FINAL YEAR PROJECT 2

THERMOELECTRIC AIR COOLING FOR CAR

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FINAL REPORT

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14385

MECHANICAL ENGINEERING

UNIVERSITY TECHNOLOGY PETRONAS

SEP 2013

CERTIFICATION OF APPROVAL

Thermoelectric Cooling For Cars

by

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL ENGINEERING)

Approved by,

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September 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

KALIDASAN A/L PALANISAMMY

CHAPTER 1

INTRODUCTION

1.1 Background History

In the automobile industry, existing air-conditioning system give arise to numerous problems such as pollution to environment (CFC emission), increase in the usage of fuel and decreased engine performance. Moreover, the current air-conditioning system is not capable to be used during the parked session. This scenario could be subdued by the introduction of thermoelectric device as an alternating cooling option for car interior. By using this option pollution, fuel usage and decreased engine performance can be prevented since the latter option was in the bracket of 'Go Green' region. Basically, the thermoelectric device known as peltier module is a semiconductor based heat pump, where heat is absorbed from one side and dissipated on the opposite side of the module.

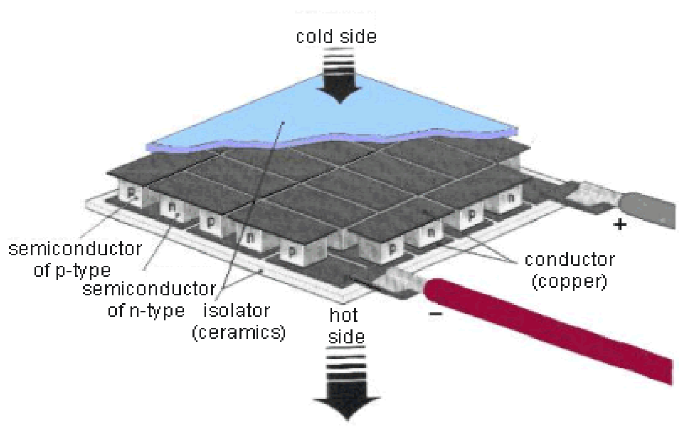


Figure 1: The TEC-module.

The peltier module (**Figure 1**) was discovered by a French watchmaker during the 19th century. It is described as a solid state method of heat transfer generated primarily through the use of dissimilar semiconductor material (P-type and N-type) . Previously, thermoelectric devices was used in for medical devices , sensor technology , cooling integrated circuits . The peltier module usually rated according to its capacity on heat removal, waste heat and maximum system temperature difference for a specified DC voltage and applied current. Another important characteristic of peltier module is the polarity of the heat removal changes when the direction of applied current changes, thus it is potential to cool or warm an object within same configuration, with respect to the polarity of the current.

When considering usage of these peltier modules, it is necessary to analyze the performance of the module over the heat removal rate. From a manufacturer data sheet of peltier module known as TE Technology, Inc, It is necessary to maintain the system temperature difference with respect to required heat removal in order to maintain the COP performance of the peltier module. Thus, in this project the development of the heat sinks must be considered to fulfill performance requirement. In the context of heat sink resistance, the leading materials that possess high thermal conductivity is copper and aluminum.

When considering peltier cooling with copper or aluminum heat sinks, of course it will cost in high price for the fabrication of the prototype but since this manner of cooling could overcome some disadvantages of existing compressor-based cooling, it is still worth of the price. By taking all these into consideration, a detailed analysis on the selection of peltier module and heat sinks will be conducted in this project. The design of the prototype will be based on air-to-air or liquid-to-air thermo-cooling since the target is to cool down the interior air.

1.2 Problem Statement(s)

When the car is parked during hot days and existing car HVAC system is not running, the exceeding car's interior temperature causes discomfort for the car users. Other than this, the existing HVAC system possesses some disadvantages in its application such as pollution and frequent maintenance . When considering thermoelectric cooling, the prototype design should be efficient in the heat removal performance by the attachment of heat sinks that bring very minimal thermal resistance. The failure of these mechanism would result in increase of peltier's system temperature difference which reduces the heat pumping capacity and contribute to overall failure of the thermoelectric device.

The new HVAC system using thermoelectric couple which shall overcome all the Disadvantages of existing HVAC system. If this system comes in present HVAC system, then revolution will occur in the automotive sector. With population and pollution increasing at an alarming rate TEC (thermoelectric couple) system have come to rescue as these are environment friendly, compact and affordable. Conventional compressor run cooling devices have many drawbacks pertaining to energy efficiency and the use of CFC refrigerants. Both these factors indirectly point to the impending scenario of global warming. As Most of the electricity generation relies on the coal power plants, which add greenhouse gases to the atmosphere is the major cause of global warming. Although researches are going on, better alternatives for the CFC Refrigerants is still on the hunt. So instead of using conventional air conditioning systems, other products which can efficiently cool a person are to be devised. By using other efficient cooling mechanisms we can save the Electricity bills and also control the greenhouse gases that are currently released into the atmosphere. Although Thermoelectric (TE) property was discovered about two centuries ago thermoelectric devices have only been commercialized during recent years. The applications of TE vary from small refrigerators and Electronics package cooling to Avionic instrumentation illumination control and thermal imaging cameras. Lately a dramatic increase in the applications of TE coolers in the industry has been observed. It includes water Chillers, cold plates, portable insulin coolers, portable beverage containers and etc.

1.3 Objective(s)

It is important to acknowledge the important aspects of the project and the end result of the project. Thus, it is important to clearly state and recognized the objective of a project. Throughout this project, these are the objectives that will enlighten in this thesis;

- To study critically existing HVAC system for its advantage and disadvantages.
- To explore various technological option to replace existing HVAC system.
- To study TEC as a substitute for present HVAC system which will overcomes the all demerits of present HVAC system.
- To fabricate working model of HVAC using TEC.
- To test HVAC using TEC for its effectiveness, efficiency, environment friendliness, comfort and convenience

1.4 Project Scope

Why Thermoelectric cooling for cars than HVAC.

Power loss – Compressor is driven by the crankshaft of the engine. It consumes 5 to 10% of engine power.

Fuel loss – Present HVAC System reduces the mileage of the vehicle.

Electric loss –Battery provide 12V current to the blowers and electromagnetic clutch of compressor for engaging the compressor.

Cost – cost of present HVAC System is very high.

Hazardous refrigerant – HFC is quit hazardous for human body & ozone layer which leads to global warming.

Repairing cost – Repairing cost of HVAC System is very high.

Maintenance – Proper maintenance is very necessary because this system can affect human body & Environment.

Size –Present HVAC system required very large space in the engine compartment and dashboard.

Delicate system –if any component fails to perform well then the whole HVAC system will either not function properly or not function at all.

The project scope involves the following elements

Sizing and Designing of the cooling system

1. Selection of the TECs
2. Selection of Fans and Heat sinks
3. DC power supply design with temperature control.
4. Prototype Assembly and Fabrication.
5. Temperature measurements for testing.
6. Power supply testing and troubleshooting.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review of this project comprises from the journal on the internet, paper proceedings and research, books and lectures. The literature review is done to investigate cases of the projects that may arise to overcome it. The literature review gives a great knowledge on the fundamentals of the project. Among the reviewed project is about the peltier technology in cooling and heating in the industry and how the heat sinks and thermo-electric module interacts to cool down the external interfering air. Among the things that given consideration is the flow rate of coolant by the pump to the liquid radiator and the required heat sink resistance as well as its dimensions. Apart from this a few experiments on the temperature rise over time in car cabin was analyzed as a preparation to run the data collection experiment.

2.2 Thermoelectric Cooler (Tec)

A typical thermoelectric module consists of a number of thermocouples sandwiched between two layers of ceramic substrates. The ceramic substrates should ideally have a very high thermal conductivity so that there is minimal temperature drop across the layer of the substrate but very low electrical conductivity to avoid any leakage current flow through the substrate. A schematic of the construction of a typical TEC module is shown in Figure 2.1. Detailed descriptions of thermoelectric module operation and applications can be found in Ioffe (1957), Gray (1961), Goldsmid (1961). Thermoelectric cooling is achieved with the penalty of DC current supply through one or a series of thermocouples electrically connected in series but thermally in parallel. The schematic of a single thermocouple which consists of one n and one p-type semiconductor material, also known as a thermo-element with its operating principle is shown in Figure 2.2. In the n and p type semiconductors there exist excess electrons and holes respectively. With the electric polarity shown in Figure 2.2, electrons in p and n-type material flow from bottom to top and from top to bottom respectively, thus resulting in a clockwise electron flow or counter clockwise current flow through this circuit. Heat is absorbed at the top and released at the bottom of the schematic shown in Figure 2.2. If the polarity is changed, the hot and cold junction as well as the heat absorption and rejection will interchange. There are three important thermoelectric effects that have been known since the nineteenth century: (i) Seebeck effect, (ii) Peltier effect and (iii) Thomson effect. Seebeck in 1821 discovered that, when a temperature difference is maintained at the two junctions of a thermocouple composed of two dissimilar conductors, a voltage is generated at the two terminals of the thermocouple.

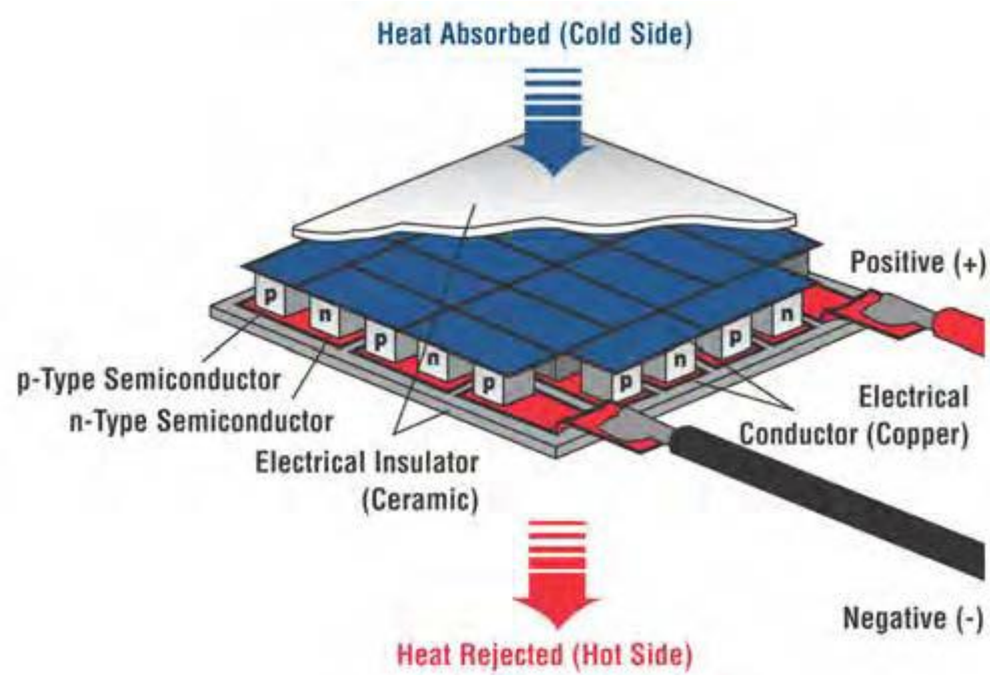


Figure 2.1 A Cutaway of Thermoelectric Module

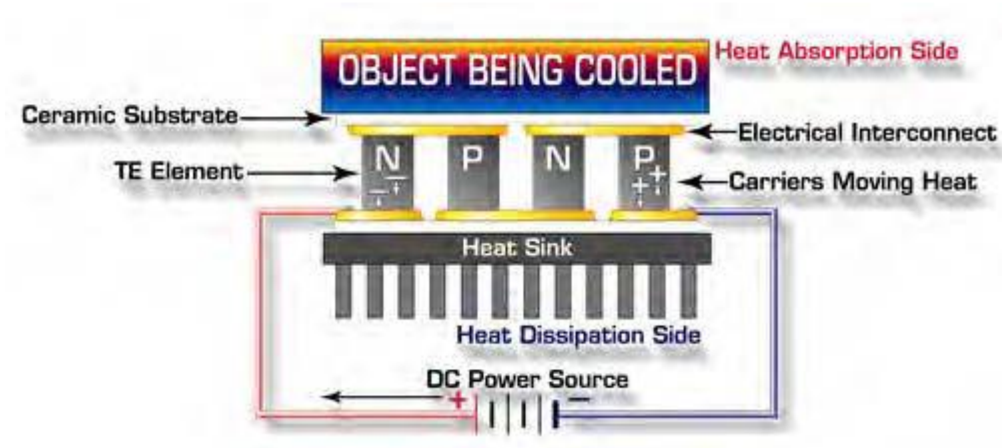


Figure 2.2 Schematic of thermoelectric module operation.

Conventional thermoelectric modules can have various specifications in terms of their geometry, number of thermocouples and power rating for various applications. These devices can be cascaded to achieve a higher temperature differential across the entire thickness. Different applications of thermo-electric modules for (i) cooling, ranging from consumer products to military or aerospace applications, (ii) power generation, e.g. waste heat recovery (iii) sensors such as cryogenic heat flux sensor, ultrasonic intensity sensor, fluid flow sensor, infrared sensor are reviewed by Riffat and Ma (2003).

A number of investigations have been performed for geometric optimization of thermo-elements in a TEC to achieve better cooling capacity and coefficient of performance (Cheng and Lin, 2005, Fukutani and Shakouri, 2006, Hodes, 2007). The maximum cooling capacity improved for an increment in the cross sectional area of the thermo-element or a decrement in the length. The maximum achievable *COP,* irrelevant of the maximum cooling capacity, remained constant for any change in the area or the length of the thermo-element. To develop better thermo-element materials to achieve a higher figure of merit, several studies were performed by Venkatasubramanian et al. (2001) and Polvani et al. (2001). Venkatasubramanian et al. (2001) demonstrated a doubling in the thermoelectric figure of merit for super-lattice materials.

The physical modeling of thermoelectric devices has been considered in a number of studies e.g., one dimensional differential control volume approach by Hodes

(2005) and finite element modeling by Seifert (2001) for the module alone and equivalent electric circuit model by Fukutani and Shakouri (2006), thermal resistance network model by Taylor and Solbrekken (2008), energy balance approach by Zhang et al. (2009) and Yamanashi (1996) for a system consisting TEC module(s). Yamanashi (1996) adopted an entropy balance approach to analyze the system and presented both dimensional and non-dimensional energy and entropy flow equations. The typical system considered is an only

TEC system which consists of a heat source or chip, a cold side thermal resistor (from the chip to the cold side of the module), TEC module(s) and a hot side thermal resistor (from the hot side of the thermoelectric module to the ambient) as shown in Figure 2.3. The performance of TEC based thermal management systems in practical cooling applications has been considered for both forced air (Phelan et aI., 2002, Zhang et aI., 2009) and liquid (Zhang et aI., 2009) cooling applications at the hot side of the system for fixed ambient temperature.

The results showed that the chip temperature can be reduced or the heat dissipation from the chip can be improved by using TEC module(s). The hot side thermal resistance had a more significant effect on the performance of a TEC based thermal management system than the cold side thermal resistance at fixed ambient temperature (Phelan et aI., 2002, Fukutani and Shakouri, 2006, Yamanashi, 1996). In particular, an increase in the hot side thermal resistance appeared to have an exponential effect on the chip temperature due to the non-linearity caused by the TEC module, while the cold side thermal resistance had a linear effect on the chip temperature. The optimized current and geometry factor used in the model proposed by Fukutani and Shakouri (2006) showed a minimum of 10°C reduction in chip temperature compared to the model proposed by Phelan et aI. (2002) for a range of heat load from the chip. An increase in hot side thermal resistance reduced the range of operating current where the TEC was effective (Yamanashi, 1996). This indicates the importance of considering all thermal resistances at the hot side including the hot side ceramic substrate which was ignored by Zhang et al. (2009). An empirical expression was proposed by Huang et al. (2000) for optimizing the performance of a TEC using its bulk properties and to obtain the required hot side thermal resistance. The empirical relation, however, was specific to the TEC module considered and was obtained from the curve fit to the experimental data. The prediction of performance of a TEC based system by Taylor and Solbrekken (2008) and Zhang et al. (2009) was found to be in reasonable agreement with experiments. Taylor and Solbrekken (2008) used temperature dependent thermo-element material properties in their model to predict chip temperature at a fixed heat load with a fixed hot side thermal resistance while Zhang et al. (2009) considered temperature independent properties to minimize chip temperature at fixed heat load and to maximize heat dissipation from chip at fixed chip temperature both at a fixed ambient temperature. Use of temperature dependent properties resulted in better agreement compared to the temperature independent properties (Taylor and Solbrekken, 2008). Thomson effect was neglected in these studies considering its small effect.

The aforementioned TEC based systems were studied to meet the most extreme condition that a thermal management system might experience. In many practical applications, the chip would experience a range of heat loads and/or a wide range of ambient temperatures. One disadvantage of an only TEC based system is that the TEC has a relatively high thermal resistance when it is off. Thus, it would have to be operational even for operating conditions where a conventional thermal management system would be sufficient, which results in a lower overall *COP* (Phelan et aI., 2002).

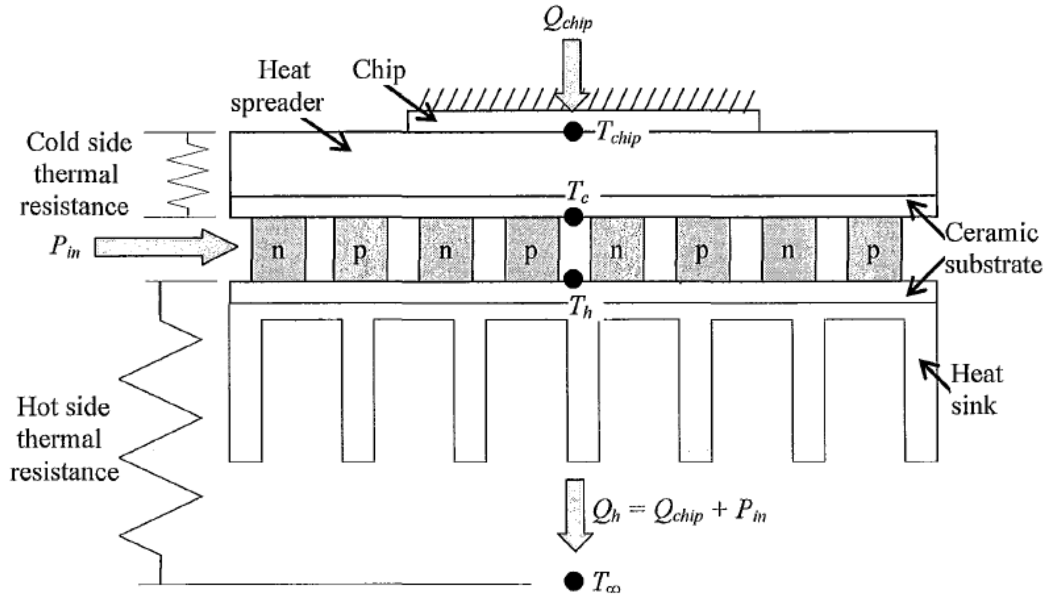


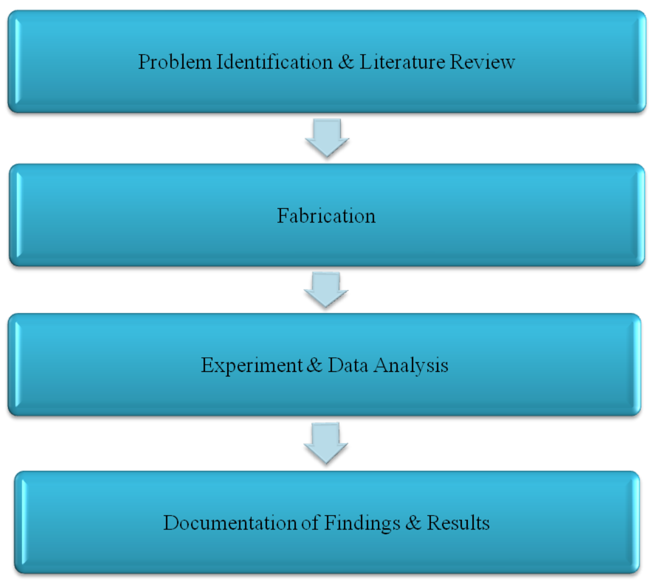
Figure 2.3 Schematic of a typical thermal management system incorporating TEC module.

CHAPTER 3

METHODOLOGY

This chapter is described briefly about the methodology used in experiment, analysis and design of thermoelectric cooler which includes interior heating due to solar radiation, parameters that affects heat sink resistance and peltiers cooling rate

3.1 flow chart

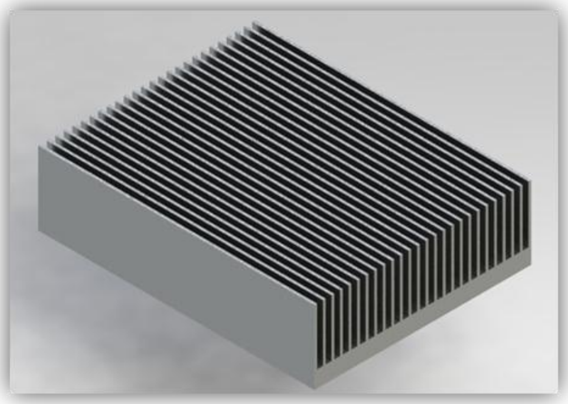


3.2 Concept Design Modeling

A concept modeling of prototype is done using SOLIDWORK. This concept modeling process begins with design of purchased models according to its technical specification in **Appendix F(i).**

3.2.1 Design of Parts

i) Design of heat sink



ii) Design of axial fan

Figure 3.2: CAD model of axial fan

CHAPTER 4

4. Project scope

4.1 Sizing and Designing of the cooling system

1. Selection of the TECs
2. Selection of Fans and Heat sinks
3. DC power supply design with temperature control.
4. Prototype Assembly and Fabrication.
5. Temperature measurements for testing.
6. Power supply testing and troubleshooting.

4.2 Proposed Approach and Method Implemented

The project implemented a structured system analysis and design methodology approach to achieve the project objectives. Block system analysis of the project is shown below (Figure 1) with the aid of a straightforward block diagram. Ambient air is blown out by the blower through a duct to the TECs. TECs are sandwiched in between heat sinks. Cold air is blown out from one end of the cold heat sinks. The TECs were powered by a power supply.

The cooling system mainly consists of the following modules Car Blower which acts as the primary source of air.

1. Duct which conveys the air from the blower to cold heat sinks.
2. One long heat sink is fitted to the hot side of TEC to absorb heat.
3. Aluminum heat sinks that are attached to the cold side.
4. Six TECs are sandwiched between cold and hot heat sinks.
5. An DC source which is used to power the fans and blower. (Car Battery)
6. Dc power supply is used to drive the TECs

A simple on off temperature controller is built in with the dc power supply Thermoelectric Air Cooling For Cars To design a cooling system using thermoelectric cooler (TEC) one has to know the basics of thermoelectric effect, thermoelectric materials and thermoelectric cooling. Thermoelectric effect can be defined as the direct conversion of temperature difference to electric voltage and vice versa. Thermoelectric effect covers three different identified effects namely, the Seeback effect, Peltier effect and the Thomson effect A thermoelectric device will create a voltage when there is temperature difference on each side of the device. On the other hand when a when a voltage is applied to it, a temperature difference is created. The temperature difference is also known as Peltier effect. Thus TEC operates by the Peltier effect, which stimulates a difference in temperature when an electric current flows through a junction of two dissimilar materials.

A good thermoelectric cooling design is achieved using a TEC, which is solid state electrically driven heat exchanger. This depends on the polarity of the applied voltage. When TEC is used for cooling, it absorbs heat from the surface to be cooled and transfers the energy by conduction to the finned or liquid heat exchanger, which ultimately dissipates the waste heat to the surrounding ambient air by means of convection.

4.3 Thermoelectric Module

A standard module consists of any number of thermocouples connected in series and sandwiched between two ceramic plates (See Figure 3). By applying a current to the module one ceramic plate is heated while the other is cooled. The direction of the current determines which plate is cooled. The number and size of the thermocouples as well as the materials used in the manufacturing determine the cooling capacity. Cooling capacity varies from fractions of Watts up to many hundreds. Different types of TEC modules are single stage, two stage, three stage, four stage, center hole modules etc. Single stage will be suitable for a wide range of cooling applications with low to high heat pumping capacities. A typical single stage is shown in Figure 2.

Figure 2: A typical single stage thermoelectric module

A thermoelectric cooler has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from p-type (low energy) semiconductor element, to the n-type semiconductor (high energy). The power supply provides the energy to move the electrons. At the hot junction, energy is expelled to a heat sink as electrons move from an n-type to a p-type. Figure 4 shows an illustration on the assembly of a Thermoelectric cooler.

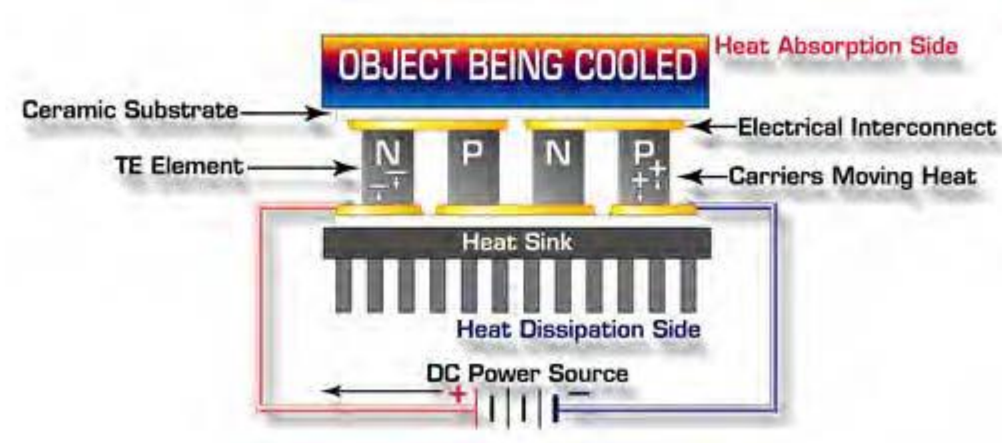


Figure 3: A Classic TE Module Assembly

Before starting to design a TEC cooling system the designer have to take note the following into consideration.

1. Temperature to be maintained for the object that is to be cooled.
2. Heat to be removed from the cooled object.
3. Time required attaining the cooling after a DC power is applied.
4. Expected ambient temperature.
5. Space available for the module and hot side heat sink.
6. Expected temperature of hot side heat sink.
7. Power available for the TEC.
8. Controlling the temperature of the cooled object if necessary

4.4 Parameters of a Thermoelectric Module

Once it is decided that thermoelectric cooler is to be considered for cooling system, the next step is to select the thermoelectric module or cooler that can satisfy a particular set of requirements. Modules are available in great variety of sizes, shapes, operating currents, operating voltages and ranges of heat pumping capacity. The minimum specifications for finding an appropriate TEC by the designer must be based on the following parameters. The cutaway of a TEC is shown in Figure 4.

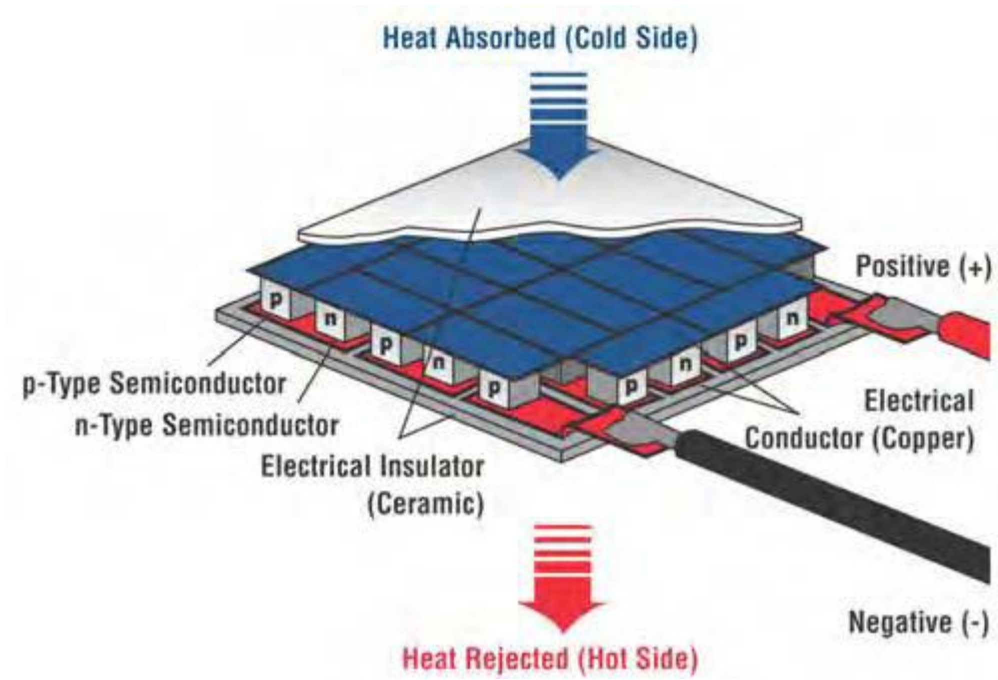


Figure 4: A Cutaway of Thermoelectric Module

• Cold side temperature (Tc)

• Hot side temperature (Th)

• Operating temperature difference (ΔT), which is the temperature difference between Th andTc .

• Amount of heat to be absorbed at the TEC's cold surface. This can also be termed as heat load. It is represented as (Qc) and the unit is Watts

• Operating current (I) and operating voltage (V) of the TEC.

4.5 Cold side temperature

If the object to be cooled is in direct contact with the cold surface of the TEC, the required temperature can be considered the temperature of the cold side of TEC (Tc).Here in this project the object is air inside the car, which has to be cooled when passed through a cluster of four Aluminium heat sinks. It is discussed in detail in the next chapter. The aim is to cool the air flowing through the heat sinks. When this type of system is employed the cold side temperature of the TEC is needed to be several time colder than the ultimate desired temperature of the air.

Hot side temperature The hot side temperature (*Th*) is mainly based on the two factors. First parameter is the temperature of the ambient air in environment to which the heat is been rejected. Second factor is the efficiency of the heat sink that is between the hot side of TEC and the ambient.

4.6 Temperature difference

The two temperatures *Tc* and *Th* and the difference between them ΔT is a very important factor. ΔT has to be accurately determined if the cooling system is expected to be operating as desired. The following equation shows the actual ΔT.

$\Delta T = Th - Tc$

ActualΔT is not same as the systemΔT. Actual ΔTis the difference between the hot and cold side of the TEC. On the other hand system ΔT is the temperature difference between the ambient temperature and temperature of the load to be cooled. Figure 5 illustrates a relationship of a classic temperature summary across a thermoelectric system.

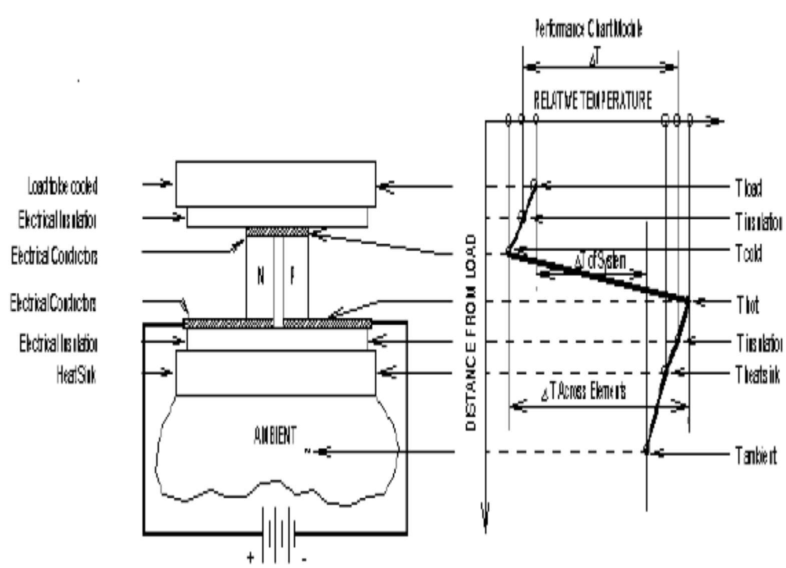


Figure 5: Characteristics temperature of relationship in a TEC

4.7 Cooling Load

The most difficult and important factor to be accurately calculated for a TEC is the amount of heat to be removed or absorbed (Qc) by the cold side of the TEC. In this project Qc was calculated by finding the product of finding the product of mass flow rate of air, specific heat of air and temperature difference. Here the temperature difference system ΔT in the difference between the inlet temperature and outlet temperature of the cooling system. The mathematical equation for Qc is as shown below.

$Qc = m\ Cp\Delta T$

4.8 **Thermoelectric Assembly - Heat Sinks**

Thermoelectric Assemblies (TEAs) are cooling or heating systems attached to the hot side of the TEC to transfer heat by air, liquid or conduction. TEAs which dissipate heat from the hot side use heat exchangers. TEC requires heat exchangers or heat sinks and will be damaged if operated without one. The two ΔTs, actual ΔT and system ΔT depend on the heat sinks fitted at the hot sides or cold sides of TEC. The thermal resistances of the heat sinks could vary theΔT across the TEC for a set ambient temperature and cooling load temperature. Therefore the thermal resistance of the heat sinks could increase the current flowing through the TEC. The three basic types of heat sinks are: forced convective, natural convective and liquid cooled, where liquid cooled is the most effective. The typical allowances forΔT at the hot side heat sink of a TEC are

1. 10 to 15 °*C* for a forced air cooling system with fins. - Forced convection
2. 20 to 40 °*C* for cooling using free convection - Natural convection.
3. 2 to 5 °*C* for cooling using liquid heat exchangers - Liquid cooled.

There are several different types of heat exchangers available in the market. As far this project is concerned a forced convection type of heat sink was be used based on theΔT. Figure 6 shows a forced convection hot side heat sink attached with a fan. The air blows towards the heat sink from the fan will cool down the temperature of heat sink.

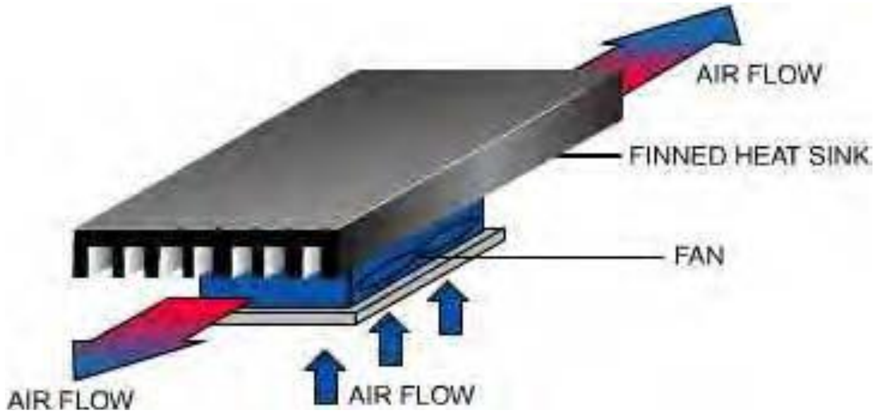


Figure 6: Forced convection heat sink system

The main heat sink parameter for the selection process is its thermal resistance. Heat sink resistance can be termed as the measure of the capability of the sink to dissipate the applied heat. The equation is as follows.

$$R = T_h - T_\infty / Q_h$$

R is the thermal resistance (in ^0C /W or K/W) and T_h - T_∞ is the hot side temperature and ambient temperature respectively. *Qh* is the heat load into the heat sink which is the sum of TEC power *Pe* and heat absorbed. $Q_h = Q_c + P_e$ the goal of a heat sink design is to lessen the thermal resistance. It can be attained through exposed surface area of the heat sink. It may also require forced air or liquid cooling. The following Figure 8 shows a simple thermal schematic of a forced convective heat sink.

Typical values of heat sink thermal resistance for natural convection range is from 0.5°C/W to 5°C/W, whereas for forced convection is from 0.02°C/W to 0.5°C/W, and water cooled is from 0.005°C/W to 0.15°C/W. Most of the thermoelectric cooling requires forced convection or water cooled heat sinks. In this project force convective heat sink is used for the design of the cooling system.

Coefficient of Performance

The Coefficient of performance (COP) of a thermoelectric module which is the thermal efficiency must be considered for a TE system. The selection of TEC will also be based on the COP factor. COP is the ratio of the thermal output power and the electrical input power of the TEC. COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power.

$$COP = \frac{Q_c}{P_e}$$

Power Supply and Temperature Control

Power supply and temperature control are two added items that must be considered wisely for a successful TE system. TEC is a direct current device. The quality of the DC current is important. Current and voltage of a TEC can be determined by the charts provided by the manufacturer. TEC's power is the product of required voltage and current. (P = IV).

Temperature control is generally categorized into two groups. One is open loop or manual and the other is closed loop or automatic. For cooling systems normally cold side is used as basis of control. The controlled temperature is compared to the ambient temperature. An on-off or a control using thermostat is the simplest and easiest techniques to control the temperature of a TEC.

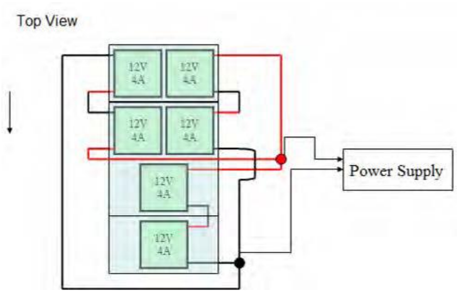
Chapter 5
Design of the project

5.1 THERMOELECTRIC COOLING FOR CAR DESIGN

The thermoelectric cooling fan design was preformed based on certain mechanical and electrical calculations. The fan's design was compromised on the availability of parts in the market and budget of the project. The prototype assembly starts with a main fan which is used to blow the ambient air through a circular duct (Appendix C.1).The duct is attached to the blower fan and leads towards the heat sinks. The air which is passed through the duct goes into the heat sink which is at bottom side. This heat sinks acts as a channel for the air to pass through. There are six TECs that are sandwiched between a four long black heat sink and long aluminum heat sinks. TEC cold side or the bottom side rests on the cool side heat sinks. The hot side or the top sides of the TECs are fastened together with the long heat sink. The TECs were installed between the heat sinks using thermal grease, which increases the thermal conductivity by balancing irregular surface of the heat sinks. When the TECs are in operation cold side of the TEC cools down the heat sink channel. Air which is coming out from the heat sink is chilled air which is lower than the ambient. Two blower fans fixed on the long aluminum heat sink which blows ambient air to pass through the cold side heat sink.

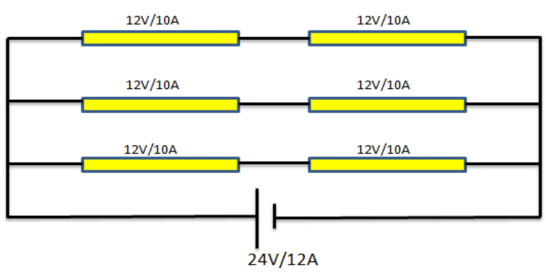
5.2 TEC Arrangement

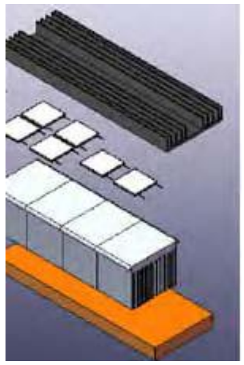
The ambient air blown from the blower is channeled into a long aluminum heat sink. It was decided to remove maximum amount heat from the point when the air started to enter the first heat sink. Keeping that in mind the first heat sink was installed with two TECs in series and the second one also was installed with another two TECs in series. This will help to remove more heat from of the air when air enters the duct. The third and fourth heat sinks were installed with one TEC each and they were connected in series also. All the two series connected TECs were connected in parallel. Figure below illustrates a top view of the connection of TECs as explained above. The arrow indicates direction of air flow



Layout of the TECs

Each of the TEC will be acting as loads. In other words the layout above can also be termed as three parallel groups of two TECs in series electrically. Figure 12 shows simpler redrawn electrical connection of the TECs.





Electrical connection of TECs

Arrangement of TECs

Chapter 6

Results and Calculations

6.1 Computation of cooling power

The amount of heat removed or the cooling power was determined before selection of the TEC. *Qc* which is the amount of heat absorbed was calculated using the equation (**$Qc = \dot{m}\, C_p \Delta T$**). Mass flow rate (**$\dot{m}$**) of air and is the product of density of air (ρ) and volume flow rate (*Q)*. Density of air at 32 °*C* was taken as1.164 *kg* / *m*3. *Q* was obtained by multiplying velocity of air pass through the rectangular duct of heat sinks and the cross section area of a heat sink. It is denoted by the equation (*Q* =*V* × *A)*. Velocity of the air passing through the duct was measured using an anemometer and resulted in a reading of 5.2 *m* / *s*2. Cross sectional area of the rectangular duct (*W* ×*H)* was calculated as 0.0042 *m*2 and the volume flow rate was 0.02184 *m*3 / *s* . Specific heat of air (*Cp*) at 32 °*C* was taken as 1005 *J* / *kgK* . As discussed that the system ΔT is the difference between the ambient temperature and the temperature of the load to be cooled. It had been targeted to attain a temp of 25°*C* form the ambient temperature (32 °*C)*. In other words the input temperature from the blower fan is 32 °*C* and the expected output is 25°*C*

$(T_{in} - T_{out}) = 32^0 - 25^0 = 7^0$

The amount of heat load for cooling the air through the rectangular duct was calculated as 178.7 W.

Please refer Appendix B.1 for detailed calculations on cooling load.

6.2 TEC Selection

The TEC was selected considering few factors such as dimensions, Qc, power supply and etc. The model of TECs used in this project was manufactured in China by Hebei I.T (Shangai) Co. Ltd. (Datasheet and Charts in Appendix A). The model no. of the module is TEC1-12710. The idea was to select a TEC which has a cooling power greater than the calculated TEC. TEC1-12710 operates with an optimum voltage of 12V. It has maximum voltage of 15.4V. At 12V it draws and maximum DC current of 10 A. The minimum power rating or the cooling power is W. The maximum power is 96W. It has a maximum operating temperature of 200°C. ∆T of the TEC are 68 when hot side temperature is 25 °*C*. The charts from the TEC manufacture were also analyzed while choosing the TEC. It had been decided to choose 6 TECs of the same model so that when the power of all the 6 TECs is higher than the calculated cooling load. The minimum power rating for 6 TECs added together was more than the cooling load calculated. So it was acceptable to select the $74.5\ W \times 6 = 447\ W > 178.7\ W$

The electrical power supplied to the TEC must be higher than the combined power rating of the six TECs and it also depends on the arrangement of the TEC.

6.3 Selection of Heat sink

There were two different types of heat sink used for this project. One sort was for the cold side and another for hot side. The initial idea of the project was to use a hollow cylinder as duct to channel air, instead of heat sink on the cold side of the TEC. Initial testing after the proposal stage with hollow cylinder, did not work out well. This was because there of less heat transfer within the cylinder and the air coming out was not cold enough. So the decision was made to use to heat sinks which acts a rectangular duct to channel air. A large heat sinks (9Y692 A00-00) were used. .Each heat sinks have 10 fins which helped to dissipate coldness fast enough from TECs cold side. In this project heat sinks (hot side and cold side) operate by conducting heat or coldness from the TEC to the heat sink and then radiating to air. A better the transfer of coldness between the two surfaces, the better the cooling will be. When the heat sinks were attached the TECs, there will be uneven surfaces or gaps. The gap will cause for poor heat transfer, even if it is negligible. To improve the thermal connection between the TECs and the heat sinks a chemical compound was used. The heat sink compound, typically a white paste made form zinc oxide in a silicone base ensures a good transfer of heat between the modules and the heat sinks.

Hot Side heat sink

The hot side heat sink used in the project was a single long one installed on the top side of the TECs. (Appendix Bi). As discussed, thermal resistance of a heat sink is an important factor while designing a system. Appendix B.1 shows a detailed calculation for the thermal resistance required for a suitable heat sink. Thermal resistance found using the equation $\boldsymbol{R = T_h - T_\infty / Q_h}$ was 0.013 K /*W* . Therefore a liquid convection heat sink had to be used. When selecting hot side heat sink for the project other factors such as dimension to fit into the whole assembly, budget and availability were also taken to consideration. The heat sink was bought from a local shop and there was no thermal resistance or datasheets available for the product. The calculated thermal resistance of the heat sink was lesser than the required. But when considered the dimensions of the cooling system the selected heat sink was very apt. A drawback expected was overheating of heat sink. However bigger fans were installed to cool the hot side heat sink to overcome this.

Results of the temperature reading.

Condition 1:

In Morning hrs., when car parked under shade.

time(min)	temperature inside car
5	32
10	31.8
15	31.1
20	30.7
25	28.8
30	28.3
35	28
40	27.6
45	27.2
50	26.8
55	26.3
60	26

Table 1: morning around 9am to 10am

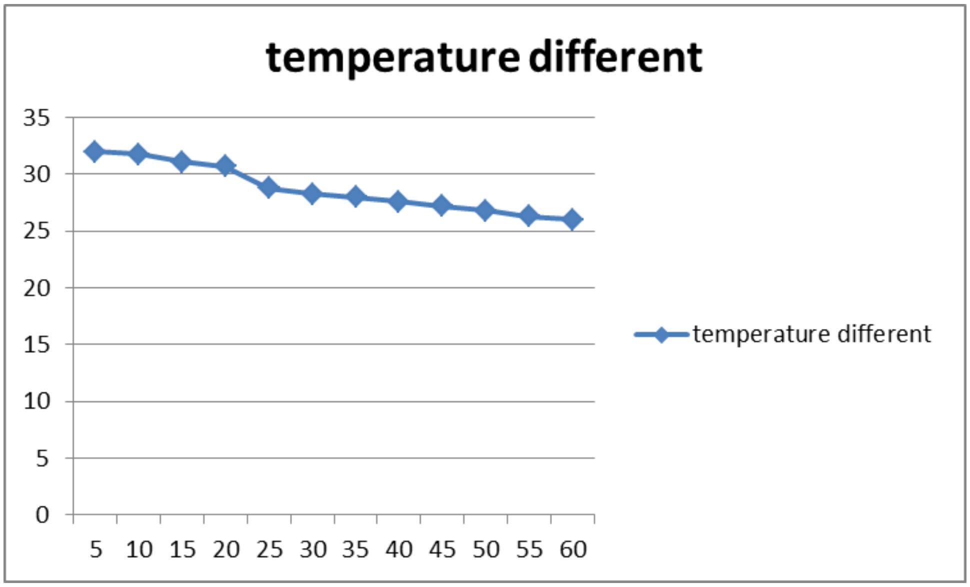


Figure 1: graph of condition 1

Condition 2:

At afternoon in peak hours around 1pm to 2pm after TEC running.

time(min)	temperature inside car
5	36
10	35.8
15	35.4
20	35.1
25	34.8
30	34.6
35	34.1
40	33.8
45	33.5
50	33
55	32.7
60	32.3

Table 2: afternoon at peak hours around 1pm to 2pm

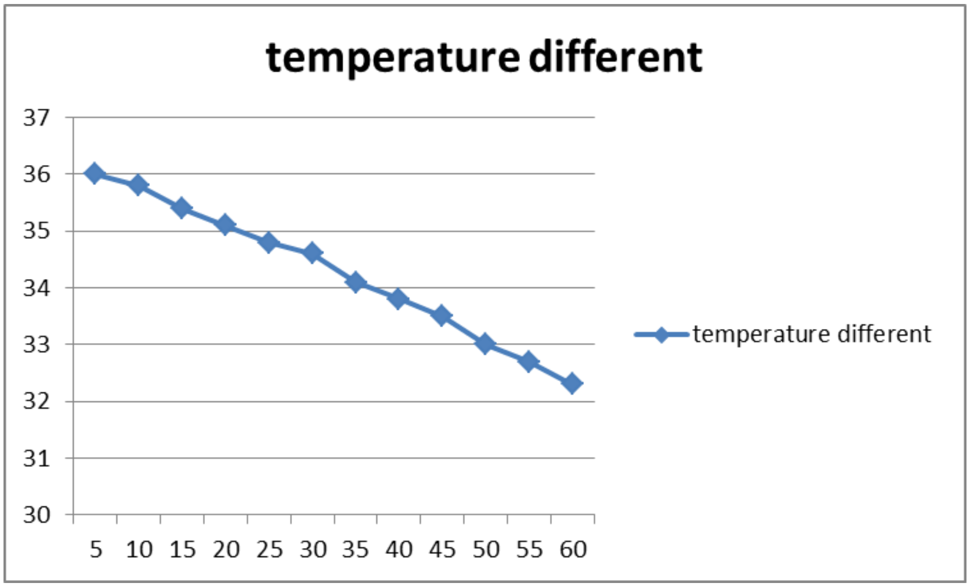


Figure 2: graph of condition 2

Condition 3:

In night hours around 8.30pm to 9.30pm.

time(min)	temperature inside car
5	29.5
10	29
15	28.5
20	28.5
25	28
30	27.7
35	27.3
40	26.1
45	25
50	24.1
55	23.6
60	23

Table 3: night at 8.30pm to 9.30pm

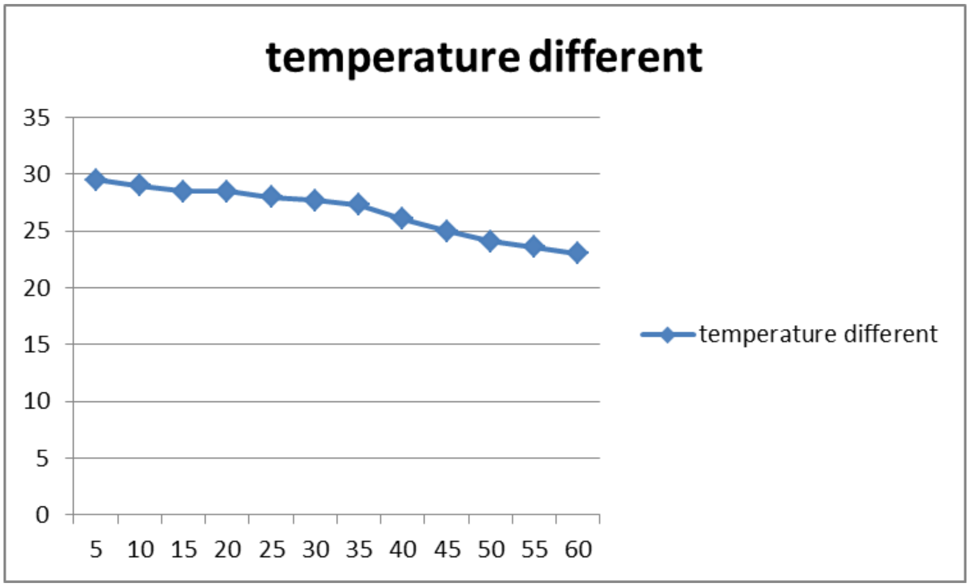


Figure 3: graph of condition 3

Chapter 7
Conclusion and further works

7.1 **Conclusions**

A Thermoelectric Air cooling for car prototype was designed and built which can be used for personal cooling inside the car. Six TECs were used for achieving the cooling with a DC power supply through car battery. It had been shown from testing results that the cooling system is capable of cooling the air when recirculating the air inside the car with the help of blower. TEC cooling designed was able to cool an ambient air temperature from 32°C to 25.8°C. Cooling stabilizes within three minutes once the blower is turned ON. The system can attain a temperature difference of set target which was 7°C. Accomplishing the set target establish the success of the project. All the components in the project had been tested individually and the results were found to be positive.

7.2 **Further Work**

The prototype can be made compact by selecting as single TEC of higher power (.i.e. of 200W or more). It can be done by choosing a better cold side heat sink that has twisted channels or pipes for circulating the air for a longer time. As an alternative for normal axial fan used in this project, if a blower fans is selected, the cooling system would provide better airflow. Even as shown in the appended figure we can mount no of TEC

cooling in Roof, Floor, Seat, Door, front dashboard with proper insulation. Well-known TEC brands (.i.e. Melcor, FerroTEC etc) must be chosen if there is only one high power TEC selected for the cooling system. Bigger hot side heat sinks have to be selected accurately based its calculated thermal resistances for best cooling efficiency. With a single TEC, one hot side and a cold side heat sink a smaller personal TEC cooler which gives comfort can be fabricated and can be installed on roof for individual cooling by changing the airflow and some mechanical or electronics section modification, the TEC air cooling for car can be used for heating applications too

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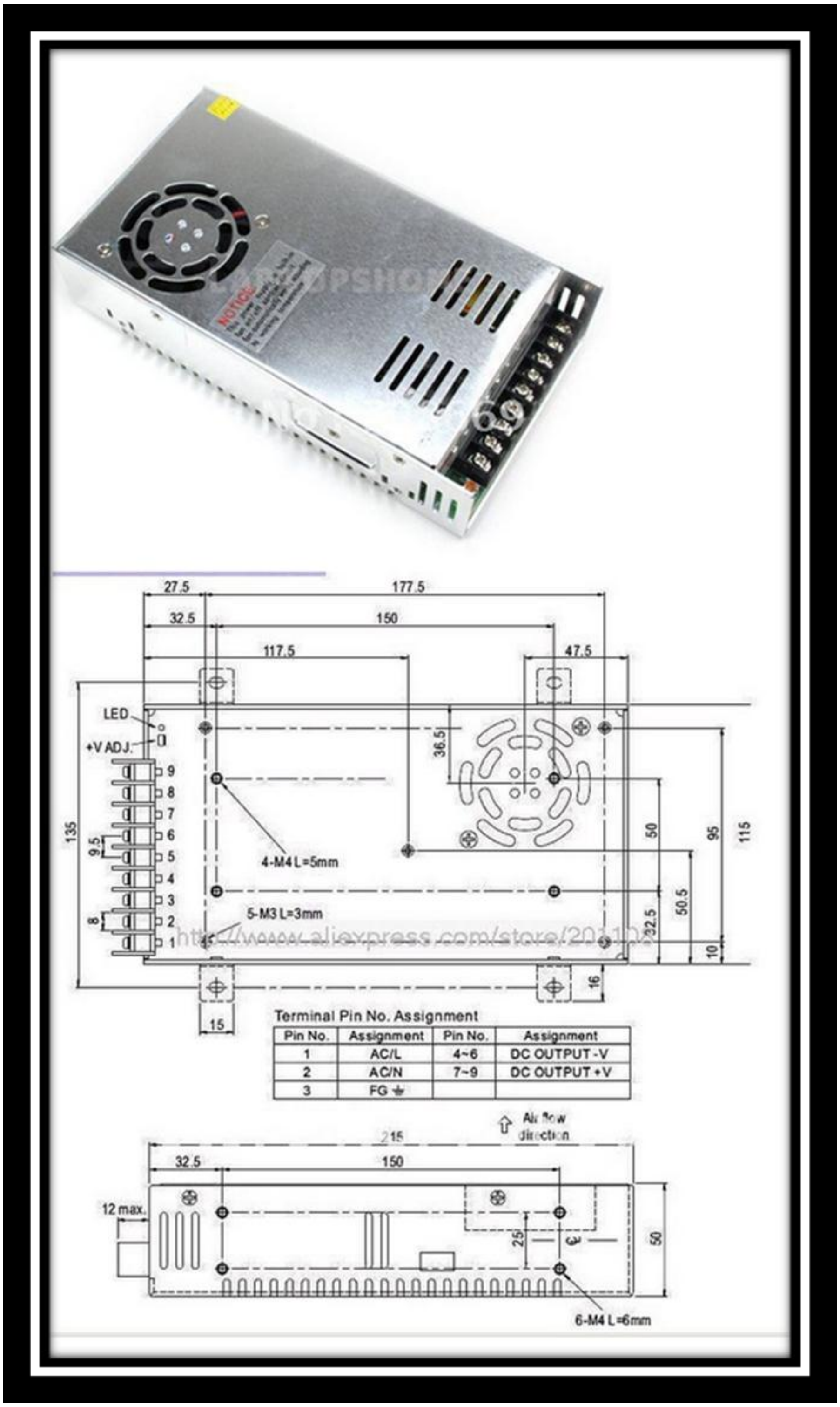
Appendix A(i): Technical Specification of Purchased Items



Regulated DC Power Supply

Features:

1.Universal AC input / full range

2.It's good quality & high performance

3.Input:AC110-240V 50/60Hz

4.Out put:DC 12V 20A

5.100% full load burn-in test

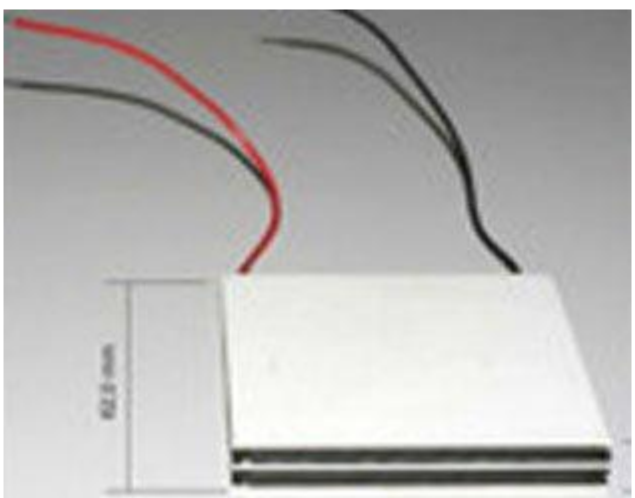
6.Protections: overload/ over voltage/ short circuit

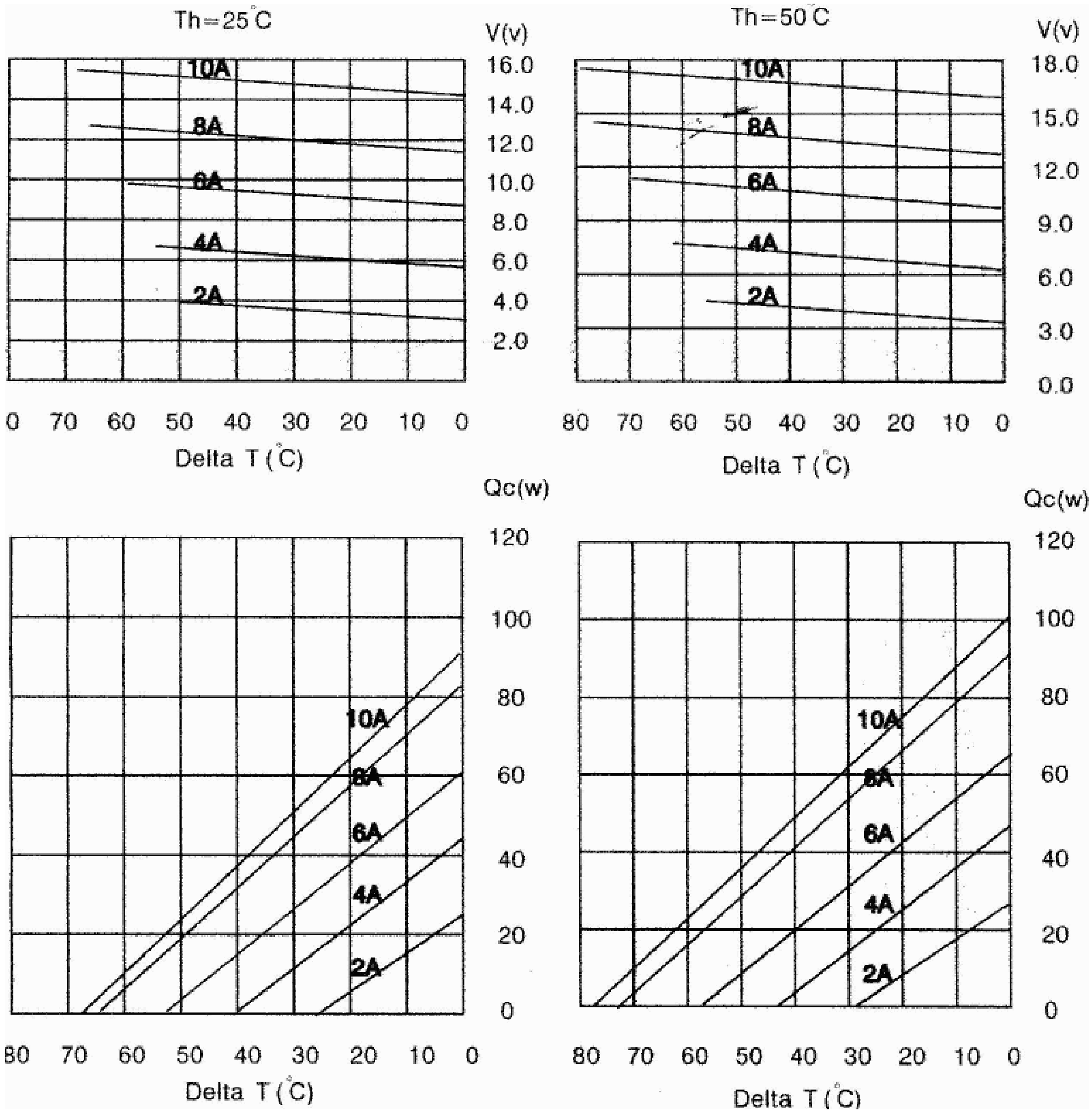
7.Cooling by free air convection

1) TEC1-12710

Benefits:
Capable of generating electricity when one side is kept cool and heat is applied to the other
No moving internal parts to damage when in transit
Makes absolutely no noise and does not vibrate
Long life
Slim and compact
Excellent quality
Brand new and unused

Hot Side Temperature (° C)	25° C	50° C
Qmax (Watts)	85	96
Delta Tmax (° C)	66	75
Imax (Amps)	10.5	10.5
Vmax (Volts)	15.2	17.4
Module Resistance (Ohms)	1.08	1.24





Performance curves

2) Axial Fan

Product Description

- Model Number:AFC1212DE
- Size: **120x120x38 mm**
- Bearing System: **Double Ball Bearing**
- Rated Voltage: **12V (4.00 ~ 13.40)**
- Input Current: **1.60A**
- **Max** Speed: **3900 RPM**
- Air Flow: **148.34 CFM**
- Tachometer (RPM Sensor): **Yes**
- PWM (Pulse Width Modulation)**: Yes**
- Connector & Wire Length: **4 10" inch wires (white, red, black, blue) to 5 pin plug**
- Also replaces AVC DD1203B12HP and NMB MAT 4715KL-04W-B56
- Dell OptiPlex GX520, GX620, 745, 740, 755, 760, 960, 320, 330, 210L ,(BTX) MT Dell Dimenision 3100, 5100, 5150, E310, E510, E520 , E521 XPS420 DIM9200

Appendix B(i): Calculations

Temperature Difference

$$\Delta T = T_h - T_c$$

Cooling load

$$Qc = \dot{m}\, C_p \Delta T$$

Thermal resistance

$$R = T_h - T_\infty / Q_c$$

$$COP = \frac{Q_c}{P_e}$$

Heat load in heat sink

$$Q_h = Q_c + P_e$$

$$P_e = IV$$

Temperature *T* in °C	**Speed of sound *c* in m·s^{-1}**	**Density of air *ρ* in kg·m^{-3}**	**Acoustic impedance *Z* in N·s·m^{-3}**
+35	351.88	1.1455	403.2
+30	349.02	1.1644	406.5
+25	346.13	1.1839	409.4
+20	343.21	1.2041	413.3
+15	340.2	1.2250	416.9
+10	337.31	1.2466	420.5
+5	334.32	1.2690	424.3
0	331.30	1.2922	428.0
−5	328.25	1.3163	432.1

−10	325.18	1.3413	436.1
−15	322.07	1.3673	440.3
−20	318.94	1.3943	444.6
−25	315.77	1.4224	449.1

Mass flow rate, $\dot{m} = \rho AV$

$= 1.1644 \times (0.03 \times 0.14) \times 5.2$
$= 0.0254$ kg/s

Heat absorbed, $Q_c = \dot{m}\, C_p \Delta T$

$= \dot{m}\, C_p (T_{in} - T_{out})$
$= 0.0254 \times 1005 \times (32-25)$
$= 178.7$ W

Ideal gas specific heat capacities of air			
Temperature K	C_P kJ/kg.K	C_v kJ/kg.K	k
250	1.003	0.716	1.401
300	1.005	0.718	1.400
350	1.008	0.721	1.398
400	1.013	0.726	1.395
450	1.020	0.733	1.391
500	1.029	0.742	1.387
550	1.040	0.753	1.381
600	1.051	0.764	1.376
650	1.063	0.776	1.370
700	1.075	0.788	1.364
750	1.087	0.800	1.359
800	1.099	0.812	1.354
900	1.121	0.834	1.344
1000	1.142	0.855	1.336
1100	1.155	0.868	1.331
1200	1.173	0.886	1.324
1300	1.190	0.903	1.318
1400	1.204	0.917	1.313
1500	1.216	0.929	1.309

Thermal resistance

$$\boldsymbol{R = T_h - T_\infty / Q_h}$$

$$P_e = IV$$

= 10x12x6
= 720 W

$$Q_h = Q_c + P_e$$

= 178.7 + 720
= 898.7 W

$$\boldsymbol{R = T_h - T_\infty / Q_h}$$

= (44.3-32) / 898.7
= 0.013 K/W(Therefore liquid cold convection to be used)

APPENDIX C1
Pictures of prototype