EXPERIMENTAL PERFORMANCE OF THERMOELECTRIC MODULES APPLIED TO AIR CONDITIONING

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Abstract. *Thermoelectric cooling system is based on an effect discovered by Jean Charles Athanase Peltier, in 1834, according to when an electric current runs through a junction between two semiconductors materials with different properties, heat is dissipated and absorbed. Thermoelectric modules are made of semiconductors materials sealed between two boards and according to the way of the current flow one board is cold and the other is heated. The most important parameter to evaluate the efficiency of thermoelectric cooling process the performance coefficient, the transferred heat rate and the maximum temperature difference possible to obtain between the cold and hot sides of the thermoelectric module. This paper presents the equations that allow evaluating the performance of a system to air conditioning based on the thermoelectric system, the available modules characteristics and also the results of tests realized in samples. In this evaluation there were used thermoelectric modules and heat sink available in the market, temperature sensor and a software to obtain, store and compare the data. The prototype allows assisting the superficial temperatures of the thermoelectric modules' cold and hot sides, the air inlet and outlet temperatures in the heat sink, the hot and cold sides' airflow, the voltage and the electric current applied in the modules. Using this data the system performance is analyzed making possible to check whether the power, voltage and the electric current that maximize the performance coefficient.*

Keywords*: thermoelectric module, Peltier effect, thermoelectric cooling, air conditioning*

1. INTRODUCTION

This paper presents the theoretical equations that allow evaluating the performance of an air conditioning system based on the thermoelectric effect and also presents the experimental results of tests applied on a thermoelectric device composed by modules confined in a duct for simulation of a small air conditioning system. The thermoelectric cooling system is based on a phenomenon discovered by Jean Charles Athanase Peltier, in 1834. According to him, when electricity runs through a junction between two semiconductors with different properties, heat is dissipated or absorbed. Thus, the thermoelectric modules are made by semiconductors materials, sealed between two plates through which a direct current keeps one plate hot and the other cold. Many researchers have studied applications of thermoelectric devices. Göktun (1995) shows that the internal and external irreversibilities in a thermoelectric refrigerator may be characterized by a parameter named *device-design parameter*; Sofrata (1996) developed an effective heat rejection method for the hot side of thermoelectric modules testing single fan, double fan and natural chimmey as alternatives; Bojic et al (1997) used a thermoelectric cooler and a coldness-recovery device for summer air conditioning of a train carriage and simulated six different control scenarios for the energy system; Lindler (1998) investigates the potential improvement in heat pump performance that can obtained by cascading two or more heat pump in series operation; Huang and Duang (2000) show a linear dynamic model of the thermoelectric cooler including the heat sink and the cooling-load heat exchanger; Huang et al (2000) present a system design method of thermoelectric cooler that utilizes the performance curve of the module determined experimentally to obtain the physical properties; Chen et al (2002) use the cycle models of a single-stage and a two-stage thermoelectric refrigeration system to derive the general expressions of coefficient of performance, the rate of refrigeration and the power input; Luo et al (2003) applied the theory of finite time thermodynamics to analyze and optimize the performance of a thermoelectric refrigerator, composite of multi-elements; Dai et al (2003) present an experimental investigation and analysis on a thermoelectric refrigerator driven by solar cells, applying solar cells to power the refrigerator in the day and using a storage battery to provide electric energy in the night; Astrain et al (2003) present a device for the dissipation the heat from the hot side of Peltier pellets based on the principle of a thermosyphon and proved experimentally that the device increases the coefficient of performance; Chein and Huang (2004) show an application of thermoelectric cooler in electronic cooling, using the cold side temperature and temperature difference between cold and hot sides as the parameters; Hansen (2004) investigates the static thermal behavior of a 61-cell silicon drift detector module; Cheng and Lin (2005) present a method of optimizing the dimensions of the thermoelectric module legs using genetic algorithms, to maximize the cooling capacity and Vasiliev (2007) presented a short review on the micro and miniature heat pipes applied to electronic components cooling .

Thermoelectric devices offer several advantages over other technologies (Riffat and Ma, 2003): they have no moving parts and, therefore, need less maintenance; they contain no chlorofluorocarbons; the direction of heat pumping is reversible, i.e., changing the polarity of the DC power supply a cooler can then become a heater; they can work in environments that are too severe, too sensitive or too small for conventional refrigeration and are not position-dependent. Due to these advantages, thermoelectric devices have found very extensive applications in wide areas, such as military, aerospace, medical, microelectronics, laboratory, instrument and sensors, industrial and commercial products. Figure 1 shows a schematic of the Peltier effect (cooling device) and Fig. 2 shows thermoelectric modules and heat sinks.

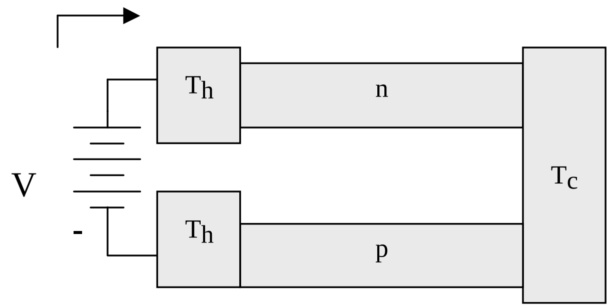

Figure 1. Schematic of a Peltier effect (thermoelectric cooling device)

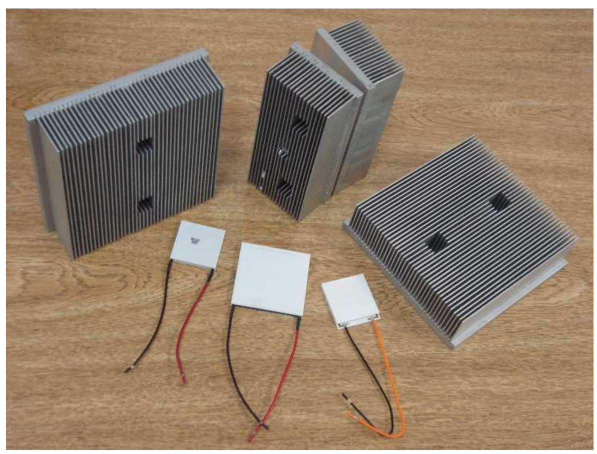

Figure 2. Thermoelectric modules and heat sinks

2. MATHEMATICAL MODEL

The parameters that are interesting to evaluate the performance of a cooling refrigerator are the coefficient of performance (φ), the heat pumping rate (Q_c) and the maximum temperature difference (ΔT_{max}) that the device will produce. The coefficient of performance φ is defined as

$$\varphi = \frac{Q_c}{P} \tag{1}$$

where: Q_c is the heat pumping rate from the cold side and P is the electrical power input.

The "cooling effect" or "thermal load" is the heat pumping rate from the cold side and it is the sum of three terms (Heikes and Ure Jr, 1961): a) the Joule heat of each side per time unit, b) the heat transfer rate when current is equal to zero between the two sides and c) the Peltier heat rate of each side, that is, the heat removal rate is

$$Q_c = \alpha T_c I - \frac{1}{2} I^2 R - K\Delta T \tag{2}$$

where: α is the Seebeck coefficient, T_c is cold side temperature of the thermoelectric module, I is the current, R is the electric resistance (Ω) , K is the total thermal conductance of the thermoelectric cooling module and ΔT is temperature difference between hot and cold sides (T_h - T_c.) The energy balance in the cold side results that

$$Q_c = \dot{m}_a \, C_p \, (T_i - T_o) \tag{3}$$

where $\dot{m}_a$ is the mass air flow of the cold side, Cp is the constant pressure specific heat, T_i is the inlet air flow temperature and T_o is the outlet air flow temperature. The power input is

$$P = V.I = \alpha.I.\Delta T + I^2.R = \frac{V(V - \alpha.\Delta T)}{R} \tag{4}$$

where: V is the applied voltage and is the sum of the electric and the Joule voltage.

$$V = \alpha \Delta T + IR \tag{5}$$

2. EXPERIMENTAL THERMOELECTRIC DEVICE

To analyze the mathematical model aiming to evaluate the performance of the air conditioning system, an experimental thermoelectric device for air conditioning was build. Figure 3 shows the schematic of the experimental system.

The apparatus consist of a thermoelectric modules physically coupled in both sides to micro channel heat sinks and these finned plate heat exchangers are each one inserted inside a duct being that by one of the ducts the air flow will be heated and by the other duct another flux will be cooled while passing by the heat sinks. Both ducts are made from aluminum and have thermal insulation of polystyrene and fiberglass. The cold and hot sides micro channel heat sinks are made from aluminum, measuring 150x80x40mm, with 19 fins with a width of 2mm. The base of heat sink is 6mm thin.

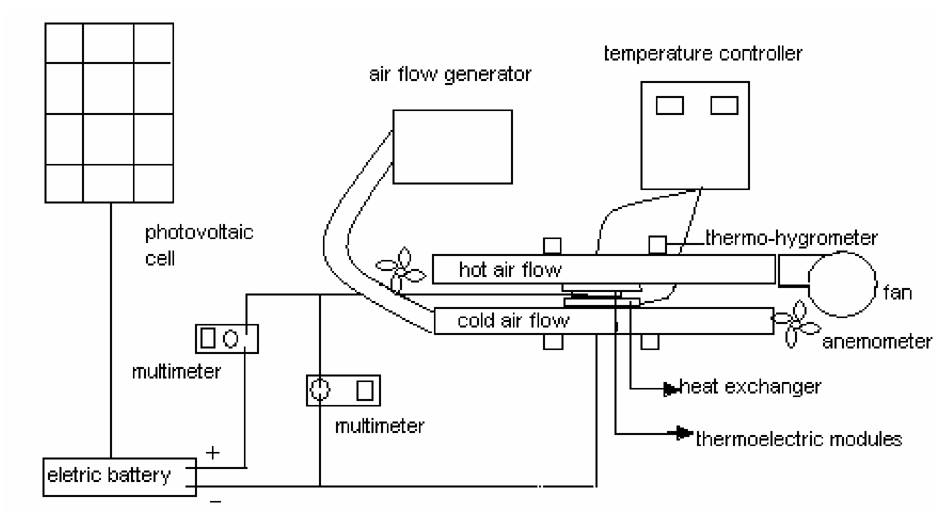

Figure 3. Schematic of the experimental system

The cold and hot side fans have adjustable power and flow. The cold air flow is controlled by an air flow generator model “Marotec 8203-B”. The hot air flow is controlled by a variable voltage transformer “Varikeld 220V”. The air temperature and humidity are measured with thermo hygrometers model “Instrutherm HT-210”. The speed of the hot and cold air flows are measured with digital hot wire thermo anemometers model “Instrutherm TAFR-180”. The electric current and voltage are measured with multimeters “Minipa ET-1502 and ET-2052”. The thermoelectric modules is a model TE Tecnology 0,04x0,04m, 16,5 V. The temperature controller and measurement of the plates is made with thermocouples and a temperature controller model “Gefran 600, 220V”. The electric source of the thermoelectric modules is a photovoltaic energy system “Solarterra”, electric power 250 Wp composed with silicon polycrystalline solar cells, electric battery controller 20 A, 12 V, LCB 20 A (Linear Buster Current) and electric battery 150 Ah C 20. The characteristics of the thermoelectric modules are presented in Table 1.

Table 1. Characteristics of the thermoelectric module

Figure of merit (Z)	0.00268 K^{-1}
Thermal conductance (K)	0.46 W/K
Seebeck coefficient (α)	0.0513 V/K
Thermal conductivity (k)	0.0151 W/ºC m
Electrical resistivity (ρ)	0.00101 Ω cm
Dimensions	40 x 40 x 3.6 mm
Number of associations (N)	127
Total resistance (R)	2.12 Ω

2.1. Methodology

Experiments had been carried through where they had been monitored: hot side inlet air temperature, hot side outlet air temperature, cold side inlet air temperature, cold side outlet air temperature, the plate temperature of the hot side (T_h), the plate temperature of the cold side (T_c), the applied electric current (I), the applied electric voltage and the air speed in the hot and cold sides of the thermoelectric module.

The tests were performed by the experimental system electrically supplied by direct current, voltage equal to 12V, from a battery that is supplied by a photovoltaic panel. Four series of tests were realized; each one with seventeen measurements, beginning with just one thermoelectric module and, in each new set of test, other module was added, electrically connected in parallel. For each set the air velocity in the hot air duct was kept constant and equal to 8,5 m/s and the velocity of air in the duct in the cold side as changed from 0,5 m/s to 8,0 m/s. This variation was controlled by a reostate coupled to the air flow generator. To a better reliability of the results, each test was done twice, in the first increasing the airflow and in the second reducing the air flow. So, there was a confirmation and validation of the obtained results. The graphs presented in Figs. 4 to 7 show the average values of all tests dates. The accuracy characteristics of the measurement instruments are presented in Table 2.

Table 2. Characteristics of the measurement instruments

INSTRUMENT	MANUFACTURER/MODEL	RESOLUTION/ACCURACY
Variable voltage transformer	Varikeld 220V	± 2,5 V
Thermo-higrometer	Instrutherm/HT-210	1°C / ± 0,05 %
Multimeter	Minipa/ET 2052	0,0005V / ± 0,5%
Multimeter	Minipa/ET 1552	0,005A / ± 0,5%
Hot wire thermo-anemometer	Instrutherm/TAFR 180	0,1 m/s / ± 5%
Temperature controller	Gefran/ 600	1°C / ± 0,5%

3. RESULTS

The performance of the air conditioning thermoelectric device can be seen in Figs. 4 to 7. Figure 4 shows the COP (Coefficient of Performance) as function of electric current, Fig. 5 shows the COP as function of temperature difference, Fig. 6 shows the electric power input as function of temperature difference and Fig. 7 shows the temperature difference as function of electric current.

The most important design parameters for a thermoelectric air conditioning are the Coefficient of Performance (COP) and the temperature difference that the device will produce. It can be seen, analyzing the graphs presented in the Figs. 4 to 6, that COP decreases when the electric current or temperature difference increases, that means, COP can be increased by decreasing temperature difference between the hot and cold sides. The power input increases when temperature difference increases and when the electric current increases the temperature difference also increases. Analyzing Fig. 7 it notes that the temperature difference increases when electric current increases, that means the heat pumping can be increasing by increasing the electric current through the modules.

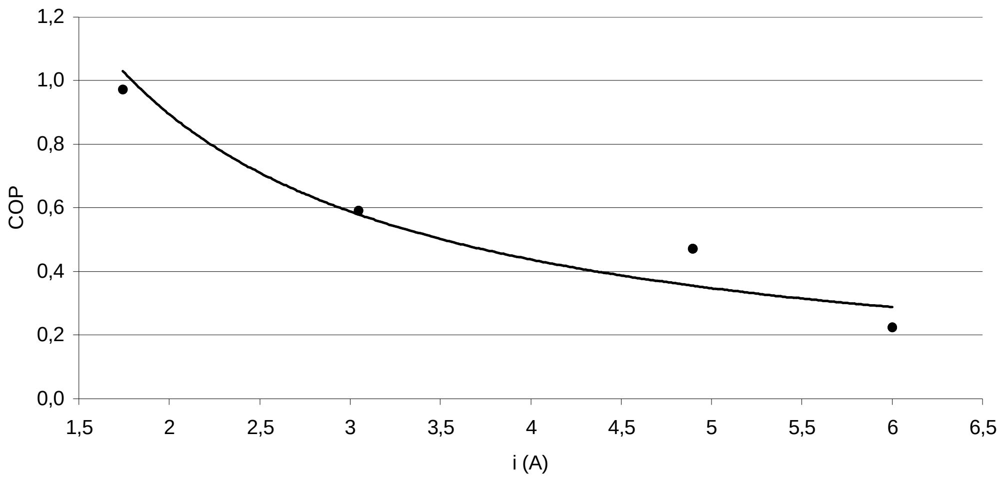

Figure 4. Coefficient of performance as function of electric current

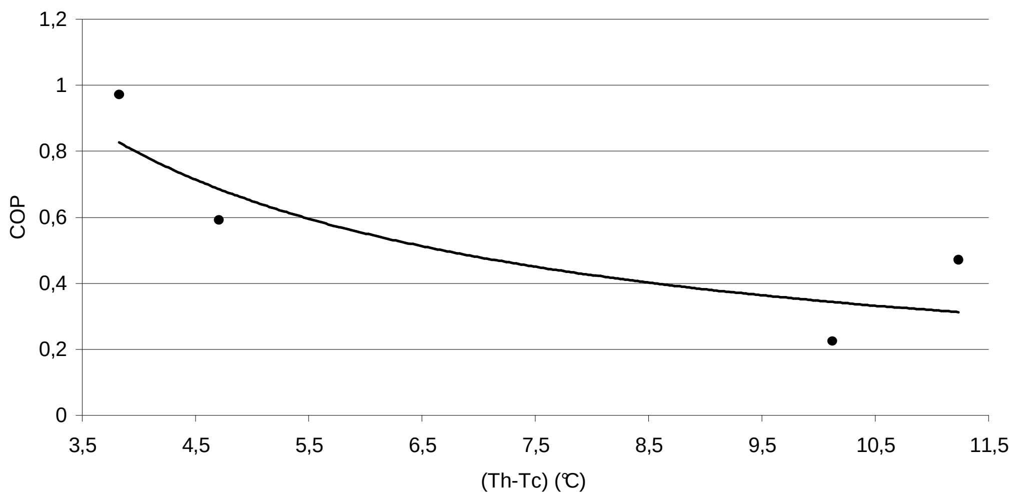

Figure 5. Coefficient of Performance as function of temperature difference

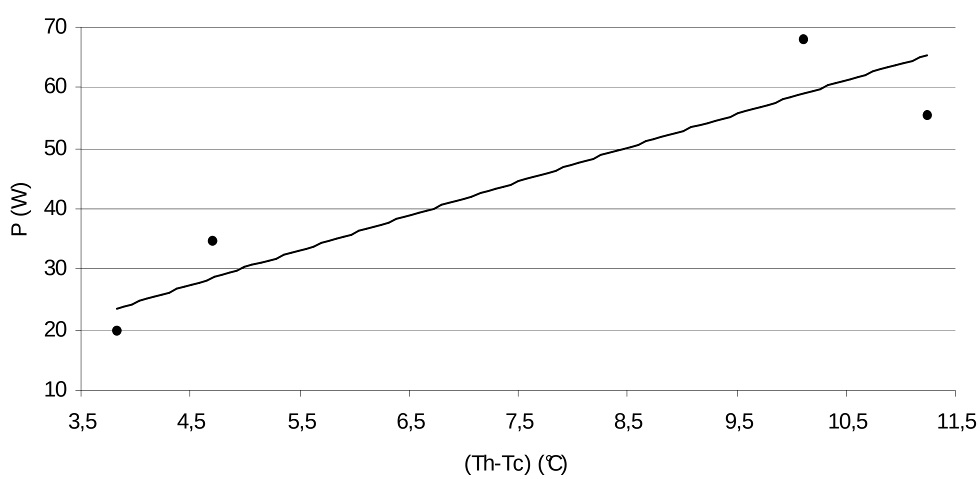

Figure 6. Power input as function of temperature difference

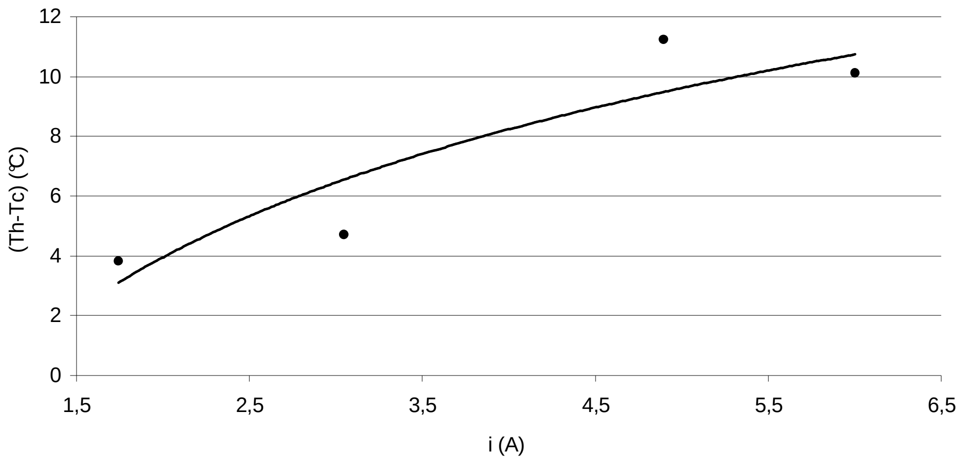

Figure 7. Temperature difference as function of electric current

Table 3 present the error analysis for each series of tests. As presented in the methodology, four series were realized, each one with seventeen measurements, beginning with just one thermoelectric module and, in each new set of test, other module was added, electrically connected in parallel.

Tabela 3. Error analysis

	1 module	**2 modules**	**3 modules**	**4 modules**	**average**
Hot side plate temperature (°C)	26.18 ± 0.728	27.41 ± 0.618	29.41 ± 1.064	29.00 ± 0.500	28.00 ± 1.496
Cold side plate temperature (°C)	22.35 ±1.320	22.71 ± 0.920	18.18 ± 1.334	18.88 ± 0.697	20.53 ± 2.301
Hot side inlet air temperature (°C)	23.87 ± 0.803	23.68 ± 0.554	23.39 ± 0.912	23.21 ± 0.515	23.54 ± 0.745
Hot side outlet air temperature (°C)	25.56 ± 0.690	26.12± 0.499	27.19 ± 0.855	26.82 ± 0.660	26.42 ± 0.924
Cold side inlet air temperature (°C)	25.41 ± 1.104	25.32 ± 0.857	25.06 ± 1.116	24.67 ± 0.671	25.11 ± 0.977
Hot side outlet air temperature (°C	23.90 ± 1.137	23.77 ± 0.782	23.05 ± 1.377	23.58 ± 0.562	23.57 ± 1.044
Electric current (A)	1.74 ± 0.029	3.05 ± 0.019	4.90 ± 0.022	6.00 ± 0.041	3.92 ± 1.654
Electric voltage (V)	11.38 ± 0.006	11.36 ± 0.024	11.32 ± 0.018	11.34 ± 0.045	11.35 ± 0.036
Hot air speed (m/s)	8.43 ± 0.110	8.21 ± 0.145	8.24 ± 0.154	8.29 ± 0.169	8.29 ± 0.166

4. CONCLUSION

A thermoelectric cooling application was studied in this paper and it was presented the experimental results of tests applied on a thermoelectric device composed by modules confined in ducts for simulation of a small air conditioning system. The thermoelectric air conditioning cooling COP can be increased by decreasing temperature difference between the hot and cold sides or decreasing the electric current. Low temperature differences are obtained with low electric current. So, the coefficient of performance's maximization, for each temperature difference, can be made adjusting the applied voltage. The development of new thermoelectric materials with large Seebeck coefficient and appropriate technology could make a breakthrough in the applications of thermoelectric devices in many fields. Better results of the thermoelectric air conditioning device can be obtained by increasing the number of thermoelectric modules and this is the next target of this research.

5. ACKNOWLEDGEMENTS

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