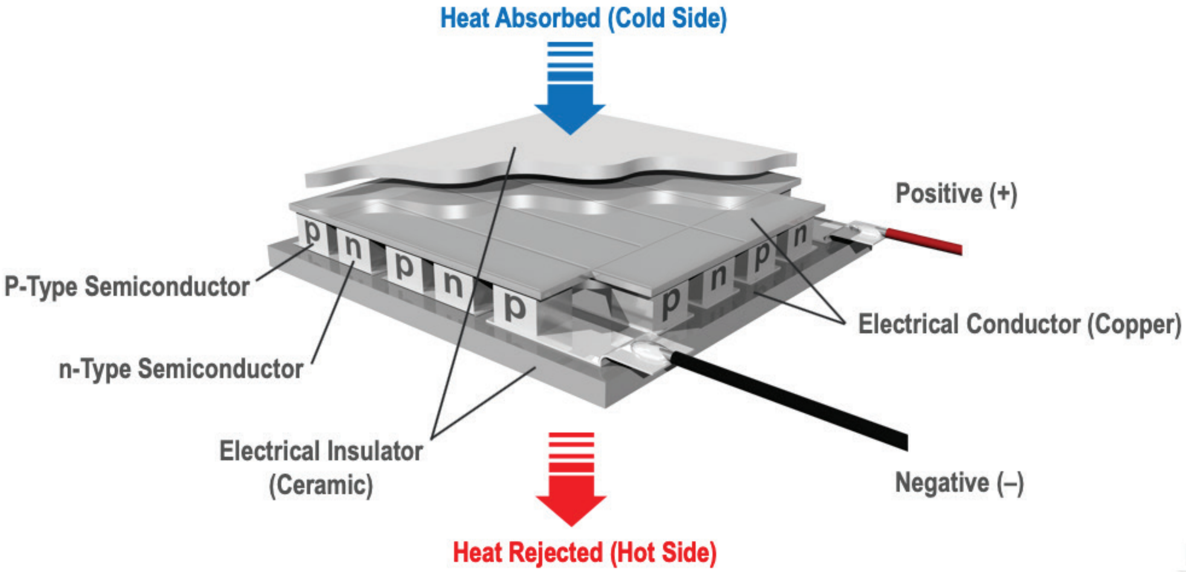
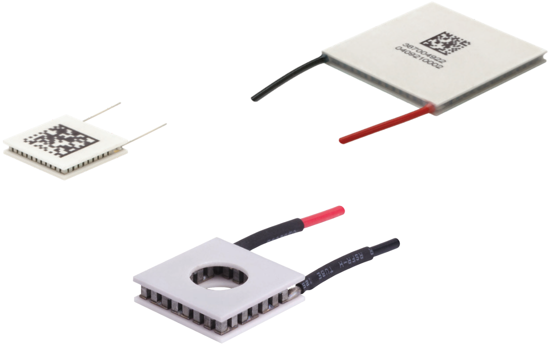
Thermoelectric Handbook



Laird™

THERMAL SYSTEMS

Table of Contents



Introduction to Thermoelectrics

Semiconductor materials with good electrical conductivity and thermal insulation are ideal properties for thermoelectric or Peltier coolers. Bismuth Tellurium is commonly used because it provides the best performance of these properties in room temperature environments. Thermoelectric devices became commercially available in the 1960's with the development of advanced semiconductor processing in combination with ceramic-based substrates.

Thermoelectric coolers (TECs) are solid-state devices that pump heat. It generally requires a heat transfer mechanism such as a heat exchanger to absorb and dissipate heat. The device operates on DC voltage and when powering on the current flows through the thermoelectric cooler and carries electrons from one side of the ceramic to the other. This causes one side of substrate to get cold, while the other side gets hot. A standard single-stage thermoelectric cooler can achieve temperature differentials of approximately 70°C at room temperature environment (Th ~27° C). Newer thermoelectric materials have come to the market and incrementally improved performance to 74°C. This has been accomplished through primarily enhancing material growth processes to limit degradation of the semiconductor materials.

Thermoelectric coolers have several advantages over alternate cooling technologies. They have compact form factors and are ideal for low heat load applications. They have no moving parts, so if designed correctly can achieve long life operation in the field with minimal to no maintenance. Thermoelectric coolers are capable of cooling to well below freezing temperatures. Multistage coolers for example can reach temperatures below -90°C in a vacuum environment under no load. The polarity to the thermoelectric cooler can be reversed enabling thermal cycling or precise temperature control, where up to +/-0.01°C can be maintained under steady-state conditions. In heating mode, thermoelectric coolers are more efficient than conventional resistant heaters because they generate heat from the input power plus additional heat generated by the heat pumping action that occurs on the cold side. Thermoelectric coolers are also environmentally friendly as no HCFC's are emitted to the ozone.

A typical thermoelectric cooler footprint ranges from 2 x 2 mm up to 62 x 62 mm and is light in weight. This makes thermoelectrics ideal for applications with tight geometric space constraints commonly found in many medical, analytical, industrial and telecom applications when compared to much larger cooling technologies, such as conventional compressor-based systems.

When should you use thermoelectrics?

Thermoelectrics are ideal for applications that require cooling below ambient temperatures and low heat loads, typically less than 400 Watts. Control temperature requirements to ambient can be solved with passive thermal solutions, such as a heat sink and fan and larger cooling capacities are better served by compressor-based systems because they have larger cooling capacity capabilities with higher COP. A design engineer should consider using TECs when the system design criteria include such factors as precise temperature control, high reliability, compact form factors, low weight requirements and zero global warming potential. Thermoelectric products are ideal for many of the medical, analytical, telecom and industrial applications requiring active cooling.

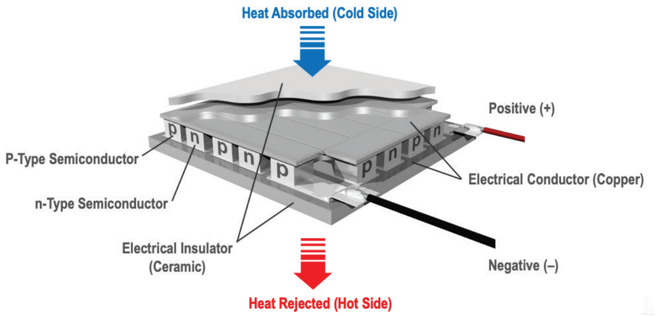


Figure 1: Thermoelectric Coolers utilize the Peltier effect to transfer heat from one side of the module to the other.

Thermoelectric Cooler Series

CP Series is a standard thermoelectric cooler for refrigeration applications commonly found in the medical and analytical markets. Cooling capacity ranges from 2 to 118 watts. This product series has many configurations and is available in numerous heat pumping capacities, geometric shapes, and input power ranges. These modules are often grouped together in an array to support refrigeration applications in lab environments at room temperature. The maximum operating temperature of this series is 80°C.

OptoTEC™ OTX/HTX Series is a premium miniature thermoelectric cooler product series using advanced thermoelectric materials to boost cooling performance. It is commonly used to temperature stabilize small optoelectronic devices such as laser diodes and image sensors, while ambient temperatures may fluctuate greatly. It offers the smallest sizes with footprints less than 13 x 13 mm, while cooling capacities are typically low ranging from 0.4 to 9.5 Watts. This Series is available in two solder constructions. The OTX Series has a maximum operating temperature of 120°C and HTX Series has a maximum operating temperature of 150°C.

HiTemp ETX Series is a premium thermoelectric cooler designed for high temperature applications. The construction of this product series is designed to survive in temperatures up to 150°C. It features advanced thermoelectric materials to boost performance and robust construction to prevent degradation in high temperature environments. This product series can be used in all markets, but is commonly found in analytical, telecom, automotive (autonomous systems) and industrial (machine vision) applications.

Multistage MS Series is a standard product series offering the highest temperature differential (ΔT). Each stage is a thermoelectric cooler stacked on top of each other creating a multistage module. This product series is available in numerous footprints, temperature differentials and cooling capacity ranges. It is designed for lower heat pumping applications for image sensing or detector cooling to minimize thermal noise.

PowerCycling PCX Series is a premium thermoelectric cooler using advanced thermoelectric materials to boost performance. It features a unique construction to survive in harsh thermal cycling applications with high frequency. This product series has both square and rectangular shapes commonly found in molecular diagnostic applications. This product series can also be used for thermal test socket applications to burn-in chips.

UltraTEC™ UTX Series is a premium thermoelectric cooler series using advanced thermoelectric materials to boost performance. It features the highest heat pumping density and is commonly used to cool industrial laser applications. Heat pumping capacities range from 69 to 299 Watts. The UTX Series can also be used for industrial applications requiring a high coefficient of performance (COP) if low cooling power is sufficient for the application.

Annular Series is a standard thermoelectric cooler with a hole in the middle to accommodate light protrusion for optical applications, mechanical fastening or access for a temperature probe.

Structure and Function

A thermoelectric cooler is composed of semiconductor material, ceramic substrates and solder. It is considered a heat pump or solid-state device with no moving parts. The semiconductor material is unique in its properties as it is one of the few materials that is highly electrically conductive yet thermally insulating. The high thermal resistance properties allow for a temperature differential to be achieved across the module. Thermoelectric material is grown into semiconductor rods and sliced and diced into P and N elements and then soldered in series between two ceramic substrates. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy state in the p-type semiconductor element, to a higher energy state in the n-type semiconductor element. The power supply provides the energy to move the electrons through the electric circuit. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy state (n-type element) to a lower energy state (p-type element).

An analogy often used to help comprehend a thermoelectric 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 and constantan, in such a manner that two junctions are formed. One junction is kept at some reference temperature and the other is attached to the control device measurement. 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.

Thermoelectric cooling couples (Fig. 2) 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.

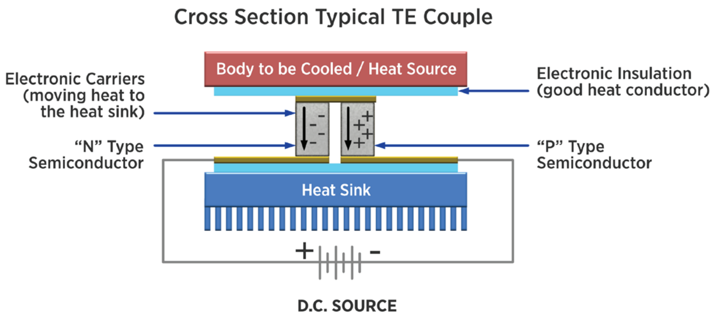


Figure 2: Cross Section of a typical TE Couple

In practical use, couples are (Fig. 3) connected electrically in series, and thermally in parallel. By adding couples, the cooling power (Qc) increases and nominal voltage input power to thermoelectric cooler also increases.

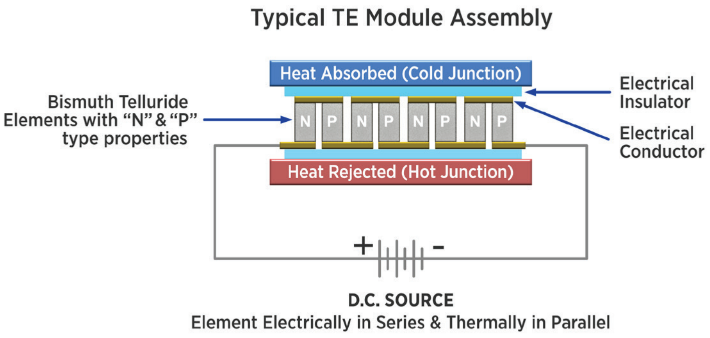


Figure 3: Typical TE Module Assembly

Thermoelectric coolers are available in a variety of footprints, operating currents, input voltages and heat pumping capacities, Qc. Often to reach maximum performance for end user application a custom configuration is engineered to optimize geometry of element and number of couples. This is matched to application constraints, such as cooling capacity requirements, desired control temperature, thermal resistance of heat dissipation mechanism and available input power budget.

There is usually a "need" to use thermoelectrics instead of other forms of cooling technologies. The "need" is usually going below ambient, geometric space constraints, environmental condition or preferred DC operation.

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

These are:

- Tc = Cold Surface Temperature
- Th = Hot Surface Temperature
- Qc = The amount of heat to be absorbed at the Cold Surface of the TEM

In most cases, the cold surface temperature is usually given as part of the problem – that is to say that some object is to be cooled to a specified temperature. Generally, if the object to be cooled is in direct contact with the cold surface of the thermoelectric cooler, the desired temperature of the object can be considered the temperature of the cold surface of the TEC (Tc). There are situations where the object to be cooled is not in intimate contact with the cold surface of the TEC, such as volume cooling where an air heat exchanger is required on the cold surface of the TEC. When this type of system is employed, the cold surface of the TEC (Tc) 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 thermal resistance of the heat exchanger between the hot surface of the TEC and the ambient environment.
3. These two temperatures (Tc & Th) 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 4 represents a typical temperature profile across a thermoelectric system.

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 thermoelectric cooler, (Qc). All thermal loads to the thermoelectric cooler must be considered. These thermal loads include, but are not limited to, the active heat load (I2R) from the electronic device to be cooled and passive heat load where heat loss can occur through any object in contact with ambient environment (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 coolers are capable of producing a "no load" temperature differential of approximately 70°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 cascade device is much more complex than that of a single stage device and is beyond the scope of these notes. Should a cascade device be required, design assistance can be provided by a Laird Thermal Systems' engineer.

Once the three basic parameters have been determined, the selection process for a particular module or array of TECs may begin. Some common heat transfer equations are attached for help in quantifying cooling capacity (Qc) & hot side temperature (Th) or user can reference Laird Thermal Systems Thermal Wizard.

There are many different thermoelectric coolers or module arrays that could be used for a specific application. One additional criteria that is often used to pick the "best" module(s) is Coefficient of Performance (COP). COP is defined as the heat absorbed at the cold junction, divided by the input power (Qc / P). The maximum COP case is the point at which minimum input power is used and therefore, minimum total heat to be rejected to the heat exchanger (Qh = Qc + P). These advantages come at a cost, which in this case is the additional or larger thermoelectric cooler required to operate at COP maximum. It naturally follows that the major advantage of the minimum COP case is the lowest initial cost.

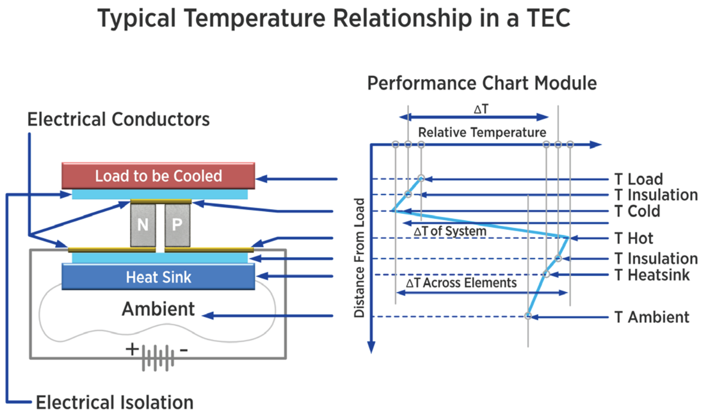


Figure 4: Typical Temperature Relationship in a TEC

Temperature Control

When designing a thermoelectric system, power supplies, temperature controllers, and temperature sensors are components that also require careful consideration.

Thermoelectric devices require a DC power source to operate. The power supply output should be matched to the operational voltage of the thermoelectric modules and fans. It is not recommended to operate thermoelectric devices above the specified maximum voltage. Doing so will degrade the performance of the thermoelectric coolers and operate less efficiently. The power supply should also have a small ripple voltage with a maximum of 10% of full output power. The ripple voltage is a fluctuation of the power supply output voltage and therefore is an AC component of the DC power source. AC power will degrade the operational performance of the thermoelectric coolers. The degradation in performance due to ripple voltage can be approximated by:

$\Delta T / \Delta Tmax = 1 / (1+N2)$, where N is a percentage of current ripple, expressed as a decimal. Laird Thermal Systems recommends no more than a 10% ripple.

Temperature control can be accomplished by using one of two control methods: Open Loop (manual) and Closed Loop (automatic).

In the Open Loop method, an operator adjusts the output of the power supply to achieve and maintain a steady control temperature. In the Closed Loop method an electronic controller runs an algorithm that utilizes feedback data from a temperature sensor within the system to vary the output of the power supply to control the temperature.

Temperature controllers can have a single directional or a bidirectional output. A temperature controller that has a single directional output can operate only in Heating or Cooling mode depending on connection polarity. Controllers with a single directional output are used to maintain a constant temperature within a system surrounded by a relatively constant ambient temperature (i.e., refrigeration or hot food storage). A temperature controller with a bidirectional output can operate in both heating and cooling modes. Controllers with a bidirectional output are used for maintaining a constant temperature within a system surrounded by an ambient environment with large temperature fluctuations (i.e., back-up battery storage or climate control enclosure during winter and summer months).

Temperature controllers can also have two regulation modes: thermostatic (On/Off) or proportional control. Thermostatic controllers operate by turning on the thermoelectric coolers in order to heat or cool to a set point. The set point temperature tolerance is defined by a hysteresis range. Once the set point is achieved the controller shuts off the thermoelectric cooler. When the control temperature changes to outside the hysteresis range the controller turns on power to the thermoelectric coolers and restarts the cooling or heating mode process. This cycle continues until the controller is shut down. Thermostatic control is often used in climate control or refrigeration, where narrow temperature swings can be tolerated.

Proportional controllers use proportional regulation to maintain a constant temperature with no swing in the control temperature. This is often accomplished by using a Proportional Integral Derivative (PID) algorithm to determine the output value and a Pulse Width Modulation (PWM) output to handle the physical control. When using a controller with a PWM output, a capacitor can be placed (electrically) across the output to filter the voltage to the TEM. Proportional controllers are often used in heating and/or cooling systems where the temperature must stay constant (with no change) regardless of the ambient temperature. For example, a thermoelectric liquid chiller system used to control the temperature of a detector plate in a medical imaging system.

Regardless of the controller used, the easiest feedback parameter to detect and measure is temperature. The sensors most used by temperature controllers are thermocouples, thermistors, and RTD's. Depending on the system, one or more temperature sensors may be used for the purpose of control. The temperature sensor feedback is compared by the controller to a set point or another temperature to determine the power supply output. The temperature feedback sensor(s) will most likely be determined by the controller specified. Some controllers even include a sensor with purchase.

To begin selection of a thermoelectric controller, consider the following questions:

1. What is the maximum voltage & current of thermoelectric coolers used in the application? (also needed for selecting a power supply)
2. Does the system need to Heat, Cool or Heat & Cool?
3. Can the system tolerate a temperature swing of 3°C? Once answered, the selection of the basic functions of a temperature controller can be identified. The controller selected needs to be capable of handling the maximum voltage and current to properly control the thermoelectric cooler and power fans.

If the answers to question 2 is "Heat" or "Cool" and the answer to question 3 is "Yes" then the required controller is single directional and thermostatic.

If the answers to question 2 is "Heat" or "Cool" and the answer to question 3 is "No" then the required controller is single directional and proportional.

If the answers to question 2 is "Heat & Cool" and the answer to question 3 is "Yes" then the required controller is bidirectional and thermostatic.

If the answers to question 2 is "Heat & Cool" and the answer to question 3 is "No" then the required controller is bidirectional and proportional.

Temperature controllers also can accommodate more advanced options to trip alarms, control fan speeds and interface remotely with PC or UI, but these are beyond the scope of this handbook. However, some basic questions to consider for temperature controller designs are:

1. What alarms/indicators are required for User Interface?
2. Does the controller need to interface with a PC?
3. Does the TEM controller provide fan control?
4. Does the temperature set point need to be changed by the end user?

Other design considerations may exist and should be considered during system level design.

Laird Thermal Systems offers a variety of Closed Loop Temperature Controllers. The controller offering includes single and bidirectional output controllers that employ thermistor temperature sensor feedback, fan controls, alarms, and a range of control algorithms ranging from thermostatic (ON/OFF) to PID. Laird Thermal Systems also has the ability to customize and design temperature controllers to meet unique application requirements. Consult with a Laird Thermal Systems Sales Engineer on available product offerings or customized solutions that may fit your design criteria.

Thermal Wizard

Engineers of all disciplines more frequently need a Thermal Wizard, someone who can solve their heat dissipation or critical thermal management problems. Laird Thermal Systems developed the Thermal Wizard to solve all of these issues.

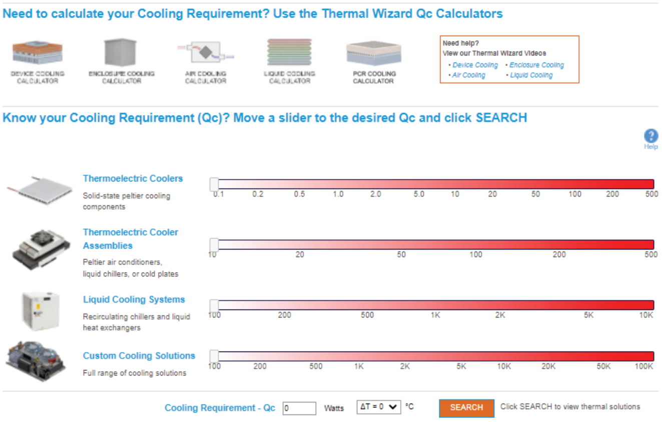
The Thermal Wizard is a web-based solution, which links product search to thermal calculators to product availability. This means it is available on any web browser and on any computing platform (PC, Mac, Iphone, Android) running a web browser. Thermal Wizard requires only two specifications, Qc (Cooling Power) and ΔT (Temperature Change) to begin the selection process

If you know these specifications, the main Thermal Wizard product search quickly displays the available thermoelectric cooler, thermoelectric cooler assembly or liquid cooling system thermal solutions, ranging from a few tenths of a watt to more than five kilowatts. If Qc and DeltaT have not yet been determined, Thermal Wizard provides five calculators (Device Cooling, Enclosure Cooling, Air Cooling, Liquid Cooling and PCR), each with three preprogrammed examples to quickly get your design underway.

Design engineers can use these calculators to model new product designs in order to observe how the trial design performs under various What-If scenarios. Linking actual thermal products and their real-world performance to application models accelerates trial design results, shortening design times.

The Thermal Wizard displays the quickest means of obtaining samples for prototyping. Whenever the Thermal Wizard displays a product, either in a selection list or in an active datasheet, a Buy Now >> button is always there to indicate a source with inventory. The Thermal Wizard Request a Quote form is also available if you require a firm quote from Laird Thermal Systems.

Learn more about the Thermal Wizard in our Technical Paper: [How to make the Laird Thermal Systems Wizard Your Thermal Wizard]



Need to calculate your Cooling Requirement? Use the Thermal Wizard Qc Calculators

Need help?
View our Thermal Wizard Videos
- Device Cooling
- Enclosure Cooling
- Air Cooling
- Liquid Cooling

Know your Cooling Requirement (Qc)? Move a slider to the desired Qc and click SEARCH

Thermoelectric Coolers: Solid-state peltier cooling components

Thermoelectric Cooler Assemblies: Peltier air conditioners, liquid chillers, or cold plates

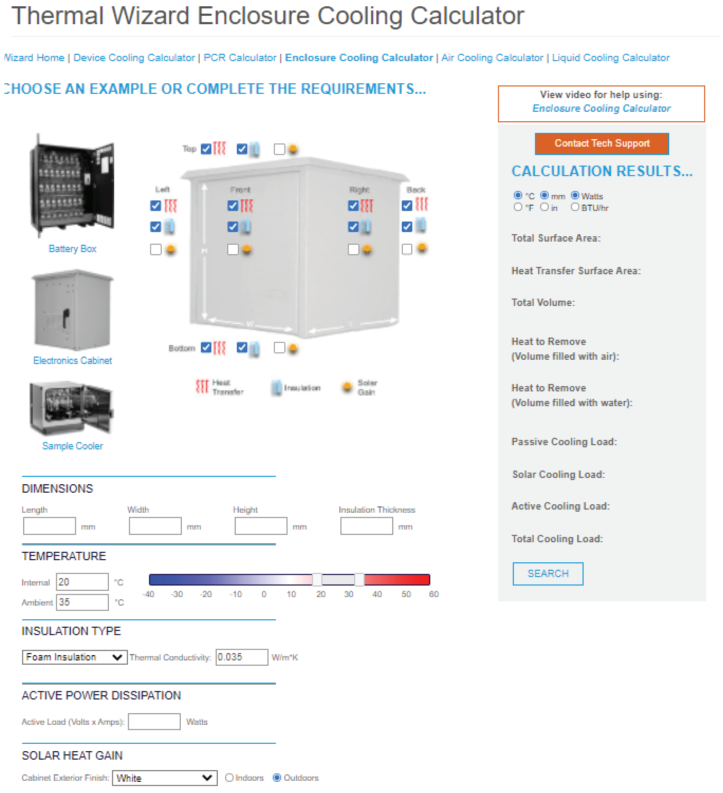
Liquid Cooling Systems: Recirculating chillers and liquid heat exchangers

Custom Cooling Solutions: Full range of cooling solutions

Cooling Requirement - Qc: 0 Watts; ΔT = 0 °C

Click SEARCH to view thermal solutions

Figure 5: Selecting Qc and ΔT for Thermal Wizard Product Search



Thermal Wizard Enclosure Cooling Calculator

Wizard Home | Device Cooling Calculator | PCR Calculator | Enclosure Cooling Calculator | Air Cooling Calculator | Liquid Cooling Calculator

CHOOSE AN EXAMPLE OR COMPLETE THE REQUIREMENTS...

View video for help using: Enclosure Cooling Calculator

CALCULATION RESULTS...

● °C ● mm ● Watts
○ °F ○ in ○ BTU/hr

Total Surface Area:

Heat Transfer Surface Area:

Total Volume:

Heat to Remove (Volume filled with air):

Heat to Remove (Volume filled with water):

Passive Cooling Load:

Solar Cooling Load:

Active Cooling Load:

Total Cooling Load:

DIMENSIONS

Length ___ mm; Width ___ mm; Height ___ mm; Insulation Thickness ___ mm

TEMPERATURE

Internal: 20 °C

Ambient: 35 °C

INSULATION TYPE

Foam Insulation; Thermal Conductivity: 0.035 W/m*K

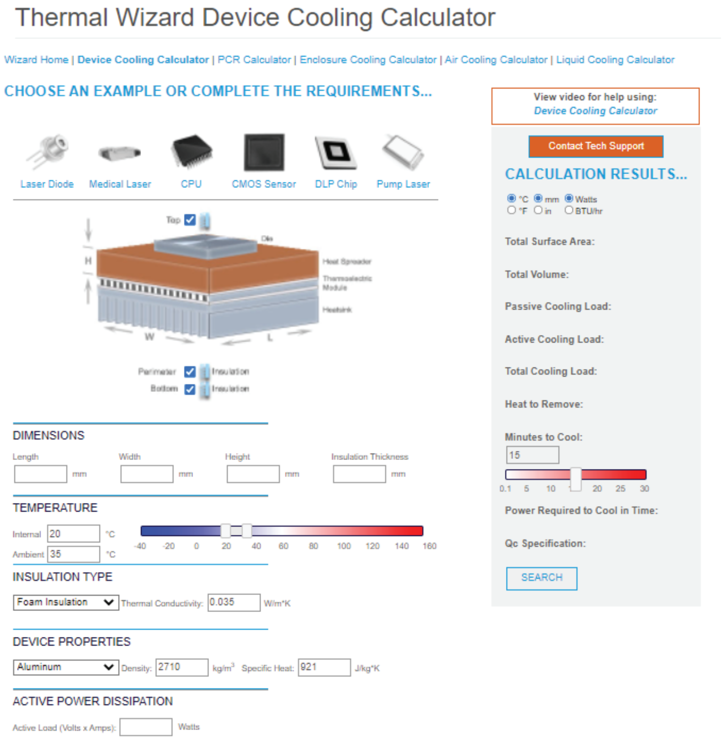
ACTIVE POWER DISSIPATION

Active Load (Volts x Amps): ___ Watts

SOLAR HEAT GAIN

Cabinet Exterior Finish: White ○ Indoors ● Outdoors

Figure 6: Thermal Wizard Enclosure Cooling Calculator



Thermal Wizard Device Cooling Calculator

Wizard Home | Device Cooling Calculator | PCR Calculator | Enclosure Cooling Calculator | Air Cooling Calculator | Liquid Cooling Calculator

CHOOSE AN EXAMPLE OR COMPLETE THE REQUIREMENTS...

View video for help using: Device Cooling Calculator

CALCULATION RESULTS...

● °C ● mm ● Watts
○ °F ○ in ○ BTU/hr

Total Surface Area:

Total Volume:

Passive Cooling Load:

Active Cooling Load:

Total Cooling Load:

Heat to Remove:

Minutes to Cool: 15

Power Required to Cool in Time:

Qc Specification:

DIMENSIONS

Length ___ mm; Width ___ mm; Height ___ mm; Insulation Thickness ___ mm

TEMPERATURE

Internal: 20 °C

Ambient: 35 °C

INSULATION TYPE

Foam Insulation; Thermal Conductivity: 0.035 W/m*K

DEVICE PROPERTIES

Aluminum; Density: 2710 kg/m³; Specific Heat: 921 J/kg*K

ACTIVE POWER DISSIPATION

Active Load (Volts x Amps): ___ Watts

Figure 7: Thermal Wizard Device Cooling Calculator

Sealant Options

Most applications operate in a room temperature environment and cool to below dew point. As a result, moisture in the environment will condense onto the cold side heat exchanger and may accumulate around mounting hardware and eventually penetrate to the thermoelectric cooler. The presence of moisture will cause corrosion that will degrade the useful life of a thermoelectric module. Two perimeter sealants are generally used because they provide moisture protection against condensation, have high dielectric strength and low thermal conductivity.

Silicone (RTV) is an all-purpose sealant that exhibits good sealing characteristics and retains its elastomeric properties over a wide temperature range, -60 to 200°C. The sealant is non-corrosive to many chemicals and exhibits good electrical properties with low thermal conductivity. It is suitable for high volume applications for ease of use and is cost effective. However, over time it is impervious to vapor migration that can trap small amounts of moisture inside the thermoelectric cooler once the vapor condenses. This may or may not be a problem dependent on life expectancy of application and environmental conditions. This sealant is also better suited for thermal cycling applications

Figure 8: Thermoelectric Cooler with RTV (translucent or white) sealant.

Epoxy (EP) is an effective barrier to moisture that exhibits a useable temperature range of -40 to 130°C. When cured the material is completely unicellular and therefore the moisture absorption is negligible. The material exhibits a low dielectric constant, low coefficient of thermal expansion and low shrinkage. Epoxies are ideal for applications requiring long life expectancies. However, applying epoxy onto thermoelectric coolers can be cumbersome as multiple fillers are required to be mixed and working life tends to be short, which makes it more difficult to automate for higher volume production runs. This sealant is recommended for refrigeration applications, but not thermal cycling.

Figure 9: Thermoelectric Cooler with Epoxy (black) sealant.

It should be noted that since sealants come in contact with the top and bottom ceramic, they act as thermal paths and transfer heat. The thermal conductivity of RTV and Epoxy is low, but it still can diminish the cooling performance of a TEM by up to 10%. However, it is necessary to specify for applications that may be susceptible to condensation.

Thermoelectric Array

Wiring multiple thermoelectric coolers together is commonly referred to as a TE array. The decision to wire thermoelectric coolers in series or in parallel is primarily based on available input power requirements. No additional performance benefit will be achieved by wire arrangement. TE arrays are commonly used for higher heat pumping capacities and can be more efficient than a single thermoelectric cooler by taking advantage of dissipating heat over a larger surface area. When mounting a TE array onto a heat exchanger, the recommended lapping tolerances are 3 0.025 mm for two thermoelectric coolers and 3 0.0125 mm for three or more. This is done to maximize the thermal contact between the thermoelectric cooler and mating heat exchangers.

One advantage of wiring a TE array in parallel versus in series is that the entire TE array will not fail if one thermoelectric cooler has an open circuit. This can be beneficial for applications that require redundancy.

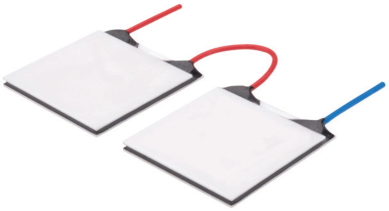


Figure 10: Thermoelectric Cooler Array

Design/Selection Checklist

If you are looking for a custom thermoelectric device, we will ask you to fill out the specifications in the Prototype Thermoelectric Cooler Requirements form on the website. These specifications, including cooling capacity, size constraints, and available input voltage, are taken into consideration when designing your thermoelectric cooler. Reference image on next page.

Prototype Thermoelectric Cooler Requirements Form

Customer Name		Name of Requestor	
Customer Project (If known)		Date	
Application		Quantities	

Module Type

☐ CP Series
☐ Annular Series
☐ ZT Series
☐ HiTemp ET Series
☐ UltraTEC UTX Series
☐ OptoTEC OT Series
☐ PolarTEC PT Series
☐ PowerCycling PC Series
☐ Multistage MS Series

Performance Requirements

		Input (Filled out by Customer)		Output (Filled in by Laird Thermal Systems)	
		Value	Notes	Value	Notes
Voltage (V)					
Current (A)					
Qc (W)	Active				
	Passive				
	Total				
dT (°C)	Ambient				
	Target				
AC Resistance Request (Ω)					
COP Request					

Size Requirements (mm)

Length - Cold Side				
Width - Cold Side				
Length - Hot Side				
Width - Hot side				
Height				
Hole size (if Annular)				

Other

Heat Sink Thermal Resistance				
Cold Side Thermal Resistance				
Ambient Environment				
Lead length				
AWG				

Type	☐ PVC ☐ PTFE ☐ None ☐ Other, please specify:
Connector	
Other Lead Notes	
Finishing Option - Cold Side	☐ L/11 ☐ L1/TA ☐ L2/TB ☐ Pre-tinned ☐ Metallized ☐ Au Plated
Finishing Option - Hot Side	☐ L/11 ☐ L1/TA ☐ L2/TB ☐ Pre-tinned ☐ Metallized ☐ Au Plated
Sealant	☐ RTV ☐ EP ☐ EC ☐ None

To be filled out by Laird Thermal Systems

Engineer	
Result	
Date Returned	
Notes	

Thermoelectric Multistage Coolers

A multistage thermoelectric cooler should be used only when a single stage module does not meet temperature control requirements. Figure 11 depicts two graphs: the first shows the ΔT vs. Normalized Power input (Pin/Pmax) of single and multistage modules. The second graph shows the ΔT vs. COP. COP is defined as the amount of heat absorbed at the cold side of the TEM (in thermal watts) divided by the input power (in electrical watts).

These figures should help identify when to consider cascades since they portray the effective ΔT range of the various stages. A two- stage cascade should be considered somewhere between a ΔT of 40°C and 65°C. Below a ΔT of 40°C, a single stage module may be used, and a ΔT above 65°C may require a 3, 4 or even 5 stage module.

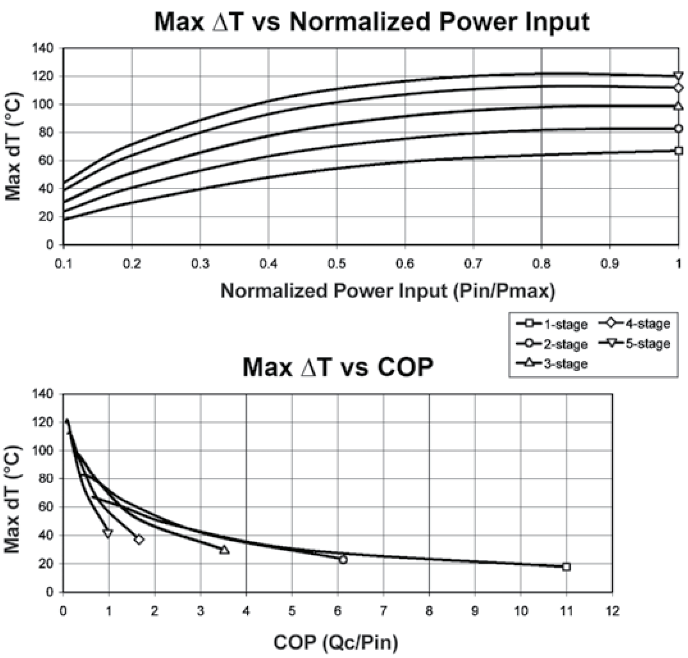


Figure 11: Multistage Temperature Differential

There is another very significant factor that must always be considered and that is cost. As the number of stages increases, so does the cost. Certain applications require a trade-off between COP and cost. As with any other thermoelectric system, to begin the selection process requires the definition of at least three parameters:

- Tc Cold Side Temperature
- Th Hot Side Temperature
- Qc The amount of heat to be removed (absorbed by the cooled surface of the thermoelectric cooler) (in watts)

Once ΔT (Th - Tc) and the heat load have been defined, utilization of Figure 4 will yield the number of stages that should be considered. Knowing COP and Qc, input power can also be estimated. The values listed in Figure 11 are theoretical maximums. Any device that is manufactured will rarely achieve these maximums but should closely approach this value.

Laird Thermal Systems offers a line of MS Series 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. Laird Thermal Systems has developed a proprietary computer aided design selection tool called the Thermal Wizard to help select a device. The three parameters listed 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. More than 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 a Laird Thermal Systems sales engineer for assistance in cascade selection.

Typical Device Performance

When PERFORMANCE vs. INPUT POWER is plotted for any thermoelectric device, the resultant curve will appear as in figure 12 below. Performance can be ΔT (Th - Tc), heat pumped at the cold side (Qc), 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 ΔTmax or Qc max, we are referring to that point where the curve peaks. The same is true when referring to either Imax or Vmax. Since operating at or near the peak is inefficient, most devices operate 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.

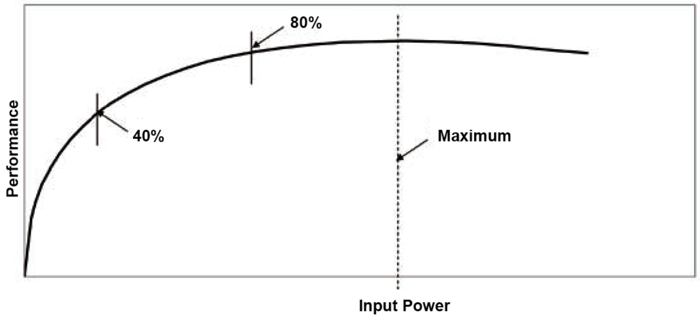


Figure 12: Performance vs Input Power

Assembly Tips

The techniques used in the assembly of a thermoelectric system can be as important as the selection of the thermoelectric cooler (TEC). It is imperative to keep in mind the purpose of the assembly – namely to transfer heat. Generally, a thermoelectric cooler, in cooling mode, moves heat from an object to ambient environment. All of the mechanical interfaces between the device to be cooled and ambient are also thermal interfaces. Similarly, all thermal interfaces tend to inhibit the transfer of heat or add thermal resistance to system, which lowers COP. Again, when considering assembly techniques every reason- able effort should be made to minimize the thermal resistance between hot and cold surfaces.

Mechanical tolerances for heat exchanger surfaces should not exceed .025 mm/mm with a maximum of .076 mm total Indicated Reading. If it is necessary to use multiple thermoelectric coolers in an array between common plates, then the height variation between modules should not exceed 0.025 mm (request tolerance lapped modules when placing order). Most thermoelectric cooler assemblies (TEAs) utilize thermal interface materials, such as grease. The grease thickness should be kept to 0.025 3 .013 mm to minimize thermal resistance. A painter's ink roller and screen work well for maintaining grease thickness. When these types of tolerances are to be held, a certain level of cleanliness must be maintained to minimize contaminants.

Once the thermoelectric coolers have been assembled between the heat exchangers, some form of insulation should be used between the exchangers surrounding the modules. Since the area within the module, (i.e. the element matrix), is an open DC circuit and a temperature gradient is present, air flow should be minimized to prevent condensation. Typically, a thermoelectric cooler is about 5.0 mm thick, so any insulation that can be provided will minimize heat loss between hot and cold side heat exchangers. The presence of the insulation/seal also offers protection from outside contaminants.

The insulation/seal is often most easily provided by inserting a die cut closed cell polyurethane foam around the cavity and sealing with either an RTV type substance or, for more physical integrity, an epoxy coat. Whatever form is used, it should provide the protection outlined above. It is often desirable to provide strain relief for the input lead wires to the thermoelectric cooler, not only to protect the leads themselves, but to help maintain the integrity of the seal about the modules.

We have included an Assembly Tips drawing (Fig. 12). This drawing shows the details of the recommended construction of a typical assembly. The use of a "spacer block" yields maximum heat transfer, while separating the hottest and coldest parts of the system, by the maximum amount of insulation. The "spacer blocks" are used on the cold side of the system due to the lower heat flux density. In addition, the details of a feed thru and vapor sealing system that can be used for maximum protection from the environment are shown.

If you follow the recommendations shown in these drawings than you will see a significant improvement in performance. When testing an assembly of this type it is important to monitor temperature. Measuring temperature of the cooling fluids, inlet and outlet temperatures as well as flow rates is necessary. This is true if either gas or liquid fluids are used. Knowing input power to the thermoelectric cooler, both voltage and current, will also help in determining the cause of a potential problem.

In addition, we have enclosed step-by-step procedure for assembling Laird Thermal Systems modules, Solderable or Lapped modules to heat-exchangers.

If you should require any further assistance, please contact one of our engineers. Our many years of experience in working with customers ensuring reliable and efficient application of our products has proven to be essential to product success.

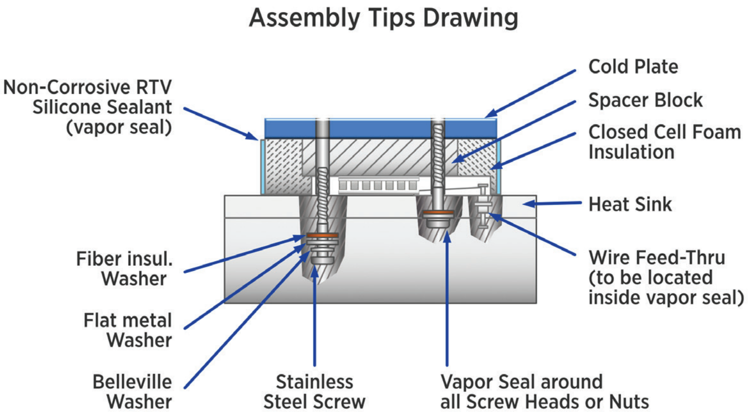

Assembly Tips Drawing

Figure 12: Assembly Tips Drawing

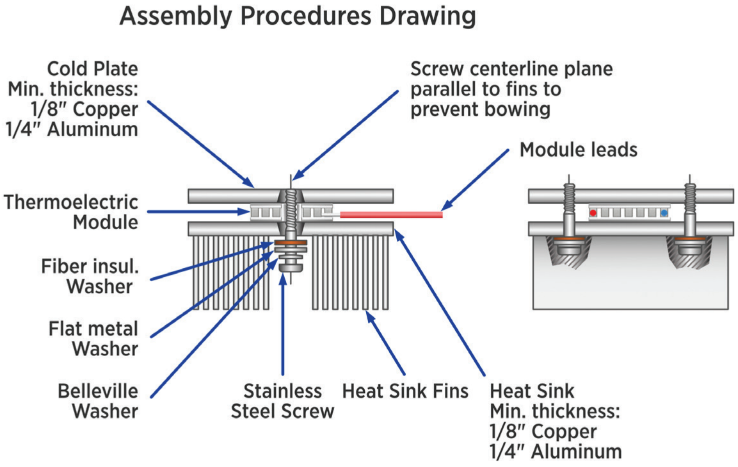

Assembly Procedures Drawing

Figure 13: Assembly Procedures Drawing

Procedure For Assembling Lapped Modules To Heat Exchangers

IMPORTANT: When two or more thermoelectric coolers (TECs) are mounted between a common heat exchanger base, the TECs thickness tolerance should not vary more than 3 0.025 mm. Contact our sales engineer for more information on tolerance lapping requirements for thermoelectric coolers in an array.

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

- Grind or lap flat to within +/- 0.025 mm in module area.
- Locate mounting holes as close as possible to opposite edges of module (3.18 mm clearance recommended, 12.7 mm 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 in Assembly Tips). If a spacer block is used to increase distance between surfaces, performance is greater if the spacer block is on the cold side of system.
- Remove all burrs, chips and foreign matter from thermoelectric module mounting area.

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

Step 3. Apply a thin continuous film of thermal grease (Laird Thermal Systems grease type 1500) 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 forth, 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. Keep the module centered between the screws, or uneven compression will result.

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 three 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 screwdriver. The recommended compression for a thermoelectric assembly is 10 to 21 kilograms per square centimeter (150 - 300 PSI) of module surface area. Using the following equation, you can solve for torque per screw:

T = (C x D x P x m2) / (# of screws)

T = torque per screw (N-m)

C = torque coefficient (0.20 as received, 0.15 lubricated) D = nominal screw size (M3 = 0.003, M4 = 0.004,

M5 = 0.005)

P = Force (N-m2)

m2 = Module surface area (length x width)

Check torque after one hour and retighten if necessary.

Use Stainless Steel Screws, fiber insulating shoulder washers, and steel spring (Belleville or split lock type) washers

(see sketch in Assembly Tips).

CAUTION

To ensure good thermal grease performance, 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 3.18 mm thick copper or 6.35 mm thick aluminum.

Reliability & Qualification Testing

MTBF is difficult to determine and highly dependent on application conditions. Thermoelectric devices can be highly reliable if design considerations for application have been fully vetted and proper qualification testing has been conducted to assure worst case attributes. Most customers create their own qualification requirements based on accelerated or severe environmental testing that goes beyond worst case application conditions.

To ensure proper long-term performance of a thermoelectric cooler in an application, performance measurements and qualification testing must be conducted to validate full compliance in an application:

- Functional testing – verifies that the thermoelectric cooler meets expected performance specifications
- Reliability testing – determines the thermoelectric cooler's mechanical integrity and ability to survive in extreme environmental conditions
- Compliance –ensures that the product meets applicable industry standards

Functional Performance Testing

Thermoelectric coolers undergo performance testing to ensure they deliver the expected cooling capacity. A vacuum temperature difference tester is used to measure electrical current and voltage input.

How is the test performed?

- The thermoelectric cooler is placed on a heatsink with the cold side facing upwards in a vacuum environment. A copper block is put on the cold side as thermal load.
- Current will be applied to the thermoelectric cooler to reach the calculated Imax that produces the maximum possible temperature differential (ΔTmax).
- Current of thermal load will then change so the temperature of the hot and cold side is equal, resulting in ΔT= 0
- The maximum cooling capacity (Qmax) is determined by the required power input to thermal load

Reliability Testing

Standard mechanical or environmental testing is conducted to Telcordia GR-468 Core or MIL-STD. Standard testing does not accommodate all application criteria and often custom environmental testing is conducted based on OEM specifications. The most common method to assess the health of a thermoelectric cooler is by measuring AC-resistance (ACR) before and after the qualification test has been conducted. A significant drop of AC resistance indicates that the thermoelectric cooler has degraded and may not be functioning properly. If the ACR change is greater than 5% it will not pass testing.

Mechanical Testing

Mechanical testing is more commonly conducted on smaller OptoTEC™ or Multistage parts used in various optoelectronic applications where the cold side surface is used to mount an optical component or thermistor. Larger form factor thermoelectric coolers generally do not conduct mechanical testing unless they are used for aerospace or automotive applications. Common mechanical testing is vibration and shear force testing.

Vibration Testing

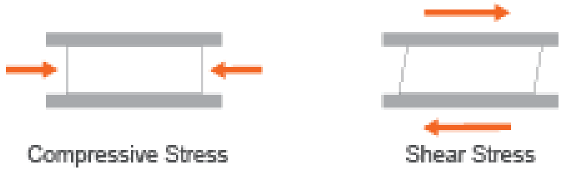
Assures thermoelectric coolers are not affected by careless handling during transportation. It is typically required for miniature thermoelectric coolers used in telecom and aerospace applications due to their sensitive module construction.

How is the test performed?

- The thermoelectric cooler is mounted on the test fixture which is then mounted on the test equipment platform in one of three axes.
- The thermoelectric cooler is subjected to vibrations during multiple sequences.

Shear Force Testing

Even though thermoelectric coolers can withstand a high level of compression stress, sheer strength is relatively weak and proper mounting is critical to ensure durability. This test is typically performed on smaller thermoelectric coolers as larger units allow for stronger and more reliable construction.



How is the test performed?

- The thermoelectric cooler will be attached to the module holding fixture.
- With one plate of the thermoelectric cooler held in place, a shear force will be applied to the other plate according to the customer specification.

Environmental Testing

Environmental testing is more commonly conducted to qualify thermoelectric coolers for customer specific applications. These types of tests thermally stress the construction of the TEC to validate its integrity in end use applications. There are more types of tests that can be done including high temperature storage, power cycling and thermal shock testing.

High Temperature Storage

Will determine the effect of long-term storage of thermoelectric coolers at a specific condition. This testing induces thermal stress on the thermoelectric cooler in a non-operation state.

How is the test performed?

The thermoelectric cooler is placed in a storage chamber at a temperature and time specified by a certain standard or customer application requirement. There is typically a low or high temperature storage requirement

- Low temperature storage testing is commonly conducted at a temperature between 80 to 100°C
- High temperature storage testing is commonly conducted at a temperature between 120 to 150°C

Power Cycling

This test will determine the effect of inducing electrical and thermal stress to the thermoelectric cooler caused by sudden changes between power conditions.

How is the test performed?

- On/Off Power Cycling – Thermoelectric cooler is placed in a fixture and powered on and off to a set duration for a specified number of cycles. Typical testing requires minimum cycle condition of 5000 cycles or more.
- Reverse Power Cycling – the thermoelectric cooler is exposed to thermal stress generated by sudden changes between positive and negative power conditions. This is often used for PCR applications when heating and cooling occurs alternately. Typical testing requires up to 200K cycles or more, with rapid temperature swings between 10~100°C.

Thermal Shock

A frequently used method to measure survivability of a product under thermal stress. The purpose is to simulate hot and cold temperature conditions exceeding the intended application.

How is the test performed?

The thermoelectric cooler will be exposed to high and low temperatures in non-operational mode. As the module contracts and expands from repeated cooling and heating cycles over a long period of time, the thermoelectric cooler will be subjected to mechanical and thermal stresses.

HALT/HASS Testing

HALT-Highly Accelerated Life Test aims to identify the operating limits of the thermoelectric cooler. By identifying weaknesses early in the product development process, HALT can reduce cost and time-to-market. This type of test is typically performed when assessing failure modes or estimating MTBF of a thermoelectric cooler.

HASS-Highly Accelerated Stress Test will detect flawed thermoelectric coolers caused by poor manufacturing processes. The testing procedure is similar to HALT but stress levels are less extreme.

How is the test performed?

- The thermoelectric cooler is powered on and placed in a hot oven.
- The thermoelectric cooler is subjected to mechanical stress by increasing temperature changes. For HALT testing, extreme conditions will lead to failure of the thermoelectric cooler.
- The test analysis will determine if the module construction must be enhanced (HALT) or if potential defects have been caused by poor manufacturing processes (HASS)

Compliance

Regulatory requirements are needed to confirm products are following safe operating conditions and are not harmful to the environment.

Thermoelectric coolers may need to comply with

- RoHS - the Restriction of Hazardous Substances
- REACH - the Registration, Evaluation, Authorization and Restriction of Chemicals (Europe).
- TSCA - Toxic Substances Control Act (US)
- CA PROP 65 - Safe Drinking Water and Toxic Enforcement Act (US, California)
- Telcordia GR-468 Core Issue 2

Thermoelectric coolers operating in harsh environments are typically required to meet Telcordia General Requirements (GR) to ensure product reliability. Telcordia (previously Bellcore) is a company that provides technical analysis, testing, and consulting services to product suppliers and service providers for the telecom market.

Due to lack of industry standards in other markets, OEM's have adopted Telcordia standards in reliability testing for thermoelectric products used in other critical applications, such as machine vision, autonomous and optoelectronic applications.

Laird™
THERMAL SYSTEMS

www.lairdthermal.com

LTS-THERMOELECTRIC-HANDBOOK-060222