Rittal White Paper 304: Thermoelectric Cooling for Industrial Enclosures

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Executive Summary

The utilization of thermoelectric technology to cool industrial enclosures can provide a number of significant advantages for certain applications when compared to “conventional” cooling methods like vapor-compression refrigeration and water-cooled systems such as air conditioners and air-to-water heat exchangers. Using an electrical current passed through semiconductors to facilitate temperature change, thermoelectric coolers eliminate the need for refrigerants and operate with fewer moving parts—cooling enclosures to temperatures below or near ambient conditions while producing far less noise and vibration than conventional cooling methods.

This paper discusses how thermoelectric coolers work, improvements that have been made in their efficiency and the advantages of thermoelectric cooling for industrial enclosures.

The Concept of Thermoelectric Cooling

A French physicist named Jean Charles Peltier laid the groundwork for modern thermoelectric cooling in the 19th century as he experimented with electricity. Passing electric currents through two dissimilar metals (wires made from copper and bismuth), Peltier noticed that a change in temperature occurred at the junctions between them. One junction point of the wires got hot while the other got cold. This phenomenon of the heat transfer of an electrical current at the junction of two dissimilar metals, known as the Peltier Effect, is the basis for thermoelectric cooling.

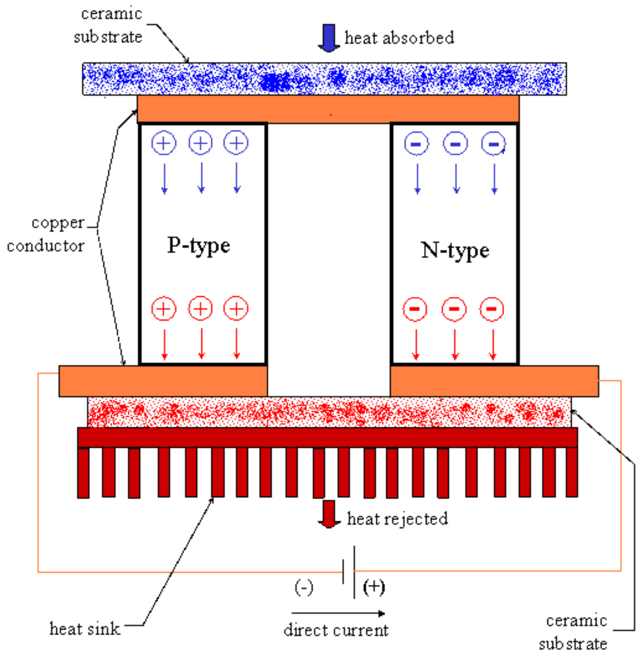
How It Works: Thermoelectric vs. Conventional Cooling

Conventional cooling systems like air conditioners and air-to-water heat exchangers rely on chemical refrigerants or water to cool, or remove heat from, enclosures. In addition to refrigerants, air conditioners use compressors, evaporators, condensers and fans to provide cooling. An air conditioner works by compressing (with the compressor) the vaporized refrigerant—making it a high pressure, high temperature gas. The refrigerant then moves to the condenser where a fan blows ambient air across the condenser coil, removing the heat from the refrigerant, transferring it to the surrounding environment and returning the refrigerant to a liquid state. At this point, the refrigerant passes through an expansion valve where, like the name implies, it is expanded and evaporated before passing into the evaporator coil. Here, air from inside the enclosure is blown across the coil by another fan, transferring the heat from installed components to the refrigerant. Then, the vaporized refrigerant returns to the compressor where the process is repeated. Air conditioners can either be mounted on the roof or sidewall of an enclosure, but the units themselves must remain upright to ensure proper functionality.

Air-to-water heat exchangers operate by removing the heat from inside an enclosure using cooled water that is supplied by a facility's chiller and channeled through an internal coil. Within the heat exchanger, a fan blows the heated enclosure air across the coil, transferring the heat to the water. The water absorbs the heat energy and carries it away to the chiller (basically a remote air conditioner used to cool water) where it is cooled again before the process repeats. Air-to-water heat exchangers can also be either roof or wall-mounted, but must have a connection to the facility's chilled water system.

Other than a fan, thermoelectric coolers do not need any of the things required by air conditioners and air-to-water heat exchangers to effectively cool industrial enclosures. The aforementioned Peltier Effect allows thermoelectric coolers to provide cooling without refrigerants, water or components such as compressors and coils. A typical thermoelectric cooler contains a "Peltier element," a fan, and a power supply.

Peltier elements are constructed of two bonded semiconductors, often consisting of bismuth doped with telluride and copper. The semiconductors used in Peltier elements are referred to as "N-type" and "P-type." An N-type semiconductor has an overabundance of electrons and the P-type semiconductor lacks a full set of electrons. This electron deficiency creates "holes" in the P-type semiconductor's molecular structure that are ready to accept the extra electrons moving over from the N-type semiconductor. These electrons move when the electric current from the power supply is passed through the semiconductor, carrying heat with them and leaving behind a cool surface. The fan then blows across this cooled surface and circulates cooled air throughout the enclosure.



Example of a Thermoelectric Cooler with N and P-type Semiconductors

The Efficiency of Thermoelectric Coolers

Although the Peltier effect was discovered nearly two centuries ago, efficiently using it for practical cooling has remained a challenge. Despite this, the continued interest in the existing and potential advantages of thermoelectric cooling has spawned technological advances in the latest generation of thermoelectric coolers that drastically improve both effectiveness and efficiency.

When we speak about efficiency, we typically refer to the amount of "work" produced by a machine in relation to the amount of power that is put into it. Efficiency in cooling is described using the term "coefficient of performance." The Coefficient of Performance (COP) is the ratio of heat energy that is removed to the amount of electrical power supplied. For the past several years, most of the thermoelectric coolers available on the market operated with a COP as low as 0.3. This means that for every 1 Watt of electrical energy invested, only 0.3 Watts of heat energy were removed, which is not very efficient at all. Thanks to design improvements, the COP of today's thermoelectric coolers can be as high as 1.2.

To further illustrate the efficiency improvements of current generation thermoelectric coolers, it's possible to use the COP figures from above to compare cooling capacities. Previous thermoelectric coolers operating with a COP of 0.3 and 100 Watts of supplied electric power had a cooling capacity of 30 Watts. With the COP of 1.2 found in some newer units and that same 100 Watts of power, the cooling capacity rises to 120 Watts. This is an increase of 400% and a dramatic example of how far thermoelectric cooling has come in a relatively short time.

A key design improvement that has helped to increase the efficiency of thermoelectric coolers is active control, and one of the best control methodologies for efficient energy usage (and improved lifespan) is Pulse Width Modulation (PWM). With PWM, power to the thermoelectric cooler is quickly switched on and off at a constant frequency. This creates a square wave pulse of power over a constant time period with a width that can be varied to create an average voltage. Since this occurs very rapidly, the Peltier (thermoelectric) elements do not have enough time to change temperature in response to the changing pulse. As a result, the elements will take on the cooling capacity of the V average.

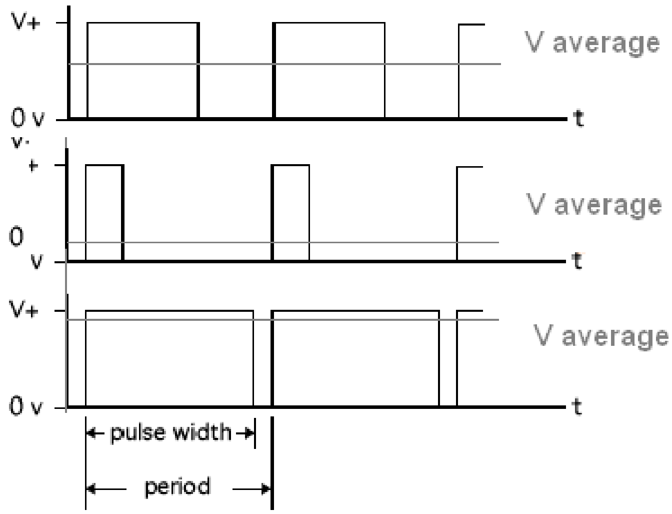


Illustration of Pulse Width Modulation (PWM)

Switching the voltage on and off in this manner will allow the thermoelectric cooler to deliver greater cooling capacity and efficiency—doing more work while consuming less power. Another benefit of this design enhancement is that since the Peltier element inside the thermoelectric cooler sees a constant V average, it doesn't repeatedly stop and start—leading to longer life and durability. Additionally, a 60% increase in energy efficiency can be realized by using, variable speed, "soft-starting" fans, like the ones found in Rittal's thermoelectric coolers.

Advantages of Thermoelectric Coolers Compared to Conventional Cooling

Fewer Moving Parts

As previously discussed, since thermoelectric coolers work electronically—using the Peltier elements to generate cooling—the only moving parts are the fans used to circulate cool air throughout the enclosure. This provides a number of benefits when compared to enclosure air conditioners. With fewer active components, there is a lower risk of component failure and less required maintenance. Along with solid-state construction, this leads to higher reliability, lower maintenance costs and consistent cooling.

Fewer moving parts also produce less vibration, acoustic and electrical/EMI noise. Many applications that might be impractical for air conditioners or air-to-water heat exchangers because of noise or vibration concerns can be cooled effectively with thermoelectric coolers. For example, thermoelectric coolers are ideal for applications that involve high-precision processes, sensitive or intricate electronics, or integral sensors that are susceptible to vibration and noise interference.

Flexibility

Because of their unique design, thermoelectric coolers can many times offer greater flexibility for meeting the challenges of certain small-to-medium and HMI enclosure applications than conventional cooling solutions. A smaller physical size (both in linear dimension and weight), thanks in part to limited internal components, creates an immediate advantage when compared to most air conditioners and air-to-water heat exchangers before the unit is ever turned on. This relatively small size—as small as 16”H x 5”W x 6”D, weighing as little as 5 lbs—allows thermoelectric coolers to be used in ways that other cooling devices cannot. Thermoelectric coolers can cool pendant arm-mounted and otherwise suspended HMI enclosures without dramatically affecting the weight load placed on the arm or pendant system. They can also be used in multi-unit configurations to deliver the required cooling capacity while providing previously mentioned advantages such as low noise and vibration.

The self-contained, solid-state construction of thermoelectric coolers greatly enhances their flexibility as well. Thermoelectric coolers require nothing but a power source to operate effectively. They do not need chemical refrigerants (like air conditioners) that could potentially be harmful to the environment, nor do they require a chiller system connection to supply cool water like air-to-water heat exchangers. This absence of refrigerant or supplied water allows for near limitless mounting flexibility since thermoelectric cooler units can work in virtually any orientation including 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. Some thermoelectric coolers, like those made by Rittal, take the flexibility of thermoelectric cooling even further by giving users the choice of “external” or “internal” mounting in which the body of the unit lies either inside or outside the enclosure as shown in the pictures below. This can prove helpful in overcoming space-related issues and to ensure the freedom of movement for support and pendant arms.

Single thermoelectric cooler mounted externally, internally.

Multiple thermoelectric coolers mounted externally, internally.

The final area of flexibility to be discussed in this paper is that of power. Thermoelectric coolers can operate with a wide range of voltages, and with either DC or AC power. For example, a unit could be rated for 24VDC or 110 to 230VAC. While a supply of DC power is necessary to generate thermoelectric cooling via the Peltier Effect, some industrial thermoelectric cooling units made by leading manufacturers, such as Rittal, feature built-in power supplies to facilitate the use of AC power and provide maximum flexibility to users.

Conclusions

There are several different types of cooling devices available to remove the heat from industrial enclosures, but as the technology advances, thermoelectric cooling is emerging as a truly viable method that can be advantageous in the handling of certain small-to-medium and HMI enclosure applications. As the efficiency and effectiveness of thermoelectric cooling steadily increases, the benefits that it provides including self-contained, solid-state construction that eliminates the need for refrigerants or connections to chilled water supplies, superior flexibility and reduced maintenance costs through higher reliability will increase as well. In an industry that is ceaselessly searching for better ways to cool enclosures, thermoelectric cooling is one option that users need to consider as they evaluate possible solutions for their application requirements.

About the Authors

Judith Koetzsch has been with Rittal since 2001—first working for Rittal GmbH & Co. Kg. in Germany as a part of the international climate control product management team, and then joining Rittal Corporation in the U.S. as Product Manager for Climate Control Products in 2006.

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