Cooling Systems for Electronic Enclosures

Do Thermoelectric Air Conditioners Have the Advantage?

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Enclosure Cooling Options

Overview

This white paper discusses four popular options for cooling electronic/electrical equipment housed in enclosures and cabinets. These options include thermoelectric air conditioners, compressor-based air conditioners, vortex coolers and air-to-air heat exchangers (heat pipes). Each cooling method is explained and the advantages of thermoelectric air conditioners are examined as compared to the other cooling methods.

The Need for Cooling Electronics

Computers and other sensitive electronic devices are being used increasingly in applications in which the components are subjected to hostile, inhospitable surroundings. High temperatures, contaminant-laden air, and humid and corrosive atmospheres can wreak havoc on electronic equipment. The inherent vulnerability of these components is a major consideration in such applications. Few companies today can afford the costs and inconvenience associated with repairs, downtime, and lost data due to inadequate protection of their investment in technology.

The Sources of Heat

Unwanted heat, which can cause an enclosure's internal temperature to exceed the manufacturer's recommended ratings for the electronic/electrical equipment installed inside, can come from two sources. These two heat sources are reviewed below:

Internal Heat Sources: All computers and electronic components generate a certain amount of heat. Ironically, the same equipment that can be damaged by heat is in many cases the primary source of the heat. These include:

- AC drives/inverters
- Battery back-up systems
- Communication gear
- PLC systems
- Power supplies
- Routers & switches
- Servers
- Transformers

External Heat Sources: The environment in which an enclosure is located can also be a major factor in adding unwanted heat to the inside of the enclosure. These include:

- Blast furnaces and foundries
- Engine rooms
- Food processing factories
- Industrial ovens
- Hot climates
- Manufacturing plants
- Outdoor solar heat gain
- Uninsulated and/or non-air conditioned buildings

Thermoelectric Air Conditioners

Pros: Reliable, low maintenance, mount in any orientation, portable, flexible input power options
Cons: Cooling capacity limited

Thermoelectric solid-state air conditioners can be a cost-effective solution for cooling electronic/electrical equipment and devices housed in enclosures and cabinets. With relatively low energy requirements and the ability to provide both cooling and heating from the same device (when needed), these systems are becoming increasingly popular for enclosure cooling applications.

The underlying phenomenon behind thermoelectric cooling systems is known as “The Peltier Effect.” This effect is harnessed by using two elements of a semiconductor constructed from doped bismuth telluride. Upon application of a direct current (DC) power source, the device transfers heat from one side to the other. The side that heat is taken from becomes cold. With the right packaging, the cooling properties of these devices can be harnessed into modular air conditioners that can dissipate loads up to 2,500 BTU/hr, which are commonly found in enclosure cooling applications. For some applications with higher cooling requirements, multiple thermoelectric systems can be used to provide the necessary cooling.

The use of solid-state technology allows thermoelectric air conditioners to operate in any orientation – vertically, horizontally, or on an angle. In addition, thermoelectric air conditioners can be used in high temperature applications up to 140°F (60°C), and some thermoelectric coolers can be designed to operate in conditions well beyond this limit. For electronic/electrical enclosures located in desert regions or in hot industrial plant operations, the high temperature limit of thermoelectric systems can provide a significant benefit.

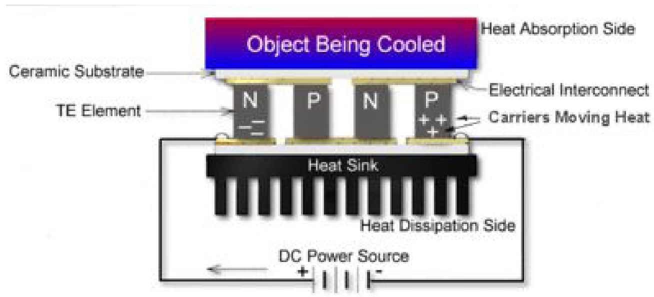

Fig. 1. Schematic Diagram of a Typical Thermoelectric Cooler. Image. March 30 2011. <http://thermal.ferrotec.com/technology/thermoelectric/thermalRef02/>.

Compressor-Based Air Conditioners

Pros: High cooling capacity

Cons: Higher maintenance, horizontal or vertical orientation only, stationary, primarily AC powered

Compressor-Based air conditioners rely on chemical refrigerants to remove heat from electronic/electrical enclosures. In addition to refrigerants, these air conditioners also use compressors, evaporators, condensers, and fans to provide cooling.

Compressor air conditioners work on the principle that a fluid heats up when compressed and cools down when expanded. First, a high-temperature, high-pressure gas is created when vaporized refrigerant is compressed. The gas is then propelled through a series of coils while a fan blows ambient air across them, removing the heat from the gas, transferring it to the surrounding environment, and returning the gaseous refrigerant to a liquid state. Next, the refrigerant passes through an expansion valve where it becomes cold as it is expanded and evaporated before passing into the evaporator coil. Here, air from inside the enclosure is blown across the evaporator coil by another fan, transferring the heat from the electronic/electrical components to the refrigerant. Lastly, the vaporized refrigerant returns to the compressor where the process is repeated. Air conditioners are designed to be mounted on the top or sidewall of an enclosure, but the units themselves must remain upright to ensure the oil does not drain from the compressor.

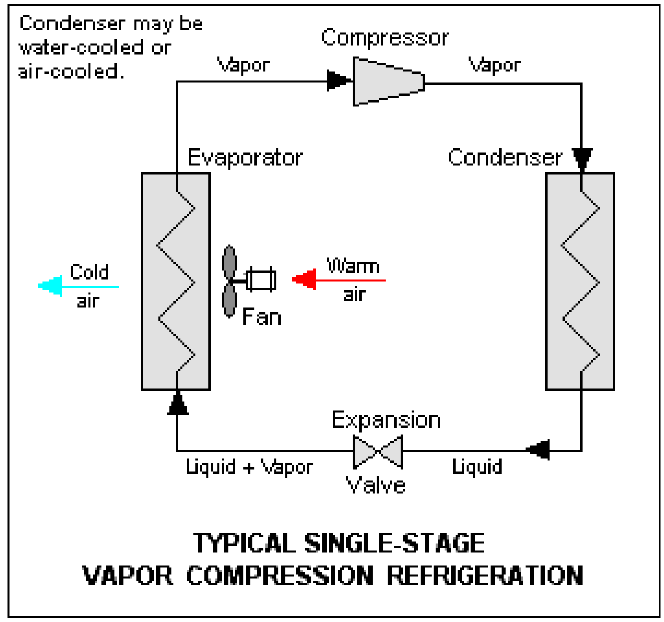

Fig. 2. Beychock, Milton. Typical Single-Stage Vapor Compression Refrigeration. Drawing. April 2006. March 30 2011. <http://www.kosmix.com/topic/refrigeration_cycle/Images>.

Vortex Coolers

Pros: Lower maintenance, small footprint, inexpensive

Cons: Require compressed air, stationary, noisy, need to change filters

Vortex coolers can be a low cost way to cool and purge electronic/electrical enclosures, especially in situations where conventional cooling by enclosure air conditioners is not possible. Applications may include small to medium size equipment enclosures and any other areas where the size of cooling devices is restricted.

Vortex coolers use compressed air to provide a cooling air flow. This means they are limited to applications where there is a ready source of clean, compressed air such as in industrial plants.

The primary component in a vortex cooler is a vortex tube, also known as the Ranque-Hilsch vortex tube. This mechanical device creates a swirling effect from the compressed air input and separates it into hot and cold air streams. A vortex cooler is unique in that it has no moving parts. The vortex tube's cylindrical generator causes the input compressed air to rotate, reaching speeds up to 1,000,000 rpm as it is forced down the inner walls of the hot longer end of the vortex tube. At the end of the hot tube, a small portion of this air exits through a needle valve as hot air exhaust. The remaining air is forced back through the center of the incoming air stream at a slower speed. The heat in the slower moving air is transferred to the faster moving incoming air. This cooled air flows through the center of the generator and exits through the cold air exhaust port. As air is pushed into the enclosure, the cooler provides its own built-in exhaust so there is no need to vent the enclosure. This effect provides a positive purge on the cabinet, which also helps to keep dirt, dust and debris out of the enclosure.

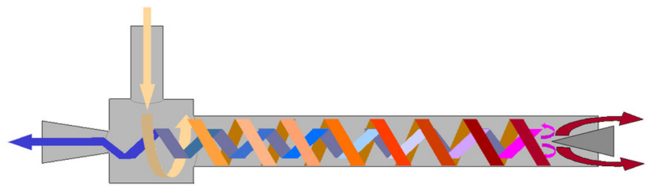

Fig. 3. Tube de Ranque-Hilsch. Image. March 30 2011. < http://sites.google.com/site/simeonlapinbleu/800px-Tube_de_Ranque-Hilsch.png>.

Air-to-Air Heat Exchangers

Pros: Low maintenance, inexpensive
Cons: Cannot cool below ambient

Efficient, cost-effective cooling can be realized through heat pipe assembly systems. These air-to-air heat exchangers remove waste heat from sealed electrical panels and enclosures to protect sensitive electronic components without exposing them to harsh, dirty environments outside the cabinet.

Heat pipes in air-to-air heat exchangers work to cool enclosures by using evaporative cooling to transport thermal energy from one place to another via the evaporation and condensation of a coolant. Heat pipes transfer heat through a "phase change" of the coolant, similar to a compressor-based air conditioner, except that they have no moving parts.

Heat pipes are typically constructed of a metal container (aluminum, copper, etc.) that holds a liquid (water, acetone, etc.) under pressure. The inner surface of the tube is lined with a porous material that acts as a wick. When heat is applied to the outer area of the tube, the liquid inside the tube boils and vaporizes into a gas that moves through the tube seeking a cooler location where it condenses. Using capillary action, the wick transports the condensed liquid back to the evaporation area. In most applications, a fan is used to move the air over the tubing and to circulate air within the enclosure.

Air-to-air heat exchangers can be used in applications where cooling the electronics to slightly above the outside ambient air temperature is sufficient. Air-to-air heat exchangers will not cool below ambient without the addition of a water supply as in an air-to-water heat exchanger. Another limitation of heat pipes is that they must be tuned to particular cooling conditions. The choice of pipe material, size and coolant all have an effect on the optimal temperatures in which heat pipes work.

The operating temperature limits for an air-to-air heat exchanger are only limited by the rating of the fan, which can typically range from -40°F to +160°F. They are also very reliable with the rated life (MTBF) of a typical heat pipe assembly in excess of 300,000 hours.

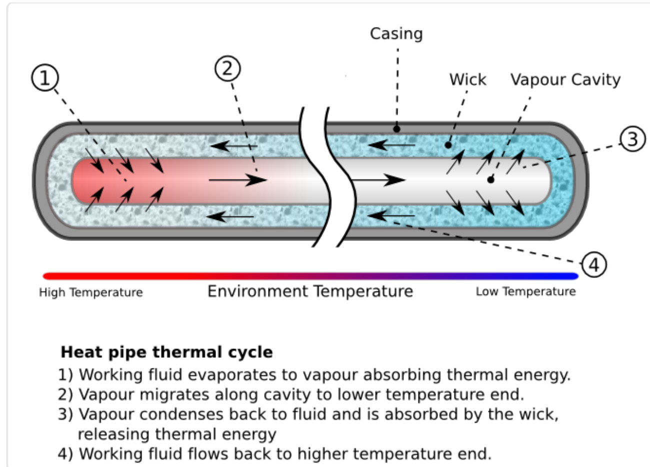

Fig 4. Heat Pipe Mechanism. Image. March 30 2011. < http://www.techreaction.net/wp-content/uploads/2010/05/Heat_Pipe_Mechanism.png>.

Comparison Chart of Enclosure Cooling Options

	THERMOELECTRIC AIR CONDITIONERS	COMPRESSOR-BASED AIR CONDITIONERS	VORTEX COOLERS	AIR-TO-AIR HEAT EXCHANGERS
DESIGN	Solid-State	Electro-Mechanical	Pneumatic	Liquid Vapor Cycle
RELIABILITY	Heat Pump >150,000 Hours MTBF	Compressor <100,000 Hours MTBF, Fan Limited	Relies on Plant Air Compressor, <150,000 Hours MTBF	>300,000 Hours MTBF, Fan Limited
MAINTENANCE	Virtually None – No Moving Parts (other than fans)	Requires Cleaning and Changing of Filters and Recharging of Refrigerant	Requires Filters/ Separators to be Changed/Drained on a Regular Basis	Virtually None – No Moving Parts (other than fans)
SIZE AND WEIGHT	Moderate Size and Weight	Moderate to Heavy Size and Weight	Small Size and Lightweight	Moderate Size and Weight
ENVIRONMENTALLY FRIENDLY	Yes	No - Uses CFCs, HCFC or Other Chemicals and Oil	No - High Energy Required	Yes
ABILITY TO COOL BELOW AMBIENT	Yes	Yes	Yes	No
TEMPERATURE CONTROL & STABILITY	Precise Bipolar Control < +/- 0.5 °C	Inefficient Resistive Control > +/- 1.0 °C	Used to Limit Temperature Rise	Used to Limit Temperature Rise
HEATING OPTIONS	Yes	Yes	No	No
ORIENTATION	Can be Used in Any Orientation	Must Remain in Fixed Orientation – Horizontal or Vertical	Can be Used in Any Orientation	Horizontal or Vertical
PORTABILITY	Standard Units Operate in Motion	Special Units Required	Requires a Portable Air Compressor of Suitable Capacity	Heat Exchangers that Use Heat Pipes Lose Cooling Ability if Not Vertical
POWER	Wide Range of AC and DC Voltages	Primarily AC Powered	Based on Plant Air Compressor	Wide Range of AC and DC Voltages
NOISE &VIBRATION	Light Noise and Vibration from Fans	Some Noise and Vibration from Compressor and Fans	Noisy Air Compressor	Light Noise and Vibration from Fans
INITIAL COST	Moderate	Moderate	Low - If an Appropriately Sized Compressor is Already Available	Low
OPERATING & MAINTENANCE COST	Low	Moderate	Very High	Very Low

The Advantages of Thermoelectric Air Conditioners

The utilization of a thermoelectric cooling system to cool electronic/electrical enclosures provides a number of significant advantages for certain applications when compared to other cooling methods such as compressor based air conditioners, vortex coolers, and air-to-air heat exchangers (heat pipes). These include:

Reliability: Thermoelectric air conditioners exhibit very high reliability due to their solid-state construction. Although reliability is somewhat application dependent, the life (MTBF) of a thermoelectric module in a typical thermoelectric cooling system is greater than 150,000 hours. In comparison, the life (MTBF) of a compressor in typical refrigerant based system is less than 100,000 hours. Because of their reliability, thermoelectric cooling systems often are used in remote locations, where they provide trouble-free service with minimal monitoring.

Maintenance: A thermoelectric cooling system has few moving parts and no filters or oil so it is virtually maintenance free, with the only moving parts being the fans used to circulate the air across the heat sinks. Compressor based systems require periodic changing of filters and charging of the refrigerant. Vortex coolers require filters/separators to remove particulate, oil and moisture from the air supply, which need to be changed or drained on a regular basis.

Size & Weight: Thermoelectric air conditioners offer a cooling system of moderate size and weight that is comparable to compressor-based air conditioners and air-to-air heat exchangers. Vortex coolers are considerably smaller, but must rely on a much larger plant air system to operate.

Environmentally Friendly: Unlike compressor-based air conditioners, thermoelectric air conditioners do not need chemical refrigerants (CFCs, HCFCs or oils) that are harmful to the environment.

Ability to Cool Below Ambient: Similar to compressor-based air conditioners and vortex coolers, thermoelectric air conditioners have the ability to cool below the ambient temperature outside the enclosure. In contrast, heat pipes are not able to cool below ambient. Additionally, the effectiveness of a heat pipe in an air-to-air heat exchanger relies on very specific environmental temperatures. A very high ambient temperature will affect the performance of a standard heat pipe, which is not a factor with thermoelectric cooling systems.

Temperature Control & Stability: Thermoelectric air conditioners also have the advantage of a readily available controller that provides more precise temperature management than a standard compressor-based air conditioner that requires down time between operating cycles. Thermoelectric air conditioners can maintain a target temperature to within ±0.5°C, while conventional refrigeration target temperatures can vary over several degrees.

Heating Options: Extreme cold can be as damaging to electronic components as extreme heat. For outdoor enclosures in regions that experience extreme variance in temperatures throughout the year, systems that can both heat and cool provide a way to protect sensitive equipment year-round. In some thermoelectric systems, the switch from cooling to heating is accomplished by reversing the polarity through the device. However, it should be noted that this effect can shock thermoelectric modules and reduce their useful life. Other thermoelectric cooling systems use embedded cartridge heaters in the base of the cold-side heat sinks. These heaters ensure that the system remains above a minimum temperature in winter without compromising the reliability and durability of the thermoelectric modules.

Orientation: The self-contained, solid-state construction of thermoelectric air conditioners greatly enhances their flexibility. There is near limitless mounting flexibility since thermoelectric air conditioners can work in virtually any orientation, including vertically, horizontally or at an angle, without concern for liquid (such as refrigerant, water, or oil) circulation or interference from external chiller connections or condensate hoses – all in direct contrast to the limitations of other cooling devices.

Portability: Thermoelectric air conditioners are ideal for portable cooling applications such as mounting in transit cases. In addition, standard units can operate while in motion and even in zero gravity environments.

Power: Similar to air-to-air heat exchangers, thermoelectric air conditioners can operate on a wide range of voltages and with either DC or AC power. Compressor-based air conditioners primarily rely on AC power only, while vortex coolers are dependent on the power supplied to the plant air system.

Noise & Vibration: Thermoelectric coolers operate with fewer moving parts, producing far less vibration than other cooling methods.

Initial Cost: Within their cooling range of up to around 2,500 BTU, the cost of thermoelectric cooling systems is comparable to that of compressor-based systems and slightly higher than vortex coolers and air-to-air heat exchangers.

Operating & Maintenance Cost: While the initial cost of a thermoelectric system is comparable to compressor-based systems, the long term reliability of thermoelectric coolers drives down the total cost of ownership over time. For example, based on MTBF data, a typical thermoelectric system will outlast a compressor-based air conditioner by 5 years.

Conclusions

While no one cooling method is ideal in all respects and the use of a thermoelectric cooling system will not be suitable for every application, thermoelectric air conditioners will often provide substantial benefits over alternative technologies.

The use of thermoelectric air conditioners often provides solutions to many complex cooling problems where a low to moderate amount of heat must be handled in a harsh environment. Using solid-state technology to accomplish temperature change, thermoelectric coolers eliminate the need for refrigerants and operate with fewer moving parts. They can cool enclosures to temperatures below ambient conditions while producing little noise and vibration. Featuring reliability and a long life span coupled with flexible input power requirements and mounting arrangements, thermoelectric air conditioners offer significant advantages over conventional cooling methods. In addition, they are ideal solutions for applications where the cooling system must be portable or subjected to motion.

EIC Solutions, Inc. specializes in the design and manufacture of thermoelectric cooling systems, air conditioned electronic enclosures and transit cases for a wide range of applications. Our products are used in a variety of enclosure cooling applications involving the protection of electronic equipment in both indoor and outdoor environments. Dedicated to protecting customer's investments in computers and sensitive electronics, EIC provides innovative solutions and superior service.

EIC Solutions, Inc.
1825 Stout Drive
Warminster, PA 18974 USA
Toll Free: 1-800-497-4524 • Fax: 1-800-726-7592
Phone: 215-443-5190 • Fax: 215-443-9564

www.eicsolutions.com