Thermoelectrics vs. Compressors in Climate-Controlled Electronic Enclosures

By Robert Smythe
Program Manager – Advanced Thermal Technology
Laird Technologies, Inc.

August 2009

Application Note

Air conditioners utilizing Thermoelectric Assemblies (TEAs) are often considered as an alternative to conventional vapor-compression systems for enclosure cooling. Because a TEA core is compact, robust, and completely solid-state, the inherent reliability of such a system is attractive to engineers and end-users alike. However, there is an inherent reluctance to choose the thermoelectric system due to preconceptions about energy efficiency and unfamiliarity with the technology.

This application note compares and contrasts the two cooling technologies in order to provide the best solution for a climate-controlled enclosure application. Comparisons of efficiency, reliability, control accuracy, as well as installation and maintenance, demonstrate that a thermoelectric solution has significant advantages over conventional compressors.

global solutions : local support.

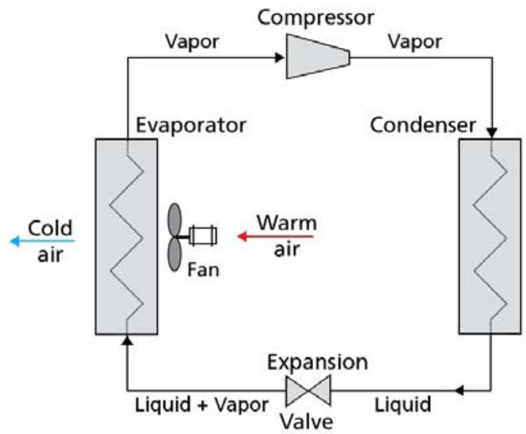
Corporate Contact:
1.636.898.6000

www.lairdtech.com

Thermoelectrics vs. Compressors in Climate-Controlled Electronic Enclosures

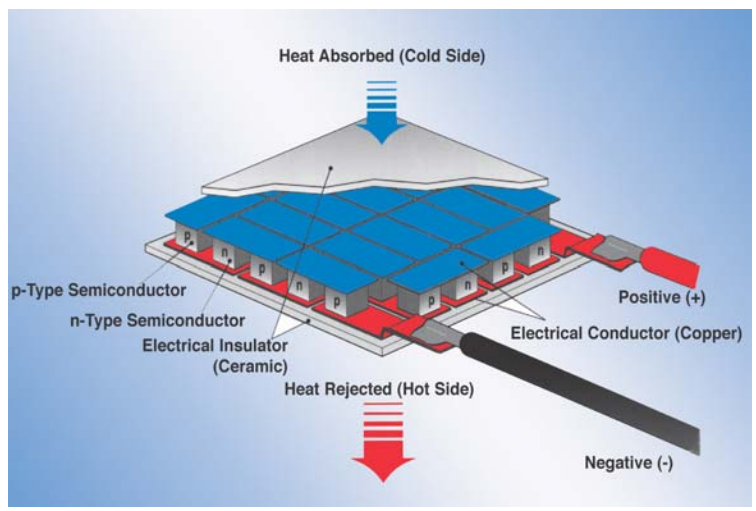
Technology Comparison – How it Works
The best way to illustrate the differences in the two refrigeration methods is to describe the systems.

A conventional cooling system contains three fundamental parts: the evaporator, compressor, and condenser. The evaporator (cold section) is the part where the pressurized refrigerant passes through the expansion valve and 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 into a liquid. The condenser expels both the heat absorbed at the evaporator and the heat produced during compression into the environment (ambient).



TYPICAL SINGLE-STAGE
VAPOR COMPRESSION REFRIGERATION

A thermoelectric system 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 to a lower energy level. Reversing the direction of current flow reverses the direction of heat pumping. This allows the thermoelectric to provide both cooling and heating.



Thermoelectric Coolers are heat pumps – solid-state devices 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.

Power Usage

Thermoelectrics are operated with DC power. A TEA engine can be configured to run on a variety of DC voltages by simply selecting a series or parallel configuration of the internal modules. The most common voltages are 12, 24, and 48 VDC. Since this requires a DC power source, a power supply is often used to convert the AC to DC.

Operating with DC power offers capabilities not possible with mechanical systems. TEAs will pump heat at a rate proportional to the power applied. Therefore, when cooling needs are low, the TEA will require less power to maintain the temperature. When additional cooling is required, the TEA will use more power. This proportional control allows efficient use of power, while reducing the temperature and power cycling inherent in on-off type control. Furthermore, because TEAs will heat or cool dependent upon the direction of current flow, they eliminate thermally overshooting the target temperature. System safety is also enhanced.

Today, power supplies accept wider input voltage and frequency ranges. This enables the cooling system to run efficiently in geographic areas that are limited in reliable power output (i.e., no “brown-out” problems). A brown-out (or low voltage condition) can leave a compressor inoperable and potentially cause damage to the unit. DC capability also provides a more universal solution.

In heating mode, a thermoelectric system requires less power than a resistive heater because all the supplied power plus the heat being pumped is provided to the enclosure. This is accomplished by simply reversing the direction of current. By enabling heating or cooling with the same unit, the system is simplified and prevents rapid cycling from thermal overshooting of competing components. The net result is control accuracy, energy efficiency, and the highest reliability.

Conventional compressor-based systems are typically AC powered. Today’s compressors are more efficient than a decade ago. In steady-state operation at maximum designed heat loads, they can be the most energy efficient choice. Under this condition, a well-designed compressor system will use 30 – 35% less power than a TEA system. However, many enclosure applications – especially those in remote or outdoor environments – have different operating conditions throughout the day, as well as the seasons throughout the year.

Compressor systems are either all “ON” or all “OFF”. There is no proportionality, so full power must be applied at all times. Furthermore, the starting current for a compressor system is often three times the operating current. Although this high current draw is brief, the circuit must be sized to handle it. Combine the non-proportionality, repeated ON-OFF control with the high power draw at start-up, and those efficiency gains at steady-state evaporate.

Various line power levels in geographic regions require specific AC compressors and fans suitable for those regions. This affects manufacturing economy, stocking flexibility, and introduces the possibility of brown-outs.

A compressor system usually incorporates a separate heating component because compressors cannot be powered in reverse like a TEA. In addition to added cost and space, the heater will require more power than a TEA system. The potential for thermal overshoot and rapid cycling of the competing systems when ambient temperatures fluctuate can affect reliability and system stabilization.

Reliability

Reliability and performance of the electronics within are the reasons for controlling the temperature of an enclosure. It makes sense that the most reliable technology be applied to climate control.

The thermoelectric engine is completely solid-state. There is no compressor, motor, liquid or gas involved. The only moving parts are the fans for circulating air through the heat sinks. While these fans are rated for up to 100,000 hours, a tachometer sensor is available to monitor fan speed for additional system safety.

An all solid-state TEA engine has inherent reliability. TEAs in steady-state operation or with proportional control, can achieve >100,000 hours of operation. With an integrated PID (Proportional Integral Derivative) controller, a TEA does not suffer the stop-start/on-off power surges or temperature variation, thereby maintaining the high reliability of steady-state conditions.

The compressor-based system relies on moving parts and fluids for operation. Both a compressor and motor are required to move the working fluid through the system, while fans are used to circulate the air through the evaporator. A compressor system's components will wear out over time due to friction, thermal expansion, and on-off control. Friction wear is constant in this system and exacerbated by temperature changes in the environment or controlled side. Additionally, leakage of the refrigerant can occur through seams that fatigue from continuous vibration. This loss of refrigerant impacts performance and operation.

Handling and Installation

Easy handling and installation should be considered when choosing a climate control system. Avoiding damage or other issues ensures timely and efficient deployment and performance.

A thermoelectric system has no working fluids and can be shipped, handled, and mounted in any orientation without affecting its performance or reliability. This not only simplifies the method of shipping and handling, but offers significant options in the installation. A single TEA design can be top-, wall- or door-mounted either vertically or horizontally. One design can satisfy multiple installation choices. Gravity does not affect its application because it is solid-state, though condensation removal or routing methods will be gravity-dependent and must be considered in the design and mounting method.

A TEA system is typically smaller, requiring less surface area and overall volume, than a compressor-based system when capacities are less than 500W (1700 BTU). Typical size and weight savings are 25 to 50%.

Because of working fluid, a compressor-based system must be kept in its design orientation during all shipping, handling, and installation or damage to the system may occur. Compressors tend to be heavier and larger than comparable TEA systems, requiring larger and stronger mounting surfaces. A compressor-based system does not allow mounting options and requires a special unit for different installations. This inhibits shipping flexibility and inventory maintenance.

Noise and Vibration

Noise reduction is important in many applications, both for personnel and security purposes. Vibration has a cumulative effect of loosening hardware connection of the cooling unit, as well as the electronics within the enclosure.

The thermoelectric engine operates silently without vibration. The only noise is from attached DC fans that are sound/vibration damped with rubberized fasteners. The TEA does not contribute to loose hardware or other vibration issues.

A compressor-based system with fans is mechanical, cyclical, and vibrates constantly when powered, contributing to overall noise levels. This vibration can be detrimental to the enclosure's components.

Temperature Control and Range

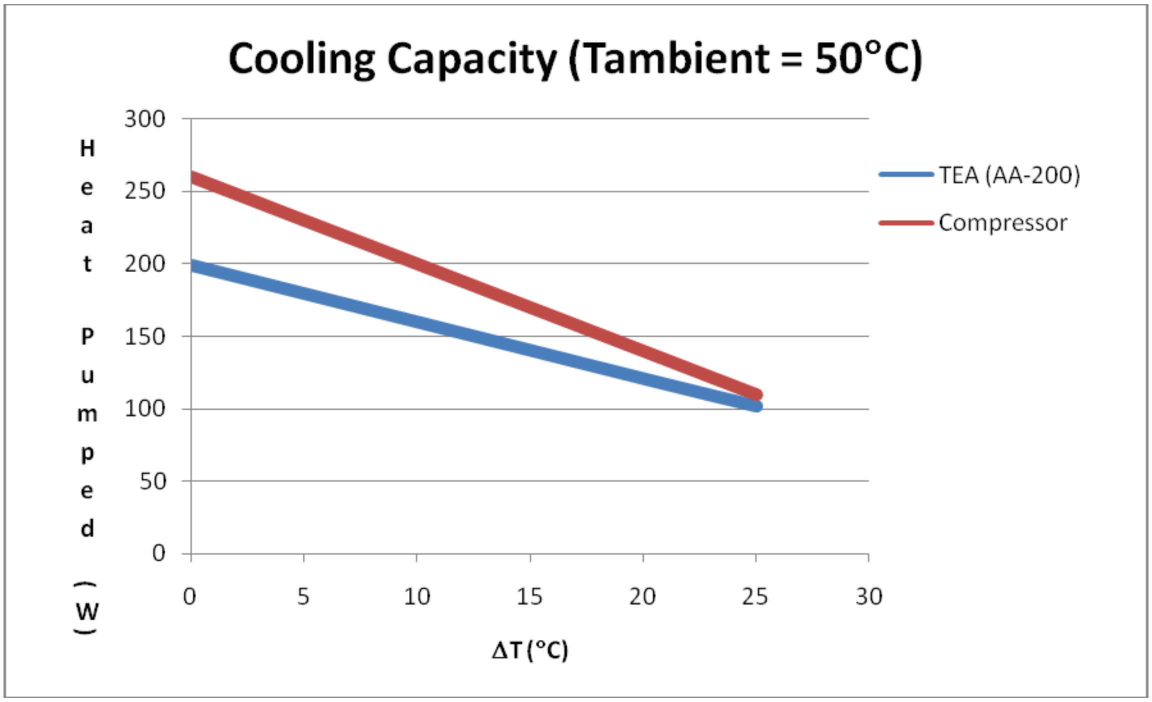
The temperature control specification for an electronics enclosure is typically +/- 2°C or greater. This allows hysteresis to be designed in, reducing cycling between cooling and heating or on/off when the enclosure is at its set point temperature. This range is suitable for thermostatic control, but a tighter tolerance requires a proportional type of control.

The thermoelectric-based TEA controls the temperature of an enclosure to within 1°C of the set point. This is accomplished with the integrated bi-polar PID control, adjusting the net power to the TEA allowing fine tuning, as well as rapid response to component or environmentally-induced heat load fluctuations. The operating range for the TEA is -20 to +65°C for most systems and can be extended to cooler or higher temperatures with minor modifications.

Compressor-based systems are typically designed for operation between 20°C and 55°C. This range is useful for most enclosure applications and operating environments. If heating is required, a separate heater and switching circuit must be used. If higher or lower temperatures are required, a special compressor for that range (working fluid, hardware) must be designed.

Thermoelectric Assembly vs. Compressor-based Air Conditioners

In the following performance graph for the thermoelectric (TEA) and compressor units from manufacturers' data, the initial interpretation is that the compressor appears to have significantly more cooling power than the TEA (260W v. 199W) under a ΔT= 0 @ 50°C ambient condition. However, in actual application conditions (20°C ΔT), the two units' capacities are well matched (140W v 121W).



Typical Enclosure Application for Telecommunications UPS Battery Back-up

- For reliability and extended life, the batteries require temperature control in changing ambient conditions

Design Requirements for Cooling/Heating Conditions:

- Ambient Temperature: -33 to +50°C (annual average +35°C)
- Control Temperature: +10 to +30°C
- Heat Leak rate through cabinet walls: 5W/°C
- Active Internal Heat Load: 20W

Model Comparison

Laird Technologies Thermoelectric AA-200-48-22

Ratings:

- Useful Cooling @ L 35, L 35 (internal, external temperature, °C) = 191W
- Useful Cooling @ L 35, L 50 (internal, external temperature, °C) = 140W
- Rated Voltage: 0 to 56VDC
- Power Usage @ L 35, L 35 (internal, external temperature, °C) = 269W
- Power Usage @ L 35, L 50 (internal, external temperature, °C) = 245W
- Dimensions W x H x D (mm): 180 x 400 x 177
- Weight (kg): 7

Leading Compressor-based AC

Ratings:

- Useful Cooling @ L 35, L 35 (internal, external temperature, °C) = 300W
- Useful Cooling @ L 35, L 50 (internal, external temperature, °C) = 150W
- Rated Voltage: 115VAC, 60Hz
- Power Usage @ L 35, L 35 (internal, external temperature, °C) = 290W
- Power Usage @ L 35, L 50 (internal, external temperature, °C) = 340W
- Dimensions W x H x D (mm): 525 x 340 x 135
- Weight (kg): 17

Overview

- In this application, a bank of batteries within an enclosure requires temperature control for reliability and increased life. The ambient temperature can range from a high of +50°C to a low of -33°C (+122°F to -27.4°F). The enclosure must be kept between +30°C and +10 °C (+86°F to +50°F) to meet the specification.
- This comparison demonstrates the performance and efficiency of the best matched, commercially available thermoelectric and compressor-based models.
- The data used in this study comes from both manufacturers' data sheets and modeling software; power usage was confirmed with manufacturers' representatives.
- The rate of heat leaking into and out of the cabinet is determined by the surface area and insulation value. In this comparison, the heat leak is 5W/°C. For example, a 20°C temperature difference between the ambient and internal temperature results in a 100W heat loss/gain (20°C x 5W/°C = 100W). The cooling/heating solution must offset these losses or gains.
- Cooling Mode: Demonstrates the power usage required to maintain the enclosure temperature to specification (+30°C).
- Heating Mode: Demonstrates the power usage required to maintain the enclosure temperature to specification (+10°C). Data compensates for the 20W active load within the cabinet.

Special Notes

- To insure accuracy and fairness, this comparison takes the following items into account:
- The DC-powered TEA is shown with both 100% and 90% efficient DC power supplied. The 90% efficient data demonstrates the power usage if DC power is not organic to the enclosure and a commercial-grade AC/DC supply is required.

- The compressor draws only 3.3A, even though the specification sheet shows 4A. The manufacturer suggests that the lower current value is more accurate.
- Start-up current was not considered due to transience and short duration. The start-up current for the TEA is ~25% greater than steady-state; start-up current for the compressor is ~300% greater than steady-state.
- The compressor unit does not have a heating function and uses an auxiliary resistive heater. This was not included in the dimension or weight values.
- The TEA may require a separate DC power source if not organic to the enclosure. This was not included in the dimension or weight values.
- TEA power usage includes inside and outside fan power.
- TEA power usage is shown with both proportional and duty cycle (on/off) control.
- Compressor power usage is based on duty cycle (on/off).
- In the heat mode, fan power is not included because both types require the same air movement.

Results

The tables and graphs below demonstrate efficiencies under a range of temperatures.

Cooling Mode

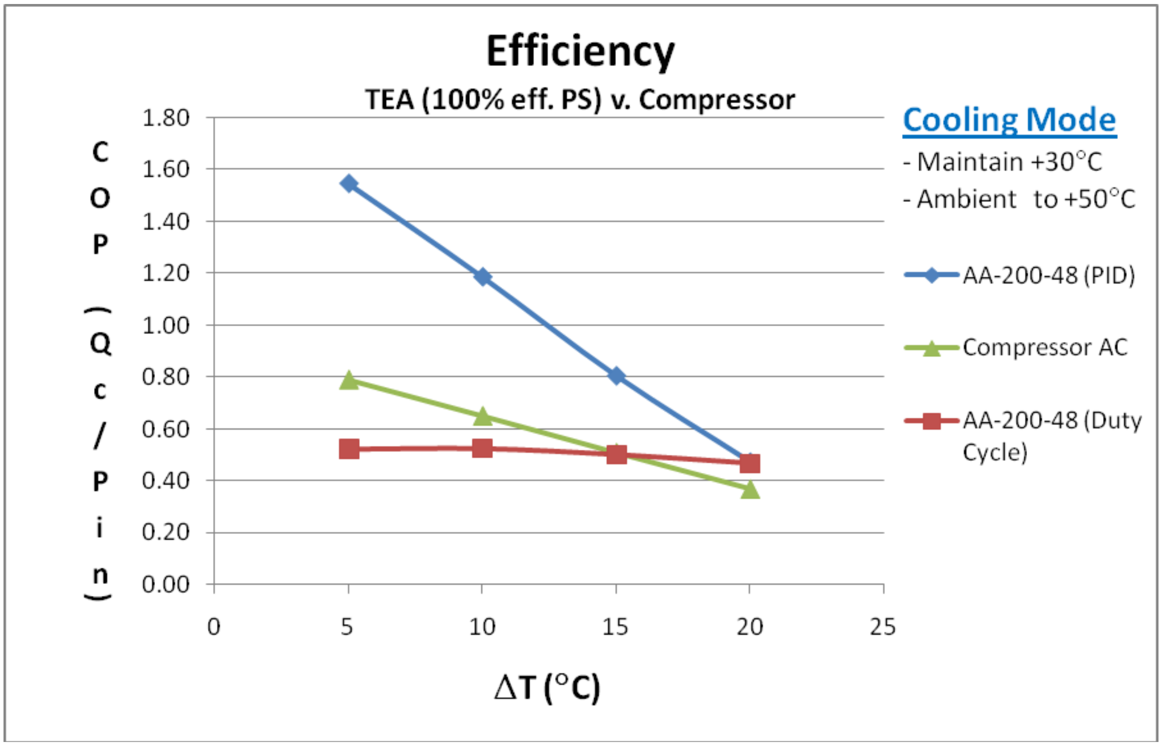
The TEA is up to two times more efficient than the compressor-based unit with proportional control in all conditions. When the TEA is cycled on/off, the compressor has advantages where the temperature difference/heat load is smaller. Overall, the

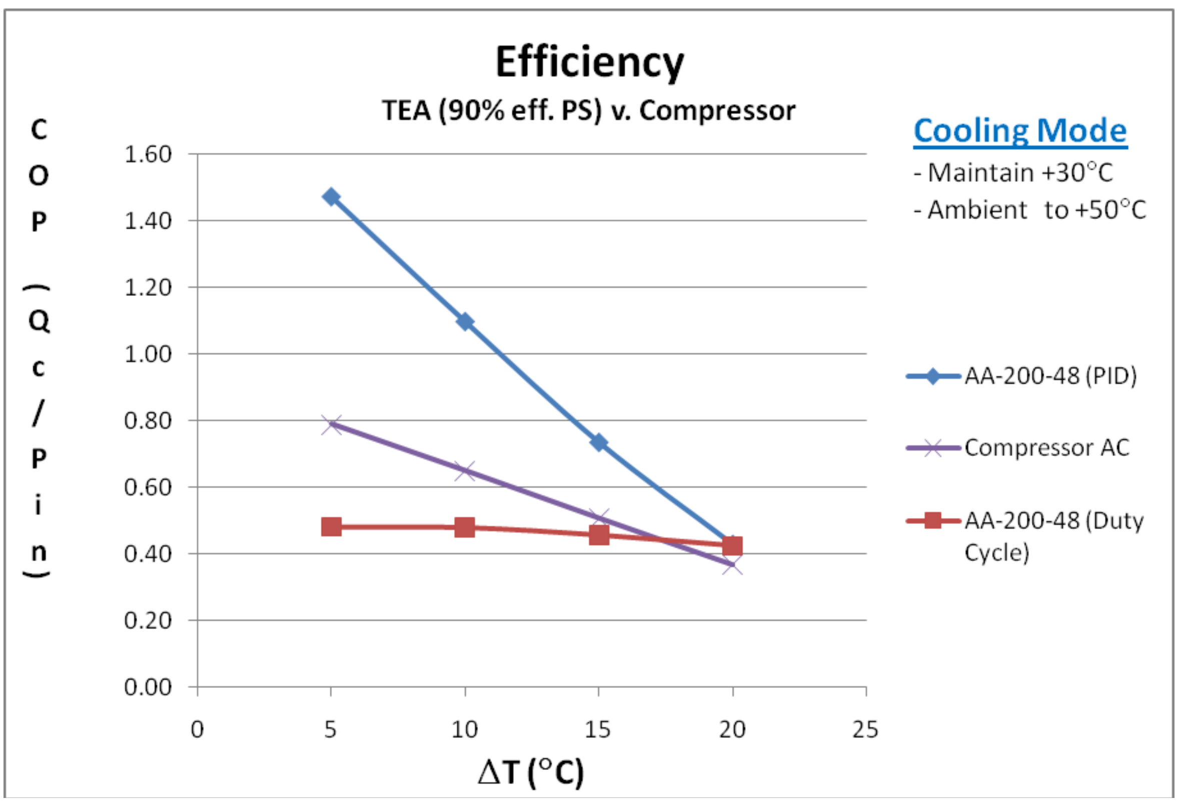
COOLING MODE
Summary Comparison

Conditions						**Power Usage (Watts)**				
Tambient (°C)	Tcontrol (°C)	**ΔT (°C)**	Passive Qc (W)	Active Qc (W)	**Total Qc (W)**	**Com-pressor AC**	**AA-200-48** (DCyc & 90% eff PS)	**AA-200-48** (DCyc & 100% eff PS)	**AA-200-48** (PID & 90% eff PS)	**AA-200-48** (PID & 100% eff PS)
50	30	**20**	100	20	**120**	**326**	283	256	280	**254**
45	30	**15**	75	20	**95**	**187**	208	189	129	**118**
40	30	**10**	50	20	**70**	**108**	146	133	64	**59**
35	30	**5**	25	20	**45**	**57**	94	86	31	**29**

Conditions						**Efficiency (Qc/Power In) %**				
Tambient (°C)	Tcontrol (°C)	**ΔT (°C)**	Passive Qc (W)	Active Qc (W)	**Total Qc (W)**	**Com-pressor AC**	**AA-200-48** (DCyc & 90% eff PS)	**AA-200-48** (DCyc & 100% eff PS)	**AA-200-48** (PID & 90% eff PS)	**AA-200-48** (PID & 100% eff PS)
50	30	**20**	100	20	**120**	**37%**	42%	47%	43%	**47%**
45	30	**15**	75	20	**95**	**51%**	46%	50%	73%	**81%**
40	30	**10**	50	20	**70**	**65%**	48%	53%	110%	**119%**
35	30	**5**	25	20	**45**	**79%**	48%	52%	147%	**155%**

thermoelectric requires less power to maintain the specified enclosure temperature.


Efficiency
TEA (100% eff. PS) v. Compressor
COP (Qc/Pin)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
5
10
15
20
25
ΔT (°C)
Cooling Mode
- Maintain +30°C
- Ambient to +50°C
AA-200-48 (PID)
Compressor AC
AA-200-48 (Duty Cycle)


Efficiency
TEA (90% eff. PS) v. Compressor
COP (Qc/Pin)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
5
10
15
20
25
ΔT (°C)
Cooling Mode
- Maintain +30°C
- Ambient to +50°C
AA-200-48 (PID)
Compressor AC
AA-200-48 (Duty Cycle)

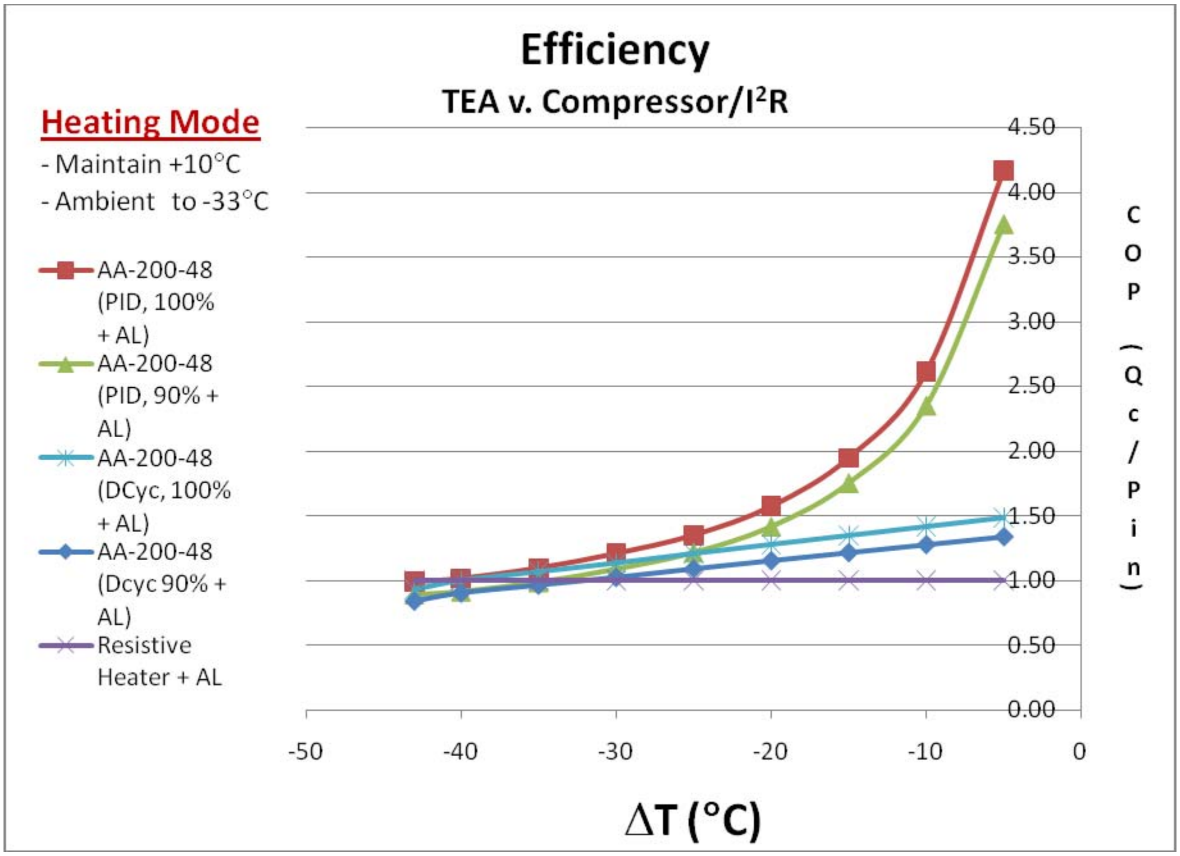
Heating Mode

The TEA is up to 20 times more efficient across condition ranges. This is because input power plus pumped heat is provided as heat. The efficiencies are most notable when the ΔT is smaller.

HEATING MODE
Summary Comparison

Conditions						Power Usage (Watts)				
Tambient (°C)	Tcontrol (°C)	**DT (°C)**	Passive Qc (W)	Active Qc (W)	**Total Qc (W)**	**Resistive Heater**	**AA-200-48** (DCyc, 90% eff PS)	**AA-200-48** (DCyc, 100% eff PS)	**AA-200-48** (PID, 90% eff PS)	**AA-200-48** (PID, 100% eff PS)
-33	10	**-43**	-215	20	**-195**	**195**	233	209	220	**198**
-30	10	**-40**	-200	20	**-180**	**180**	200	180	198	**178**
-25	10	**-35**	-175	20	**-155**	**155**	161	145	158	**142**
-20	10	**-30**	-150	20	**-130**	**130**	127	115	120	**108**
-15	10	**-25**	-125	20	**-105**	**105**	97	87	87	**78**
-10	10	**-20**	-100	20	**-80**	**80**	70	63	57	**51**
-5	10	**-15**	-75	20	**-55**	**55**	45	41	31	**28**
0	10	**-10**	-50	20	**-30**	**30**	24	21	13	**12**
5	10	**-5**	-25	20	**-5**	**5**	4	3	1	**1**

Conditions						Efficiency (Qc/Power In) %				
Tambient (°C)	Tcontrol (°C)	**DT (°C)**	Passive Qc (W)	Active Qc (W)	**Total Qc (W)**	**Resistive Heater**	**AA-200-48** (DCyc, 90% eff PS)	**AA-200-48** (DCyc, 100% eff PS)	**AA-200-48** (PID, 90% eff PS)	**AA-200-48** (PID, 100% eff PS)
-33	10	**-43**	-215	20	**-195**	**100%**	84%	93%	89%	**98%**
-30	10	**-40**	-200	20	**-180**	**100%**	90%	100%	91%	**101%**
-25	10	**-35**	-175	20	**-155**	**100%**	96%	107%	98%	**109%**
-20	10	**-30**	-150	20	**-130**	**100%**	102%	113%	108%	**120%**
-15	10	**-25**	-125	20	**-105**	**100%**	109%	121%	121%	**135%**
-10	10	**-20**	-100	20	**-80**	**100%**	115%	128%	141%	**157%**
-5	10	**-15**	-75	20	**-55**	**100%**	121%	135%	175%	**194%**
0	10	**-10**	-50	20	**-30**	**100%**	127%	141%	235%	**261%**
5	10	**-5**	-25	20	**-5**	**100%**	133%	148%	375%	**417%**



Summary Comparison

	Thermoelectric (TEA)	Compressor Based	Comments
Power Usage	Best with proportional control in cooling mode. Best in heating mode.	No proportional control; affects overall efficiency.	TEA is more efficient over wider range of temperatures.
Reliability	>100,000 hours	Unpublished	Fan is only moving part in TEA.
Power Input	DC required	AC required	DC more flexible for global use.
Reliability	Solid-state heat pumping; proportional control; fan is only moving part.	Mechanical pump, fluids, fans. On-off switching duty cycle.	Fan is only moving part in TEA.
Handling and Installation	Solid-state; can be shipped, stored, and installed in any orientation (top, side, vertical, horizontal…)	Working fluid (R134a) requires unique orientation.	Condensation control may dictate some design-for-orientation in the TEA.
Noise / Vibration	< 61 dB(A)/ none	< 61 dB(A) / mechanical	Fan is only moving part in TEA
Maintenance	Periodic compressed air. No disassembly needed	Disassembly required to access coils and chambers. Compressed air	TEA is designed for access to heat sinks/fans.
Temperature Control	<1°C	≥2°C	TEA control accuracy to <1°C, if required, using proportional control
Size	0.0127 m3 (0.45 ft3)	0.0273 m3 (0.965 ft3)	TEA is less than half the size of Compressor
Weight	7 kg (15.4 lbs)	17 kg (37.4 lbs)	TEA is less than half the weight of compressor

Conclusion

A Thermoelectric Assembly (TEA) has considerable advantages over a comparably-sized, compressor-based solution in climate-controlled electronic enclosures. It both cools and heats, offering more precise temperature control than a compressor-based unit; and it is more energy efficient throughout the temperature range of the application, by 25% to 95% in cooling and up to 400% in heating.

The TEA's solid-state construction provides advantages in reliability, installation, vibration, and maintenance. Additionally, it's smaller size and weight allows easier mounting and occupies less space than a compressor-based unit. Because it operates on DC power, a TEA can be utilized globally regardless of available AC line voltage and frequency.

Utilizing a TEA in climate-controlled electronic enclosures is the ideal solution because of its efficiency, reliability, accuracy, compact design, quietness, and easy installation.

About Laird Technologies, Inc.

Laird Technologies designs and manufactures customized, performance-critical products for wireless and other advanced electronics applications.

The company is a global market leader in the design and supply of electromagnetic interference (EMI) shielding, thermal management products, mechanical actuation systems, signal integrity components, and wireless antennae solutions, as well as radio frequency (RF) modules and systems.

Custom products are supplied to all sectors of the electronics industry including the handset, telecommunications, data transfer and information technology, automotive, aerospace, defense, consumer, medical, and industrial markets.

Laird Technologies, a unit of Laird PLC, employs over 10,000 employees in more than 39 facilities located in 13 countries.

Contact Information

For additional information, visit http://www.lairdtech.com or contact us at:

Americas: +1.888.246.9050
Europe: +46.31.420530
Asia: +86.755.2714.1166
e-mail: CLV-customerservice@lairdtech.com

Trademarks