THERMICOOL

Thermoelectric cooling using innovative multistage active control modules

State of the art – Background

The use of thermoelectric cooling 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.

Thermoelectric coolers have been successfully commercialized for high-performance, niche cooling systems that require high heat-flux dissipation to a very low temperature at a precise rate. The general design criteria for these TECs include high reliability, flexibility in packaging and integration and low weight. In cooling applications, a well-designed thermoelectric cooler forces heat to flow from the cold surface to the hot one. The purpose of a TEC is to maintain the junction temperature of a device below a safe temperature by pumping heat away from the device.

The search for environmental-friendly, cleaner, and more sustainable energy sources is an ever-growing global concern because of the escalating energy costs and the global warming phenomenon that is associated with the fossil fuel sources. Viable technologies for this purpose include devices and systems that take advantage of thermoelectricity.

The thermoelectric (TE) effect includes the transformation of heat to electric energy and vice versa, and its applications can consequently expand to two domains: (a) electricity generation from heat sources and (b) (micro-) cooling. In the first case, thermoelectric (TE) energy converters transform the heat released from sources such as power plants, factories, motor vehicles, computers or even human bodies into electric power using the Seebeck effect.

In the opposite case, solid-state thermoelectric devices can also transform electrical energy into thermal energy for cooling or heating using the Peltier effect. The exploitation of this energy-conversion phenomenon allows the design of reliable systems built with solid-state devices that enable long-life operation, do not need any moving parts, nor leave any toxic residuals, thus achieving the goal of low environmental impact.

Objectives

The aim of this work was to develop an innovative TEC for avionic application, with maturity level at TRL5, low power consumption, high efficiency and a combination of thermoelectric materials and energy harvesting techniques. The work was based on the experience gained in previous works of the research team, concerning marine (ECOMARINE) and avionic (RENERGISE) environments and it investigate advanced TE materials with ZT >>1, in multistage module configurations to cope with the harsh avionic environment and novel active control schemes to achieve high COP values.

Description of work

THERMICOOL consisted of three main technical Work Packages (WPs); WP1 was entitled "Bibliographical Review" and included the bibliographical review of thermoelectric materials and cooling solutions, as well as a survey on the available commercial systems. The main theoretical analysis of the project was included in WP2, which was entitled "Technology Selection"; in more details, extended FEM modelling and simulation analysis have been carried out for the two case studies that were provided by the Topic Manager and the final technology selection has been decided, based on the FEM analysis outcomes. Finally, in WP3 entitled "Experimental Validation" the construction of the laboratory test bench took place, as well as the conduction of extended evaluation tests.

Some of the challenges that have been faced in THERMICOOL project were the following:

- Selecting the right TE materials that balance cost against efficiency. Materials with an increased figure of merit (ZT>>1) are needed to get more cooling power. However, building them can be hard and costly, since complex fabrication processes might be involved.
- Matching the temperature of the heat source to the proper thermoelectric module type. Part of the problem is that the source temperature varies under normal operation. The temperature of the machine can vary from -55°C to +125°C, while the ambient temperature from -70°C to +160°C. Therefore, the temperature gradient between the hot and the

cold side of the device can get as high as 200°C. Apart from selecting the right materials that perform efficiently within the target temperature ranges, care should be taken to avoid damaging the module at peak temperatures.

- Maintaining a satisfactory power conversion for the cooling system as a whole. Although a high-ZT material is a prerequisite for an efficient device, it cannot guarantee an efficient performance in total. In this project, a high coefficient of performance (COP>1) is also required, in order to provide a cooling power of 100W with a density of 30 W/cm^2.

Results

a) Timeline & main milestones

The experimental setup and prototype consisted of the Thermal Closet, the Air Heating System (blower, heaters, and temperature controller), the Power Supplies (for the supply of the heat sources inside the enclosure), the Heat Flux and Temperature Measurements and the Line Panel (for the system overall operation management and protection). In addition, the DSPACE platform and the laboratory constructed PWM converters are included in the experimental setup for the implementation of the active PWM control schemes.

The experimental procedure has evaluated the proposed double modulation frequency active PWM control method as a tool for the achievement of high thermoelectric cooling capabilities under harsh aeronautic conditions. Thanks to this method the TEC system under study meets the project requirements, proving that Thermoelectric Cooling is a promising technique for the aircraft industry. In addition, the experimental process has shown that sophisticated control loops are necessary for a successful TEC system design under such harsh environmental conditions; meanwhile, TEC operation has to be active even under moderate temperature conditions, otherwise their cooling capability may be restricted in case of fast temperature rise (e.g. under the sudden raise of the consumption of the electronic equipment). Hence, a lot of research has to be made focusing on the control loop design and the incorporation of fuzzy / expert systems architecture.

Finally, the experimental procedure has been completed successfully, providing valuable data for further research and evaluating the effectiveness of the proposed control method. Although the outcomes for the average temperature values are generally in line with the corresponding simulation results, there are notable deviations between minimum / maximum temperature values. The main reason for this is the distribution of heat sources which was considered uniformly in the simulation model. In addition, there are some differences on the materials and the modification of the various system components between the simulation design and the experimental development. However, these differences can be justified by the research nature of the THERMICOOL project and consequently the fact that some system data were not fully determined during the simulation phase.

In conclusion, the main targets of THERMICOOL project have been successfully fulfilled, coming up with a novel active cooling method that meets the project requirements. In addition, enhanced control algorithms for multi-stage TEC schemes have been invented, calling for further research and development actions.

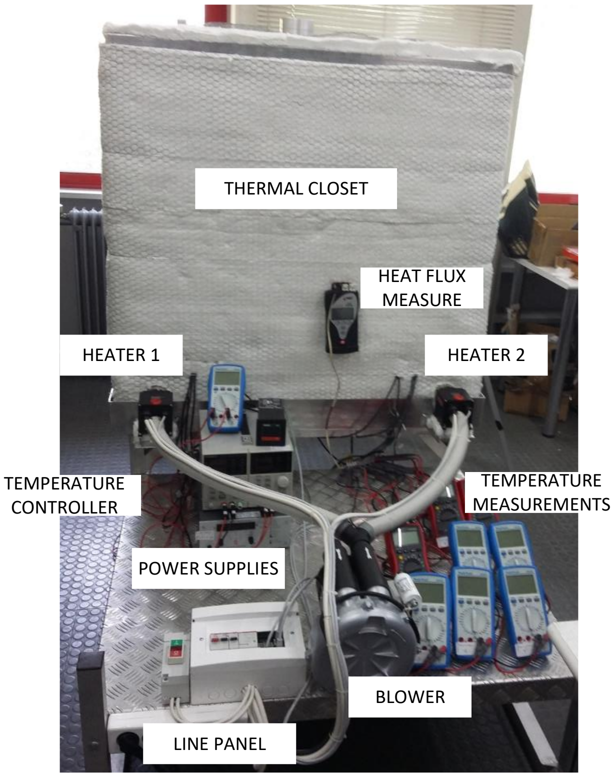
b) Environmental benefits

The objective of this project aligns well with the vision of the all-electric aircraft and the reduction of carbon and other undesirable emissions through improved overall systems energy efficiency by exploitation of new electrical system technologies. This framework encourages the development of solutions that are cost effective and energy efficient through long life. Two additional benefits are the reduction of noise and the increased reliability. Moreover, adoption of all-electric technologies could reduce the operating empty weight of the aircraft and could lead to reduction in fuel load, thrust required, maximum take-off weight, etc. Reductions in maximum aircraft take-off weight could reduce the wing area, which in turn could allow for reduced wing span and increased aspect ratio, thus improving the aerodynamic efficiency of the aircraft.

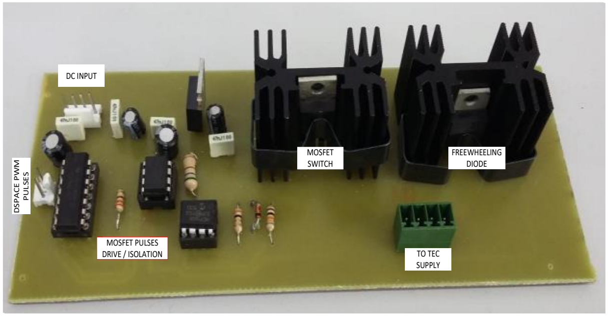
c) Maturity of works performed

The consortium delivered a thermoelectric cooling (TEC) device at Technology Readiness Level 5 (a prototype validated in a relevant environment), using mainly commercial off the shelf (COTS) thermoelectric elements. The experimental procedure has evaluated an innovative double modulation frequency active PWM control method as a tool for the achievement of high thermoelectric cooling capabilities under harsh aeronautic conditions.

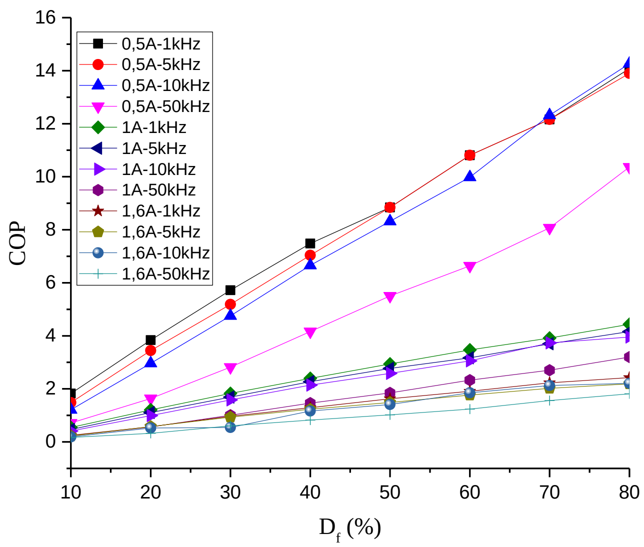
Experimental setup.



PWM Control



Achieved COP Values



Project Summary

Acronym: THERMICOOL

Name of proposal: Thermoelectric cooling using innovative multistage active control modules

Technical domain: Energy, Thermoelectricity

Involved ITD: SGO

Grant Agreement:	CSJU-GAM-02-2013-632436
Instrument:	Clean Sky JU
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Clean Sky contribution:	250,800.00
Call:	SP1-JTI-CS-2013-02
Starting date:	01/06/2014
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Duration:	22
Coordinator contact details:	Prof. Michael Loupis
	Innovative Technologies Centre s.a.
	25 Alketou Street, 11633 Athens, Greece
	Tel.: +30 210 7560322, 7561429 Fax: +30 210 7560324
	http://www.itcnet.gr
Project Officer:	Antonio Vecchio
	Antonio.Vecchio@cleansky.eu
Participating members	MILTECH HELLAS s.a.
	DEMOCRITUS UNIVERSITY OF THRACE