American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-11, pp-21-28
www.ajer.org
Research Paper Open Access

International Journal of Current Trends in Engineering & Technology Seeing beyond the surface, Understanding the Design, Construction and Testing of a Solar Powered Thermoelectric Cooler

Eze, Blessing E.
Department of Computer Engineering, The Federal Polytechnic, Ilaro, Ogun State. Nigeria.

ABSTRACT: Thermoelectric cooler is a cooling system which uses thermoelectric module as its means of cooling instead of the conventional means of cooling. The objective of this is to design thermoelectric cooler using a solar power as a source of energy due to unstable power supply and high consumption of electricity in the country. Thermoelectric coolers are environmentally safe, much quieter, have no moving parts, almost virtually vibration free and consume less electricity compared to regular refrigerators. Thermoelectric cooler uses the pettier effect to create a heat flux between the junctions of two different types of materials. At the completion of this work, it took four hours before the total coldness could be felt in the cooler box and great reliability of the work was achieved.

Keywords: Thermo-Electric module, Peltier circuit, Solar Panel

---

Date of Submission: 17-10-2017 Date of acceptance: 04-11-2017

I. INTRODUCTION

A. Overview

In the mid-1990s NASA JSC began work on a solar powered refrigerator that used phase change material rather than battery to store "thermal energy" rather than "chemical energy." The resulting technology has been commercialized and is being used for storing food products and vaccines. Solar-powered refrigerators and other solar appliances are commonly used by individuals living off-the-grid. Solar refrigerators are also used in cottages and camps as an alternative to absorption refrigerators, as they can be safely left running year-round.

B. Objective

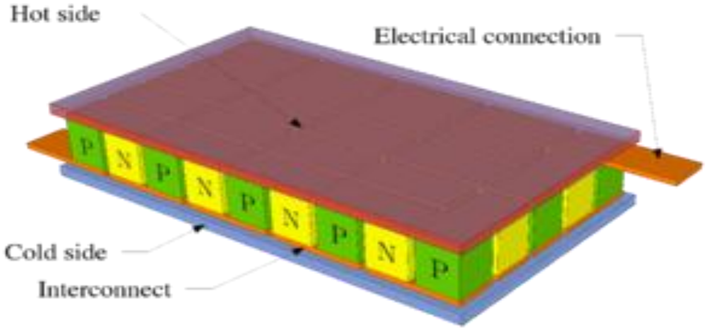
The main objective of this project focused on the design of refrigerator that uses thermoelectric modules has a means of cooling system. Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two difference types of materials. A Peltier cooler is a solid state active heat pump which transfers heat from one side of the device to the other with consumption of electrical energy, depending on the direction of the current.

C. Applications

This project was able to designed and construct a cooler using thermoelectric module instead of the convection means of cooling (using of refrigerant) in other to reduce environmental pollution. Thermoelectric cooling systems have advantages over conventional cooling devices such as compact in size, light in weight, high reliability, no mechanical moving part and no working fluid.

II. LITERATURE REVIEW

Thermoelectric cooling uses the pettier effect to create a heat flux between the junctions of two difference types of materials. A pettier cooler is a solid state active heat pump which transfers heat from one side of the device to the other with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a pettier device or pettier heat pump. It can be use either for heating or for cooling (Taylor R.A, and Solbrekken G., 2013). Although in practice the main application is cooling and can be used as a temperature controller that either heats or cools (Thermoelectric coolers basics, 2013).



Fg 1: electronic configuration of thermoelectric couple.

The primary advantages of a Peltier cooler compared to a vapour compression refrigerator are its lack of moving parts or circulating liquid, very long life, invulnerability to leaks, small size, and flexible shape. Its main disadvantages are high cost and poor power efficiency. A Peltier cooler can also be used as thermoelectric generator. When operated as a cooler, a voltage is applied across the device, and as a result a different in temperature will build up between the two sides (Tellurex, 2013). When operated as a generator, one side of the device is heated to a temperature greater than the other side, and as a results a difference in voltage will be build up between the two sides(the seebeck effect).However, a well designedPeltier cooler will be mediocre thermoelectric generator and vice versa, due to different design and packaging requirements.

Karimi et al. (2011) Analyzed and fabricated a new device with multistage or stack of single stage TE module. Multi-stage thermoelectric coolers offer larger temperature differences between heat source and heat sink than single or two stage thermoelectric coolers. The study concludes that multistage TER system allows use of heat sink with higher thermal resistance which helps in improvement of COP (Karimi et al., 2011).

Roeb M. et al. (2011). In this article author has present and describe the realization and successful test operation of a 100kw Pilot plant for two step solar thermo-chemical water splitting on a solar tower at the platform Solar de Almeria which aims at the demonstration of the feasibility of the process on a solar tower platform under real condition.

Muhammad Hanif Khalil et al.,(2012),The research study is on development and performance evaluation of a solar thermal collector that warms up air as transferring medium of heat for drying of grains. The statistical analysis showed that increase 1 in mass flow rate significantly ($P > 0.003$) increases the performance of the solar collector. Also there was decrease in performance by the change of months of year. The efficiency was 10% higher in November 2011 as compared to January 2012.

Serag-Eldin M.A.(2013), described thermal storage design to store hot water at a temperature of around 180°C required for running a double effect absorption chiller to cool a zero-energy-house in a desert environment. It was demonstrated that high storage efficiency may be reached, providing that appropriate insulation materials are used. It is also revealed that the soil conductivity has little effect on storage efficiency.

Ghassan M. Tashtoush, (2012), A statistical ANOVA approach was used to analyze and to optimize the solar adsorption refrigeration unit for general applications. It was found that the coefficient of performance of a SAR system does not depend sharply on the evaporator temperature without any relation of the system conditions. Instead COP depends significantly on condenser temperature; type of couple used in the refrigeration system and on some factors that concern about the design such as surface areas. From the optimization model the maximum value of COP where found under low condenser temperature below 27º C and at high generator temperature above 80º C.

II. METHODOLOGY

The project focused on the design of refrigerator that uses thermoelectric modules has a means of cooling system. Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two difference types of materials.

Suppose,
Load = 800 Watts
Inverters Rating =?
Required Backup time for batteries = 3 Hours
Required No of Solar Panel =?
No of batteries =?

Solution:

Inverter should be greater 25% than the total Load
800 x (25/100) = 200
800+200 = 1000 Watts
Suppose we are going to install 100Ah, 12 V batteries,
12V x 100Ah = 1200 Wh
Now for One Battery (i.e. the Backup time of one battery)
Therefore, 3/1.5 = 2→ i.e. we will now connect two (2) batteries each of 100Ah, 12V.
If the number of batteries given, and you want to know the Backup Time for these given batteries, then Use this formula.
1200 Wh x 2 Batteries = 2400 Wh
2400 Wh / 800 W = 3 hours.
So this is a 12 V inverter system. Now we will install two (2) batteries (each of 12V, 100 Ah) in Parallel.

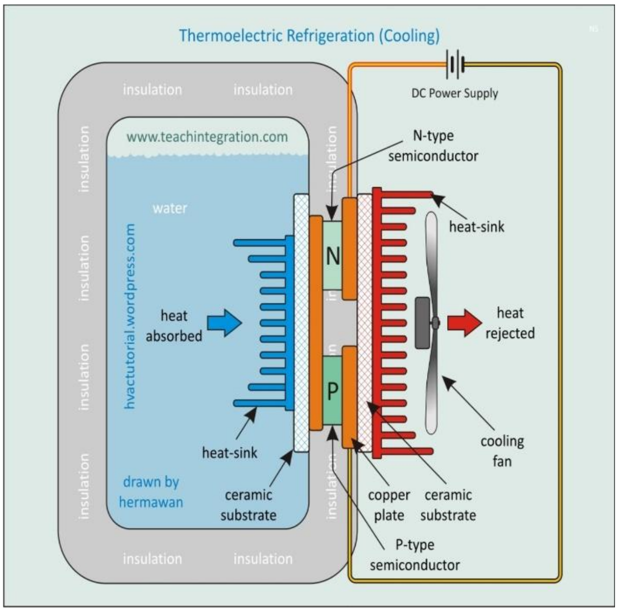
Why Batteries in Parallel, not in Series?
In parallel Connection, Voltage will be same in each wire or section, while current will be different i.e current is additive e.g. I1+I2+I3…+In = 100Ah +100Ah = 200Ah
In Series Circuits, Current is same in each wire or section while voltage is different i.e. Voltage is additive e.g.V1+V2+V3….Vn.
For The above system if we connect these batteries in series instead of parallel, then
The rating of batteries become V1+V2 = 24V while the current rating would be same i.e.100Ah.
We will now connect 2 batteries in parallel (each of 100Ah, 12V)
Therefore for 2 Batteries,
200 Ah 12V,
200Ah x (1/10) = 20A
Now the required No of Solar Panels
P = VI
P = 12V x 20 A
P = 240Watts
This is our required watts for solar panel (only for battery charging, and then battery will supply power to the load)
Now
240W/60W = 4 Solar panels
This was only for battery Charging (and then battery will supply power to the desired Load) i.e. for those electrical appliances, which will get power through inverter (from charged batteries)
In this case, required current (20 A for Batteries Charging and 10 A for direct connected load through Inverters during sunshine only but batteries will be also charging while panel supply power to the direct connected load.
In this case, total current,
20A + 10 A = 30A
360/60W = 6
Therefore, we will Connect 6 No of Solar panels (each of 60W, 12V, 5A)
And we use Charge Controller about ampere rating i.e, the charging current for 200Ah battery is 20-22 Amperes (22A (For Battery charging) +10A (for direct DC Load). So we can use a charge controller about 30-32 Amp.

IV. CONSTRUCTION

The Solar Panel supplies the thermoelectric couple DC power. When DC power is apply to the terminals of the thermoelectric couple, it causes temperature change between the surfaces of the thermoelectric couple. One side of the thermoelectric couple gets hot and the other side gets cold. Heat sink mounted on the surface of the thermoelectric couple to absorb the heat from the thermoelectric couple. The DC fans mounted on the heat sink serve as blower for the hot sides of the thermoelectric couple facing outside and heat extractor for the cold sides inside the cooler.

A. Hardware Configuration

The thermoelectric cooler is a cooling device based on TER principle which has been widely used in military, aerospace, instrument, and industrial or commercial products, as a cooling device for specific purposes. The schematic of the thermoelectric cooler is shown in Figure below.



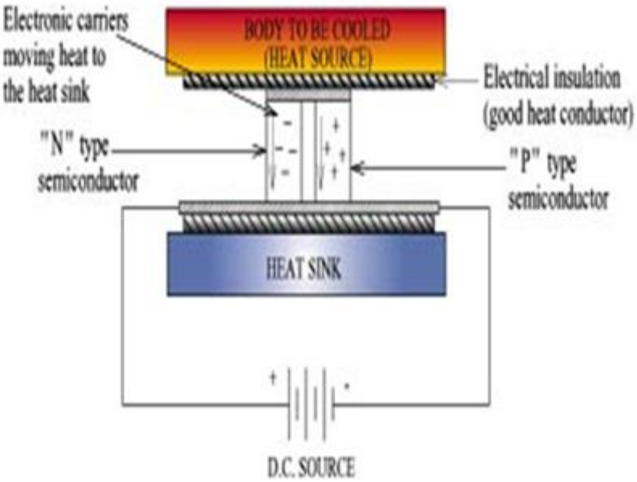
Fg2: circuit diagram of the cooling system

Thermoelectric couples are solid state devices capable of generating electrical power from a temperature gradient, known as Seebeck Effect or converting electrical energy into a temperature gradient known as Peltier Effect.

B. How the Thermoelectric Works

Thermoelectric are based on the Peltier Effect discovered in 1834, by which DC current applied across two dissimilar materials causes a temperature differential. The Peltier Effect is one of the three thermoelectric effects, the other two are known as Seebeck Effect and Thomson Effect. Whereas the last two effects act on a single conductor, but the Peltier Effect is a typical junction phenomenon

The typical thermoelectric module is manufactured using two thin ceramic wafers with a series of P and N doped bismuth-telluride semiconductor material sandwiched between them. The ceramic material on both sides of the thermoelectric adds rigidity and necessary electrical installation. The N type material has an excess of electrons while the P type material has a deficit of electrons. One P and one N make up a couple as shown in the figure below



Fg3: Cross section of a typical thermoelectric couple

The thermoelectric couples are electrically in series and thermally in parallel. A thermoelectric module can contain one to several hundred couples. As the electrons move from the P type material to the N type material through an electrical connector, the electrons jump to a higher energy state absorbing thermal energy (cold side). Continuing through the lattice of material, the electrons flow from the N type material to the P type material through an electrical connector, dropping to a lower energy state and releasing energy as heat to the heat sink (hot side).

Thermoelectric can be used to heat or to cool, depending on the direction of the current. In an application requiring cooling, the designed focused on the cooling mode.

C. Thermal Parameters Needed

The appropriate thermoelectric for an application depends on at least three parameters, these parameters are the hot surface temperature (Th), the cold surface temperature (Tc), and the heat load to be the absorbed at the cold surface (Qc) .

The hot side of the thermoelectric is the side where heat is released when DC power is applied. This side is attached to the heat sink when using an air cooled heat sink (natural convection), the hot side was determined by using the formulae below:

Th = Tamb + Ө(Qh)……………… (i)

Where,

Th= the hot side temperature (oc)

Tamb = the ambient temperature (oc)

Ө = thermal resistance of heat exchanger (oc/watt)

Qh = Qc+ Pin --------------------- (ii)

Where,

Qh = the heat released to the hot side of the thermoelectric (watts)

Qc = the heat absorbed from the cold side (watts).

Pin = the electrical input power to the thermoelectric (watts).

The thermal resistance of the heat sink causes a temperature to rise above ambient. If the thermal resistance of the heat is unknown, then estimate of acceptable temperature rise above ambient are:

Natural convection 20oc to 40oc

Forced convection 10oc to 15oc

Liquid cooling 2oc to 5oc (rise above the liquid coolant temperature)

The heat sink was a key component in the assembly. A heat sink that is too small means that the desired cold side temperature may not be obtained.

The cold side of the thermoelectric is the side that got cold when DC is applied. This side is may need to be colder than the desired temperature of the cool object. This is especially true when the cold is not in direct contact with the object such as when cooling an enclosure. The temperature difference across the thermoelectric (T) related to Thand Tc according to equation below

T = Th – Tc……… (iii)

The thermoelectric performance curves in fg. 2 and 3 shows the relationship between T and the other parameters.

Estimating Qc, the heat load in watts absorbed from the cold side is difficult because all thermal loads in the design must be considered. Among these thermal loads are:

1. Active: I2R heat load from the electronic devices any load generated by chemical reaction
2. Passive:(i) Radiation (heat loss between two close objects with difference temperature).

(ii) Convection (heat loss through the air, where the air has difference temperature than the object)

(iii) Conduction losses (heat loss through leads and screws e.t.c.)

(iv)Transient load (time required to change temperature of an object)

D. Powering the Thermoelectric

All thermoelectric are rated for Imax, Vmax, Qmax, and Tmax, specific value of Th. Operating at or near the maximum power is relatively in efficient due to internal heating (Joulian heat) at high power. Therefore, thermoelectric generally operate with 25% to 80% of the maximum current. The input power to the thermoelectric determined the hot side temperature and cooling capability at a given load.

Has the thermoelectric operates, the current flowing through it has two effects: (1) the Peltier effect (cooling) and (2) the Joulian effect (heating). The Joulian effects is proportional to the square of the current, therefore as the current increases the joule heating dominate the Peltier cooling and causes a loss in Net cooling. This cut-off defines Imax for thermoelectric.

For each device, Qmax, is the maximum heat load that can be absorbed by the cold side of the thermoelectric. This maximum occur at Imax, Vmax, and with T= 0oc. the Tmax value is the maximum temperature difference across the thermoelectric. This maximum occur at Imax, Vmaxand with no load (Qc= 0 watt). These values of Qmaxand Tmaxare shown on the performance curve below as the end points of the Imax line.

E. Other Parameters Considered

i. The material used for the assemble component deserved careful thought. The heat sink and cold side mounting surface was made out materials that have high thermal conductivity (i.e copper) to promote heat transfer. The insulation and assemble hardware used was made of material that have low thermal conductivity (i.e polyurethane foam) to reduced heat loss.

ii. Environmental concerned such has humidity and condensation on the cold side was alleviated by using copper sealing method.a parameter seal in the diagram below protect the couple from contact with water or gasses, eliminating corrosion, thermal and electrical short that can damage the thermoelectric module.

iii. Power supply and temperature control were addition items that was considered for a successful thermoelectric system. Because it operate on DC. Voltage, any AC component on the DC is detrimental. Degradation due to ripple was approximated by:

$$T/\quad Tmax = 1/(1 + N2)$$

Where N = % current ripple.

iv. The temperature was controlled using open loop technique approached

The importance of other factors such as the thermoelectric footprint, its height, its cost, the available power supply and type of heat sink was considered.

F. Selections of Materials

Thermoelectric cooler (TEC1- 12706): The 127 couples, 40 mm × 40 mm size single module which is made of high performance to achieve superior cooling performance and 70°C or larger delta Tmax, is designed for superior cooling and heating applications. The TEC1 – 12706 was responsible for the cooling effect.

G. Construction Procedure

i. Surface Preparation

The mounting surface was flat to less than 0.08mm over the mounting area. Also the surface was cleaned and free from oil, nicks and burrs.

ii. Mounting the Thermoelectric Module to the Heat Sink

Since there is no permanent bond between the heat sink and the thermoelectric module, mounting with the compression method was used.

Step one: I prepared the heat sink and cold sink surfaces by matching the module area to within +/- 0.03mm.

Step two: I removed all burrs. Then the mounting surfaces was cleaned and prepared the mounting surface with methanol.

Step three: I applied a thin 0.05mm layer of thermal paste to the hot side of the thermoelectric cooler. I placed the cooler on the heat sink and rotate the cooler back and forth, squeezed out excess thermal past until resistance is felt.

Step four: I repeated step three and rotate cold plate back and forth, squeezed out excess thermal paste.

iii. Connecting Wire to the Header

Step one: the excess wire was trimmed from the thermoelectric cooler. The lead wires ¾ of a turn around the connector post on the header.

Step two: a solder and burrs mounting flux was used to solder the lead wire to the wire post. The outline wire was visible but welled covered. Excess solder was wick off with the soldering iron.

iv. Final Cleaning and Inspection

Step one: both the header and the thermoelectric cooler was rinsed in hot water, then scrubbed with cleaning solution and then rinsed again with hot water. Excess flux residue around the pins was brushed away. It was wash with hot water and dried with force air.

Step two: the solder joint was checked for crack and bubbles

v. Lead Wire Attachment

The female spade lug was inserted over the lead tab. A side-to-side motion was used to secure the lug on the tab.

vi. Fitting of DC Fans

After the mounting of the heat sink on the thermoelectric cooler, a DC fan was mounted on the heat sink of the hot side to serve as a blower to the heat sink. On the cold side, another DC fan was attached to the heat sink to serve as heat extractor.

vii. Fabrication

One side of the cooler box was cut using a cutter in other to fit the thermoelectric, heat sink, and the DC fan to it. The cold side of the thermoelectric couple was placed in such a way that it faced inside the box, while the hot

side facing outside. A screw and nut was used to hold the devices firmly to the cooler in other to avoid lagging and to avoid heat loss.
Vmax = 12V
Pmax = Imax * Vmax
Pmax = 6 * 12 =72 watts
For the DC fan:
Imax =0.9amps
Vmax = 12V
Pmax = 0.9 * 12 = 10.8watts
For the battery:
Imax = 0.6amps
Vmax = 12V
Pmax = 0.6 * 12 = 7.2amh
Therefore, the solar panel suitable for the construction is 80watts, 12V solar panel.

V. RESULTS AND DISCUSSION

Before the coupling of the thermoelectric module to the cooler, the performance of the thermoelectric module was tested using computer power pack to determine the functionality and the time consumed before the thermoelectric module can cold a substance. The reason why computer pack was used is that in other to get the thermoelectric module to its maximum operation, it required constant power supply which cannot be obtained by solar panel due to variation of the intensity of the sunshine. At each stage, each of the components used was put into test to confirmed there workability. After the completion of the thermoelectric cooler, it was put into test using solar panel as the source of energy which worked perfectly.

a. Presentation of Results

When the thermoelectric was being test using system power pack. It took the thermoelectric couple about 2 hours of undisturbed power supply for the total coldness could be felt in the cooler box. When the thermoelectric couple was connected to the solar panel as a source of energy, it took more than 4 hours before the total coldness could be felt in the cooler box.

b. Discussions of the Results

The output voltage supply from the solar panel depends on the intensity of the sun rays. The higher the intensity of the sun, the higher the power supply to the thermoelectric couple. The result shows that the best operation of the thermoelectric was obtained during the time range within 12pm to 3:30pm (during this period the sun intensity is always high). During this period the voltage supplied from the solar panel to thermoelectric is usually within the range of 11.5v to 12v. And the current is within the range of 3amps to 4amps.

VI. CONCLUSION

This project was able to designed and construct a cooler using thermoelectric module instead of the convection means of cooling (using of refrigerant) in other to reduce environmental pollution. Thermoelectric cooling systems have advantages over conventional cooling devices such as compact in size, light in weight, high reliability, no mechanical moving part and no working fluid.

VII. RECOMMENDATION

Further research should be carried out on this topic based on the following reasons:

1. Since the thermoelectric couple has two sides (hot and cold side), the next research should focus on the construction of cooler with one side for frozen and the other side for de-frozen.
2. I suggested that the next project should focused on construction of thermoelectric cooler using electric power supply instead of the solar powered in other to reduce the time taken for the thermoelectric modules to reach its maximum efficiency.

REFERENCES

[1] Astrain D., Vián J., and Domınguez M., (2003). "Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation," Applied Thermal Engineering, vol. 23, no. 17, pp. 2183-2200.
[2] BBC, 30 April 2008: Keep your fridge- freezer clean, and ice.
[3] Chen J., Zhou Y., Wang H, and Wang J. T., (2002). "Comparison of the optimal performance of single - and two-stage thermoelectric refrigeration systems," Applied Energy, vol. 73, no. 3-4, pp. 285-298.
[4] Denis R. H., (2003). ‘Encyclopedia of Agriculture, Food, and Biological Engineering. CRC Press pg. 350. ISBN 978-0-8247-0938-9.

[5] Ghassan M. Tashtoush, (2012). ‘A statistical Approach to Optimize the Solar Adoption Refrigeration System’. Journal for Energy Science and Technology vol. 3, No 2 pg 18 -28.

[6] Karimi G., Culhamand J. and Kazerouni V., (2011). "Performance analysis of multi-stage thermoelectric coolers," International Journal of Refrigeration, vol. 34, no. 8, pp. 2129-2135.

[7] Luoet H. L., Wang R.Z., Dai Y.J., Wu J.Y., Shen J.M, and Zhang B.B., (2007). “An efficient Solar Powered Adsorption Chiller and its Application in Low Temperature Grain Storage’’ Journal for Solar energy Vol. 81 PP. 607-613.

[8] Muhammad Hanif Khalil, Mansoor Khan Khattack, Mazullah Khan, and Aamir Khan, (2012), ‘Development and Evaluation of a Solar Thermal Collector Designed for Drying grain Iranica Journal of Energy & Environment” Vol 3 (4): pg. 380-384.

[9] Refrigerator – Adjusting Temperature Controls. Retrived Date 06 oct. 2016 from http://www.geappliances.com

[10] Roeb M. , Jan-Peter Sack, Rietbrock P. Konstandopoulos A. G., (2011). “Test Operation of a 100kw Pilot Plant for Solar Hydrogen Production from Water on a Solar Tower Journal of Solar energy” Vol. 85 pg. 634-644

[11] Rowe D. and Min G., (2006.). "Experimental evaluation of prototype thermoelectric domestic refrigerators," Applied Energy, vol. 83, pp. 133-152.

[12] Riffat S. and Qiu G., (2004). "Comparative investigation of thermoelectric air conditioner versus vapour compression and absorption air conditioners," Applied Thermal Engineering, vol. 24, pp. 1979-1993.

[13] Serag-Eldin M. A., (2013). ‘Design of a chilled Water Storage Unit for Solar Air Conditioning’. Journal of sustainable Energy, Vol. 32(5) pg 107-116,

[14] Taylor, R.A., Solbrekken, G., (2013).” comprehensive system – level optimization of thermoelectric devices for electronic cooling application” component and packaging technologies, IEEE transactions volume 31, issue 1

[15] Tellurex (retrieved date 2016, September) “frequently ask questions about TEC product” www.tellurex.com/wp.content/

[16] Thermoelectric cooler basics “TEC Microsystems’(retrieved 2016, September 16) www.tecmicrosystems.com

[17] Design and Construction of Solar Operated Thermo-Electric Heating and Cooling System http://www.ijetae.com/files/Volume6Issue3/IJETAE_0316_14, issue 1

Eze, Blessing E International Journal of Current Trends in Engineering & Technology Seeing beyond the surface, Understanding the Design, Construction and Testing of a Solar Powered Thermoelectric Cooler.” American Journal of Engineering Research (AJER), vol. 6, no. 11, 2017, pp. 21-28.