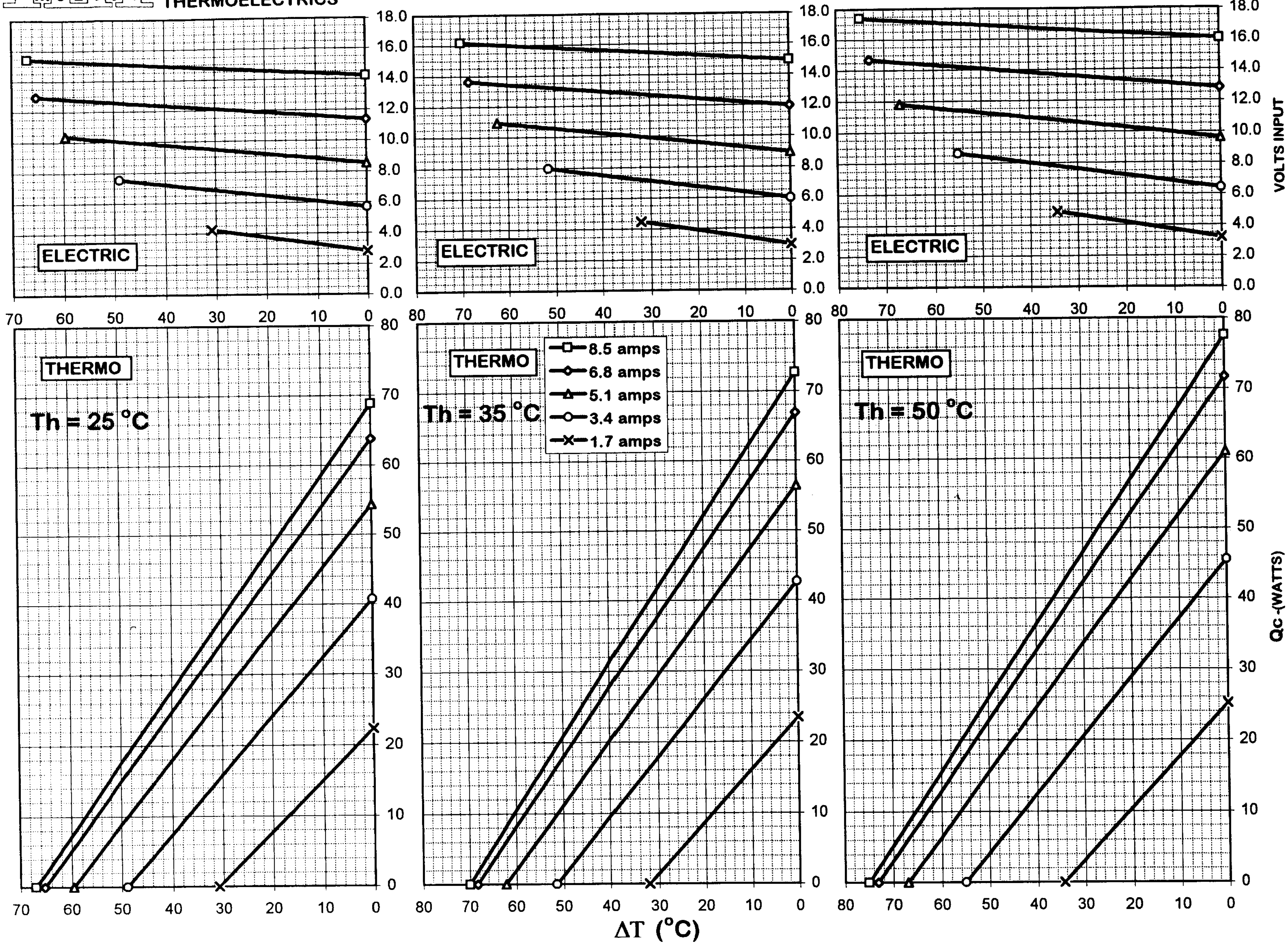


MELCOR THERMOELECTRICS

PERFORMANCE GRAPH

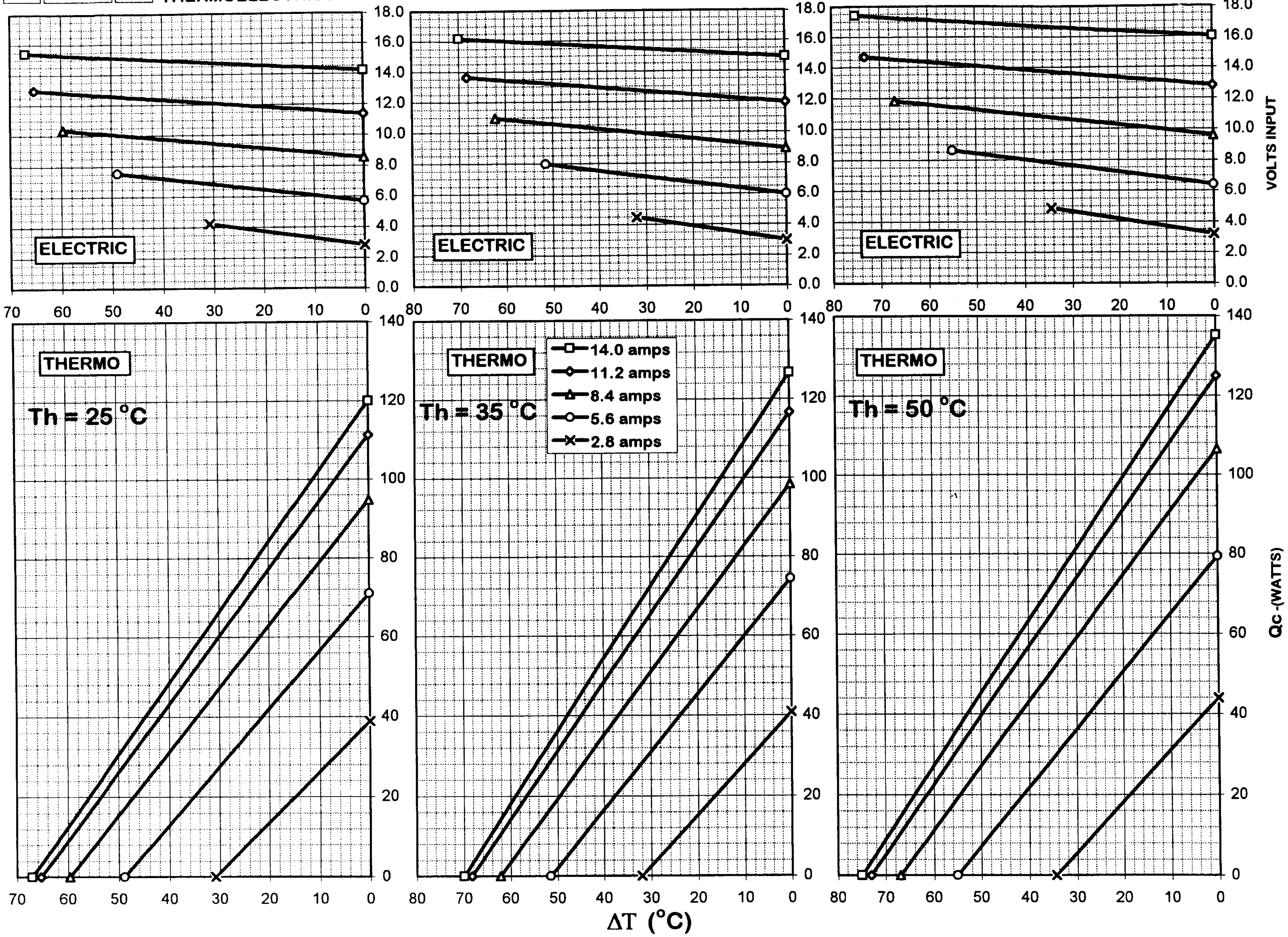
CP 1.4-127-045 L



MELCOR THERMOELECTRICS

PERFORMANCE GRAPH

CP 2-127-06 L



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DEVICE PERFORMANCE FORMULAE

Heat Pumped at Cold Surface:

$$Q_c = 2N\,[\,\alpha\, I\, T_c - I^2 \rho / 2G - \kappa\, \Delta T\, G\,] \qquad \textit{(watts)}$$

Voltage:

$$V = 2N\,[\,I \rho / G + \alpha\, \Delta T\,] \qquad \textit{(volts)}$$

Maximum Current:

$$I_{max} = (\kappa\, G / \alpha)\,[\,\sqrt{1 + 2\,Z\,T_h} - 1\,] \qquad \textit{(amps)}$$

Optimum Current:

$$I_{opt} = \kappa\, \Delta T\, G\,(\,1 + \sqrt{1 + Z\,\bar{T}}\,) / (\,\alpha\, \bar{T}\,) \qquad \textit{(amps)}$$

Optimum COP (calculated at I_{opt})

$$\text{COPopt} = (\bar{T} / \Delta T) \left(\frac{\sqrt{1 + Z\bar{T}} - 1}{\sqrt{1 + Z\bar{T}} + 1} \right) -1/2$$

Maximum ΔT with Q = 0

$$\Delta T_{max} = T_h - (\,\sqrt{1 + 2\,Z\,T_h} - 1\,) / Z \qquad \textit{(°K)}$$

Geometry Factor (G)

TEC	G
FC 0.5 -xx- 05	0.016
FC 0.6 -xx- 06	0.024
FC 0.6 -xx- 05	0.030
FC 0.65 -xx- 04	0.040
CP 0.8 -xx- 06	0.042
CP 0.8 -xx- 05	0.052
CP 1.0 -xx- 08	0.050
CP 1.0 -xx- 06	0.064
CP 1.0 -xx- 05	0.078
CP 1.4 -xx- 10	0.078
CP 1.4 -xx- 06	0.117
CP 1.4 -xx- 045	0.171
CP 2 -xx- 10	0.193
CP 2 -xx- 06	0.296
CP 2.8 -xx- 06	0.496
CP 5 -xx- 10	0.803
CP 5 -xx- 06	1.255

Miscellaneous Expressions:

T_h = Hot Side Temperature *(°K)*

T_c = Cold Side Temperature *(°K)*

ΔT = $T_h - T_c$ *(°K)*

$\bar{T}$ = $1/2\,(T_h + T_c)$ *(°K)*

G = Area / Length of T.E. element *(cm)*

N = Number of Thermocouples

I = Current *(amps)*

COP = Coefficient of Performance = $Q_c / I\,V$

α = Seebeck coefficient *(volts/°K)*

ρ = Resistivity *(ohm-cm)*

κ = Thermal Conductivity *(watt/cm °K)*

Z = $\alpha^2 / \rho\,\kappa$ (Figure of Merit $°K^{-1}$)

S = $2\alpha N$ (device Seebeck voltage *volts/°K*)

R = $2\rho N / G$ (device electrical resistance *ohms*)

K = $2\kappa N G$ (device thermal conductance *watt/°K*)

Material Property Coefficients

$\alpha = (\,\alpha_0 + \alpha_1 \bar{T} + \alpha_2 \bar{T}^2\,) \times 10^{-9}$ *volts / °K*

α_0 = 22224.0

α_1 = 930.6

α_2 = -0.9905

$\rho = (\,\rho_0 + \rho_1 \bar{T} + \rho_2 \bar{T}^2\,) \times 10^{-8}$ *ohm - cm*

ρ_0 = 5112.0

ρ_1 = 163.4

ρ_2 = 0.6279

$\kappa = (\,\kappa_0 + \kappa_1 \bar{T} + \kappa_2 \bar{T}^2\,) \times 10^{-6}$ *watt / cm °K*

κ_0 = 62605.0

κ_1 = -277.7

κ_2 = 0.4131

Z = $\alpha^2 / \rho\kappa$ $°K^{-1}$

Typical material parameters @ $\bar{T}$ = 296 °K :

α = 2.0×10^{-4} *volts/°K*

ρ = 1.0×10^{-3} *Ω-cm*

κ = 1.5×10^{-2} *watt/cm- °K*

Z = 2.67×10^{-3} $°K^{-1}$

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THERMOELECTRIC POWER GENERATION DEVICE SELECTION FORMULAE

E_L = required load voltage
I_L = required load amps
T_h = hot side temperature of thermoelectric (°C)
T_c = cold side temperature of thermoelectric (°C)
ΔT = $T_h - T_c$
N = number of thermoelectric couples
G = Geometry Factor (see Module Specification)

1) TO DETERMINE # OF COUPLES REQUIRED (N)

$$N = \frac{5{,}000 \times E_L}{\Delta T}$$

2) TO DETERMINE MODULE TYPE (G)

$$G = \frac{10 \times I_L}{\Delta T}$$

EXAMPLE:

The generator requirements are as follows:
Provide 2.0 volts at 0.5 amps with a heat source temperature of 85°C, and an ambient of 0°C.

NOTE: The actual ΔT across the thermoelectric ($T_h - T_c$), may be smaller than the ΔT of the system (heat source - ambient), due to thermal losses at the interfaces through radiation, conduction, etc. These losses must be taken into account. For this example we'll assume losses of 10°C at each interface, resulting in T_h = 75°C, T_c = 10°C, ΔT = 65°C.

E_L = 2.0 V
I_L = 0.5 A
ΔT = 65°C

1) DETERMINE # OF COUPLES REQUIRED (N)

$$N = \frac{5{,}000 \times 2.0}{65} = \mathbf{153.8}$$

2) DETERMINE MODULE TYPE (G)

$$G = \frac{10 \times 0.5}{65} = \mathbf{0.077}$$

3) SELECT THE THERMOELECTRIC(S)

Couples (N) = _ _ _._ - 154 -_ _ _
G ≈ CP 1.0 - XX - 05L (from Module Specifications, G = 0.078)
CP 1.0 - 154 - 05L

NOTE: The CP1.0-154-05L is not a standard MELCOR module, so a combination of devices is required.

SUGGESTION:		
	Two CP1.0-71-05L	N = 142, G = 0.078
	One CP1.0-127-05L and one CP1.0-31-05L	N = 158, G = 0.078

EFFICIENCY:

The "Efficiency" of the system is defined as the power (watts) generated, divided by the heat (watts) flowing through the thermoelectric. This is normally expressed as a percentage.

$Q_{load} = E_L \times I_L$ Example: 2.0 volts x 0.5 amps = 1.0 watt

$Q_{heat} = 0.03\,(N \times \Delta T \times G)$ Example: 0.03 (158 x 65 x 0.078) = 24.03 watts

$$\text{Efficiency} = \frac{1.0}{24.03} = 0.042 = 4.2\%$$

Reliability & Mean Time Between Failures (MTBF)

Thermoelectric devices are highly reliable due to their solid state construction. Although reliability is somewhat application dependent, MTBF's calculated as a result of tests performed by various customers are on the order of 200,000 to 300,000 hours at room temperature. Elevated temperature (80°C) MTBF's are conservatively reported to be on the order of 100,000 hours. Field experience by hundreds of customers representing over 7,500,000 of our CP type modules and over 800,000 FC type modules during the last ten years have resulted in a failure return of less than 0.1%. Over 90% of all modules returned were found to be failures resulting from mechanical abuse or overheating on the part of the customer. Thus, less than one failure per 10,000 modules used in systems could be suspect of product defect. Therefore, the combination of proper handling, and proper assembly techniques will yield an extremely reliable system.

Historical failure analysis has generally shown the cause of failure as one of two types:

Mechanical damage as a result of improper handling or system assembly techniques.

Moisture:

Moisture must not penetrate into the thermoelectric module area. The presence of moisture will cause an electro-corrosion that will degrade the thermoelectric material, conductors and solders. Moisture can also provide an electrical path to ground causing an electrical short or hot side to cold side thermal short. A proper sealing method or dry atmosphere can eliminate these problems.

Shock and Vibration:

Thermoelectric modules in various types of assemblies have for years been used in different Military/Aerospace applications, Thermoelectric devices have been successfully subjected to shock and vibration requirements for aircraft, ordinance, space vehicles, shipboard use and most other such systems. While a thermoelectric device is quite strong in both tension and compression, it tends to be relatively weak in shear. When in a sever shock or vibration environment, care should be taken in the design of the assembly to insure "compressive loading" of thermoelectric devices.

Mechanical Mounting:

A common failure mode for thermoelectric modules is uneven compression forces induced by improper torqing, bolting patterns, and mechanical conditions of heat exchangers.. The polycrystalline thermoelectric material exhibit less strength perpendicular to the length (growth axis) than the horizontal axis. thus, the thermoelectric elements are quite strong in compressive strength and tend to be weak in the shear direction. During assembly un-even torquing or un-flat heat exchangers can cause severe shear forces. Recommended compression values are 150 pounds/sq. inch. (See assembly instructions for proper mounting techniques)

Inadvertent overheating of the module.

The direct soldering process does result in temperature restriction for operation or storage of the modules.

At temperatures above 80°C two phenomena seriously reduce useful life:

Above 80°C copper diffusion into the thermoelements occurs due to increasing solid solubility in the thermoelectric material and increasing diffusion rate. At 100 - 110°C the combined solubility and diffusion rate could result in approximately 25% loss of device performance within 100 hours.

Above 85°C in the soldering process (using Bismuth-Tin alloy) small amounts of selenium, tellurium, antimony and nickel are inherently dissolved into the bismuth-tin solder. Although the melting point of the base solder is 136°C, the combined mixture of all elements results in either a minute eutectic phase or a highly effective solid state reaction occurring at above 85°C that starts to delaminate the ends of the thermoelements by physical penetration between cleavage planes in the thermoelectric material. This results in a mechanical failure of the interface.

December 1, 1992

Procedure For Assembly CP and FC (Type L) Lapped Modules To Heat Exchange Surfaces

Refer to Illustrations On Reverse Side

IMPORTANT: When two or more Thermoelectric devices are mounted between a common plate, the thermoelectric devices thicknesses should vary no more than .0015-inches. Contact our Engineering Department for more information on close tolerance lapped thermoelectric devices.

Step 1. Prepare cold plate and heat sink surfaces as follows:

A) Grind or lap flat within +/- .001" in module area.

B) Locate bolt holes as close as possible to opposite edges of module (1/8" clearance recommended, 1/2" maximum), in the same plane line as the heat exchanger fins. This orientation utilizes the additional structural strength of the fins to prevent bowing. Drill clearance holes on one surface and drill and tap opposite surface accordingly (see sketch). If platforming is used to increase distance between surfaces, performance is greater if platform is on cold side of system.

C) Remove all burrs, chips and foreign matter in thermoelectric module area.

Step 2. Thoroughly clean and degrease thermoelectric module, heat exchanger and cold surface.

Step 3. Apply a thin continuous film of thermal grease (Wakefield Engineering Type 120 or Dow Type 340) to module hot side surface and to module area on heat exchanger.

Step 4. Locate module on heat exchanger, hot side down.

Step 5. Gently oscillate module back and fourth, exerting uniform downward pressure, noting efflux of thermal compound around edges of module. Continue motion until resistance is felt.

Step 6. Repeat Step #3 for cold side surface and cold plate.

Step 7. Position cold plate on module.

Step 8. Repeat Step #5, sliding cold plate instead of module. Be particularly careful to maintain uniform pressure.

Step 9. Before bolting, best results are obtained by preloading in compression the cold plate/heat exchanger/module assembly, applying a light load in line with center of module, using clamp or weights. For two module assemblies, use 3 screws located on module center line, with middle screw located between modules. To preload, torque middle screw first. Bolt carefully, by applying torque in small increments, alternating between screws. Use a torque limiting screw driver. The recommended compression for a TEC assembly is 150 to 300 pounds per square inch of module surface area. Using the following equation we can solve for torque per screw:

$$T = \frac{C\,x\,D\,x\,F\,x\,in^2}{\#\ of\ screws}$$

T = torque per screw (in-lbs)

C = torque coefficient (0.20 as received, 0.15 lubricated)

D = nominal screw size (4/40 = 0.112, 6/32 = 0.138, 8.32 = 0.164)

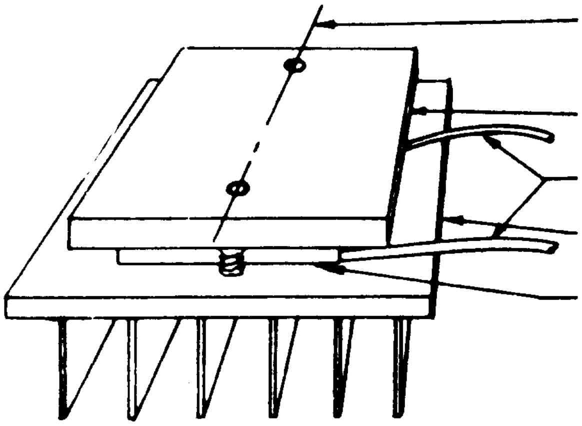
F = Force (lbs/in^2)

in^2 = Module surface area (length x width)

Check torque after one hour and retighten if necessary. Use Stainless Steel Screws, fibre insulating shoulder washers, and steel spring (Belleville or split lock type) washers (see sketch).

CAUTION

1. To assure good thermal grease interfaces there should be no bowing of either surface due to torquing. To prevent bowing, apply less torque if one or both surfaces are less than 1/8 inch thick copper or 1/4 inch thick aluminum.
2. Lead wires are soldered to module tabs with bismuth/tin solder (136°C). If lead wire replacement is necessary, use bismuth/tin solder. DO NOT use lead/tin solder (180°C).



Plane of screws in same plane as fins to prevent heat sink bowing

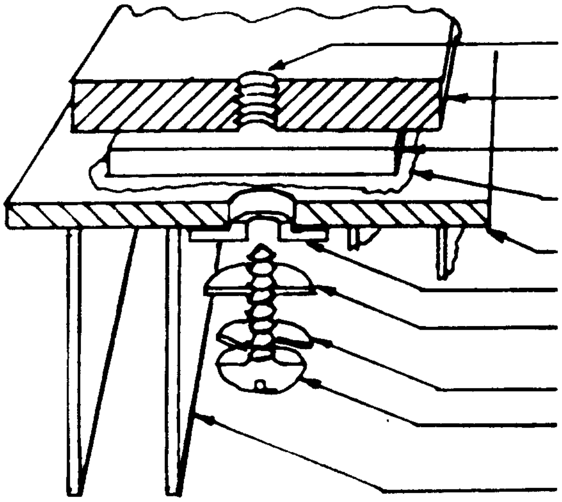
Cold Plate (Min. Thickness 1/8" copper, 1/4" alum.)

Module Leads

Heat sink (Min. Thickness 1/8" copper, 1/4" aluminum)

Thermoelectric Module

End View



Pretapped Hole

Cold plate with thermal grease in module area

Modules with thermal grease on Top and Bottom

Thermal Grease

Heat Sink

Fibre Insulating Washer in Clearance Hole

Metal Flat Washer

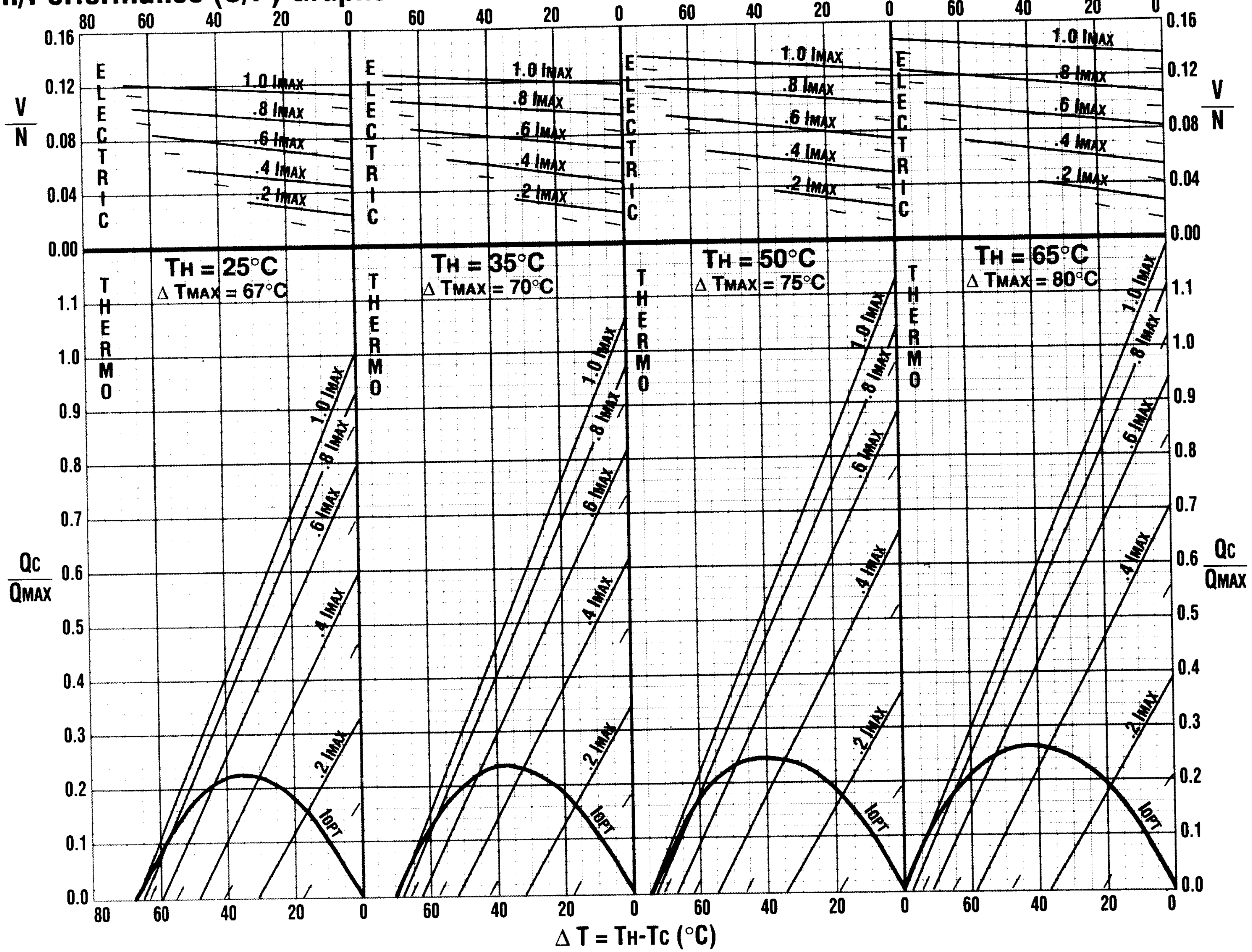
Belleville or Split Lock Washer (Steel)

Stainless Steel Screw

Fin

Exploded Cross Section

Selection/Performance (S/P) Graphs



I	Input current [Amps]
IOPT	Optimum (most efficient) input current required for a given ΔT [Amps]
IMAX	Input current resulting in greatest ΔT (ΔTMAX) [Amps]
N	Number of thermocouples (p- and n-type pairs)
QC	Amount of heat absorbed at cold face of TEC [Watts]
QMAX	Maximum amount of heat that can be absorbed at cold face (occurs at I = IMAX, ΔT = 0) [Watts]
TC	Temperature of the TEC cold face during operation [°C]
TH	Temperature of the TEC hot face during operation [°C]
ΔT	Temperature difference between TEC faces, TH - TC [°C]
ΔTMAX	Maximum temperature difference a TEC can achieve (occurs at I = IMAX, QC = 0) [°C]
V	Input Voltage [Volts]
VMAX	Voltage at ΔTMAX