Performance and Analysis of Peltier Operated Portable Refrigerator

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Abstract : The global increasing demand for refrigeration in field of refrigeration air-conditioning, food preservation, vaccine storages, medical services, and 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 climate change. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling, is expected to play an important role in meeting today energy challenges. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed. The objectives of this study is design and develop a working thermoelectric refrigerator interior cooling volume of 5L that utilizes the Peltier effect to refrigerate and maintain a selected temperature from 5 °C to 25 °C. The design requirements are to cool this volume to temperature within a time period of 6 hrs and provide retention of at least next half an hour. The design requirement, options available and the final design of thermoelectric refrigerator for application are presented.

IndexTerms - Carbon dioxide, Thermoelectric refrigerator, Thermoelectric, refrigeration system, HVAC

I. INTRODUCTION

Conventional cooling systems such as those used in refrigerators utilize a compressor and a working fluid to transfer heat. Thermal energy is absorbed and released as the working Fluid undergoes expansion and compression and changes phase from liquid to vapor and back, respectively. Semiconductor thermoelectric coolers (also known as Peltier coolers) offer several advantages over conventional systems. They are entirely solid-state devices, with no moving parts; this makes them rugged, reliable, and quiet. They use no ozone-depleting chlorofluorocarbons, potentially offering a more environmentally responsible alternative to conventional refrigeration. They can be extremely compact, much more so than compressor-based systems. Precise temperature control (< ± 0.1 °C) can be achieved with Peltier coolers. However, their efficiency is low compared to conventional refrigerators. Thus, they are used in niche applications where their unique advantages outweigh their low efficiency. Although some large-scale applications have been considered (on submarines and surface vessels), Peltier coolers are generally used in applications where small size is needed and the cooling demands are not too great, such as for cooling electronic components (Astrain and Vian, 2005).

Objective of this project is to design thermoelectric Refrigerator Utilize Peltier effect to refrigerate and maintain a specified temperature, perform temperature control in the range 5 °C to 25 °C. Interior cooled volume of 5 Liter and Retention for next half hour.

II .DESIGN OF THERMOELECTRIC COMPONENTS

2.1 Heat Transfer Methods

There are several methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric to the surrounding. These methods are described in the following three sections. Natural convection, Liquid cooled, Forced convection when the co-efficient of thermal transfer (K) was investigated, the K for natural convection was approximately 25 W/mK. This value compared to 100W/mK for forced convection. Clearly the size of the heat sink for a natural convection apparatus would need to be 4 times that for a forced convection set-up.

2.2 Geometry

Two main geometries were considered for the device the first was a rectangle. The advantage of rectangle is its simplicity to build and insulate. A door can easily be attached to one of the sides. Finally any insulation, thermoelectric modules or heat sinks are easily fastened to the sides. The second choice for cooler geometry was a cylinder. The advantage found with this shape is that it has the largest volume to surface area ratio of the two designs considered. This is a good property when the objective is to minimize heat loss. But considering the simplicity to build and insulate rectangle box is considered.

2.3 Material

We explored three different materials for the construction of the outer casing and frame of the device. These were aluminum, stainless steel and Hips.

High impact polystyrene is desirable as it has a low thermal conductivity. Building the device out of would make it very light, portable while maintaining rigidity is readily available and reasonably priced, is easy to cut and drill. The outer casing and container would be made by first making a positive mold and applying a cloth coated with resin.

III .Design of Thermoelectric Components

To design thermoelectric components we need to calculate heat load on refrigerator due to active, passive and air changing load, the total heat load is calculated for following specification mentioned in Table 1 and Environmental condition mentioned in Table 2.

Table 1: Specifications of Rectangular Box

Parameters		Value
Outside Dimension (mm)	Width (w)	200
	Depth (d)	240
	Height (h)	200
Inside Dimension (mm)	Width (w)	160
	Depth (d)	200
	Height (h)	160
Machine Compartment Dimension (mm)	Width (w)	55
	Depth (d)	240
	Height (h)	200
Door Dimension (mm)	Width (w)	200
	Depth (d)	125
	Height (h)	200
Note: Usable Volume = 5.12 Lit.		

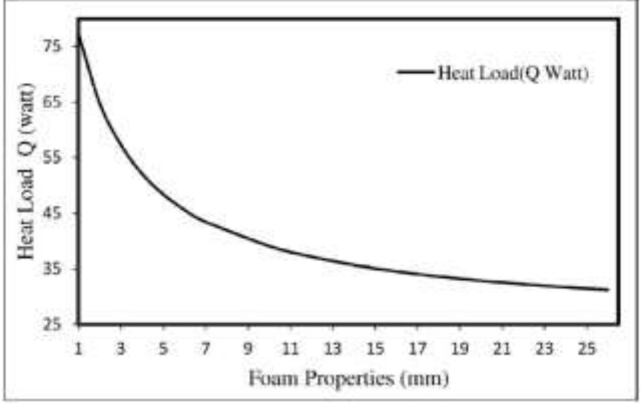
Table 1: Specifications of Rectangular Box

Table 2: Inputs to Heat Load

Sr No	Parameters	Values
1	Outside Temperature (Do) (°C)	43
2	Inside Temperature (Di) (°C)	3
3	Internal Fan Motor Wattage (W)	1
4	Gasket Thickness (m)	0.01
5	Gasket Height (m)	0.025
6	Outside Material Thickness (m)	0.00028
7	Outside Material Thickness (m)	0.00036
8	M/C Area Top Temperature (°C)	48
9	Inside Heat Transfer Coefficient $\frac{W}{m^2k}$	10
10	Outside Heat Transfer Coefficient $\frac{W}{m^2k}$	10
11	Outside Material Thermal Conductive HPS $\frac{W}{mk}$	0.188
12	Inside Material Thermal Conductive HPS $\frac{W}{mk}$	0.188
13	Gasket Thermal Conductivity $\frac{W}{mk}$	0.07
14	Heat Extender Material $\frac{W}{mk}$	373
15	Top Foam Thickness (m)	0.025
16	Foam Thermal Conductivity $\frac{W}{mk}$	0.01944

Using Tables 1 and 2 for the input the total heat load calculated as 33 Watts using standard conduction and convective heat transfer equations. The optimum foam thickness considering cost vs. heat load Figure 1 represent the 20 mm is optimum range of foam thickness.

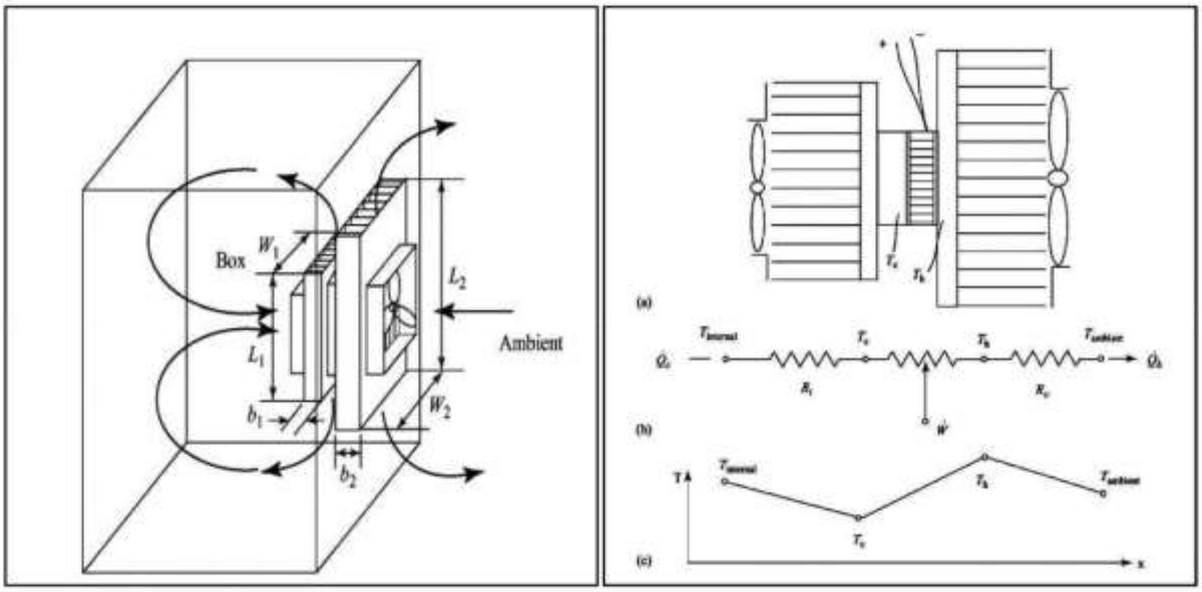
Figure 1: Heat Load vs. Foam Thickness



3.1 Heat Sink Design

In order to visualize the energy flow in the entire system, a thermal circuit is constructed, which is schematically shown in Figure 2. $R_c$and $R_{\,h}$and are the overall thermal resistances for the internal heat sink and external heat sink, respectively. The components of the air cooler are an internal heat sink, a thermoelectric module, and an external heat sink as shown in Figure 2 is the amount of heat transported at the internal heat sink, which is actually the design requirement (33 Watts).

Figure 2: Air Flow of a Thermoelectric Air Cooler



Considering the dimension available at the machine area and various options keeping the weight, cost and manufacturing feasibility as the main consideration for selection for mounting of heat sink both at hot cold side area Fin thickness of 1mm with profile length of 20 mm is selected Tables 3 and 4 represent the summary result for hot side and cold side fin respectively.

Table 3: Summary Results for Optimum Hot Side Fins

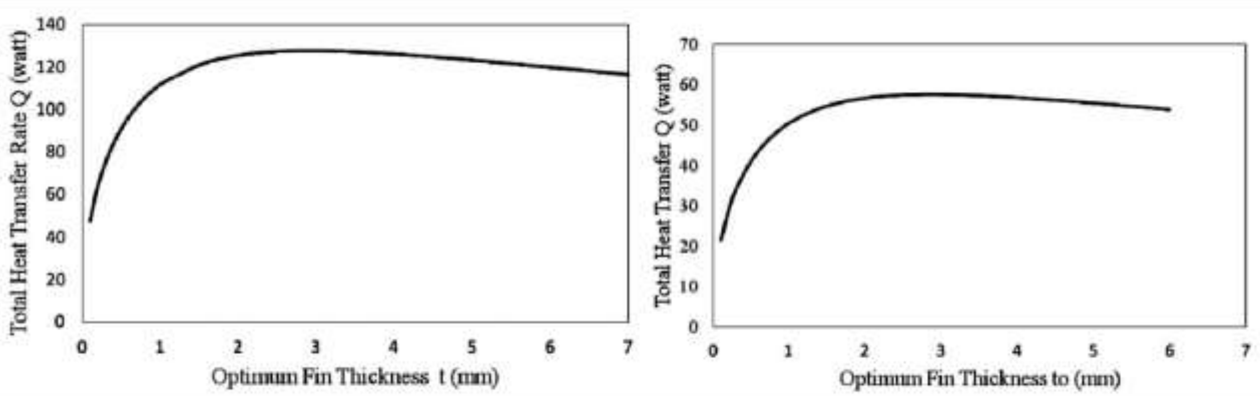
Parameters	Optimum Array I Without Constrains	Optimum Array II with Constrains	Optimum Array III with Constrain	Optimum Array IV with Constrain
Fin Thickness *t* (mm)	1	0.1	0.5	1
Profile Length *b* (mm)	104.00	20.00	20.00	20.00
Spacing *z* (mm)	3.16	3.16	3.16	3.16
Heat Transfer Coefficient *h* (w/m2K)	16.24	16.24	16.24	16.24
Total Heat Transfer *Q* (Watt)	104.80	49.36	94.24	112.64
No of Fins	30.04	38.34	32.35	30.04
Mass of Fin (kg)	0.90	0.02	0.10	0.17
Fin Efficiency $_f$	0.63	0.17	0.37	0.50
Fin Effectiveness $_f$	131.95	467.14	207.46	142.05

Overall Thermal Resistance R_h (°C/W)	0.15	0.60	0.67	0.76

Table 4: Summary Results for Optimum Cold Side Fins

Parameters	Optimum Array I Without Constrains	Optimum Array II with Constrains	Optimum Array III with Constrain	Optimum Array IV with Constrain	Optimum Array V with Constrain
Fin Thickness t (mm)	1	1.5	1	0.5	0.1
Profile Length b (mm)	109.90	20.00	20.00	20.00	20.00
Spacing z (mm)	2.92	2.92	2.92	2.92	2.92
Heat Transfer Coefficient h (w/m2K)	14.76	14.76	14.76	14.76	14.76
Total Heat Transfer Q (Watt)	50.57	49.36	47.74	40.44	21.32
No. of Fins	25.99	23.05	25.99	29.79	33.72
Mass of Fin (kg)	0.64	0.15	0.11	0.07	0.02
Fin Efficiency $_f$	0.63	0.61	0.52	0.38	0.17
Fin Effectiveness $_f$	156.88	115.29	147.94	217.20	490.05
Overall Efficiency $_o$	0.63	0.63	0.63	0.63	0.63
Overall Thermal Resistance R_c (°C/W)	0.23	1.39	1.24	1.09	0.97

Figure 3: Total Heat Transfer (Q) vs. Optimum Fin Thickness (t_o) for Hot Side and Cold Side Fin



After looking at various options keeping the weight, cost and Manufacturing feasibility as the main consideration for selection Fin thickness of 1 mm with profile length of 20 mm is selected.

3.2 Thermoelectric Cell

Using Standard correlation available in handbooks the commercial available module with the calculated maximum performance is represented in Table 5.

Table 5: Model Number for TER

Module: Model TEC1-127-06L			
Q_{max}	51.4 Watts	Dimensions	
I_{max}	6 Amp	Width	40 mm
V_{max}	15.4 V	Length	40 mm
T_{max}	67 °C	Thickness	3.8 mm
Number of Thermocouple	127		

IV. EXPERIMENTATION

This presents the detailed information of instruments, working procedure, operating parameters of thermoelectric cooler.

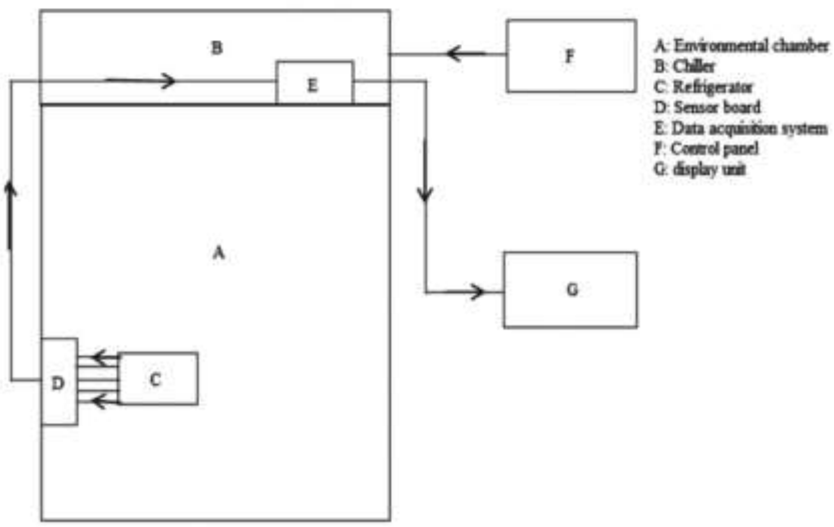
4.1 Experimental Test Facility

The test facility is used to test cooling performance, Energy measurements of Refrigerators and Freezers based on National and International standards in an environmentally Controlled chambers. This lab has NABL Accreditation capable of testing cooling performance, Energy Measurements of Refrigerators and Freezer based on National and International Standards in environmentally controlled chambers. The lab has well instrumented to perform tests as per International Standards like ISO-15502:2005, IEC-60335-2-24, UL-250, etc.

4.2 Instrumentation

This control panel is used in Environmental chamber is to set the temperature and Relative humidity values in the climate chamber. It operates chiller to supply air in required quantity and of desired quality so proper temperature and humidity is maintain in environmental chamber. The Layout of the chamber was shown in Figure 4.

Figure 4: Layout of Test Chamber

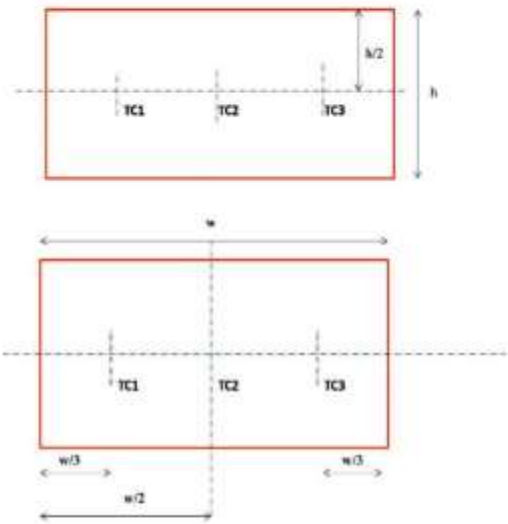


A data acquisition system has been developed for automatic reading of temperature at various points. Temperature indicators are of RTD type (Make omega) and having capability to measure temperature ranging from with the accuracy ± 0.5. 30 temperature sensors were available for one test unit.

4.3 Thermocouple Set-Up

The thermocouple of 15 mm 15 mm dimension is installed in TEC as per Figure 5 below:

Figure 5: Build of TEC Thermocouple



4.4 Test Procedure

The following test procedure is followed during the testing of :

- The cabinet, with all compartment doors, pans, and grilles open, is to have been electrically disconnected for at least 16 hours in an ambient temperature of (43 °C, 32 °C or 21 °C) immediately preceding the start of the test.
- During the test, all refrigerating system controls (thermostats, automatic defrost controls, etc.) are to be electrically inactivated (if necessary) to insure a continuous operation of the refrigerant motor-compressor assembly.
- Test rooms and Measuring Instruments shall meet the requirements as per ISO 15502:2007/Au/Nzs 4474.1.2007.
- Start the Unit once the product reaches the temperature of ambient condition.
- To observe the lowest" compartment temperatures attained at the end of the specified test period of 6 hours.
- The retention time is calculated from the time the product reaches 20 °C to the time taken to reach ambient condition when tested at 32 °C.

V. RESULTS AND DISCUSSION

To verify the above system design analysis, we designed and built a prototype thermoelectric cooler and perform an experiment. The picture built of the thermo-electric cooler is shown in Figure 6. The thermoelectric module form melcor is used for the experiment.

5.1 Cooling Rate Test Data

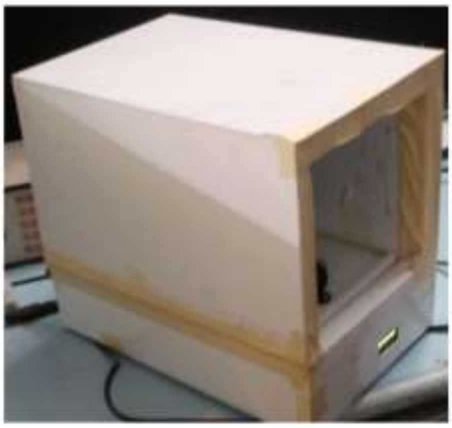
The test was conducted at different ambient 21 °C, 15 °C, 32 °C and 43 °C represented in Figure 7. The temperature vary from 15 °C to 5 °C with temperature variation within the TEC is less than 1 °C as this was the proto sample with improvement in prototyping we can achieve even lower temperature.

5.2 TEC Retention

The retention time is calculated as per test procedure. As the current carrying capacity of pettier cell is high as 6 Amp the battery to beused will large than battery which is used to run the automobile. Therefore different method has to be employed to achieve the desired temperature.

Figure 6: Prototype of Thermoelectric Cooler

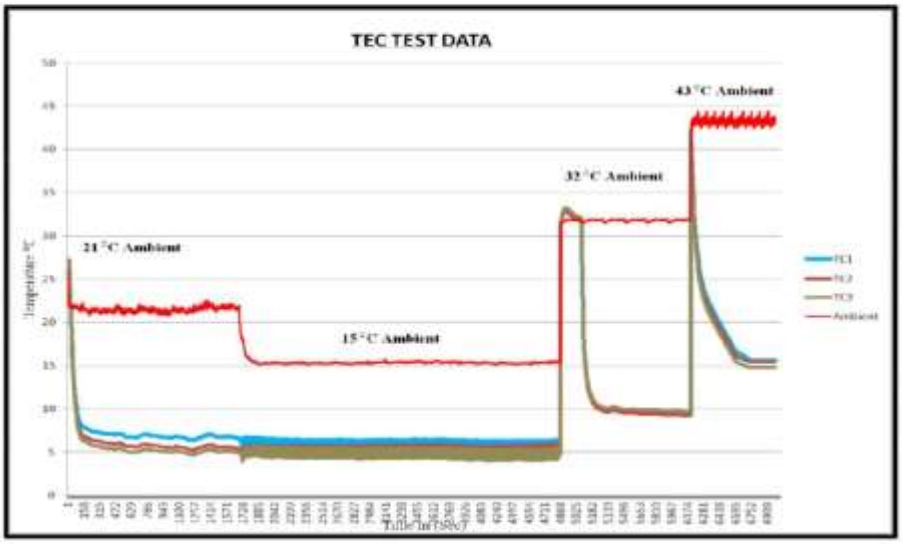
a) Inside View



b) Side View

c) Top View of Box

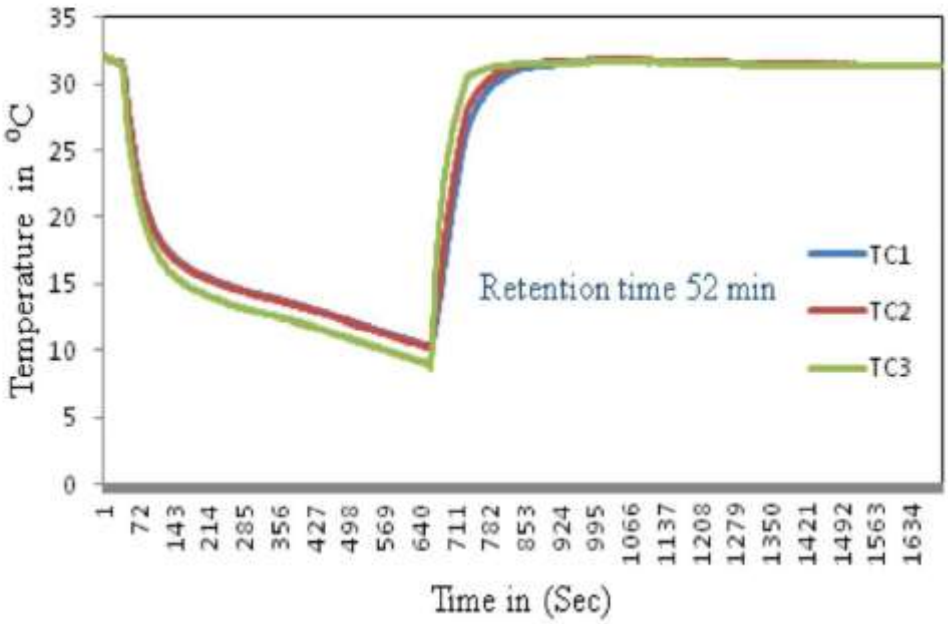
Figure 7: Data at Various Ambient Conditions



5.3 TEC Retention Data with Modification

The first method used was the retention by using large foam thickness this can be employed but the disadvantage of using high foam thickness is it reduces the available interior space as the outer dimension are constrain therefore cannot be increased beyond certain limit also which add high cost and weight with current foam thickness of 20mm the retention time achieved was 52 min represented in Figure 8.

Figure 8: Temperature Retention Data Without Modification



Considering the high current carrying capacity of the TEC module is high therefore we cannot use battery it will be bigger than the Product. Therefore second method is used to generate the electricity is by heating the Heat sink to temperature and maintain the temperature same as hot side heat sink temperature so that electrons inside the semiconductor excites and generate the electricity which is method to other than supplying electricity to TEC module.

From Figure 8, it can be seen that the retention time is around 52 min which can be improved using alternative tech of heating TEC module with separate heater. In order to increase the retention time of TEM cooler, an electric heater can be sandwiched in between heat sink and TEC module.

As shown in Figure 9 with 100 W and 0.8 A heater was installed at the inlet of the exhaust to raise and maintain the temperature of heat sink as the peltier module at same level as during the running as housing material is prototype and effected by temperature therefore temperature cannot be raised above Maximum temperature limit of the design limit of the peltier module.

Figure 9: Modification of TEC

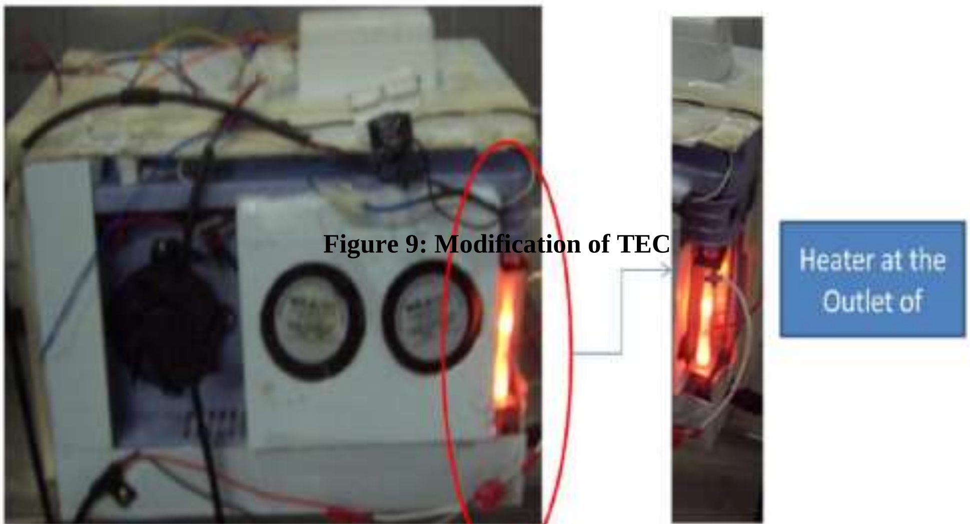
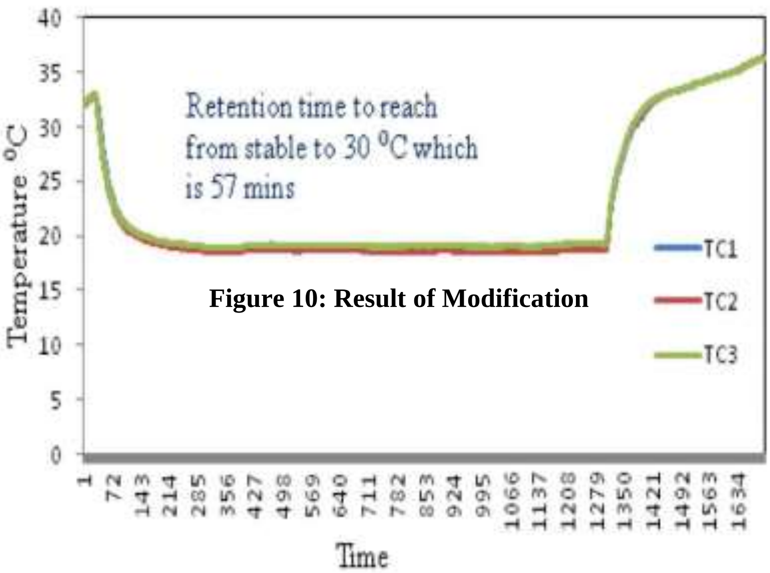


Figure 10: Result of Modification



From Figure 10 shows that with modification the retention time is increased this can be further improved with installing the heater sandwiched between thermoelectric cell and hot side heat sink with fast triggering of thermoelectric cell from period the power is OFF to heater ON time, so that the temperature does not increase in thermoelectric refrigerator.

VI. CONCLUSION AND FUTURE SCOPE

The objective project is to achieve the long term cooling in case of power failure for refrigerator A TER Cooling system is has been designed and developed to provide active cooling with help of single stage 12 V TE module is used to provide adequate cooling.

First the cooling load calculations for this TER compartment considered under study were presented. Simulation tests in laboratory have validated the theoretical design parameters and established the feasibility of providing cooling with single stage thermoelectric cooler was tested in the environmental chamber. As TER not available in open market which we can retain cooling at case of power outage due to high current carrying capacity.

The retention time achieved was 52 min with the designed module in this project. In order to achieve the higher retention time, another alternative was incorporate. This consists the additional heater on heat sink. The highest retention time achieved was 57 mins.

VII. FUTURE SCOPE

With recent development taking place in field of thermoelectric and nanoscience different thermoelectric material with figure of merit ZT more than 1 with high temperature difference to be explored this will further help to reduce the temperature, current below and can also perform better at higher ambient conditions. To improve the power retention in this thermoelectric cooler sandwich heater needs to be explored with quick switching mechanism from thermoelectric cell off state of heater to on state, so that temperature drop in thermoelectric cell can be reduced.

VIII. REFERENCES

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