*International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-4,April 2016*
*ISSN: 2395-3470*
*www.ijseas.com*

# Design and Fabrication of Thermoelectric Refrigerator with Thermosiphon System

**Sujith G[1], Antony Varghese[2], Ashish Achankunju[3], Rejo Mathew[4], Renchi George[5], Vishnu V[6]**

[1] Assistant Professor, Department of Mechanical Engineering, SNIT, Adoor, India
[2, 3, 4, 5, 6] Final Year B.Tech Students, Department of Mechanical Engineering, SNIT, Adoor, India

**Abstract**

The increase in demand for refrigeration globally in the field of air-conditioning, food preservation, medical services, vaccine storages, and for electronic components temperature control led to the production of more electricity and consequently an increase in the CO2 concentration in the atmosphere which in turn leads to global warming and many climatic changes. Thermoelectric refrigeration is a new alternative because it can reduce the use of electricity to produce cooling effect and also meet today's energy challenges. Therefore, the need for thermoelectric refrigeration in developing countries is very high where long life and low maintenance are needed. The objectives of this study is to develop a working thermoelectric refrigerator to cool a volume of 40 L that utilizes the Peltier effect to cool and maintain a selected temperature range of 5 0C to 25 0C. The design requirements are to cool this volume to temperature within a short time and provide retention of at least next half an hour. The design and fabrication of thermoelectric refrigerator for required applications are presented.

***Keywords:*** *Seebeck Effect, Peltier Effect, Thermoelectric module, Thermosiphon System.*

## 1. Introduction

Due to the increasing demand for refrigeration in various fields led to production of more electricity and consequently more release of harmful gas like $CO_2$ all over the world which is a contributing factor of global warming on climate change. Thermoelectric refrigeration is a new alternative method. The thermoelectric modules are made of semiconductor materials electrically connected in series configuration and thermally in parallel to create cold and hot surfaces. Although they are less efficient than the vapour compression system, they are very light, low in cost, silent in operation, and are environmentally friendly.

The objectives of this project is to design and develop a working thermoelectric refrigerator that utilizes the Peltier effect to refrigerate and maintain a temperature between 5 $^0$C to 25 $^0$C. The design requirements are to cool the volume to a temperature within a short time and provide retention of at least next half an hour. And a thermosiphon cooling system is used for cooling the hot side of TEC module. It will be used in remote locations in the world where there is no grid electricity, and where electrical power supply is unreliable when a solar panel charger is added for battery charging.

A thermoelectric module thus uses a pair of fixed junctions into which electrical energy is applied causing one junction to become cold while the other becomes hot. Because thermoelectric cooling is a form of solid-state refrigeration, it has the advantage of being compact and long lasting. It uses no moving parts except for some fans, employs no fluids, and do not require bulky piping and mechanical compressors used in vapour-cycle cooling systems. Such sturdiness favour thermoelectric cooling over conventional refrigeration in certain situations. The compact size and weight requirements, as well as portability in the design, rule out the use of conventional refrigeration.

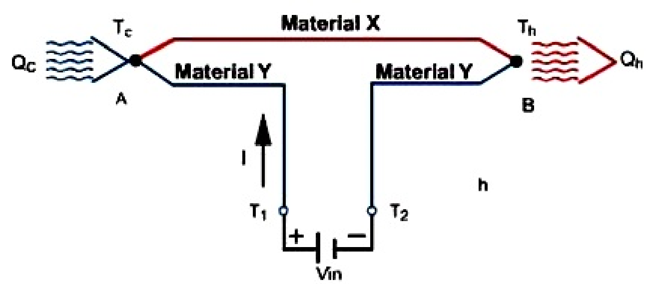


Fig. 1.1 Peltier effect

Thomas Seebeck in 1821 discovered that a continuously flowing current is created when two wires of dissimilar materials are joined together at the ends and heated at one end. This phenomenon is known as the Seebeck Effect. Later in 1834, Jean Charles Athanase Peltier a French watchmaker and physicist found that if two dissimilar metals are joined together and an electrical current is supplied it will produce heating and cooling at the ends and that phenomenon is known as Peltier effect and is shown in the figure 1.1. In 1838 Lenz showed that depending on the direction of current flow in the system, heat could be either removed from a junction to convert water into ice, or by reversing the direction of current, heat can be generated to melt ice. The amount of heat absorbed or rejected at the junction is proportional to the electrical current intensity. The constant of proportionality is known as the Peltier coefficient.

## 2. Thermoelectric Cooling Modules

Although Peltier effect was discovered more than 150 years ago, thermoelectric devices have only been applied commercially during recent decades. Lately, a dramatic increase in the application of TE solutions in optoelectronic devices has been observed, such as diode lasers, photo detectors, solid- state pumped lasers, charge-coupled devices (CCDs) and others. The thermoelectric module consists of thermocouple formed by pairs of P-type and N-type semi-conductor thermo element which are electrically connected in series configuration and thermally connected in parallel configuration. Due to their solid state construction the modules are considered to be highly reliable. For most application they will provide long, trouble free service. For cooling application, an electrical current supply is given to the module, heat is transferred from one side to the other, and the result is that the module will become cooler at one side and hotter at the other side.

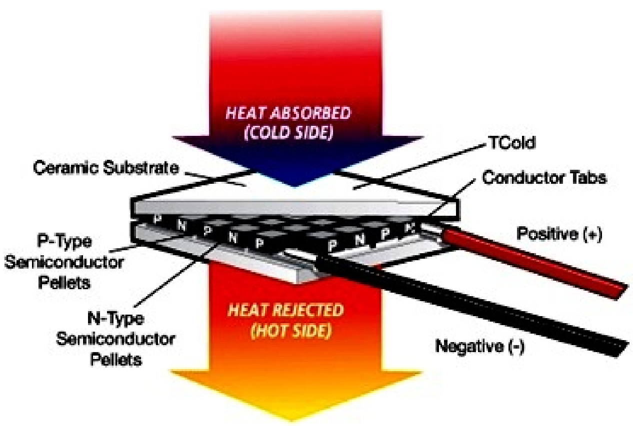


Fig. 2.1: Thermoelectric module assembly

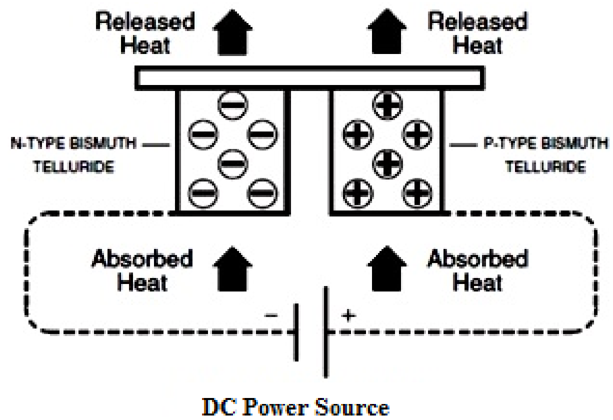


Fig. 2.2: Module working

The figure 2.1 shows a particular thermoelectric module assembly. The main advantages of using TE modules in cooling applications are, they are solid state, have no moving parts and are miniature in size, its reliability and flexibility in design to meet particular requirements.

The figure 2.2 shows the working of thermoelectric module. When a DC voltage is applied to the TE module, the positive and negative charge carriers in the pellet assemblage absorb heat energy from one of the surface and reject it to the other at the opposite side. The surface area where heat energy is absorbed gets cooler; the opposite surface where heat energy is released gets hotter. Reversing the polarity will result in reversed hot and cold sides.

## 3. Literature Review

Review of a number of patented thermoelectric refrigerator designs, a photovoltaic-direct/indirect thermoelectric cooling system, and research studies from the literature are described in the following section. A simple design was proposed by Beitner in 1978 consisting of thermoelectric modules directly powered by an external DC source and an external thermal sink to dissipate heat to ambient by using natural convection cooling. Reed and Hatcher in 1982 proposed an effective way to increase the heat dissipating capability at the hot end of thermoelectric modules by using the cooling fan. Park et al. in 1996 introduced the new design of thermoelectric refrigerator by combining the benefits of super insulation materials with thermoelectric system and phase change materials to provide an environmentally benign system that was energy efficient and could maintain relatively uniform temperature for the extended periods of time with relatively low electrical power requirements. Gillery and

Tex in 1999 proposed the design of a thermoelectric refrigerator by employing evaporating/condensing heat exchanger to improve heat dissipation at hot end of thermoelectric modules.

## 4. Design of Thermo Electric Refrigerator

### 4.1 Project Objectives

In this proposed work, the main aim is to develop a refrigeration system with a capacity of 40L of cooling chamber. It is necessary to design a system capable of maintaining the temperature of the materials between $10^0$C to 15 $^0$C for a long duration. Since the system has to be used in remote areas where power is scarce, alternative sources of energy like battery or solar power has to be incorporated in the design. Moreover the system is meant for outdoor use which makes better insulation and radiation control mandatory. In order to meet worse scenario, even though the system is to designed for maintaining a fixed chamber temperature throughout the operational period, the design should be such that it can adaptable for refrigerating the chamber from ambient temperature to the required temperature.

### 4.2 Geometry

With the constraints imposed by the objectives a double walled rectangular box with an insulation sandwiched between the walls is selected and having the following dimensions
Top and bottom panel dimensions = 0.35 x 0.35m
Vertical side panel dimension = 0.35 x 0.35m
Front and back panel dimensions = 0.35 x 0.35 m

### 4.3 Materials

Mild steel sheets with thermal conductivity of 52W/mK were used as outer wall. Expanded polystyrene (EPS) slabs with 5cm thickness having a density of 30kg/m$^3$ and thermal conductivity of 0.33W/mK were used to give the required thermal insulation. Typical values range from 0.032 to 0.038 W/mK depending on the density of the EPS board. The value of 0.038 W/mK was obtained at 15 kg/m$^3$ while the value of 0.032 W/mK was obtained at 40 kg/m$^3$.

### 4.4 Design Procedure

In designing a thermoelectric cooling system, one of the most critical processes is to reach an understanding of the thermal load. With this vital information, we can able to choose the best TE device or heat exchangers for the job. Each of the thermoelectric cooling system has a unique capacity for moving heat. In order to achieve the performance objectives estimate of the amount of heat must be removed from the thermal load is calculated. Once the module is selected, thermosiphon system for heat dissipation from the hot side of the module is designed based on the amount of heat that has to be removed.

### 4.5 Heat load calculation

The two elements of thermal load in thermoelectric refrigeration systems include active and passive loads.
Active load is considered whenever part of the load actually produces heat. For example in an electronic circuit the circuitry would dissipate wattage depending upon its voltage and current requirements. Many TE applications don't have an active load and this term can be entirely discarded in these cases. To maintain a temperature difference between the thermal load of the system and the ambient environment, a small amount of energy must be continually moved into or out of the load. The rate at which this energy is moved is the passive load.

With a TE system, the main aim is to keep the thermal load colder than the ambient temperature. But unfortunately, no matter how well the design of the system, there will be some leakage in the system. There is no insulation available with an infinite thermal resistance, so some heat will pass right through the primary line of defense. Furthermore, seals used to cope with the inevitable holes will also be imperfect. Thus, in a cooling application, some heat leakage into the thermal load will occur from the ambient environment.

*Passive heat load*: First we have to identify the greatest temperature difference between the thermal load and the ambient environment that can occur. For cooling, what is the highest ambient temperature and how cold will the load need to be in that circumstance. This is generally the worst case. If we design the system so that we will have the required cooling capacity in that worst case, we will have more than enough potential for every other situation. The worst-case difference between the ambient and load temperatures will be the temperature difference, 'ΔT' in the equations which follow. Including both the conductive and convective heat transfer components of the load, we can use this equation:

$$Q = \frac{\Delta T \; A}{\frac{1}{h} + \frac{L}{k}}$$

Temperature to be maintained inside the cabin = 10 $^0$C
Outside temperature or ambient temperature = 30 $^0$C
Temperature difference between the cabin walls = 30 – 10
= 20 $^0$C

$K_{MS}$ = 52 W/mK

$K_{EPS}$ = 0.033 W/mK
$h_{AIR}$ = 10 W/m$^2$K
Area, $A_1 = A_2 = A_3 = 0.35 \times 0.35 = 0.1225$ m$^2$

$$Q = \frac{\Delta T.A}{2\times\frac{1}{h_{AIR}}+\frac{l_1}{K_{EPS}}+\frac{l_2}{K_{MS}}}$$

$$= \frac{0.1225\times 20}{2\times\frac{1}{10}+\frac{0.05}{0.033}+\frac{0.002}{52}} = 1.42 \text{ W}$$

i.e., $Q_1 = Q_2 = Q_3 = 1.42$ W
Passive load through the walls ,
$Q_P = (Q_1 + Q_2 + Q_3) \times 2 = (1.42 + 1.42 + 1.42) \times 2$
$= 8.52 \text{ W} \approx 9$ W
Infiltration air load due to opening and closing, $Q_C \approx 10$ W
$Q_{TP} = Q_P + Q_C = 9 + 10 = 19$ W
For safety, $Q_{TP} \approx 25$ W

4.6 System Design

Our known design values are:
Q = 25 Watt heat load
$T_A = 30^0$C maximum ambient air temperature
$T_C = 10^0$C required temperature of the cabin
Then identify the hot side temperature ($T_H$) and the resultant temperature differential across the module ($\Delta$T). The temperature at the hot side will be equal to the sum of ambient temperature ($T_A$), the rise in temperature across the heat sink from rejecting the heat load (Q) and the TE module power (V x I).
$T_H = T_A + (V \times I + Q) R_Q$
Where,
$R_Q$ is the thermal resistance of heat sink in $^0$ C temperature rise per Watt dissipated. In this design, we will keep the rise of temperature of the heat sink to not more than about $15^0$C above ambient. This would give us a thermoelectric module hot side temperature of about $45^0$C.
$T_H = 30^0C + 15^0C = 45^0C$
The temperature differential across the thermoelectric module can be calculated as follows:
$\Delta T = T_H - T_C = 45^0C - 10^0C = 35^0C$

4.7 TEC Selection

It is required to choose a TEC module that not only has sufficient cooling capacity to maintain the proper temperature, but also meet the dimensional requirements imposed by the housing. A module is arbitrarily chosen by considering the geometrical constrain imposed due to the size of cabin and also appears to have appropriate performance characteristics. The performance data is presented graphically and referenced to a specific heat sink base temperature. Most performance graphs are normally standardized at a heat sink temperature ($T_H$) +50°C and the resultant data is usable over a range of around 40°C to 60°C with only a slight error. ΔT is the governing parameter required for arbitrarily selecting the module. To derive relevant parameters for making mathematical calculations the performance graphs for this TE module is usually considered. In order to begin the design process we must first evaluate the heat sink and make an estimate of the worst case module hot side temperature ($T_H$) and module temperature differential, ΔT. The heat in-leak or heat load $Q_C$ should be calculated. In this problem since it is required only to maintain the required temperature, only heat infiltration & others heat losses contributes to the heat load, $Q_C$.

The TEC module was selected by considering few factors such as dimensions, $Q_C$, power supply etc. The model number of the module is TEC1-12706. It is decided to select a TEC module which has a cooling power greater than the calculated cooling load. TEC1-12706 operates with an optimum voltage value of 12V. It has a maximum voltage of 15.4V. At 12V it draws and maximum DC current of 6 A. The nominal power rating or the cooling power is 60 W. It has a maximum operating temperature of $200^0$C. ΔT of the TEC is 68 when hot side temperature is 25 $^0$*C*. It had been decided to choose 6TECs of the same model so that when the power of all the 6 TEC modules are greater than the calculated cooling load. The minimum power rating for 6 TEC modules added together was more than the cooling load calculated. More number of TEC reduces the time required for cooling of a particular material.

4.8 Specification of TEC

Table 6.1 specifications of TEC

| Product | TEC-12706 |
|---|---|
| Operational voltage | 12V DC |
| Current max | 6 Amp |
| Voltage max | 15.4 V |
| Power max | 92.4 |
| Power nominal | 60 |
| Couples | 127 |
| Dimensions | 40 x 40 x 3.5 mm |

4.9 Heat sink selection

The values obtained in the preceding analysis are used to assess overall system feasibility. We want to qualify our assumption of 15°C temperature rise across heat sink. The efficiency of the heat sink has a significant influence on the heat pumping capability of the thermoelectric module. The hot side of the module must interface with an efficient heat removal system in order to achieve a useful temperature differential across the thermoelectric module.

Natural convection type, forced convection type, and liquid cooled are three of the most common variety of heat sinks. Thermal resistance varies among the different types and sizes of sinks in which natural convection being the least efficient and liquid cooled the most efficient. Most of thermoelectric cooling applications use forced convection heat sinks with thermal resistance values ($R_{ht}$) ranging from 0.10 $^0$C/W to 0.5$^0$C/W.

Using the known values for $T_A$, V, I, and Q, $R_{ht}$ is solved to determine if it is reasonable

$R_{HT} = (T_H - T_A) / (V \times I + Q)$

$R_{HT} = (45 - 30)/ (12 \times 5 + 20) = 0.176\ ^0$C/W

Our proposed system using a TEC1-12706 module and a thermosiphon water cooling system meets the criteria for this application.

*Heat load required to be dissipated from hot side:*

The Peltier module is running at 12V and 5 amps of current at nominal operation

$$Q_H = P_{TEC} + Q_T = 6 \times V \times I + Q_T$$

$$= 6 \times 12 \times 5 + 25 = 385 \text{ W}$$

So Aluminium tank of Thermosiphon system must carry the sufficient amount of water to carry away the heat.

## 5. Design for Thermosiphon water cooling system

Thermosiphon is a cooling technique used in early automobile engines. In this system, circulation of water is obtained from the difference of densities of hot and the cold regions of cooling water. In this project this system consists of an Aluminium tank, a radiator and a cooling fan. The hot side of the TEC is attached to one side of the Al tank which contains water. The heat rejected from the TEC is absorbed by the water in the tank, its density gets vary. This variation of density leads to the circulation of water in the system. The hot water which reaches the radiator is cooled by forced convention by the cooling fan. This system is provided outside the cooling space.

The volume of water needed to dissipate the heat can be found by the equation, $Q = m\, C_p\, \Delta T$

Where Q is the amount of heat to be dissipated, m is the mass of water, $C_p$ is the specific heat capacity of water and $\Delta T$ is the temperature difference.

Volume of water = $6.199 \times 10^{-6}$ m$^3$

i.e., $6.199 \times 10^{-6}$ m$^3$ of water is needed to remove 385W of heat.

By consideration for keeping the inclination of tube connecting the aluminium tank and radiator is in between 10 to 15 degree, the proposed dimensions of Al tank is 32.5 x 12 x 5cm

Therefore, Volume of the tank = 0.325 x 0.12 x 0.05

= $1.95 \times 10^{-3}$ m$^3$

So the volume of water contained in Al tank is higher than the volume of water needed to dissipate the heat. Therefore, the thermosiphon heat sink design meets requirement.

## 6. Fabrication and Assembling

### 6.1 Fabrication of the Cabin

*Cabin Walls*- The rectangular double walled cabin is made using Mild steel sheets of 1mm thickness. The Designed dimension (35cm x 35cm x 35cm), of the cabin is obtained by performing suitable bending operations on the MS sheet. The sides are welded and riveted to give better surface finish. The top door panel of the cabin is fastened using spot welding .Rubber beading is given to prevent the heat leakage, through the sides of the top door panel. To prevent radiation heat transfer and to give better surface finish, the outside of the cabin is coated with black paint.

*Insulation*- EPS slabs with 50 mm thickness which is having a density of 30kg/m$^3$ were used to obtain the required thermal insulation. For the selected expanded polystyrene foams the mechanical resistance varies from 0.4 to 1.1 kg/cm$^2$. There are various grades of foams available with density varies from 10 to 33 kg/m$^3$, and also with thermal conductivities that are lowered with the increase in density. The slabs having a thermal conductivity of 0.33 W/mK, were pasted to the inside walls of the cabin. The gaps between the walls are filled with silicon paste.

### 6.2 Assembling Module Unit with Cabin

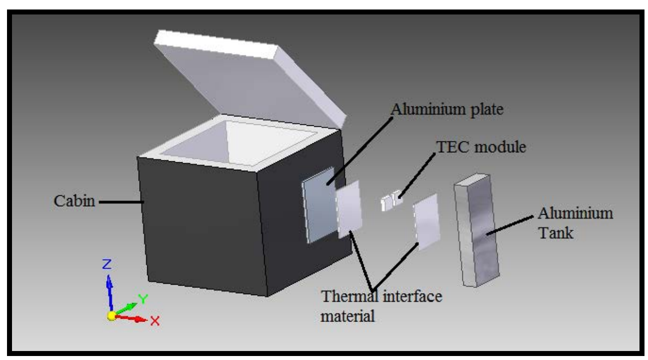


Fig. 6.1 The ‘exploded view’ of assembly of the TER

Once the TE module has been mounted, it is ready to be installed on to the insulated double walled cabin. The module assembly is integrated into the cabin with the help of fastening screws. The cold plate (Al) should be concurrent with the inner wall and the fin is exposed to outside.

Fig. 6.2 TEC assembled to cooling cabin

In order to enhance the cooling rate screws are extended up to the inside cabin space. The lateral side and all other exposed sides of the module assembly are insulated. So as to augment the convective heat transfer through the plate, cooling fans are provided. Provisions are provided on the outer shielding cover for mounding the cooling fan. The shield cover also includes the control panel and the power input socket.

The associated components includes, Battery charging unit, 12 V DC battery etc. for continuous working. During experimental investigation a 12 V dc adaptor is used as power source for the thermo electric module. The TEC assembled to cooling cabin is shown in figure 6.2.

## 7. Experimental Investigation

An experimental and performance analysis on fabricated thermo electric refrigerator was conducted. The cold end of the thermoelectric module was used in the system to cool the refrigerator cabin and a digital thermo meter is used to measure the temperature. The hot end is attached to a heat sink for heat rejection. In order to validate the performance of the system cool down experiment was conducted on the system.

### 7.1 Cool down test

For analyzing the performance of system, water load is considered is considered as the active heat load to the system. Water at 33˚C was filled in the container before switching ON the system. The temperature at every 20min.intervel was tabulated. The readings were recorded for 450 mins.

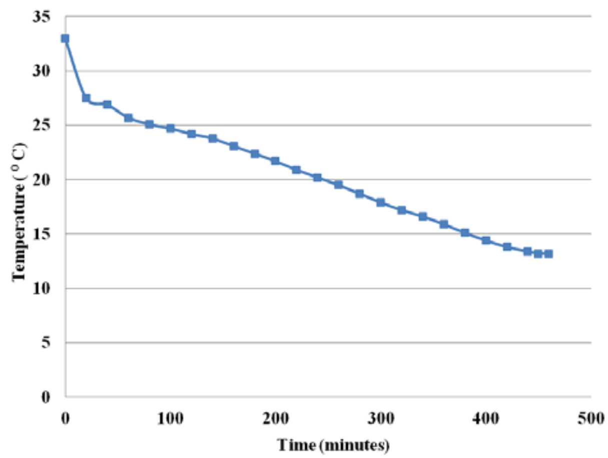


Fig. 7.1 Variation of temperature with time

Even though the conventional system is mainly designed for maintain a fixed temperature, the above cool down experiment was proved that the system can be adapted for sensible cooling also. The figure 7.1 shows the variation of temperature with time in the given setup. The lower steady temperature was attained around 13$^{o}$C at a time of 450 minutes. It took about 7 hours and 30 minutes to attain the same from 33$^{o}$C (ambient temperature).The cabin temperature drop was at an average rate of 2.67 $^{o}$ C per hour.

### 7.2 Performance of the thermoelectric refrigerator

The active heat load is expressed as the equivalent cooling power that the unit will need to provide when the sample at ambient temperature is placed in the container. It was decided that two liter of water at room temperature took as the test sample .When the designed thermoelectric refrigerator was tested, it was found that the inner temperature of the refrigeration area was reduced from 33.1 ˚C to 13.2 ˚C in approximately 450min. Coefficient of performance of the refrigerator ($COP_R$) was calculated. Water is used in place of vaccine for taking measurements and calculation. In these calculations, the properties of water are (density = 1 kg/L and $C_P$ = 4187 J/kg).V = 2.0 L.

Coefficient of performance of the refrigerator ($COP_R$) was calculated, $COP_R = \frac{Q_{cooling}}{W_{in}}$

$Q = m\, C_P \Delta T$
Mass of water, m = density x volume = 2 kg
Total heat removed from the water = 166642.6 J

$$Q_{cooling} = \frac{Q}{\Delta T} = \frac{166642.6}{450 \times 60} = 6.17 \text{ W}$$

Power given to the system for working,
$W_{IN}$ = V x I + fan input
= 12 x 4 + 2
= 50 W

Coefficient of performance of this refrigeration system is given by, $COP = \frac{Q_{cooling}}{W_{in}} = \frac{6.17}{50} = 0.124$

COP of this refrigerator system is lower than conventional refrigerator. This is because the efficiency of thermoelectric modules is usually four times lesser than that of vapour compression system. And the heat leakage is also detected through doors; this too reduces the efficiency of the system.

## 8. Conclusion

We have been successful in designing a system that fulfils the proposed goals. However we do realize the limitations of this system. The present design can be used only for light heat load to lower its temperature to a particular temperature. The system is unable to handle fluctuations in load. Extensive modifications need to be incorporated before it can be released for efficient field use. This is one of the advantageous project which uses low power to drive refrigerator. This project work has provided us an excellent opportunity and experience, to use our limited knowledge. Thermoelectric refrigeration is one of the key areas where researchers have a keen interest. Some of the recent advancements in the area surpass some of the inherent demerits like adverse COP. Cascaded module architecture has defined new limits for its application. Moreover recent breakthrough in organic molecules as a thermoelectric material assure an excellent future for TER. Integration of renewable energy as power source this refrigerator can be used for remote rural places where there is no electric supply.

## Reference

[1] Manoj S. Raut, Dr.P. V. Walke, “Thermoelectric Air Cooling For Cars”, International Journal of Engineering Science and Technology (IJEST), Vol. 4 No.05 May 2012 ,ISSN : 0975-5462.

[2] Mr. Swapnil B. Patond,“ Experimental Analysis of Solar Operated Thermo-Electric Heating and Cooling System”, International Journal of Engineering Trends and Technology (IJETT) – Volume 20 Number 3 – Feb 2015 , ISSN: 2231-5381.

[3] MayankAwasthi and K V Mali, “Design and development of thermoelectric refrigerator”, Int. J. Mech. Eng. & Rob. Res. 2012, Vol. 1, No. 3, October 2012, ISSN 2278 – 0149.

[4] Sabah A. Abdul-Wahab , Ali Elkamel b, Ali M. Al-Damkhi , Hilal S. Al-Rubai’ey, Abdulaziz K. Al-Battashi , Muhammad U. Chutani (2009), Design and experimental investigation of portable solar thermoelectric refrigerator;An International Journal for Renewable Energy.

[5] Dai YJ, Wang RZ, Ni L;. Experimental investigation and analysis on a thermoelectric refrigerator driven by solar cells. Sol Energy Mater Sol Cells 2003