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Fabrication of Solar based Thermoelectric Refrigerator

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Abstract : A substantial portion of the population in developing nations continues to suffer from the absence of electrification, particularly in rural and off-grid regions where refrigeration is essential for the preservation of food and pharmaceutical products. The lack of grid-based power infrastructure, coupled with the environmental drawbacks of conventional refrigeration methods-such as low efficiency and significant greenhouse gas emissions from combustible fuels-necessitates the exploration of sustainable alternatives. Solar energy offers a viable solution for low temperature applications, with three major approaches identified: photovoltaic(PV)-powered refrigeration, solar absorption systems, and solar mechanical systems. Among these, PV-powered thermoelectric refrigeration stands out due to its portability, simplicity, and environmental compatibility. Commonly referred to as a “freezer on wheels," this system is compact, fluorine-free, and devoid of moving parts, making it suitable for decentralized and mobile deployment. This study presents the design and performance evaluation of a solar-powered thermoelectric refrigeration system developed to serve energy-deficient areas. The system demonstrated effective instantaneous cooling and achieved a coefficient of performance (COP) of 3.7 under standard conditions. The proposed solution not only addresses critical off-grid refrigeration needs but also contributes to sustainable development goals by minimizing dependency on fossils fuels and reducing environmental impact.

I. Introduction

1.1About solar based thermoelectric refrigerators

Refrigerators used in daily life are one of the indispensable tools. Uninterrupted power should be supplied to refrigerators in order to maintain cooling service. Photovoltaic (PV) systems provide an independent, reliable electrical power source at the point of use, making it particularly suited to remote locations. For this reason, nowadays, the use of PV solar energy in refrigeration has been increasing in rural regions. But, the design conditions and operating performance of a PV-refrigeration system are significantly affected by local climatic conditions. In this study, a PV-powered multi-purpose refrigerator system has been established to investigate experimentally its daily and seasonal operating performance. Operational parameters affecting system capacity and performance were determined under a semi-arid climate condition of Anliurfa province in Turkey’s GAP Region. The region’s critical need for refrigeration comes also from, that it is one of the sunniest rural regions of the world. Detailed results obtained during daily experimental measurements are presented here. The results in overall reveal that, PV-refrigerator system can be reliably used at where the local grid is not continuously available whereas refrigeration need is critical.

Renewable & alternative non-conventional green energy technologies used for heat-pumping applications have shown real merits and received renewed interest in recent years especially in small scale portable heating applications. Solar-driven thermoelectric heat pumping is one of these innovative technologies [1]. Solar energy is the most low cost, competition free, universal source of energy as sunshine's throughout. This energy can be converted into useful electrical energy using photovoltaic technology. Thermoelectric heating (or cooling) technology has received renewed interest recently due to its distinct features compared to conventional technologies, such as vapor compression and electric heating (or cooling) systems. Thermoelectric (TE) modules are solid state heat pumps (or refrigerators in case of cooling) that utilize the Peltier effect between the junctions of two semiconductors. The TE modules require a DC power supply so that the current flows through the TE module in order to cause heat to be transferred from one side of the TE module to other, thus creating a hot and cold side [2, 3]. The main objective of the heating & cooling system service is to be suitable for use by the people who live in the remote areas of country where load-shading is a major problem. The system can also be used for remote parts of the world or outer conditions where electric power supply is not readily available [6]. Solar energy is one of the most well-known green sources of energy. Solar absorption refrigeration systems increasingly attract research interests. The performance of the refrigerator was simulated using Mat lab under varying operating conditions. The system consisted of the refrigeration chamber, thermoelectric modules, heat source and heat sink. When two conductors are placed in electric contact, electrons flow out of the one in which the electrons are less bound, into the one where the electrons are more bound. The performance of thermoelectric solar refrigerator was simulated using Mat lab under varying operating conditions. The system consisted of the thermoelectric solar refrigeration chamber, thermoelectric modules, heat source and heat sink[7]. Results show that the Coefficient of Performance (C.O.P) which is a criterion of performance of such device is a function of the temperature between the source and sink.

The function of compressor in the vapor compression system is to continuously withdraw the refrigerant vapor from the evaporator and to raise its pressure and hence temperature, so that the heat absorbed in the evaporator, along with the work of compression, may be rejected in the condenser to the surroundings. In vapor – absorption system, the function of the compressor is accomplished in a three step process by the use of the absorber, pump and generator or re-boiler. Solar powered refrigerators may be most normally consumed in the evaluative world to help reduce poverty and environment change[8]. By solar energy, these refrigerators are able to keep perishable goods such as meat and dairy cool in hot season and are used to keep much needed vaccines at their appropriate temperature to avoid spoilage. The portable devices can be caused with simple components and are refrigerator beneficial for areas of the developing world electricity is unreliable or non-existent. Solar refrigerator based on the thermoelectric cooling technology it's differ from the refrigerator mainly used in present time [9, 10].In this type of refrigerator, they don't have any requirement of compressor, evaporator, condenser, and not any pump also .in this refrigerator solar panel in used for power supply.

2 RESEARCH METHODOLOGY

2.1Thermoelectric Cooling

Thermoelectric cooling employs Peltier effect to create a heat flux between two different kinds of metals. A Peltier cooler, after the consumption of electrical energy, transfers heat from one side of the device to the other, depending on the direction of the current. This is a relatively new approach of cooling designed to reduce the number of moving parts and to reduce the usage of refrigerants. It is a solid state heat pump that causes heating or cooling when electric current passes through two conductors. A voltage is applied at the free ends of two dissimilar metals, which causes temperature difference. With this temperature difference, the cooling due to Peltier will cause heat to move from one end to another. This is achieved through small p-n junction semiconductors called thermoelectric modules. The absence of refrigerants makes it a more eco-friendly cooling system. Thermoelectric Modules require heat sinks, fan, and cooling arrangement. The performance and efficiency of a thermoelectric cooling system is given by its COP. A typical block diagram with thermoelectric module and the arrangement can be shown as follows:

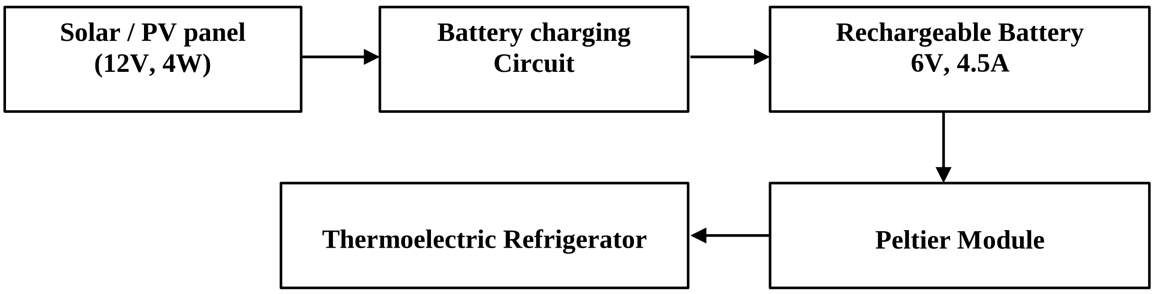


Figure 1.1: Block diagram of solar based thermoelectric refrigerator

3 Theory of Operation

3.1 Basic Concept of Energy and Power

All work with energy is founded in the First Law of Thermodynamics, also known as the Law of Conservation of Energy. It states that "The total energy of an isolated system is constant; energy can be transformed from one form to another but can neither be created nor destroyed." The word energy comes from the Greek word ergon which means work or force. In other words energy can be seen as storage of work. Work divided by time, or work performed per time unit is called power, P. Power has the unit 1 J/s or 1 W and is defined as:

$$P = \frac{dw}{dt} \quad (1)$$

Electric energy is commonly expressed as Wh or kWh. These units are mostly used to expresses the energy needed to use a device with a certain electric power for an hour. It is, however, important not to confuse the units. kWh is an expression for energy, not power. Energy expressed in Joules can be transformed to kWh through the following equation:

$$1MJ = \frac{1}{3.6}kWh \quad (2)$$

Heat machines and heat pumps Heat machines uses heat to perform mechanical work. The heat is taken from a reservoir with a hot temperature, TH, and transferred to a reservoir with a cold temperature, T_C. As the heat, Q_H, is transferred from the hot to the cold reservoir mechanical work, W, is taken out and the remaining heat, Q_C, ends up in the cold reservoir.

$$W = Q_H - Q_C \quad (3)$$

Figure 1.2: Function of a he

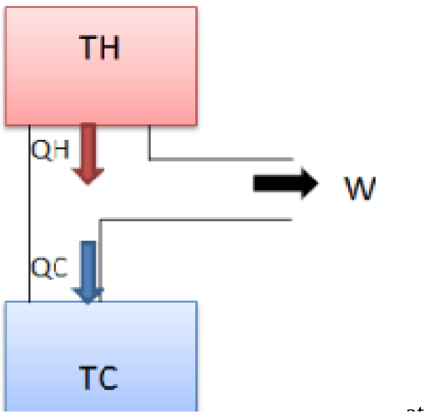
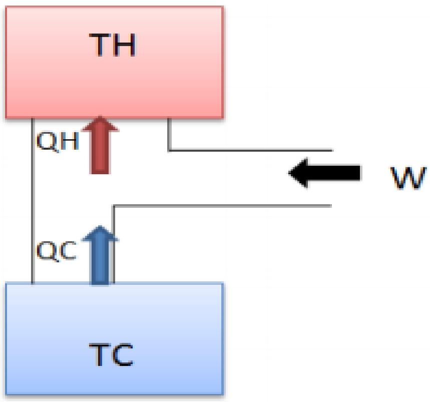


Figure 1.3: Function of a heat pump



The thermal efficiency of the system is defined as the ratio between the work, W, and the energy content in the hot reservoir, Q_H, which can be expressed as:

$$e = 1 - \frac{Q_C}{Q_H} \quad (4)$$

The ideal thermodynamic efficiency is that of a Carnot machine, which has a reversible process. This is defined as the Carnot efficiency:

$$\eta = 1 - \frac{T_C}{T_H} \quad (5)$$

The Carnot efficiency is the maximum possible efficiency of a heat machine with a temperature difference of T_H-T_c K. If the process of the heat machine is reversed, so that mechanical work is added, the heat flow will be going the opposite direction (from cold to hot). This machine is called a heat pump and is described in figure 3.

Heat pumps are commonly used for heating buildings and the efficiency is called heat factor. The heat factor is defined as:

$$e = \frac{Q_H}{W} = \frac{T_H}{T_H - T_C} \quad (6)$$

If the machine is instead used to produce cold from heat it is called cooling machine and the cool factor is defined as:

$$e = \frac{Q_C}{W} = \frac{T_C}{T_H - T_C} \qquad (7)$$

Both the heat and cool factor has to be larger than 1 or there is no point of using the machine.

3.2 Thermoelectric Device

A Peltier element is a thermoelectric cooler, or TEC, which is simply a small heat pump. In 1821 J.T Seebeck discovered that two dissimilar metals connected at two different junctions create a micro voltage between them if held at two different temperatures. If two wires are connected, for example iron and copper, and the other ends applied to the terminals of a galvanometer a voltage can be recorded if the junction between the wires is heated. The wires are called a thermocouple. J. Peltier realized, in 1834, that the inverse effect is possible as well. If a voltage is applied to a thermocouple a temperature difference will be initiated between the junctions. This is known as the Peltier effect. A heating or cooling effect of the junction is created depending on the direction of the current. In 1855 the dependency between the temperature change and the current application was proven by W. Thomson (or Lord Kelvin) who, by applying thermodynamics, established the relationship between the coefficients that described the Peltier and Seebeck effects, which is now known as the Thomson effect. This effect described reversible heating or cooling when there is a temperature gradient along with an electric current. What happens is the electrons carrying out the current possess different energy depending on the material. When the current reaches the junction it is transferred from one material to another and the energy is altered, causing the junction to heat up or cool down. Likewise, if the junction is heated the electrons can pass from the material with lower energy to that with higher, giving rise to an electromagnetic force.

3.3 Seebeck Voltage

In 1821 Seebeck detected that a needle of a magnet placed close to dissimilar metals connected electrically in series and thermally in parallel is deflected and exposed to a thermal gradient. This discovery is the basis for thermoelectric power generation. If different temperatures are applied to a semi-conductive pair an electrical current will be produced. The voltage potential created by the temperature difference drives the flow of electrons. This is called the Seebeck voltage. Good electrical conductors are needed in order to make the process effective. The thermal conductivity however needs to be poor, or the there will be a backflow of heat which reduces the temperature difference between the junctions. As the moving electrons produce heat (Joule heating) and increased electrical current will reduce the Seebeck effect. Therefore it is necessary to optimize the properties of the semi-conductors. The best performance is found to be achieved by using heavily doped semi-conductors such as Bismuth-Telluride or Silicon-Germanium. A base material that can be both n- and p-doped is preferable to use so that the same material can be used on both sides.

3.4 Peltier effect

A Peltier element works inversely to the Seebeck device and consist of a pair semi-conductors which, when imposed by a direct current, generate a heat flow and a temperature difference between the two plates. This effect, the Peltier effect can be expressed as:

$$\dot{Q} = \alpha T I \quad (8)$$

Q is the heat power, α is the Seebeck coefficient, T the temperature and I the current.

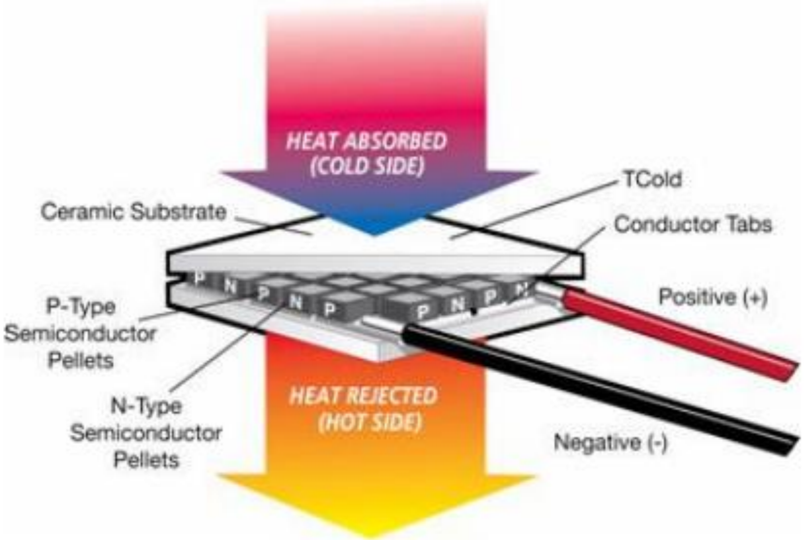


Figure 1.5: Structure and function of a Peltier element. (Tellurex, 2011)

3.5 Relation between seebeck and peltier effect

If two isotropic semiconductors, A and B, are joined together and a temperature difference, ΔT, is applied at the junction whereas the two ends are kept at the same temperature a voltage potential, V, will appear. The differential Seebeck coefficient, αAB, is defined as:

$$\alpha_{ab} = \frac{V}{\Delta T} \quad (9)$$

The Seebeck coefficient is said to be positive if the electromotive force drives the current through the conductor A from the hot to the cold junction. If the circuit is connected the Peltier coefficient, π_{AB}, is defined as positive if the current enters A is heated and the junction at which the current leaves A is cooled. The Peltier coefficient is equal to the ratio of heating/cooling rate, q, and the electric current, I, at each junction:

$$\pi_{ab} = \frac{q}{I} \quad (10)$$

The Peltier coefficient can be expressed in terms of the Seebeck coefficient as follows:

$$\pi_{ab} = \alpha_{ab} * T \quad (11)$$

The Kelvin relation connects the Seebeck coefficient with the Thomson coefficient of the two conductors. The Thomson coefficient ,τ, is defined as “ the rate heating per unit length that results from the passage of unit current along the conductor in which there is unit temperature gradient”. Mathematically this is expressed as:

$$\tau_A - \tau_B = T * \frac{d\alpha_{AB}}{dt} \quad (12)$$

Thermoelectric devices are usually made up by a number of thermocouples connected electrically in series and thermally in parallel. This enables the usage of a power source that delivers a manageable current and an acceptable voltage drop. The theory of thermoelectric refrigeration is based on Altenkirch’s model using a single thermocouple of two elements with a non-resistive junction between them. The other ends of the

elements are assumed to be connected to a battery and kept at a constant temperature and have a uniform cross section. The maximum possible temperature difference to be reached by a single thermocouple was tested by Altenkirch in 1911, along with the coefficient of performance for temperature differences less than that.
The properties of importance are for the thermoelectric elements are:

- Thermoelectric power
- Thermal conductivity
- Electrical conductivity
- Length
- Cross-section area

There is assumed to be no thermal resistance between the thermocouple and the heat source/sink. The heat flow takes place within the thermocouple, hence the thermal radiation losses to the environment are negligible. The quantity of interest and importance for a refrigerator is the coefficient of performance, or COP, which is defined as the ratio between the heat extracted and the electrical energy added. The ideal COP value is the Carnot efficiency, which can be reached only if there were no losses due to heat conduction or expenditure electrical energy.
The Peltier cooling increases linearly but the Joule heating depends on I2 meaning there is a maximum cooling power that can be achieved before the Joule heating becomes too great. The maximum cooling is reached is twice as large as the Joule heating reaching the cold junction. The current, Iq, that yields the maximum cooling power is given by:

$$I_q = \frac{(\alpha_p - \alpha_n) * T_c}{R_p + R_n} \quad (13)$$

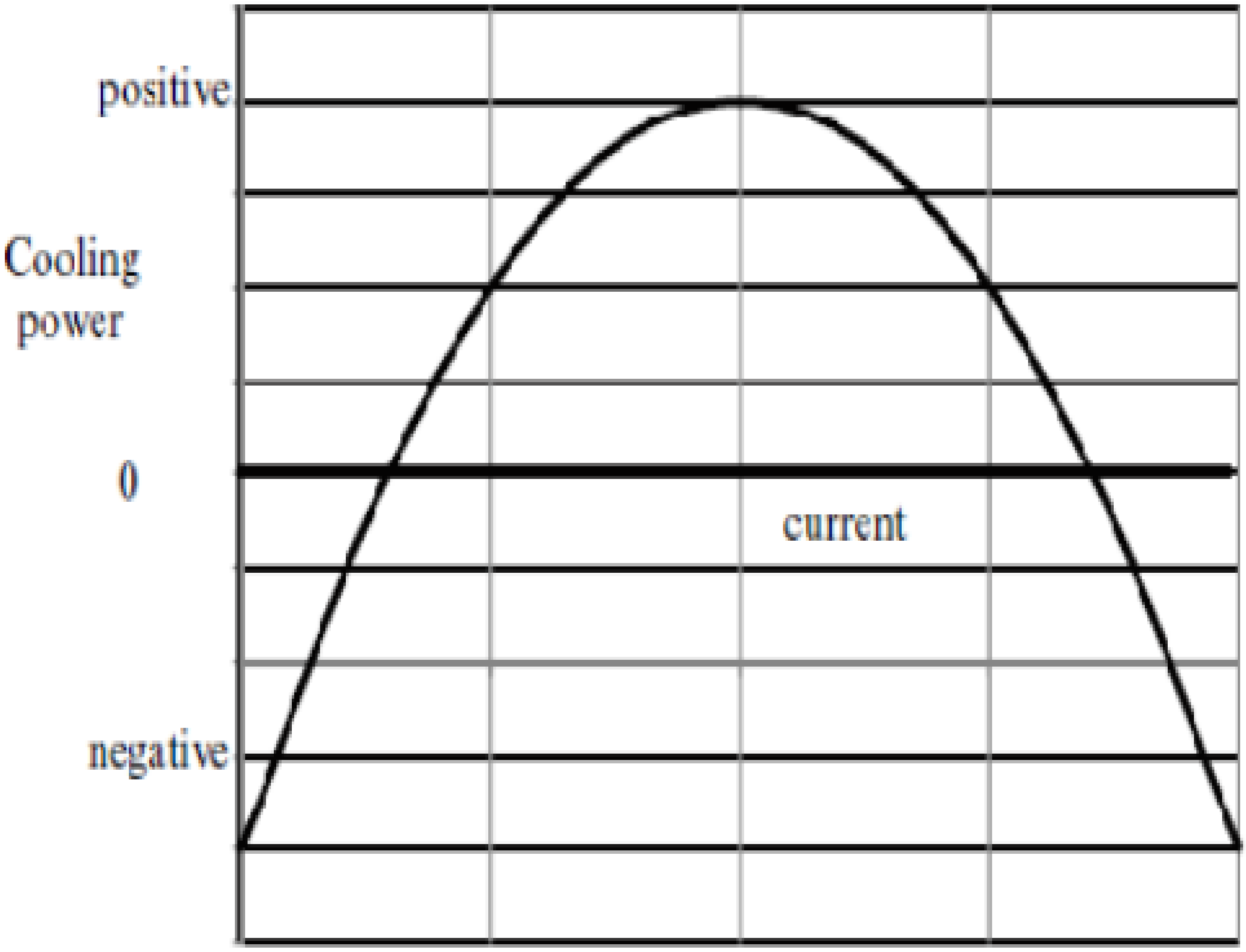


Figure1.6: Cooling power of an electric cooler plotted against the current. The cooling power is negative until the Peltier effect becomes large enough to overcome the Joule heating

3.6 Thermoelectric Refrigeration

When a current flows through a thermoelectric material it generates resistive heating. 50% of the heat goes to the cold end and 50% to the hot end of the thermoelectric device. The Joule heating is given by:

$$Q = \frac{2NI^2R}{g} \tag{14}$$

N is the number of thermocouples within the module and g is the cross section area divided by the thermoelectric element, called geometry factor. A thermoelectric refrigerator, or TER, consist of thermoelectric components and uses the Peltier effect to remove heat. A DC current is applied to the two dissimilar components creating a temperature difference which is dependent on the Peltier cooling, Joule heating and heat convection. When analyzing a TER two factors need to be taken into account; heat rejection, Q_H, and heat absorption, Q_C.

4 Objectives

To design a Solar Refrigerator that could generate a cooling effect on one side and heat sinking on other side with solar heat as input. The complete Solar Refrigerator would be based on Peltier Effect. The purpose of this design is to use the solar energy, not to generate some electricity but to directly convert solar heat applied on one side of the surface of our Thermo electric element into refrigeration effect on the other side based on peltier effect and Thermo Electric Cooling. The idea is to present a design for compact refrigeration systems that is powered by solar energy and does not use any coolants or condensers for cooling. In the end, the basic idea is to provide a pollution free model for a solar based thermoelectric refrigerator.

Figure 1.7: Final designed model of solar based thermoelectric refrigerator

5. RESULTS AND DISCUSSION

The solar based thermoelectric refrigerator was designed and tested for various voltage values across its input. Various results were obtained by calculating the temperature difference between hot and cold junction and corresponding voltages on a multimeter device. The temperature readings were taken with the help of digital thermometers having LCD displays. The output voltage generated giving the performance of thermoelectric refrigerator has been improved by designing various heat sink cooling techniques.

The 3Watts, 14V Solar panel was kept at different lighting conditions under sunlight and generated following voltages:

S.No.	Ambient Sunlight	Duration / Time	Output Voltage
1.	Least (Evening time)	2-3 hrs.	3 Volts
2.	Full (day time)	4-5 hrs.	12 Volts - 14.5 Volts
3.	Medium (early morning)	2 hrs.	6-8 Volts

Figure 1.4

Specifications of peltier plate used:

Sr. No.	Specification	Value
1.	Maximum Operating Voltage (V)	14
2.	Maximum Current (A)	6
3.	Maximum temperature (°C)	138
4.	Delta T_{max}(°C)	75
5.	Dimensions L x W x H (mm)	40 x 40 x 3.5
6.	No. of Junctions	127

Figure 1.5

5.1 Different readings were taken for hot side and cold side temperature for different lighting conditions. These are depicted below:

I. DURING EARLY MORNING (Medium sunlight)

During early morning, the temperature of cold side decreases from 27°C to 16.5°C . Although the heat sink temperature increases from 28°C to 41°C . The temperature drop is also not very significant due to medium voltage coming from solar panel of around 8-10 Volts.

The temperature vs time graph is depicted below:

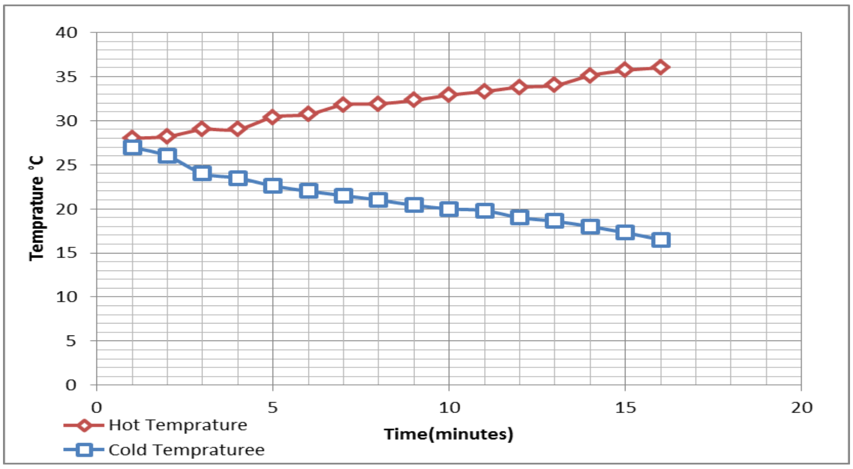


Figure 1.6

II. DURING DAY TIME (Maximum sunlight)

During day time, the temperature of cold side decreases from 28°C to 11°C Although the heat sink temperature increases from 28°C to 42°C . The temperature drop is maximum due to very maximum voltage coming from solar panel and full battery charging of around 14Volts.

The temperature vs time graph is depicted below:

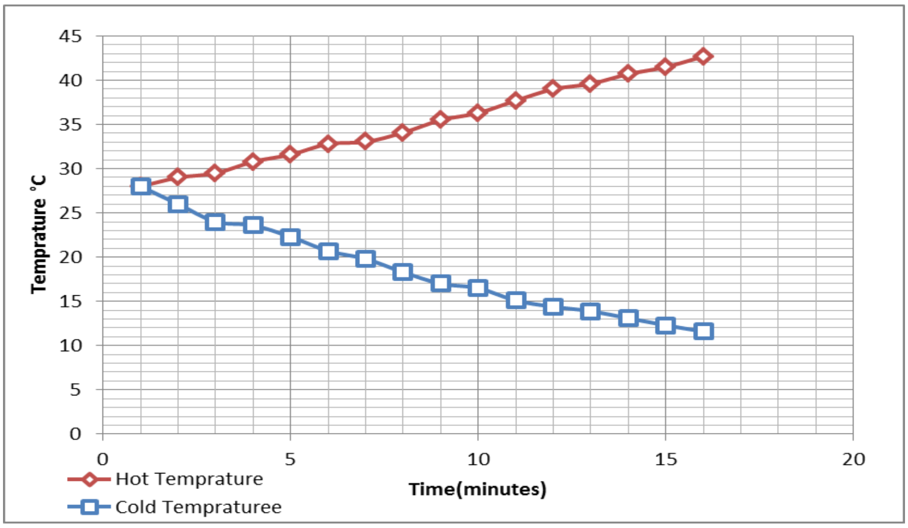


Figure 1.7

III. DURING NIGHT TIME (Least sunlight):

During night time, the temperature of cold side decreases from 27°C to 25°C in around 30 minutes approximately. Although the heat sink temperature increases from 28°C to 34°C . The temperature drop is less due to very low voltage coming from solar panel and lesser battery charging of around 4-5 Volts.

The temperature vs time graph is depicted below:

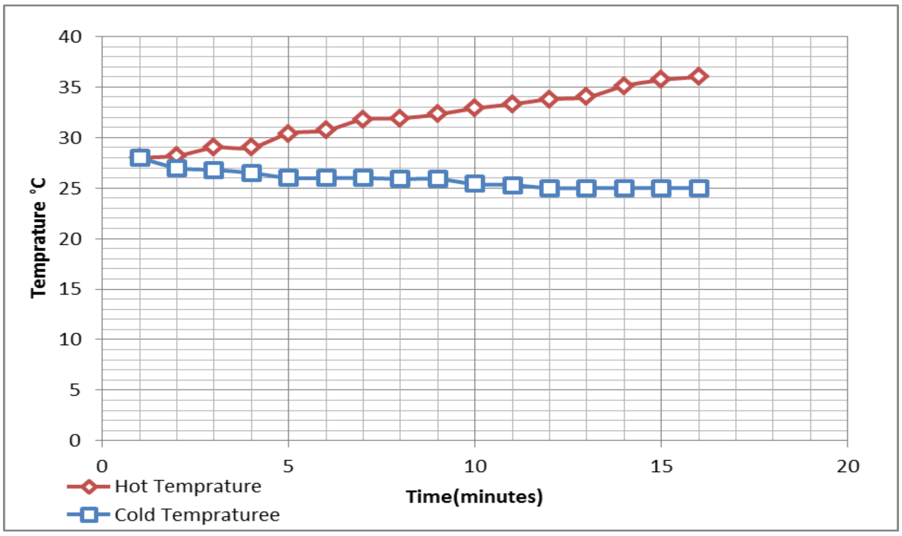


Figure 1.8

6. Conclusion

In this work, a portable solar thermoelectric refrigerator unit was fabricated and tested for the cooling purpose. The refrigerator was designed based on the principle of a thermoelectric module to create a hot side and cold side. The cold side of the thermoelectric module was utilized for refrigeration purposes whereas the rejected heat from the hot side of the module was eliminated using heat sinks and fans. In order to utilize renewable energy, solar energy was integrated to power the thermoelectric module in order to drive the refrigerator. Furthermore, the solar thermoelectric refrigerator avoids any unnecessary electrical hazards and provides a very environmentally friendly product. In this regard, the solar thermo electric refrigerator does not produce chlorofluorocarbon(CFC), which is believed to cause depletion of the atmospheric ozone layer. In addition, there will be no vibration or noise because of the difference in the mechanics of the system. In addition the rejected heat from the solar thermoelectric refrigerator is negligible when compared to the rejected heat from conventional refrigerators. Hence, the solar thermoelectric refrigerator would be less harmful to the environment. Several tests were carried out with the prototype to determine the minimum temperature that a refrigerated object could be reached. A canned drink with fixed volume was used as the refrigerated object in these tests. Experiment and analysis on the prototype were conducted mainly under sunny outdoor conditions. It was found that the system performance was strongly dependent on the intensity of solar light and the temperature difference of hot and cold sides between the thermoelectric modules. The minimum temperature on cold side was reported to be around 16°C from 27°C with temperature drop (Delta T_{max}) of around 11°C in maximum sunlight in a very short duration of around 30 minutes. This The maximum temperature difference Delta T_{max} was least for lesser light during night time and nominal during early morning conditions. The energy efficiency of solar thermoelectric refrigerators, based on currently available materials and technology, was still lower than its compressor counterparts

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