

# Performance of the Electric Energy Generation in a Photovoltaic System (PV) Based on PELTIER Effect (TEC) in Two Different Locations, La Mesa and Girardot in the Department of Cundinamarca

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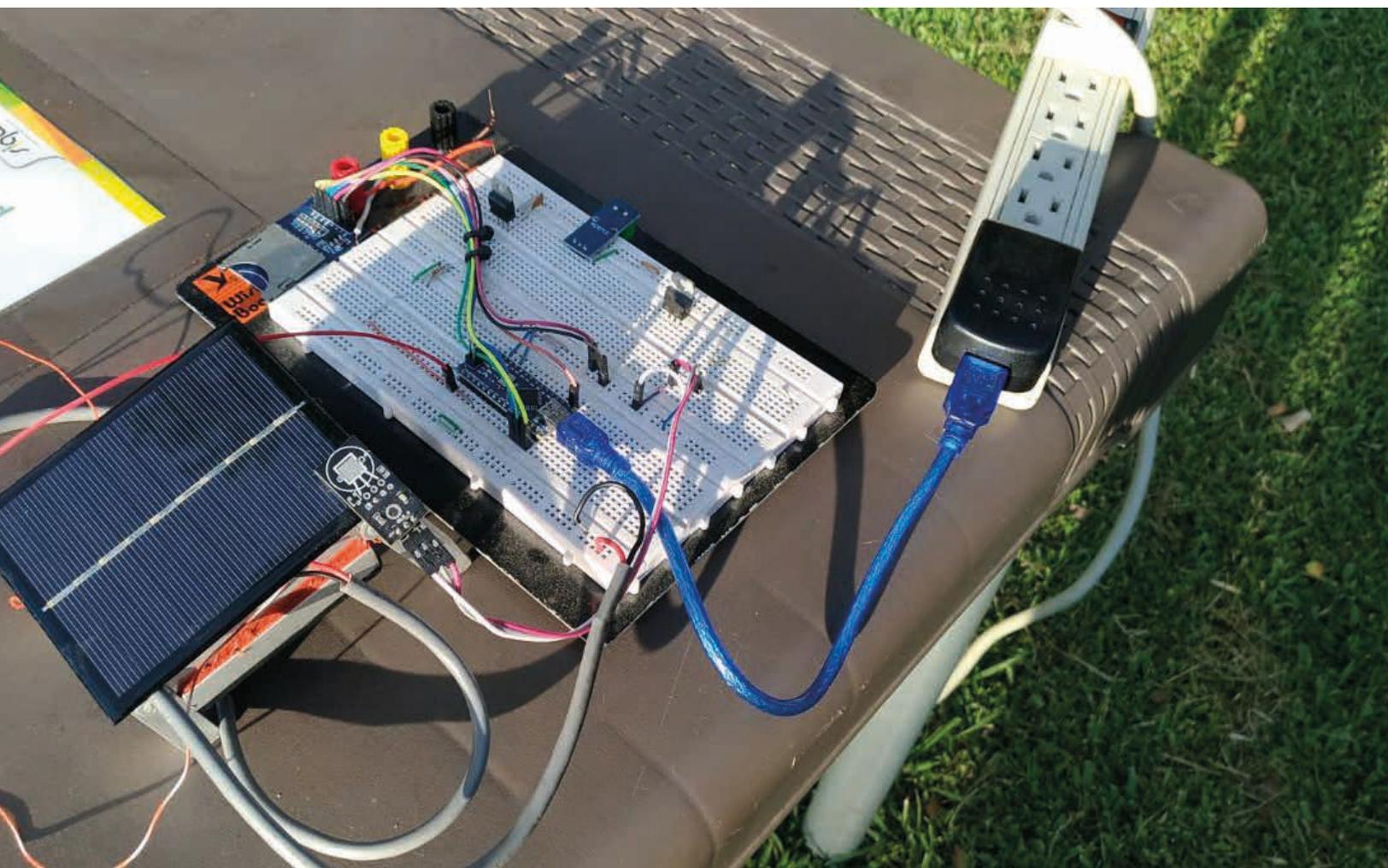
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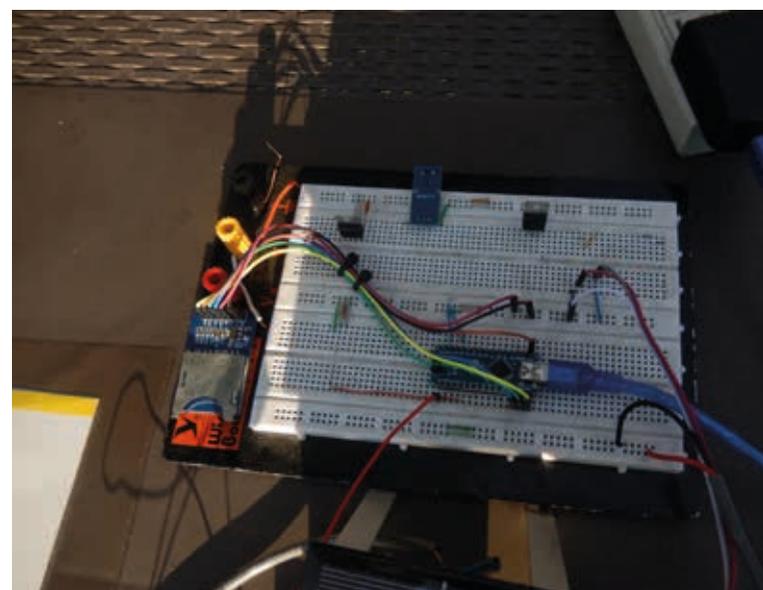
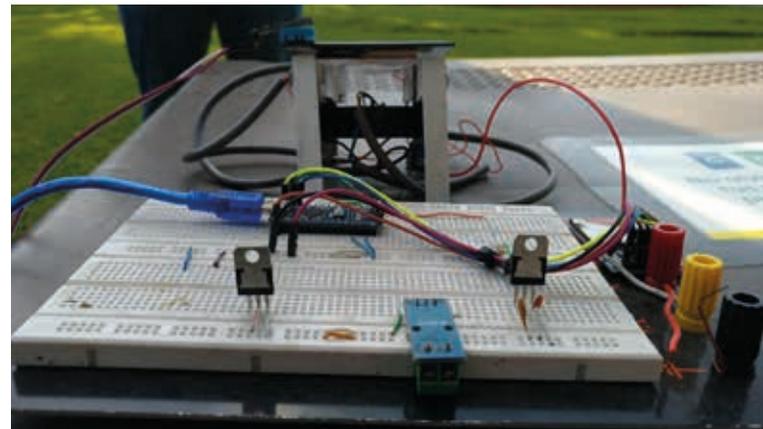
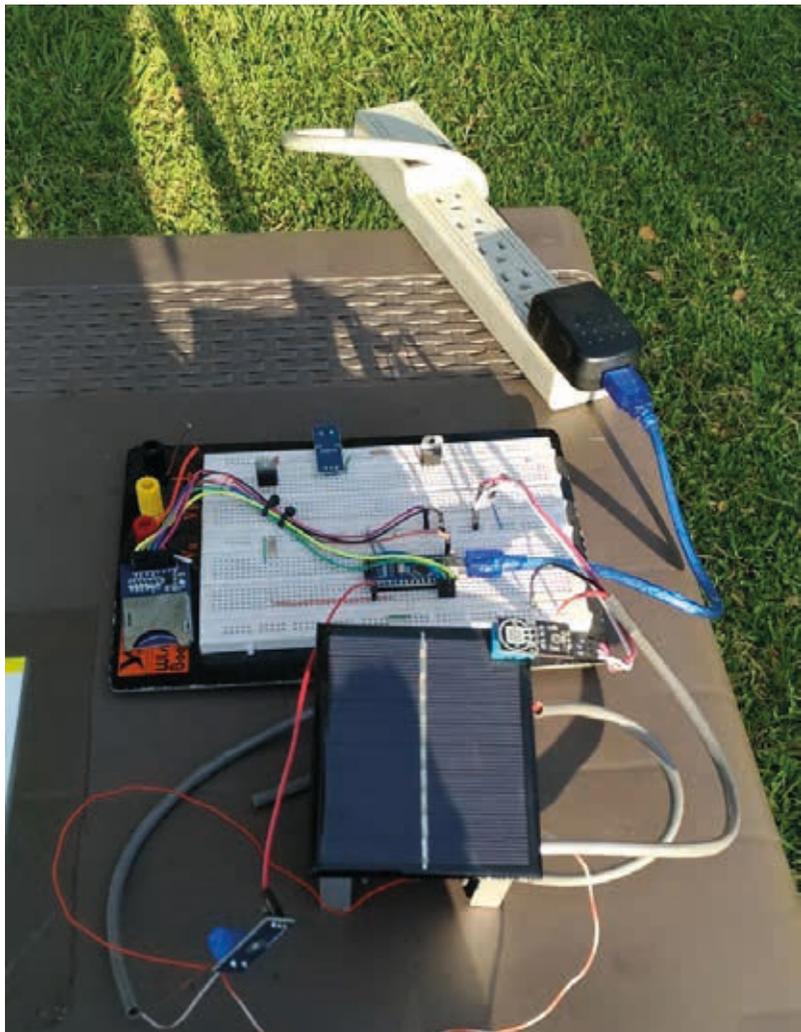
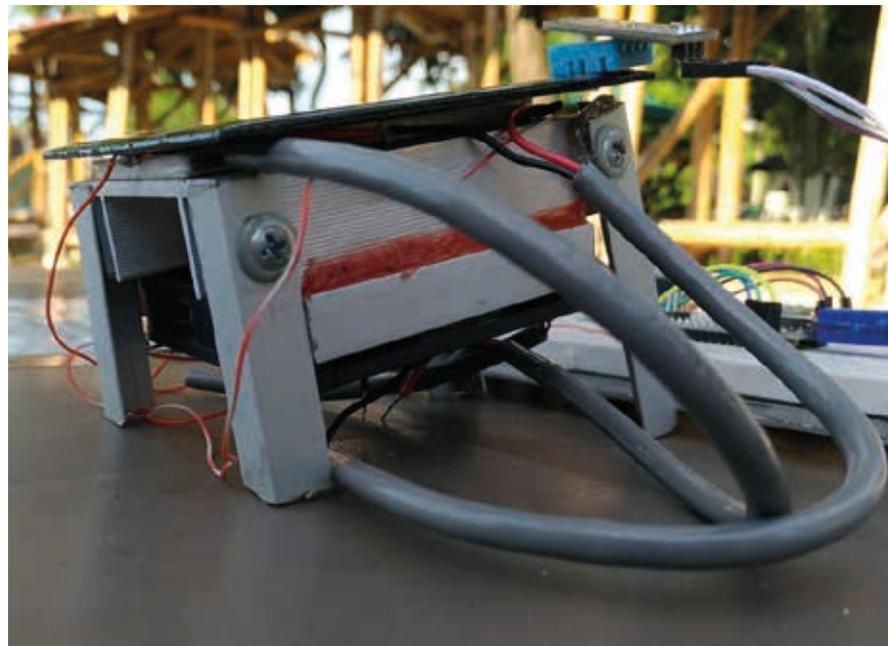
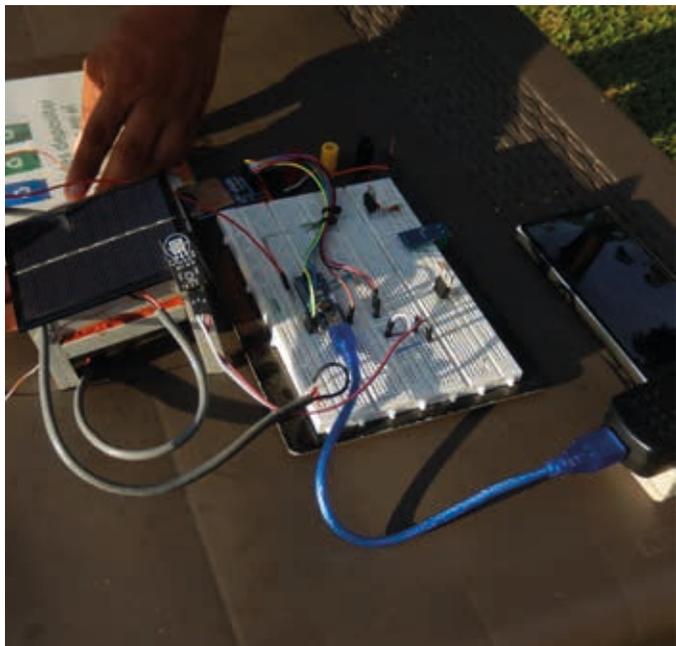
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# Performance of the Electric Energy Generation in a Photovoltaic System (PV) Based on PELTIER Effect (TEC) in Two Different Locations, La Mesa and Girardot in the Department of Cundinamarca

## *Abstract*

Due to magnitude of the project to develop in the CTDPE – SENA GIRARDOT associated with the process of innovation and development which is targeted for the reduction of energetic consumption based on energies renewable use, it will be useful to evaluate the performance of photovoltaic generation through a quantitative and exploratory applied investigation in locations like Girardot and La mesa. This study will be carried out implementing devices that use PELTIER effect to increase the energy production of a PV with constant monitoring of the different electrical and environmental variables.

As a result of investigative process, important data about PELTIER effect has been obtained. However, the project's focus was to determinate the characterization of a hybrid solar photovoltaic (PV) and thermoelectric cooler (TEC) system to improve the energy electric generation. Having finished the research, a PID controller was developed in order to control diverse variables automatically.

*Keywords:* Efficiency, Solar Panel, Photovoltaic, Peltier Cell.

## **Introduction**

The city of Girardot is located in alto Magdalena region near Magdalena river with an altitude of 289 M.A.S.L. As a consequence, this metropolis has a warm weather around 33 °C during the entire year, being one of the cities with most sunshine duration per day in middle-Colombia. On the other hand, La Mesa is situated in the Tequendama region at approximately 26 °C of temperature per year and an average altitude of 1200 M.A.S.L.

Consequently, this sort of scenario can have significant effects on the production of energy in a photovoltaic system installed in both municipalities.

In 2015, the production of more efficient modules was announced by SolarCity, reaching 22,04%. However, Panasonic introduced a similar new solar prototype into the market showing a peak of maximum efficiency of around 22.5%. This data was verified by the national institute of industry science and technology in Japan. It was possible thanks to the new photovoltaic cells with an throughput just over 25.6% that were produced last year.

The new photovoltaic unit called Panasonic HIT N330 was made with 96 cells and 330W, which can generate an efficiency of 19.7% per module. Furthermore, the company confirmed that the new photovoltaic unit can provide a peak energy of 27% more than similar standard products with 260 W.

The peak of power is the maximum power which can deliver a photovoltaic cell in a normal condition (radiation of 1000W/m<sup>2</sup> and temperature of 25 °C) and it is the parameter standard to classify the power of the modules.

A new research published by NATURA energy shows the solution to resolve the low efficiency which is one of the biggest problems with solar energy. This investigation proved that solar panels of silicon developed by kunta yoshikawa in Japan are the most effective panels in the world.

Kunta Yoshikawa, who is expert in the photovoltaic area, exhibited the first silicon plaque. This plaque is able to rise up to 26% in efficiency of transformation between solar radiation and electricity. Overall, by using new technologies, the improvement of efficiency has increased considerably about 2.7% (*Espectador*, 2017).

## Methodology

The research process was implemented by instructors associated to renewable energy and electricity area of CTDPE-SENA GIRARDOT. Moreover, apprentices of the research group called SEMINEER were involved in the project. They have been using their knowledge that they learned in two courses: firstly, construction and assembly of electrical installations and maintenance (Girardot, Cundinamarca) and secondly, installation of solar photovoltaic systems (La Mesa, Cundinamarca). These courses were very helpful throughout the research as they gave technical solutions to the project.

In order to have autonomy in the process of obtaining data and to reduce the possibility to have a mistake in data

acquisition, two measuring prototypes were designed.

The data acquisition system (ADQ) was made base on Arduino systems in order to collect information and to analyze three different phenomenon. Moreover, a program was designed to acquire data every five minutes.

The description of each outstanding point is being shown in the next section.

## Monitoring variables

As mentioned before, the aim of our research was focused on the improvement in the generation of electrical energy. Hence, this investigation considered that the temperature in the photovoltaic cell might improve the energy generation in the silicon plaque. Thus, the following variables were monitored:

- Temperature (°C)
- Photovoltaic cell's temperature (°C)
- Intensity of current in the cell (A)
- Voltage in the cell (V)

## Materials

The materials shown in table 1 were used during the research. Other materials as wire and connectors were employed as well.

Table 1. General characteristics of the materials.

Material	Characteristics
Solar cell photovoltaic	Voc: 5V Isc: 200mA Wp: 1Wp °T: 25°C
Peltier cell	Type: TEC Voperation: 12VDC Imax: 6A °T:
Temperature sensor	Voperation: 5V. Humidity range: 20%~90% RH Humidity Precision: ±5% RH. Res. Humidity: 1% RH. Temperature range: 0~60 °C. Temperature precision: ±2.0 °C. Temperature RES: 0.1°C

Table 1 continuation.

Material	Characteristics
Voltage Sensor	$V_{IN}$ : 0 – 25VDC max Res. Module: AD de 10 bits 0.00489VDC $V_{min}$ . Detection: 0.02445V. Res. analogic: 0.00489 V.
Current Sensor	Range detection: -5A a 5 ADC Sensibility: 185mV/A
Arduino Nano	Arduino Nano v3.0 Chip: ATmega328 CH340. Microcontroller: Atmel $V_{operation}$ : 5 V. $V_{IN}$ : 7-12 V. voltage de Pines E/S Digital: 14 input Analogic: 8 $I_{max}$ PIN E/S: 40 mA Memory Flash: 32 KB SRAM: 2 KB EEPROM: 1 KB Frequency clock: 16 MHz
Shield SD	$V_{IN}$ : 3.3V/5V Output pin: SD y SPI MOSI SCK MISO y CS Size: 5.1cm x 3.1cm
SD	Capacity 32GB

### Equipment

In order to determine the working parameters of the TEC-PV prototype in different operation conditions, the following measuring equipment has been used. In which data acquisition such as voltage, current and temperature was realized by sensors and instruments which are illustrated by table 2.

Table 2. Used equipment for measurement.

Equipment	Characteristics
Source ATX	$V_{ACIN}$ : 110V/230V AC $I_{ACOUT}$ : 8A/4A Frequency: 50 – 60 Hz $V_{DCOUT}$ : 3.3V/+12V/-12V/+5V/-5V $I_{DCOUT}$ : 14A/12A/0.5A/14A/0.5A Power: 600W
PC Desktop	HDD: 1TB Processor: AMD 8 RAM: 16GB S.O: Windows 10
Circuit ADQ	$V_{operation}$ : 5 – 12 $V_{DC}$ Capture Range (V): 0 – 25 $V_{DC}$ Capture Range (A): -5 – 5 $A_{DC}$ Frequency: 16MHz Frequency: 3,33mHz

### Location

The equipment that was used to take the data acquisition was installed in two different cities in Cundinamarca. In addition, other important factor, which facilitated the execution of the project was that apprentices involved in the project took lectures in the places where the project was implemented.

- Data equipment N°1, Located in CTDPE-GIRARADOT, 4° 18' 18.8" N – 74° 48' 9.8" O
- Data equipment N°2, located in CTDPE-La Mesa 4.632147 Latitude -74.463014 longitude

### Installation process

The installation of the equipment was defined in relation to recollected information and the state of the art. Here, we proposed that the implementation of a PELTIER cell was a power supply connected in a direct form to permit that one of the face in the cell could dramatically decrease its temperature. Its face was situated in horizontal contact with the solar panel to allow to control the temperature. We can see the prototype in the image 1.

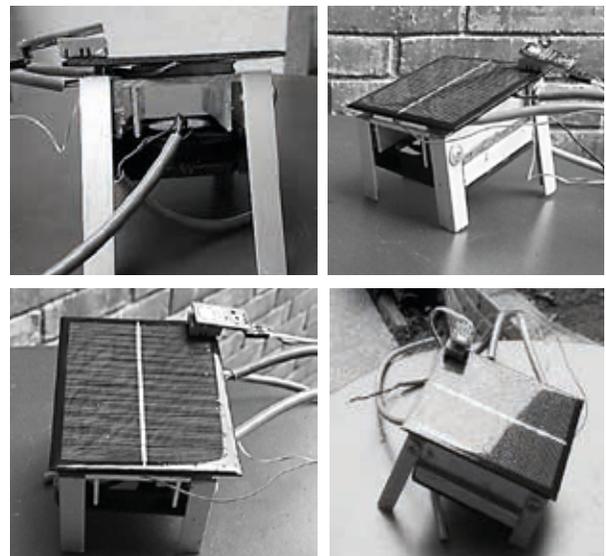


Image 1. Photovoltaic and PELTIER equipment.

Otherwise, the other face was installed with a heat sink which has two components: the first one is made of aluminum which allows to dissipate evenly the heat, the second one is a Fan which permits air to flow into the dissipater to create an interchange between hot air and cold air. As a result, we can protect the whole system from overheating and guarantee the transmission of temperature. Moreover, the power of supply that was installed, support the entire requirements of the systems.

### Acquisition of data

The data was obtained in a time period of 5 minutes so as to generate a first perspective of research hypothesis. According to this, table 3 shows temporally characteristics in the data which was acquired in the process of research.

Table 3. Table of data resume.

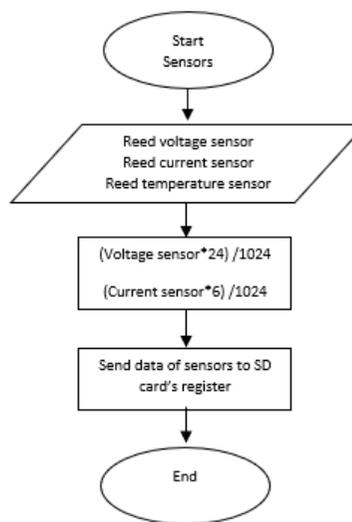
Information	Characteristics
Start date	10 of July
Ending date	10 of September
Start hour	10:00
Ending hour	14:00

In our experiment, data was recollected with autonomy through a prototype of ADQ based on Arduino from 10th of July 2017 to 10th of September 2017 completing 8 weeks. The information about technical recompilation data is in table 4.

Table 4. Characteristics of ADQ equipment.

Variable	Characteristics
$V_{IN}$	0 – 25 $V_{DC}$
$I_{IN}$	0 – 5 $A_{DC}$
Sampling time	5 minutes per sampling
Data per day	50

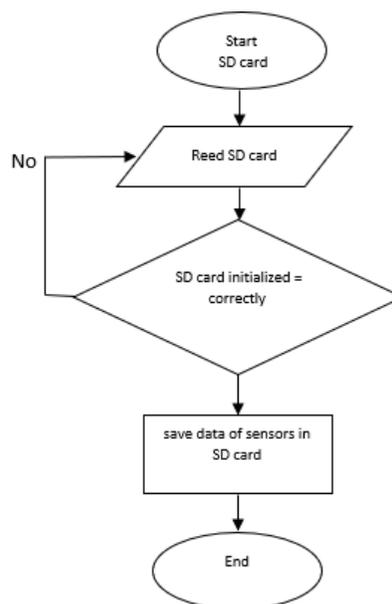
To acquire information of the sensors, it was necessary to program a code in Arduino microcontroller. In the table 2 and 4, we can find flowcharts of code program.



Graphic 1. Flow chart of DAQ.

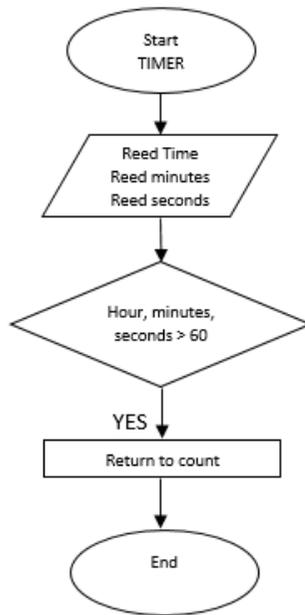
Three important parts in the algorithm can be seen in graphs: the illustration 1 describes the flow chart of measurement in which was contemplate whole variables in our project, as for example temperature.

Graphic 2 explains a flow chart that permits storing data in SD card with autonomy and real time. Moreover, this system allows to have security in our prototype.



Graphic 2. Flow chat of storage data.

Graphic 3 illustrates a flow chart where it can be seen how the timer of the Arduino was programmed, and it is clear that a counter was programmed in the code which changes each second in order to count time respectively.



Graphic 4. Flow chart of timer.

## Results and discussion

It can be seen that at the end of eight weeks, we obtained 50 data samples each one with an interval of 5 minutes. In the table 5, 6, 7, 8, 9 and 10, this information can be see it.

Tables 5 and 8 compare information about temperature during the whole phases of measurement. Firstly, in the table 5, three variables such as the photovoltaic cell without the correction of the temperature, the correction of this made by the TEC and the atmospheric temperature where were installed the PV cell is compared.

It can be clearly seen that tables 6 and 9 allow to analyze the previous information about the typical variables as for example voltage and current that were measured in the cell according to the atmospheric conditions and radiation in the cities.

Finally, tables 7 and 10 show the results obtained after the use of Peltier cell as cooling module in the photovoltaic panel. It can also be noted that current and voltage have been compared in tables named previously.

### Results of La Mesa

Table 5. Comparison of temperature in the photovoltaic cell.

Time	Temperature PV Cell without TEC (°C)	Temperature PV Cell with TEC (°C)	Atmosphere Temperature (°C)
10:00	28,10	28	24
10:05	29,4	27,8	24
10:10	30,8	25,5	24
10:15	31	21	24
10:20	31,6	18,5	24
10:25	32	14,5	24
10:30	32,4	14,9	24
10:35	33	16	25
10:40	33,3	17	25
10:45	34	17,5	25
10:50	35,2	18,2	25
10:55	35,7	19	25
11:00	36	19,6	26
11:05	37,5	20	26
11:10	38	20,5	26
11:15	39,4	21	26
11:20	39,5	21,4	26
11:25	40,2	21,8	26
11:30	40,9	22,5	26
11:35	41,3	23	27
11:40	42,2	23,8	27
11:45	42,9	24,1	27
11:50	41,1	23	27
11:55	41,4	23,5	27
12:00	42,6	24,5	27
12:05	43,5	25,6	27
12:10	44,1	26	27
12:15	44,5	26,4	27
12:20	43	24,5	27
12:25	44,7	26	27
12:30	45,1	26,3	27
12:35	44,2	26	27
12:40	41,2	23,4	27
12:45	43,8	24,5	27
12:50	42,5	24,1	27
12:55	41,7	23	27
13:00	42,3	23,5	27
13:05	43	25,3	27
13:10	41,3	23,4	27
13:15	44,5	26,3	27
13:20	42,7	24,5	27
13:25	43,2	25,6	27
13:30	40,2	21,8	27
13:35	41,5	23	27
13:40	40,1	21,8	27
13:45	40,6	22,5	27
13:50	39,8	21,4	27
13:55	39,6	21	27
14:00	40,2	21,8	27

**Table 6.** Sampling of voltage and current without TEC.

Time	Voltage (V) without TEC	Current (A) without TEC
10:00	6,226	0,202
10:05	6,226	0,198
10:10	6,216	0,194
10:15	6,116	0,196
10:20	6,016	0,19
10:25	5,965	0,185
10:30	5,945	0,183
10:35	5,985	0,181
10:40	5,895	0,185
10:45	5,845	0,176
10:50	5,825	0,175
10:55	5,775	0,177
11:00	5,725	0,166
11:05	5,705	0,173
11:10	5,685	0,171
11:15	5,655	0,17
11:20	5,635	0,172
11:25	5,615	0,175
11:30	5,585	0,17
11:35	5,515	0,175
11:40	5,475	0,166
11:45	5,335	0,169
11:50	5,555	0,165
11:55	5,515	0,167
12:00	5,365	0,162
12:05	5,325	0,159
12:10	5,285	0,155
12:15	5,265	0,157
12:20	5,325	0,157
12:25	5,245	0,159
12:30	5,235	0,155
12:35	5,285	0,157
12:40	5,555	0,166
12:45	5,325	0,155
12:50	5,335	0,162
12:55	5,515	0,169
13:00	5,475	0,165
13:05	5,325	0,167
13:10	5,555	0,159
13:15	5,245	0,17
13:20	5,335	0,177
13:25	5,325	0,168
13:30	5,615	0,171
13:35	5,515	0,177
13:40	5,625	0,174
13:45	5,615	0,188
13:50	5,635	0,175
13:55	5,645	0,176
14:00	5,625	0,176

**Table 7.** Sampling of voltage and current with TEC.

Time	Voltage (V) with TEC	Current (A) with TEC
10:00	6,236	0,202
10:05	6,265	0,216
10:10	6,285	0,246
10:15	6,325	0,236
10:20	6,515	0,218
10:25	6,555	0,245
10:30	6,585	0,245
10:35	6,555	0,236
10:40	6,555	0,236
10:45	6,525	0,236
10:50	6,515	0,236
10:55	6,515	0,216
11:00	6,495	0,216
11:05	6,485	0,218
11:10	6,485	0,22
11:15	6,455	0,216
11:20	6,455	0,216
11:25	6,425	0,22
11:30	6,425	0,206
11:35	6,415	0,205
11:40	6,415	0,202
11:45	6,385	0,21
11:50	6,385	0,202
11:55	6,355	0,211
12:00	6,355	0,202
12:05	6,315	0,198
12:10	6,315	0,211
12:15	6,285	0,211
12:20	6,355	0,202
12:25	6,315	0,211
12:30	6,285	0,211
12:35	6,315	0,211
12:40	6,355	0,206
12:45	6,355	0,202
12:50	6,385	0,21
12:55	6,415	0,202
13:00	6,355	0,205
13:05	6,315	0,198
13:10	6,355	0,206
13:15	6,315	0,211
13:20	6,355	0,21
13:25	6,315	0,213
13:30	6,425	0,22
13:35	6,415	0,215
13:40	6,425	0,22
13:45	6,425	0,206
13:50	6,455	0,216
13:55	6,455	0,216
14:00	6,425	0,222

## Results of Girardot

**Table 8.** Comparison of temperature in the photovoltaic cell.

Time	Temperature PV cell without TEC (°C)	Temperature cell PV cell with TEC (°C)	Atmosphere Temperature (°C)
10:00	33,00	31	33
10:05	34,40	28,8	33
10:10	35,80	26,5	33
10:15	36,00	24	33
10:20	37,60	22,5	33
10:25	38,00	21,5	33
10:30	39,40	21,9	33
10:35	40,00	23	33
10:40	41,30	24,5	33
10:45	42,00	25,6	33
10:50	45,20	26,2	33
10:55	46,70	27	33
11:00	48,00	29,6	33
11:05	49,50	30	34
11:10	50,00	30,5	34
11:15	51,40	31	34
11:20	52,50	31,4	34
11:25	51,20	30,5	34
11:30	52,90	29,5	34
11:35	51,30	30	34
11:40	52,20	29,8	34
11:45	52,90	30,1	34
11:50	51,10	31	34
11:55	51,40	30,5	34
12:00	52,60	32	34
12:05	53,50	30,6	34
12:10	52,10	30	35
12:15	52,50	30	35
12:20	52,50	30	35
12:25	51,70	29,5	35
12:30	51,10	29,3	35
12:35	52,20	31	35
12:40	52,20	30,4	35
12:45	51,80	28,4	35
12:50	52,50	28,1	35
12:55	51,70	29	35
13:00	52,30	32	35
13:05	51,00	30	35
13:10	51,20	31	35
13:15	52,40	32,3	35
13:20	51,30	31,3	35
13:25	51,00	30,8	35
13:30	50,80	30,5	35
13:35	50,70	30	35
13:40	49,50	28,8	35
13:45	49,00	28	35
13:50	50,30	29,5	35
13:55	50,20	29,5	35
14:00	50,20	29,1	35

**Table 9.** Sampling of voltage and current without TEC.

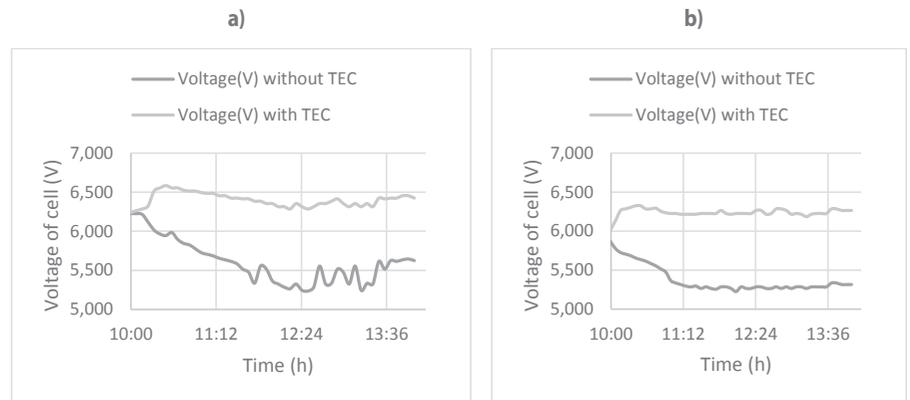
Time	Voltage (V) without TEC	Current (A) without TEC
10:00	5,865	0,185
10:05	5,775	0,176
10:10	5,725	0,177
10:15	5,705	0,173
10:20	5,685	0,173
10:25	5,655	0,171
10:30	5,635	0,17
10:35	5,615	0,17
10:40	5,585	0,166
10:45	5,555	0,166
10:50	5,515	0,155
10:55	5,475	0,155
11:00	5,365	0,163
11:05	5,335	0,163
11:10	5,315	0,161
11:15	5,295	0,163
11:20	5,285	0,161
11:25	5,295	0,163
11:30	5,265	0,159
11:35	5,285	0,163
11:40	5,265	0,159
11:45	5,255	0,159
11:50	5,285	0,165
11:55	5,285	0,163
12:00	5,265	0,159
12:05	5,225	0,155
12:10	5,285	0,155
12:15	5,265	0,157
12:20	5,265	0,157
12:25	5,285	0,159
12:30	5,285	0,155
12:35	5,265	0,157
12:40	5,265	0,163
12:45	5,285	0,155
12:50	5,265	0,162
12:55	5,285	0,163
13:00	5,265	0,165
13:05	5,285	0,167
13:10	5,285	0,163
13:15	5,265	0,162
13:20	5,285	0,177
13:25	5,285	0,168
13:30	5,285	0,163
13:35	5,285	0,163
13:40	5,335	0,163
13:45	5,335	0,161
13:50	5,315	0,161
13:55	5,315	0,161
14:00	5,315	0,161

Table 10. Sampling of voltage and current with TEC.

Time	Voltage (V) with TEC	Current (A) with TEC
10:00	6,016	0,194
10:05	6,136	0,202
10:10	6,265	0,211
10:15	6,285	0,226
10:20	6,305	0,218
10:25	6,325	0,236
10:30	6,325	0,236
10:35	6,285	0,218
10:40	6,285	0,218
10:45	6,295	0,211
10:50	6,255	0,211
10:55	6,235	0,202
11:00	6,226	0,194
11:05	6,226	0,194
11:10	6,216	0,194
11:15	6,216	0,216
11:20	6,216	0,19
11:25	6,216	0,194
11:30	6,226	0,194
11:35	6,226	0,194
11:40	6,226	0,194
11:45	6,226	0,194
11:50	6,265	0,202
11:55	6,226	0,202
12:00	6,216	0,196
12:05	6,226	0,211
12:10	6,226	0,202
12:15	6,226	0,202
12:20	6,226	0,202
12:25	6,265	0,202
12:30	6,265	0,211
12:35	6,216	0,196
12:40	6,226	0,206
12:45	6,285	0,202
12:50	6,285	0,211
12:55	6,265	0,202
13:00	6,216	0,196
13:05	6,226	0,202
13:10	6,216	0,202
13:15	6,185	0,196
13:20	6,216	0,196
13:25	6,226	0,202
13:30	6,226	0,202
13:35	6,226	0,211
13:40	6,285	0,232
13:45	6,285	0,232
13:50	6,265	0,202
13:55	6,265	0,202
14:00	6,265	0,202

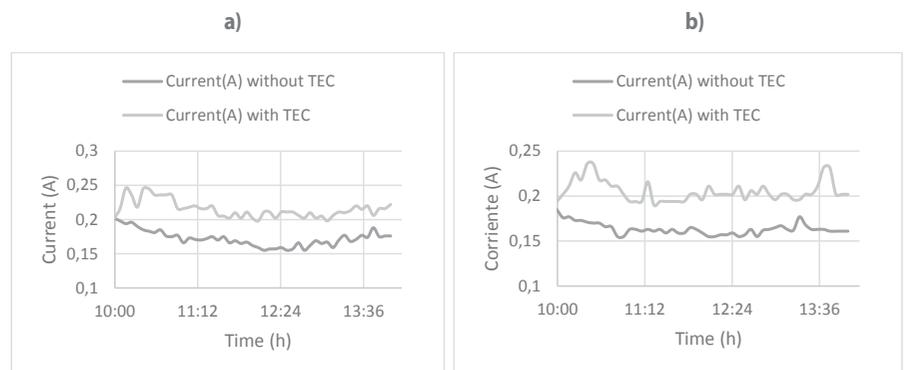
### Discussion

It is notable that the improvement of energy generation in the photovoltaic cell is notable in graphics. Nevertheless, when the variables were analyzed separately, we can observe a slight difference in data between Girardot and La Mesa. This information will be discussed in the following two paragraphs in order to clarify which is more profitable in terms of voltage and current.



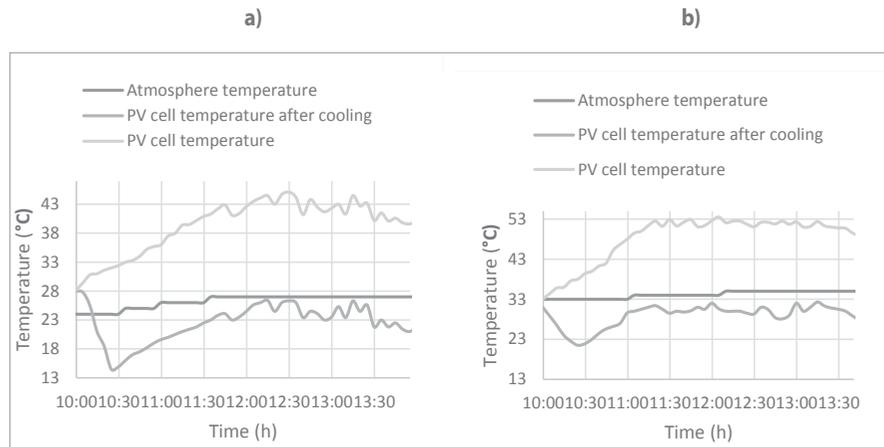
Graphic 5. Voltage with TEC and without TEC vs Time a) La Mesa b) Girardot.

Graphic 4 illustrates that the voltage rose substantial in the PV cell after the system with TEC was used. Furthermore, the higher point of energy generation occurs when the orientation of the systems is perpendicular to solar radiation angle. Also, we can see that in the voltage illustration, La Mesa and Girardot had different behavior because of their location and height. The biggest rise was seen in La Mesa climbed steady to about a 20,40% whereas, Girardot increases approximately up to 19,37%. Interestingly, it is noticed that the correction of the temperature allows to stabilize the generation of voltage in the solar cell. On the other hand, the capacity of voltage generation dropped gradual without prototype TEC.



Graphic 6. Current without TEC and with TEC vs Time a) La Mesa b) Girardot.

In terms of intensity, the lines graph show a slowly constant improvement while the TEC system was not working. In detail, it is evident that in La Mesa, there was a slightly growth of current of approximately 36.13% while, Girardot had an increment just about under 44% which was roughly at 12:10 PM.



Graphic 7. Comparison of temperature on PV cell a) La Mesa b) Girardot.

In relation with temperature in PV cell without TEC, we noticed that this was far higher than the atmosphere temperature. Thus, the cell temperature in La Mesa had a significantly increase of about 67,04%. Similarly, there was an upward in Girardot cell's temperature just under 57.35%. In conclusion, we can see that temperature in the solar panel might be twice the atmosphere temperature.

In our experiments, the hybrid system TEC-PV causes a correction of temperature in the solar panel. It means that the function of Thermoelectric Cooler in the prototype does not allow an increment of temperature in the cell. Thus, the minimal solar panel temperature registered in mesa and Girardot were 14.5 °C and 21.5 °C respectively, which is far less that the ideal typical conditions of measurement.

## Conclusions

- When temperatures are below 25 °C which is the ideal working conditions for solar panel, it allows the photovoltaic cell to have better results being congruent with the measurements obtained.
- The research was developed based on measures of voltage and current which have no ideal conditions given by the manufacturer, having the option to analyze the solar panel under real conditions.
- The data collection of the research was implemented in the transition between winter solstice and the summer solstice, which generate not enough data to analyze what is the behavior of the hybrid prototype in each solstice. However, improvements can be made if the PV-TEC model will be measured over a longer period.
- When the control of temperature was applied in the photovoltaic cell, there was a percentage improvement in the generation of energy in both intensity and voltage.
- The cell of Peltier TEC makes the process slightly inefficient, because the energy consumption in the thermoelectric cooler is bigger than the energy which is generated by the solar panel.
- A determinant factor in the generation of electric energy through photovoltaic cells is the temperature both environmental and on the plate. Since a consi-

derable improvement in the throughput of the panel is obtained, when the temperature can be controlled.

- This first stage of the research proposes to continue in the search and development of prototypes that allow the improvement of photovoltaic energy efficiency with better performance.

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