Design of Solar Based Thermo Electric Refrigeration System

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Abstract: **The global increasing demand for refrigeration in the field of air conditioning, food preservatives, medical services, vaccine storage, cooling of electronic devices led to production of more electricity and consequently more release of CO2 all over the world which it is contributing factor of global warming on climatic change. In the present scenario, with the increase in awareness towards environmental degradation due to production, use and disposal of Chloro-Fluoro-Carbons (CFC) and Hydro Chloro Fluoro Carbons (HCFC) as refrigerators in conventional refrigeration and air conditioning systems has become a subject of great concern and resulted extensive research in to development of alternate refrigeration systems. Thermoelectric refrigeration is new alternative because it can convert low grade energy into useful cooling, is expected to play an important role in meeting todays energy challenges. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed.**

The objective of this research is to design and develop a working solar based thermoelectric refrigerator with interior cooling volume of 8 liters that utilizes the Peltier effect to refrigerate and maintain a selected temperature from 5 degree to 25 degree.

The design requirements are to cool this volume to temperature with in a time period of 5 hours and provide retention of at least next half an hour. The design requirement, option available and the final design of the thermoelectric refrigerator for application are presented. The developed thermoelectric refrigeration system is having potential applications of storage and transportation of life saving drugs and biological materials at remote areas of our country where grid power is unavailable.

***Key Words*- Thermo Electric Refrigeration System**

I. Introduction

Refrigeration is the process of keeping an item below room temperature by storing the item in a system or substance designed to cool or freeze. Refrigeration has many applications including but not limited to, household refrigerators, industrial freezers, cryogenics, air conditioning, and heat pumps. Cold is the absence of heat, hence in order to decrease a temperature, one remove heat, rather than adding cold, in order to satisfy the second law of thermodynamics, some form of work must be performed to accomplish this. The work is traditionally done by mechanical work but can also be done by magnetism, laser or other means. Thermoelectric cooling uses the Peltier effect to create het flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling small instruments and electronic components. When DC voltage is applied to the module, the positive and negative charge carriers in the pellet array absorb heat energy from one substrate surfaces and release it to the substrate at the opposite side. The surface where heat energy is released becomes hot. Using this simple approach to heat pumping, thermoelectric technology is applied to many widely-varied applications- small laser diode coolers, portable refrigerators, scientific thermal conditioning, liquid coolers, and beyond The choice of a cooling technology will depend heavily on the unique requirements of any given application; however, thermoelectric coolers offer several distinct advantages over other technologies or cooling methods.

All these advantages make thermoelectric coolers the best alternative to the vapour absorption and compression refrig-eration systems that are widely being used these days for preserving the perishables.

II. Literature Review

Matthieu Cosnier ET al [1] presented an experimental and numerical study of a thermoelectric air-cooling and air-heating system. They have reached a cooling power of 50W per module, with a COP between 1.5 and 2, by supplying an electrical intensity of 4A and maintaining the 5C temperature difference between the hot and cold sides.

Suwit Jugsujinda ET al [2] conducted a study on analyzing thermoelectric refrigerator performance. The refrigeration sys-tem of thermoelectric refrigerator (TER; 25 25 35 cm3) was fabricated by using a thermoelectric cooler (TEC; 4 4 cm2) and applied electrical power of 40 W. The TER was decreased from 30 C to 20 C for 1 hr and slowly decreasing temperature for 24 hrs. The maximum COP of TEC and TER were 3.0 and 0.65.

Wei He et al [3] Conducted did Numerical study of The-oretical and experimental investigation of a thermoelectric cooling and heating system driven by solar. In summer, the thermoelectric device works as a Peltier cooler when electri-cal power supplied by

PV/T modules is applied on it. The minimum temperature 17 degree C is achieved, with COP of the thermoelectric device higher than 0.45.Then comparing simulation result and experimental data.

Riff and Guoquan [4] Conducted an experimental study of comparative investigation of thermoelectric air conditioners versus vapour compression and absorption air conditioners. Three types of domestic air conditioners are compared and compact air conditioner was fabricated.

Riffat and Qiu [5] compared performances of thermoelectric and conventional vapor compression air-conditioners. Results show that the actual COPs of vapor compression and thermo-electric air-conditioners are in the range of 2.6-3.0 and 0.38-0.45, respectively. However, thermoelectric air conditioners have several advantageous features compared to their vapor-compression counterparts.

Astrain, Vian Domnguez [6] conducted an experimental investigation of the COP in the thermoelectric refrigeration by the optimization of heat dissipation. In thermoelectric refrigeration based on the principle of a thermo syphon with phase change is presented. In the experimental optimization phase, a prototype of thermo syphon with a thermal resistance of 0.110 K/W has been developed ,dissipating the heat of a Peltier pellet with the size of 40 into 40 into 3.9 cm , Experimentally proved that the use of thermo syphon with phase change increases the coefficient of performance up to 32 percent.

Shen, Xiao et al[7] investigated a novel thermoelectric radiant air-conditioning system (TE-RAC). The system Re-view Paper on Thermoelectric Air-Conditioner Using Peltier Modules employs thermoelectric modules as radiant panels for indoor cooling, as well as for space heating by easily reversing the input current. Based on the analysis of a commercial thermoelectric module they have obtained a maximum cooling COP of 1.77 when applying an electric current of 1.2 (A) and maintaining cold side temperature at 20 degree centigrade.

Virjoghe, Diana ET al [8] conducted a numerical investi-gation of thermoelectric System. The thermoelectric systems have attracted renewed interest as concerns with the efficient use of energy resources, and the minimization of environmental damage, have become important current issues. This paper presents of numerical simulation for several the thermoelectric materials. Numerical simulation is carried out by using a finite element package ANSYS.

Maneewan et al [9] conducted an experimental investiga-tion of thermal comfort study of compact thermoelectric air conditioner. In this paper analyze the cooling performance of compact thermoelectric air-conditioner. TEC1-12708type ther-moelectric modules used for heating and cooling application. The compact TE air conditioners COP was calculated to its optimum parameters. Then analyze the cop with respect to time and calculated cop at various considerations.

Manoj and Walke [10]conducted an experimental study of thermoelectric air cooling for cars. They are trying to overcome these demerits by replacing the existing HVAC system with newly emerging thermoelectric couple or cooler which works on peltier and Seebeck effect.

Yadav and Mehta11 [4] presented combined experimental and theoretical study of thermoelectric materials and appli-cation. The present study develops an optimization design method for thermoelectric refrigerator. This device is fabri-cated by combining the standard n- and p-channel solid-state thermoelectric cooler with a two-element device inserted into each of the two channels to eliminate the solid-state thermal conductivity.

Manoj Kumar et al [11] presented an experimental study of naval potential green refrigeration and air-conditioning technology. They are analyzing the cause and effect of an ex-isting air-conditions system. Thermoelectric cooling provides a promising alternative RAC technology due to their distinct advantages. The available literature shows that thermoelectric cooling systems are generally only around 515 Percent as effi-cient compared to 4060 Percent achieved by the conventional compression cooling system.

Huang. B ET al [12] conducted an experimental study of design method of thermoelectric cooler. They are fabricated the thermoelectric cooler and analyze various considerations. The system simulation shows that there exists a cheapest heat sink for the design of a thermoelectric cooler. It is also shown that the system simulation coincides with experimental data of a thermoelectric cooler.

III. THERMO ELECTRIC REFRIGERATION PRINCIPLES

Thermoelectric cooling uses the Peltier effect to create het flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling small instruments and electronic components. Thermoelectric cooling is used in medical and pharmaceutical equipment. Spectroscopy systems, various types of detectors, electronic equipment, portable refrigerators, chilled food and beverage dispensers, and drinking water coolers. Requiring cooling devices with high reliability that fit into small spaces, powerful integrated circuits in today's personal computers also employ thermoelectric coolers. Using solid state heat pumps that utilize the Peltier effect, thermoelectric cooling devices are also under scrutiny for larger spaces such as passenger compartments of idling aircraft parked at the gate.

Some of the other potential and current uses of thermoelec-tric cooling are,

Military/Aerospace: Inertial Guidance Systems, Night Vi-sion Equipment, Electronic Equipment Cooling, Cooled Per-sonal Garments, Portable Refrigerators. Consumer Products: Recreational Vehicle Refrigerators, Mobile Home Refrigera-tors, Portable Picnic Coolers, Wine and Beer Keg Coolers, Residential Water Coolers/Purifiers.

Laboratory and Scientific Equipment : Infrared Detectors, Integrated Circuit Coolers, Laboratory Cold Plates, Cold Chambers, Ice Point Reference Baths, Dew point Hygrometers, Constant Temperature Baths, Thermostat Calibrating Baths, Laser Collimators.

3.1 Seebeck Effect

The conductors are two dissimilar metals denoted as mate-rial X and is maintained at a relatively cool temperature (T_c). The junction temperature at Y is used as temperature higher than temperature T_c. With heat applied to junction Y, a voltage (E_{out}) will appear across terminals T_1 and T_2 and hence an electric current would flow continuously in this closed circuit.
This voltage as shown in figure, known as the seebeck EMF, can be expressed as

$$E_{out} = \alpha(T_h - T_c) \qquad \text{Where} \quad \alpha = \frac{dE}{dT}(\alpha_A - \alpha_B)$$

α is the differential seebeck coefficient or (thermo electric power coefficient) between the two materials, X and Y, positive when the direction of electric current is same as the direction of thermal current, in volts per K^0

E_{out} is the output voltage in volts.

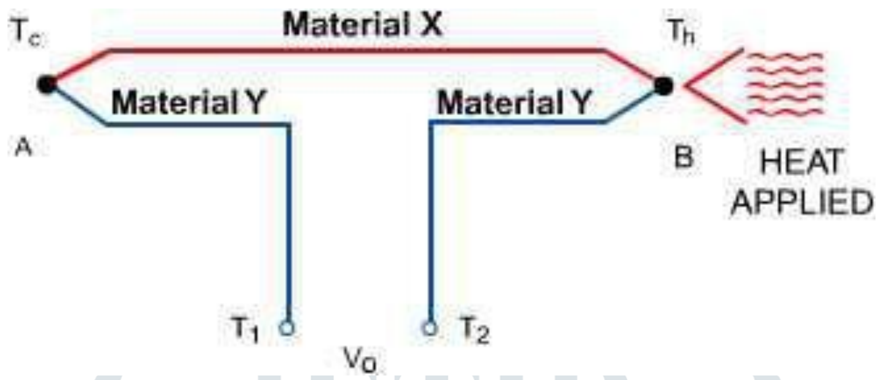

Figure.1. Seebeck Effect

3.2 Peltier Effect

Peltier found there was an opposite phenomenon to be see-beck effect, whereby thermal energy could be to one dissimilar metal junction and discharged at the other junction when an electric current flowed within the closed circuit. In the Fig.2, the thermocouple circuit is modified to obtain different configuration that illustrates the Peltier effect, a phenomenon opposite that of the seebeck effect. If voltage (E_{in}) is applied to terminals T_1 and T_2 an electric current

(I).will flow in the circuit. As a result of the current flow, a slight cooling effect (Q_c) will occur at thermocouple junction X (where heat is absorbed), and a heating effect (Q_h) will occur at junction Y (where heat is expelled).
Note that this effect may be reversed where by change in the direction of electric current flow will reverse the direction of het flow. Joule heating, having magnitude I^2R (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This joule heating effect acts in opposition to the Peltier effect and causes a net reduction of the available cooling.
The Peltier effect can be expressed mathematically as

$$Q_c \text{ or } Q_h = \beta \times I = (\alpha T) \times I$$

Where is the differential Peltier coefficient between the two materials X and Y in volts. I is the electric current flow in amperes. Q_c and Q_h are the rates of cooling and heating, respectively, in watts.

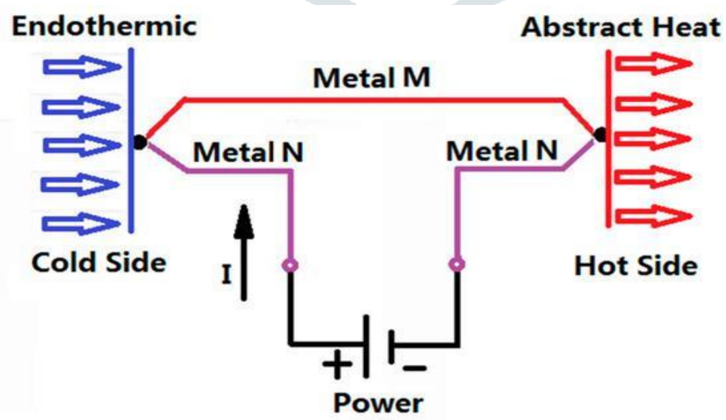

Figure.2. Peltier Effect

3.2 Thomson Effect

William Thomson, who described the relationship between the two phenomena, later issued a more comprehensive ex-planation of the seebeck and Peltier effects. When an electric current is passed through a conductor having a temperature gradient over its length, heat will be either absorbed by or expelled from the conductor. Whether heat is absorbed or expelled depends on the direction of both the electric current and temperature gradient. This phenomenon is known as Thomas effect.

IV. DESIGN OF THERMO ELECTRIC REFRIGERATION SYSTEM

4.1. Thermo Electric Module

A practical thermoelectric cooler consists of two or more elements of semiconductor material that are connected elec-trically in series and thermally in parallel. These thermoelec-tric elements and their electrical interconnects typically are mounted between two ceramic substrates. The substrates serve to hold the overall structure together mechanically and to insulate the individual elements electrically from one another and from external mounting surfaces. After integrating the various component parts into module, thermoelectric modules ranging in size from approximately 2.5-50mm (0.1 to 2.0 inches) square and 2.5-5mm (0.1 to 0.2 inches) in height may be constructed.

Both N-type and P-type Bismuth Telluride thermoelectric materials are used in thermoelectric cooler. This arrangement causes heat to move through the cooler in one direction only while the electrical current moves back and forth alternately between the top and bottom substrates through each N and P element. N-type material is doped so that it will have an excess of electrons (more electrons than needed to complete a perfect molecular lattice structure) and P-type material is doped so that it will have a deficiency of electrons (fewer electrons than are necessary to complete a perfect lattice structure). The extra electrons in the N material and the holes resulting from the material. Typical thermoelectric cooler with het being moved as a result of an applied electrical current (I). Most thermoelectric cooling modules are fabricated with an equal number of N-type and P-type elements where one N and P element pair form a thermoelectric couple.

Heat flux (heat actively pumped through the thermoelectric module) is proportional to the magnitude of the applied DC electric current. By varying the input current from zero to maximum, it is possible to adjust and control the heat flow and temperature.

4.2. Thermo Electric Materials

The thermoelectric semiconductor material most often used todays TE coolers is an alloy of Bismuth telluride that has been suitably doped to provide individual blocks or elements hav-ing distinct N and P characteristics. Thermoelectric materials most often are fabricated by either directional crystallization from melt or pressed powder metallurgy. Each manufacturing method has its own particular advantage, but directionally grown materials are most common. In addition to bismuth telluride (Bi_2Te_3), there are other thermoelectric materials including lead telluride (PbTe), silicon Germanium (SiGe), and bismuth-Antimony (Bi-Sb) alloys that may be used in specific situations. Figure illustrates the relative performance or figure-of-Merit of various materials over a range of temperatures. It can be seen from this graph that the performance of Bismuth Telluride peaks within temperature range that is best suited for most cooling applications.

V. LOAD CALCULATIONS

The heat load calculations were carried out to determine the capacity of the system. The following parameters were considered for determining the cooling load calculations. They are: * Product load * Transmission load * Additional load

5.1 Product Load

The following parameters were considered for determining the product load. They are:

5.1.1. Sensible heat load:

Sensible heat load,Q = $(m*C_p*\Delta T)/(t)$ in W

Where, Mass of the food preservatives, m=10Kg

Mass of the food preservatives, m=10Kg

Specific heat, C_p =3.98 KJ/Kg.k

Temperature difference, ΔT=33k

Cooling rate time, t=24*3600=86400 in sec

Sensible heat factor= (10*3.98*1000*33)/ (86400)

= 15.2 W

Cooling rate time, t=86400 in sec,

Sensible heat factor = 15.2 W

5.1.2. Heat gain from tomatoes (respiration load):

The heat emitted from the food preservatives to be stored is very important in case of refrigerators and given in the following Table.I

Table 5.1: Heat emission values from food preservatives

Commodity	Temperature, ℃	KJ/ Ton,24hr
Food preservatives	0	1050
	4	1340
	15	5680

Heat gain from tomatoes, Q_r= (mass× Heat emission)

$$Q_r=\frac{(10\times5680)}{(1000\times24)}=2.36667 \text{ KJ/ hr}$$

$$=\frac{2.36667\times1000}{3600}=0.657\text{W}$$

5.1.3 Transmission load

Heat transfer through insulation by conduction and convection through insulated walls,

$$Q_i=\frac{A(Ta-Tc)}{\left(\frac{1}{h}\right)+\left(\frac{t}{K}\right)}$$

Where,

Ambient temperature, T_a=40℃

Lowest desired temperature, T_c =7℃,
Insulation thickness, t=40mm=0.02m,
Thermal conduction of poly urethane foam, K=0.025W/mk

Convective heat transfer coefficient, h=25W/m^2$_K$

Area of the insulation, A=2(L*B) +2(L*H) +2(B*H)

=2(0.1*0.01) +2(0.1*0.05) +2(0.01*0.05)

$$= 0.64m^2$$

Heat transfer through insulated walls, $Q_i=\frac{A(T_a-T_c)}{\left(\frac{1}{h}\right)+\left(\frac{t}{K}\right)}$

$$=\frac{0.64\times(40-7)}{\left(\frac{0.02}{0.025}\right)+\left(\frac{1}{25}\right)}$$

= 25.14W

5.1.4 Additional load

Heat loss by radiation and fan, Q_a = 10% of heat load

$$= 10\%(Q_r + Q_s + Q_i)$$

$$=\frac{10}{100}\times(15.2+0.657+25.14)$$

= 4.1W

Total cooling load, $Q_c = Q_r + Q_s + Q_i + Q_a$

= 15.2+0.657+25.14+4.1

=45.1W

5.2 Selection of TEC

The following parameters are to be determined for selection of TEC module and which give required cooling capacity to the refrigerator.

- Number of Stages Required
- Number of Couples Required
- Rate of het rejection to the ambient
- Power input to the TEC
- C.O.P

5.2.1 Number of Stages Required

The numbers of stages were required for TEC element based on maximum temperature difference of the refrigerator. For this refrigerator, a single-stage TEC was sufficient, since 67°Cis greater than the desired 33°C DT max.

Table: 5.2, Typical maximum obtainable DT values for single and multi-stage TEC's

Number of stages	ΔT_{max}(°C)
1	67
2	91
3	109
4	115

5.2.2 Number of couples required

Number of couples required, N=Q_c/C [(Z$\frac{T_c{}^2}{2}$)-ΔT]

Where,

Cooling load, Q_c= 45.1W

Overall conduction coefficient, C =2.0828*10^{-3} W/K

Figure of Merit, Z=2.9*10^{-3} K^{-1}

Cold side temperature, T_c =7°C=7+273 =280K

Temperature difference, ΔT=33K

Number of couples required, N=45.1/0.002808 [(0.0029*280^2/2)-25]

=45.1/0.249

=182 couples

5.2.3 Rate of heat rejection to the ambient

The rate of heat rejected to the ambient from the heat sink was determined. Rate of heat rejection, Q_h=N [(α_p-α_n) Ta*I_{opt}-C(T_h-T_c)+($I_{opt}{}^2$ * R/2)]

Where,

Number of couples required, N=182

Seebeck coefficient of p-type element, α_p=197*10^-6 V/K

Seebeck coefficient of n-type element, α_n=-216*10^-6 V/K

Overall conduction coefficient, C=2.0828*10^-3 W/K

Overall electric resistance, R= 0.0284Ω

Cold side temperature, T_c= 7°C = 7+273= 280 K

Hot side (or) atmospheric temperature, T_a= 40°C =40+273= 313K

Electric current, I_{opt} = 4.13 A

Rate of heat rejection, Q_h= 182[(413*10^-6 *313*4.13)-(0.0021*33)+(4.13^2 *(0.0284/2))]

=128.62 W

5.2.4 Power input to the TEC

The input DC power of TEC was determined for producing required cooling capacity for the refrigerator.

Input power, Pin= $Q_h - Q_c$

Where,

Rate of heat rejection to the ambient, Q_h= 128.62 W

Cooling load, Q_c= 31 W

Input power, P_{in}= 128.62-45.1 =83.52 W

5.2.4 C.O.P

The ratio of cooling load to input power to the TEC is called Coefficient of performance.

Coefficient of performance of TEC, C.O.P= Q_c/P_{in}

Where,

Cooling load, Q_c= 45.1W

Input power, P_{in}= 83.52 W

Coefficient of performance of TEC, C.O.P= 45.1/83.52= 0.539

The suitable TEC module was selected from standard single stage

Thermoelectric coolers of kryotherm technology with the product value of maximum voltage (V_{max}) and maximum current (I_{max})of standard cooler is greater than or equal to the calculated input power(P_{in})of the system. Some standard single stage TEC's are listed in Table.5.3

Table: 5.3, standard single stage thermoelectric coolers

Type	I_{max}	Q_{max}	V_{max}	ΔT_{max}	Dimensions(mm)		
	Amps	Watts	Volts	K	A	B	H
TB-127-0.8-1.5	2.0	19.1	15.7	69	25	25	3.8
TB-127-1.0-1.5	3.1	29.9	15.7	69	30	30	3.8
TB-127-1.4-2.5	3.7	37.4	16.3	72	40	40	4.8
TB-127-1.4-2.0	4.6	57.0	20.1	70	40	40	4.3
TB-127-1.4-1.5	6.1	60	12	70	40	40	3.9
TB-127-1.4-1.5	6.1	76	20.1	70	40	40	3.9
TB-127-1.4-1.5	6.1	113.8	30	70	55	55	4.0

Where,

A – Length of the TEC,

B – Breadth of the TEC,

H – Thickness of the TEC.

The TB-127-1.4-1.5 module was selected for the refrigerator from table

Where,

TB- thermoelectric battery (cooler)

127- Number of couples in the cooler,

1.4- width of the rib of the square shaped thermoelectric element (in mm)

1.5- height of the thermoelectric element (in mm)

Maximum input power to the TEC module, P_{max}= $V_{max} * I_{max}$

=12*6.1

VI. EXPERIMENTAL RESULTS AND DISCUSSION

The Fig.3 shows the experimental setup of the thermoelectric refrigerator. The thermoelectric refrigerator is connected with switch mode power supply (SMPS), digital thermometers. Switch mode power supply is used to regulate the power supply to the refrigerator that works on the switching regulation. It is highly reliable, efficient, and noiseless. Digital thermometers are used to display the values of temperature inside the cabin.

Figure.3 Chamber

6.1 Experimental results

To verify the above system design analysis, we designed and built a prototype model of thermoelectric refrigerator and performed experiments.

6.1.1 Cooling rate test data:

The test was conducted at different ambient temperatures 35^0c, 40^0c represented in Table 6.1 and 6.2, as this was prototype with improvement in prototyping we can achieve even lower temperature.

Experiment 1: Variations of cold side temperatures and atmospheric temperature based on its time are determined and the values are shown in table 6.1

Test conditions:

Atmospheric temperature,T_a=35^{o}c ,input power,P_{in}=90 Watts DC power

Table 6.1: variation of cold side temperature with variation in time at 35℃ ambient temperature.

S.NO	**Time (min)**	**Ambient temperature (℃)**	**Cold side temperature (℃)**

1	0	35.0	35.0
2	30	35.0	28.4
3	60	35.2	20.7
4	90	35.3	13.7
5	120	35.4	11.7
6	150	35.5	10.5
7	180	35.7	9.7
8	210	35.8	9.1
9	240	36.0	8.7
10	270	36.1	8.4
11	300	36.2	8.2
12	330	36.0	8.0
13	360	36.0	7.9
14	390	35.8	7.8
15	420	35.7	7.8

The cold side temperature dropped to around 8^0c in 5 hours, and may go down continuously. Variations of cold side temperature and ambient temperature are shown in graph model in Fig. 4

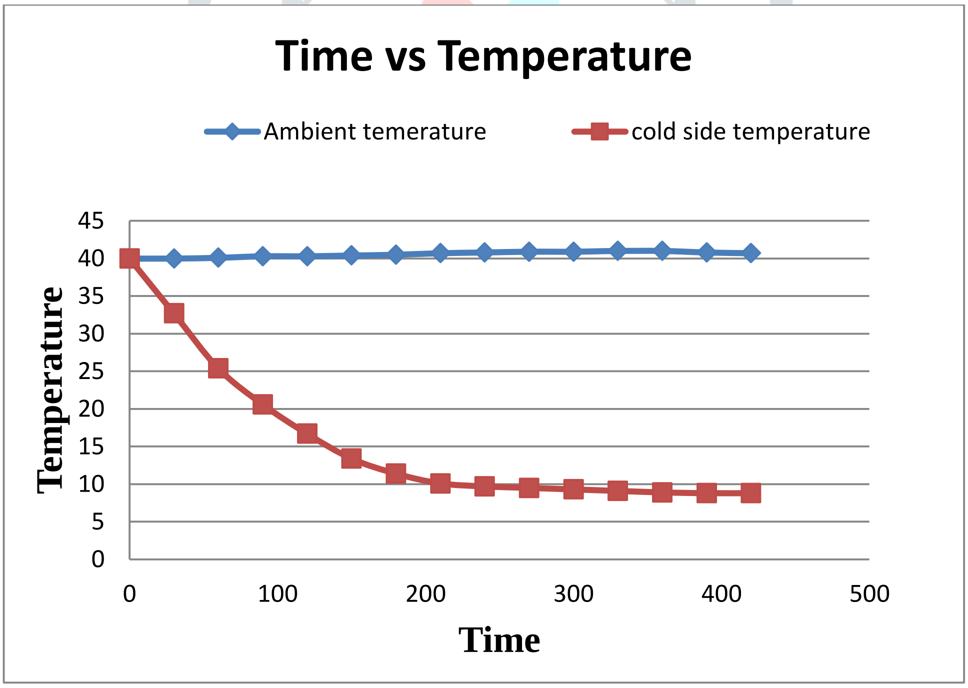

Figure: 4, Time vs Temperature of experiment 1

Experiment 2: Variations of cold side temperatures and atmospheric temperature based on its time are determined and the values are shown in Table 6.2

Test conditions:

Atmospheric temperature,T_a=40°c ,input power,P_{in}=90 Watts DC power

Table 6.2: Variation of cold side temperature with variation in time at 40℃ ambient temperature.

S.NO	Time	Ambient temperature	Cold side temperature

	(min)	(°C)	(°C)
1	0	40.0	40.0
2	30	40.0	32.7
3	60	40.1	25.4
4	90	40.3	20.6
5	120	40.3	16.7
6	150	40.4	13.4
7	180	40.5	11.4
8	210	40.7	10.1
9	240	40.8	9.7
10	270	40.9	9.5
11	300	40.9	9.3
12	330	41.0	9.1
13	360	41.0	8.9
14	390	40.8	8.8
15	420	40.7	8.8

The cold side temperature dropped to around 9^0c in 5 hours, and may go down continuously. Variations of cold side temperature and ambient temperature are shown in graph model in Fig. 5

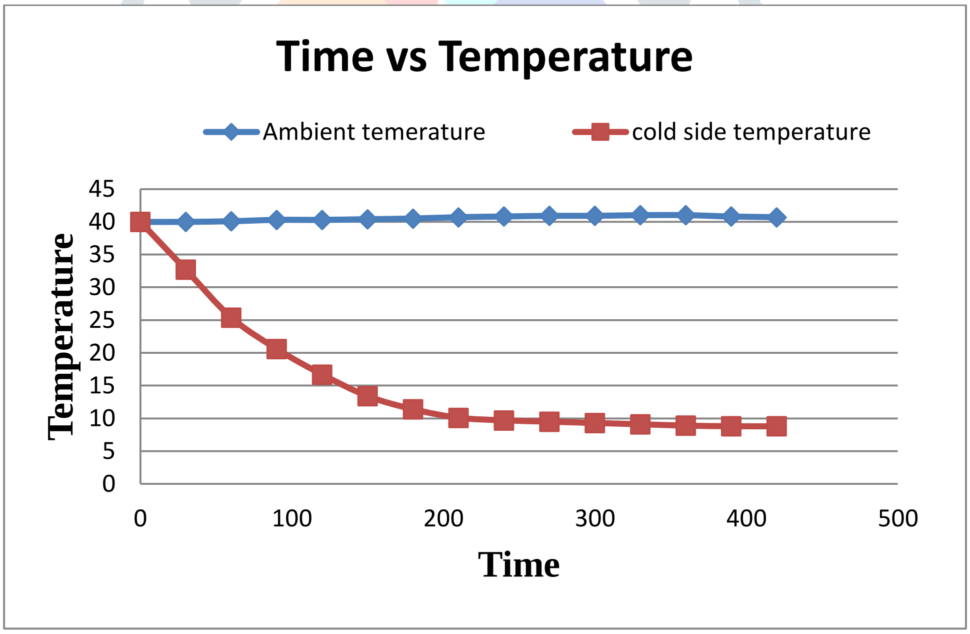

Figure: 5, Time vs temperature of experiment 2

VII. CONCLUSION

The objective of this project is to achieve the long term cooling with solar powered battery for refrigeration. A thermoelectric refrigerator system is has been designed and developed to provide active or passive cooling with help of 12V thermoelectric module is used to provide adequate cooling. First the cooling load calculations for thermoelectric refrigerator component considered under report were presented. Simulation test in laboratory have validated the theoretical design parameters. Tests were conducted at various ambient temperatures and results were shown In this paper the retention time achieved was 15 min with the designed module. In order to achieve the higher retention time, additional heat sink must be incorporated.\

VIII. ACKNOWLEDGMENT

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