

## Prototype of a Reduced Scale of a Refrigeration System of Environments Controlled with Pulse Width Modulation (PWM) Using Thermoelectric Modules by Peltier Effect

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### Abstract.

*This paper presents the design of a scaled-down prototype of a proposed for a cooling system on environments for replacement of air conditioners by compressor. The operation of the proposed system differs from current systems by compressor to be a system based on the Peltier effect (thermoelectric modules) controlled by PWM ensuring maximum efficiency and precise control of the desired temperature. The prototype foresee the removal of air from the external environment (environment), making him circular of forced mode by a channel which will have its temperature reduced by heat exchange that occurring by indirect contact with the cold surface of the thermoelectric modules, thus arriving to at the environment to be cooled with temperature reduced at relative temperature taken by outside. The system is sensed and controlled via PWM modulation of a electronic apparatus comprising an temperature sensors LM35, development kit ARDUINO UNO and LABVIEW 2014 software which together aim to ensure efficient temperature control and efficiency in the consumption of electrical energy. It is presented in this paper the experimental development of prototype and its validation, thus confirming the technical feasibility of construction of an air conditioner using thermoelectric modules.*

### Key words

*Peltier Effect, thermoelectric cooling, PWM, Air conditioner, Thermoelectric Modules.*

### 1. Introduction

The air conditioners have evolved throughout its existence with its evolution always focused on high yield, ie, to generate maximum thermal exchange with the lowest possible power consumption, ie with maximum energy efficiency [1].

Already in the part of development exist some studies for the application of thermoelectric phenomena focused to development the Peltier devices for cooling use. [2]. However, the coefficients of performance shown in thermoelectric materials have been inferior to the coefficients compared to the Carnot cycle, this that is the most traditionally used in refrigeration processes. The efficiencies between a process and other one can be compared on the basis the maximum efficiency reached in operating temperatures. The figure 1 graphically displays the differences between the performances of the systems.

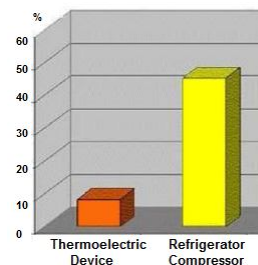


Fig. 11 - Comparative of Coefficient of Performance [3]

According to Souza, the differences are considerable, the thermoelectric materials have an efficiency of 5 to 10%, and compressor refrigerators have an average maximum efficiency of 45%. [3]

Hence, this paper aims to contribute by proposing a cooling system using thermoelectric modules by Peltier effect, that with a focus on electronic control aims at optimizing the power consumption indicator presenting feasibility of transformation into a commercial product.

## 2. Thermoelectric Effect

Thermoelectric materials are semiconductors that formed when applied to temperature differences can generate energy in the form of electrical voltage when applied to electric energy generate in the temperature gradient [4].

Thermoelectric modules are typically formed of semiconductor materials, and has its structure formed to increase the current density and hence the output power. Are manufactured from materials such as tellurium, antimony, germanium and silver, with high doping to create semiconductor materials [5]. These in turn are welded in a sandwich of two ceramic plates, ensuring heat transfer and sufficient mechanical strength. Figure 3 shows how the formation of the tablet, with PN junctions connected in series.

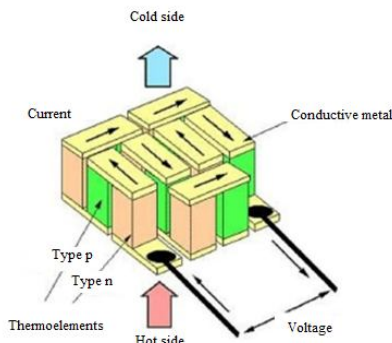


Fig. 2 Formation of the Thermoelectric [6]

By applying a temperature greater on one side there is a current flow constant over the semiconductor material, and therefore a voltage formed by the association of several elements. All commercial thermoelectric modules are based on the principle mentioned above, these modules are manufactured for different values of temperature, size and power, Figure 4 shows a commercial tablet.



Fig. 3 Comercial Thermoelectric Module [6]

Among the advantages of thermoelectric materials, we can list the high reliability, low maintenance, application versatility, size, lightness, is silent and highly secure. [7] Recent researches presented efficiencies higher than 20% by using new techniques in the development of thermoelectric materials [8, 9]. With the development of thermoelectric materials, one can apply it in various areas where there are operating conditions. For example, can be used for power generation in industries where heat loss is present (thermoelectric power plants, foundries), or even in the exhaust of a car. In these two cases, there may be a considerable increase in overall system efficiency [10].

In other cases, its use applies in cooling of foodstuffs, electronics and air conditioning systems (but is takes consider that the cooling efficiency is still low

compared to existing devices such as compressors). [11]

The Peltier effect used consist in removing rate of heat  $Q_c$  absorbed of a environment to be cooled that is at any temperature. The heat that will be dissipated at the hot side of the material is defined as the sum of the heat absorbed at the cold end with the electric power to be applied. The coefficient of performance (COP) to the cooling system using thermoelectric materials yet has not present satisfactory performances, but is studied as liquid heat absorbed at the cold end divided by the electrical potency to be applied. [2]

$$COP = \frac{Q_c}{P_{in}} \quad (1)$$

Onde:

COP: Coefficient of Performance

$Q_c$  [W]: Liquid heat absorbed

$P_{in}$  [W]: Electrical potency to be applied

It can also be stated that the input power dissipated is the heat is subtracted from the liquid heat that had been absorbed. [2]

$$P_{in} = Q_h - Q_c \quad [W] \quad (2)$$

Onde:

$P_{in}$  [W]: electrical potency to be applied

$Q_h$  [W]: Dissipated heat

$Q_c$  [W]: Liquid heat absorbed

Thus, the coefficient of performance it can be expressed: [3]

$$COP = \frac{Q_c}{Q_h - Q_c} \quad (3)$$

Therefore, the temperature coefficient can be summarized in a combination of dissipated heat and absorbed heat.

## 3. Prototype of the Cooling System

The prototype small-scale of refrigeration system developed using thermoelectric modules of Peltier effect controlled with PWM to optimize the energy consumed by the modules and precise temperature control is composed of distinct units as can be seen in Figure 4.

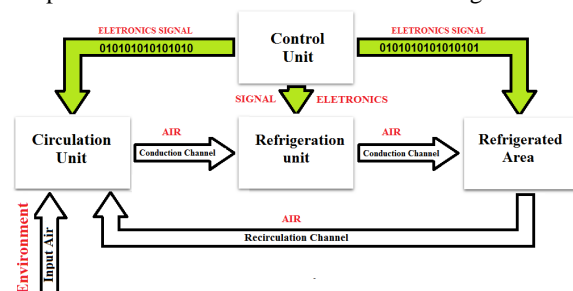


Fig. 4 – Schematic Block of the Proposed System

The circulation unit is responsible for the moving of air of system, to making possible that it is taken from the external environment or of the internal environment to abeam the recirculation channel, forced him to go through the conduction channel where are the

refrigeration unit and coming finally the area to be cooled.

The refrigeration unit is responsible for the decrease in air temperature through temperature aluminum conductors connected to fría face of thermoelectric modules that in contact with the circulating air, heat exchange leading later-the refrigerated area. The figure 3 shows of the prototype assembly.

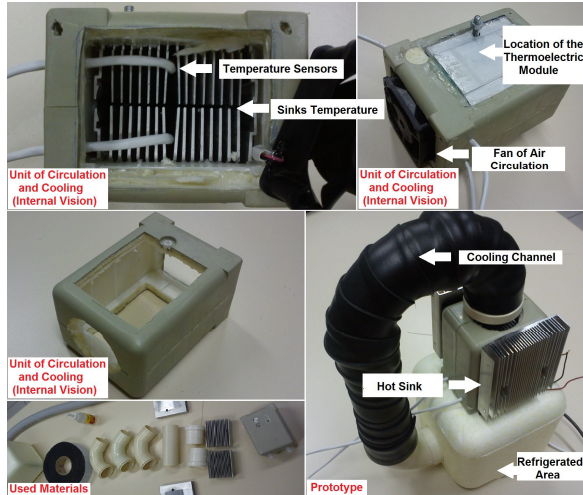


Fig. 5 – Prototype Construction

The management realized by the control unit is done on the prototyping platform ARDUINO UNO V3 and software LABVIEW 2014 that together as can be seen in Figure 6 read the signals from temperature sensors and through of algorithm developed for conditioning the signal, process them and act on a potency PWM drive ensuring the efficiency of the system and precise temperature control. To measure the cooling capacity and a correct functioning, sensors are located inside and outside the refrigerated area to obtain the temperature gradient, as well as the sinks for measuring the thermal power generated in the thermoelectric modules.

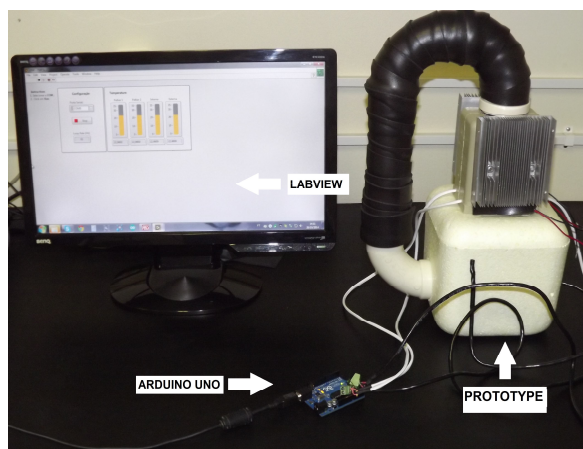


Fig. 6 – Refrigeration system proposed

#### 4. Validation

The prototype was subjected to validation tests in order to verify their cooling capacity of the air from the heat exchange with the thermoelectric modules. During the tests were collected internal and external temperature data

to confirm the reduction of temperature inside the environment refrigerated, they were also collected temperatures of internal and external sinks to check their behavior during the process. In addition, electrical voltage and current data were also collected in order to assess the true performance and assess its feasibility for implementation.

The validation methodology presented in figure 6, constitutes experimental operation within an air conditioned room having a temperature of about 21 ° C to 22 ° C throughout the period of testing. Initially the experiment was supported on the table and completed the electrical connections and after the system was energized. It is waited up to five minutes for the sensors had their stabilized temperatures. After this time, the system was powered by the 40-minute period, with records of a second totaling 2400 records. The choice of time validation is given by the fact that previous pre-tests demonstrated that the prototype does not suffer large variations after this time slot.

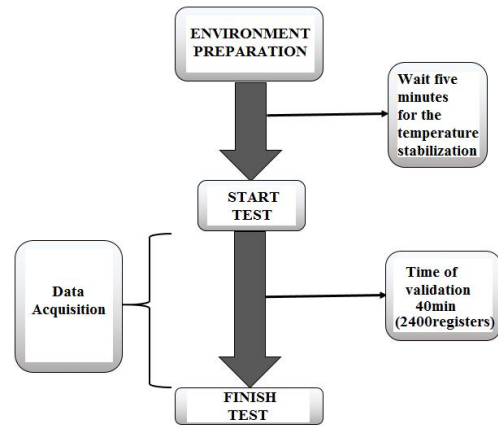


Fig. 6 – Validation Block Diagram

The results of the acquisition system presented are very interesting data and now are presented and discussed from this point.

The figure 7 shows all temperatures of entries made during a period of 40 minutes.

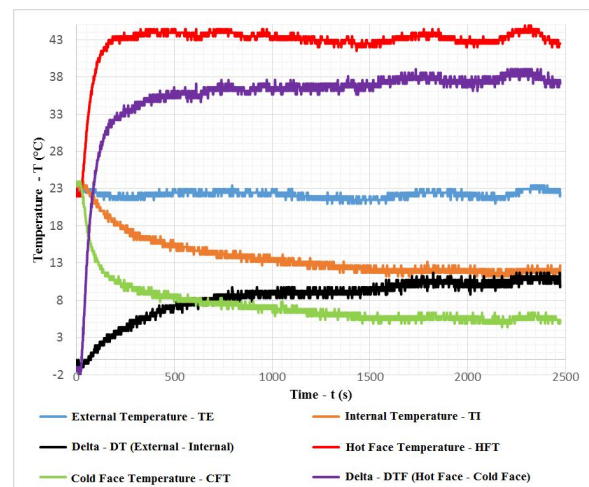


Fig. 7 – Graph of the results (all temperatures)



For better viewing and discussion of the results, the figure 8 shows only the values of the internal temperature, external and delta of the prototype.

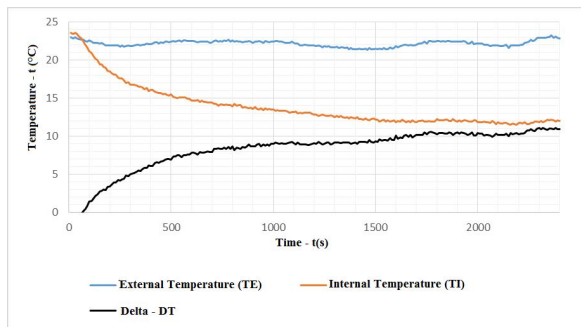


Fig. 8 – Graph of the results (Internal and External Temperature)

In the chart, easily can be observed that external temperature (TE) remains throughout the validation period, ranging very little and that this occurred because the room conditioned where the tests were conducted. The internal temperature (TI) in environment to be cooled, has a slightly higher onset than the external temperature (TE) and this is partly because the closed living box and does not suffer the influence of air conditioning of the room where the tests were conducted. After the start, the internal temperature (TI) and suffers a decreases and in 500 seconds (approximately 8 minutes) the temperature is already at 15°C and therefore have a decrease of approximately 8°C compared to 23°C initials. Evaluating the curve of the internal temperature (TE), it is observed that there is a higher initial variation and, from the time of 500 seconds the change already being slower reaching a minimum of 11°C near the end of time test. The delta curve represented on the chart clearly shows how the difference between the temperature internal and external increases over time, giving clarity as to the success of the proposal regarding the aspect of functionality, needing further assess the issue efficiency. It stands out even in the chart that the temperature delta starts below zero, like the previous explanation. This occurs because initially the internal temperature (TI) is one degree higher than the external temperature (TE) probably due to the fact that inside the box that serves as a simulation of the refrigerated environment there is no influence of external cooling of the room where the tests were performed. For greater understanding the table 1 summarizes the obtained validation data.

Table 1: Summary of validation data

Data	Value
Acquisition time (s)	2400s (40min)
Initial external temperature	22°C
Final external temperature	21°C
Initial internal temperature	23°C
Final internal temperature	11 °C
Voltage (V)	30Vcc
Current (A)	5,37A

## 5. Final Considerations

The prototype showed results confirming the actual derating of environment internal temperature using thermoelectric modules. This confirmation opens the possibility to maximize the study for application in real scale, replacing the existing air conditioning compressor. As advantages of this replacement we can mention the reduction of vibration and noise generated by the compressor, and in addition, the development of devices with different geometries that can be adapted to adverse situations.

From a technical point of view it confirms the feasibility of the proposal, since the monitored room temperature had a 11°C reduction as the data presented. However, it is necessary to expand the study to determine the economic feasibility because as seen, the efficiency of current thermoelectric modules are greatly reduced and that means much greater energy consumption for to meet the desired temperature reach.

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