TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

B-15-BME-2018/2023

STUDY AND FABRICATION OF THERMOELECTRIC REFRIGERATOR WITH ITS PERFORMANCE ANALYSIS

By:
Mahesh Thapa (075BME025)
Rahul Kumar Jha (075BME033)
Saroj Thapa (075BME041)

A PROJECT REPORT
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
LALITPUR, NEPAL

March, 2023

COPYRIGHT

Head of Department
Department of Mechanical and Aerospace Engineering
Pulchowk Campus, Institute of Engineering
Lalitpur, Nepal

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled "Study and Fabrication of Thermoelectric Refrigerator with its performance analysis" submitted by Mahesh Thapa, Rahul Kumar Jha, and Saroj Thapa in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Supervisor, Mr. Vishwa Prasanna Amatya,
Associate Professor
Department of Mechanical and Aerospace Engineering

External Supervisor, Mr. Sunil Risal,
Associate Professor

Tribhuvan University
Institute of Engineering
Department of Mechanical and Aerospace Engineering
Pulchowk Campus

Committee Chairperson, Dr. Surya Prasad Adhikari,
Head of Department
Department of Mechanical and Aerospace Engineering

March 13, 2023

Date

ABSTRACT

A thermoelectric refrigeration system is a solid-state cooling technology that utilizes the Peltier effect to create a temperature difference across a thermoelectric module (TEM). The system is highly versatile, reliable, and environment-friendly, making it a suitable alternative to conventional refrigeration systems. Small size, portability, zero emission, noise free, economical are some of its advantageous features. This project/study presents an overview of the thermoelectric refrigeration system, including its operating principle, design and fabrication and its performance analysis. The performance test of the fabricated model was done in different conditions: (i) varying hot-side heat sink (fan enhanced heat pipe and normal air cooling) ii) Varying the shape of cold side heat sink having same surface area iii) Varying the air circulation method through cold side heat sink iv) Varying the number of modules under same hot side heat sink. It was found that a fan enhanced heat pipe decreased the cabin temperature by 5.6 °C more than a normal air cooling system. Also, using tunnel arrangement at cold side fins improved air circulation which resulted in decreasing the cabin temperature by 1.4°C more. Higher number of modules was found inefficient when the heat dissipation rate of the hot side heat sink is limited. Additionally, this study highlights the current scenario in thermoelectric cooling technology and its potential applications in various industries, such as electronics, aerospace, and healthcare.

ACKNOWLEDGEMENTS

First of all, we would like to express our deepest gratitude to the Department of Mechanical and Aerospace Engineering, IOE, Pulchowk Campus, Lalitpur, for providing us with the opportunity to work on a project to enhance the knowledge we have learned throughout our Bachelor of Mechanical Engineering.

Similarly, we would like to thank our supervisor, Associate Professor Vishwa Prasanna Amatya, for his guidance and motivation. We would also like to thank him for his valuable suggestions in each step of our project and for always pushing us to do better. It certainly wouldn't have been possible without him. We would also like to thank Assistant Campus Chief (Facility Management), and Assistant Professor Banshee Ram Pradhan for giving us permission to work at Carpentry. We would also like to thank the staff of Carpentry for helping us in the fabrication of the prototype. We would also like to thank the Center for Energy (CES) and Robotics Club, Pulchowk for helping us with the instrument like Anemometer, thermal gun, thermal camera, multimeter, drilling machine and so on.

Finally, we would also like to extend thanks to all our friends and seniors who helped us with their valuable suggestions.

Mahesh Thapa (075BME025)
Rahul Kumar Jha (075BME033)
Saroj Thapa (075BME041)

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

NOMENCLATURE

CAD	Computer-aided Design
CFC	ChlorofluoroCarbon
COP	Coefficient of performance
HFC	HydrofluoroCarbon
I	Current
K	Thermal Conductivity
Q	Heating and Cooling Rate
Q_H	Heat Rejection
Q_L	Heat Absorption
R	Electric Resistance
T	Temperature
T_C	Cold side Temperature
T_h	Hot side Temperature
ΔT	Temperature Difference
TEC	Thermoelectric Cooler
S	Seebeck Coefficient
$Vopt$	Optimum Working Voltage
Z	merit of thermocouple

CHAPTER ONE: INTRODUCTION

1.1 Background

Refrigeration is the act of obtaining and maintaining a temperature below ambient in order to cool a product or place to a desired temperature. Therefore, refrigerator is the mechanism used to transfer heat from a lower to a higher temperature. Energy is taken from the cold storage tank and transferred to the hot storage tank in the form of heat. However, heat, magnetism, electricity, lasers, and other forces can also be used to power energy transfer processes in addition to the usual mechanical techniques. There are several applications for freezing, including air conditioning, cryogenic temperatures, domestic refrigerators, and industrial freezers.

Different types of Refrigeration systems commonly used in practice are given below:

1.1.1 Evaporative Cooling

Evaporative cooling is a process where water is used to cool the air. The process works by utilizing the fact that water evaporates when it is exposed to air, and that this evaporation causes the surrounding air to become cooler. Evaporative cooling is a natural process that occurs in our environment. For example, when you sweat, the moisture on your skin evaporates and cools you down.

The compressor, which elevates the temperature and pressure of the refrigerant gas by compressing it, starts the process. After entering the condenser, the high-pressure, high-temperature gas is cooled and condensed into a liquid by transmitting heat to the environment, often through a system of coils or fins. After passing through the expansion valve, the condensed liquid enters the evaporator at a lower pressure and temperature.

In the evaporator, the low-pressure, low-temperature liquid evaporates into a gas by absorbing heat from its environment, such as the air in a room or the contents of a refrigerator. Once the surrounding region or material has cooled as a result of the heat transfer process, the gas is compressed once more by the compressor into a high-pressure, high-temperature state, and the cycle repeats.

Evaporative cooling has several advantages over traditional air conditioning. It is a more energy-efficient and cost-effective way to cool large areas. It also provides fresh air and increases humidity in dry climates. However, it is less effective in humid climates, where the air is already saturated with moisture.

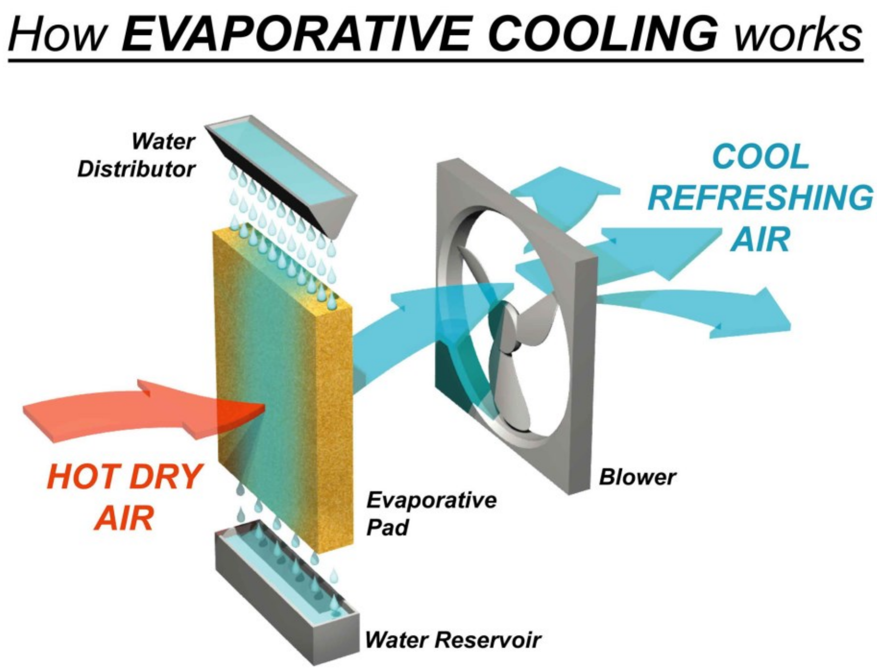

Figure1.1: Evaporative Cooling

1.1.2 Mechanical Compression Refrigeration system

A mechanical compression refrigeration system is a type of refrigeration system that uses mechanical energy to compress and circulate a refrigerant in order to transfer heat from one location to another. The basic components of a mechanical compression refrigeration system include a compressor, condenser, expansion valve, and evaporator. The refrigerant circulates through these components in a closed loop, changing state from a liquid to a gas and back to a liquid as it absorbs and releases heat.

The process begins with the compressor, which compresses the refrigerant gas and raises its temperature and pressure. The high-pressure, high-temperature gas then moves into the condenser, where it is cooled and condensed into a liquid by transferring heat to the surrounding environment, usually through a set of coils or fins. The condensed liquid then moves through the expansion valve, which reduces its pressure and temperature as it enters the evaporator.

In the evaporator, the low-pressure, low-temperature liquid absorbs heat from its surroundings, such as the air in a room or the contents of a refrigerator, and evaporates into a gas. This heat transfer process cools the surrounding area or material, and the resulting gas is then compressed back into a high-pressure, high-temperature state by the compressor, and the cycle begins again.

Mechanical compression refrigeration systems are commonly used in homes, businesses, and industrial settings to provide air conditioning and refrigeration. They are highly efficient and can be designed to operate on a variety of refrigerants, although some refrigerants have been found to have negative environmental impacts and are being phased out in many applications.

Advantages:

- High efficiency and cooling capacity
- Easy to maintain and repair
- Can be used for a wide range of applications

Disadvantages:

- Uses a lot of energy
- Produces greenhouse gasses that contribute to climate change
- Requires regular maintenance and can be noisy

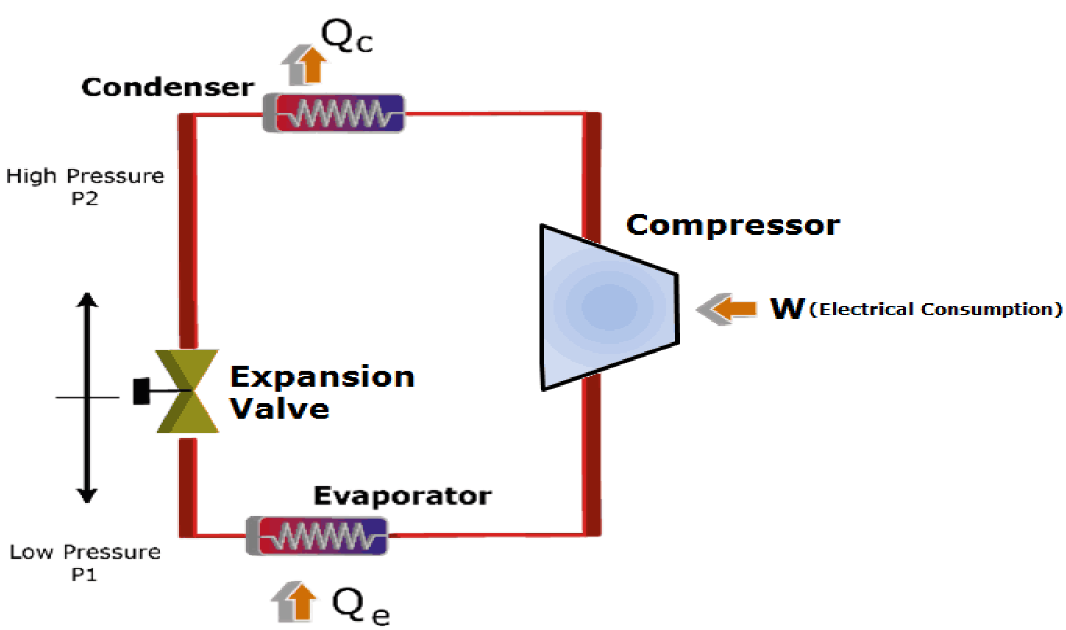

Figure1.2: Mechanical compression Refrigeration System

1.1.3 Absorption Refrigeration

A vapor absorption refrigeration system is a type of refrigeration system that uses a combination of heat and a working fluid to produce cooling. Unlike mechanical compression refrigeration systems, which use a compressor to circulate refrigerant, vapor absorption refrigeration systems use a heat source to generate a vapor that drives the refrigeration process.

The basic components of a vapor absorption refrigeration system include an absorber, a generator, a condenser, and an evaporator. The working fluid, typically a mixture of water and a refrigerant, circulates through these components in a closed loop, changing state from a liquid to a vapor and back to a liquid as it absorbs and releases heat.

The process begins with the absorber, where the working fluid absorbs refrigerant vapor from the evaporator. This process is facilitated by a liquid absorbent, such as lithium bromide, that has a high affinity for the refrigerant vapor. The resulting mixture of a liquid absorbent and refrigerant vapor then moves into the generator.

In the generator, the mixture is heated, typically by burning natural gas or another fuel, causing the refrigerant to vaporize and separate from the liquid absorbent. The refrigerant vapor is then condensed in the condenser, releasing heat to the surrounding environment, usually through a set of coils or fins, and returning to a liquid state. The liquid refrigerant then moves back to the evaporator, where it absorbs heat from its surroundings, such as the air in a room or the contents of a refrigerator, and evaporates into a vapor. This process cools the surrounding area or material, and the resulting vapor is absorbed back into the absorbent solution in the absorber, completing the cycle.

Vapor absorption refrigeration systems are commonly used in large-scale applications, such as industrial processes, as well as in commercial and residential buildings. They are highly efficient and can be powered by a variety of heat sources, including waste heat from industrial processes, solar energy, or natural gas. However, they are typically more complex and expensive than mechanical compression refrigeration systems and require a larger physical footprint.

Advantages:

- Energy efficient, as it can be powered by renewable energy sources
- No moving parts, making it quieter and requiring less maintenance
- Uses fewer harmful chemicals compared to vapor-compression refrigeration

Disadvantages:

- Lower cooling capacity compared to vapor-compression refrigeration
- Requires a heat source, which may not always be available
- Can be expensive to install and maintain

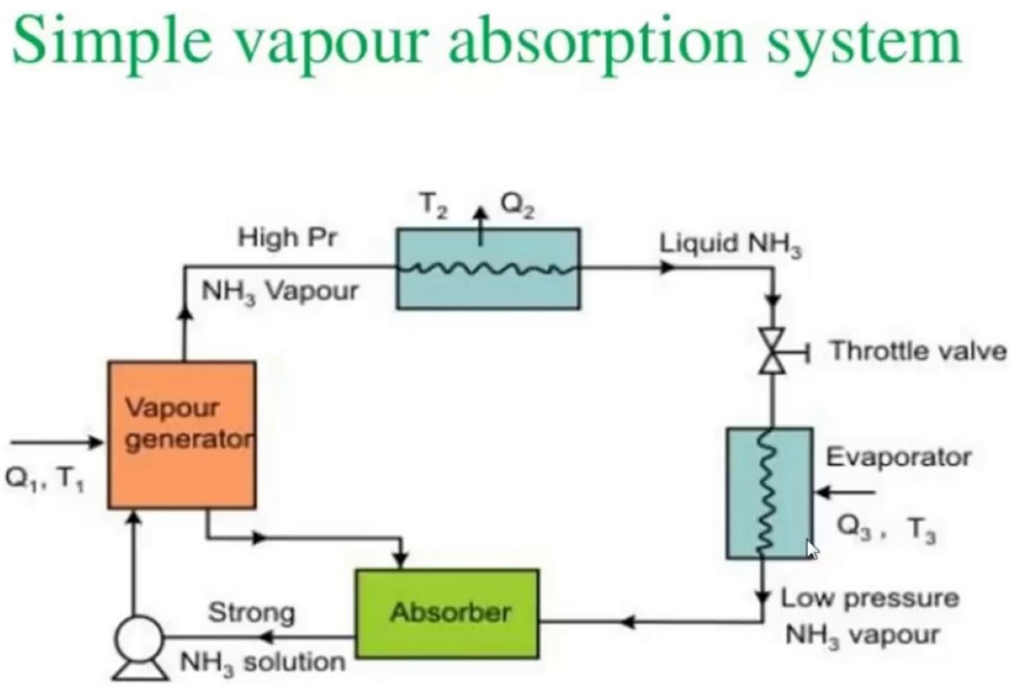

Figure1.3: Vapor Absorption system

1.1.4 Thermoelectric Refrigeration

A thermoelectric refrigeration system is a type of refrigeration system that uses the Peltier effect to produce cooling. The Peltier effect is a phenomenon in which a current flowing through two dissimilar conductors creates a temperature difference between them, with one end becoming hotter and the other end becoming cooler. In a thermoelectric refrigeration system, this effect is used to transfer heat from one side of a thermoelectric device to the other, creating a temperature differential that can be used for cooling.

The basic components of a thermoelectric refrigeration system include a thermoelectric module, heat sinks, and a power supply. The thermoelectric module consists of two dissimilar conductors, typically made of semiconductor materials, that are sandwiched together with a thin layer of insulating material between them. When a current is applied to the module, one side becomes hotter and the other side becomes cooler, creating a temperature differential that can be used for cooling.

In a thermoelectric refrigeration system, one side of the thermoelectric module is typically placed in contact with the object or material that needs to be cooled, such as the contents of a cooler or a computer processor, while the other side is exposed to the surrounding environment. Heat is transferred from the object or material to the hot side of the module, which is then cooled by a heat sink, such as a fan or a water-cooled radiator. The cool side of the module is then able to absorb more heat from the object or material, creating a cooling effect.

Thermoelectric refrigeration systems are relatively simple and compact and can be powered by a variety of power sources, such as batteries, solar panels, or AC power. They are also silent and vibration-free, making them ideal for use in applications where noise and vibration are a concern, such as in medical or laboratory settings. However, they are typically less efficient than other types of refrigeration systems and are best suited for cooling small spaces or objects. They are commonly used in portable coolers, wine chillers, and small refrigeration units for electronic devices.

The certain benefits of thermoelectric cooling's are as follows:

1. Quietness
2. Compactness
3. Controllable
4. Localized heating and cooling
5. Long lifetime and low maintenance
6. No emission of any chlorofluorocarbons or refrigerants

It has wide applications. Some of the key applications of thermoelectric refrigeration systems include:

- **Cooling electronic devices:** Thermoelectric refrigeration systems are commonly used to cool electronic devices such as computer processors, which generate a lot of heat and require efficient cooling to prevent damage.
- **Medical applications:** Thermoelectric refrigeration systems are used in medical applications such as vaccine refrigeration, where precise temperature control is critical to maintain the effectiveness of the vaccine.
- **Automotive applications:** Thermoelectric refrigeration systems can be used in automotive applications such as cooling seats, steering wheels, and beverage holders.
- **Aerospace applications:** Thermoelectric refrigeration systems can be used in spacecraft to cool electronics and maintain a stable temperature environment.

- **Portable refrigeration:** Thermoelectric refrigeration systems are lightweight and compact, making them ideal for portable refrigeration applications such as camping, boating, and RVs.

However, having low COP cannot be used for applications that have higher cooling loads. So many studies and research are going on to increase the COP of thermoelectric refrigeration systems.

1.1.4.1 Peltier Effect

When direct current is supplied to a pair of dissimilar metals, there is heating at one junction and cooling at another. This phenomenon is known as the Peltier effect. French physicist Jean Charles Athanase Peltier 1834 discovered this phenomenon. This effect is even stronger in circuits that contain different semiconductors.

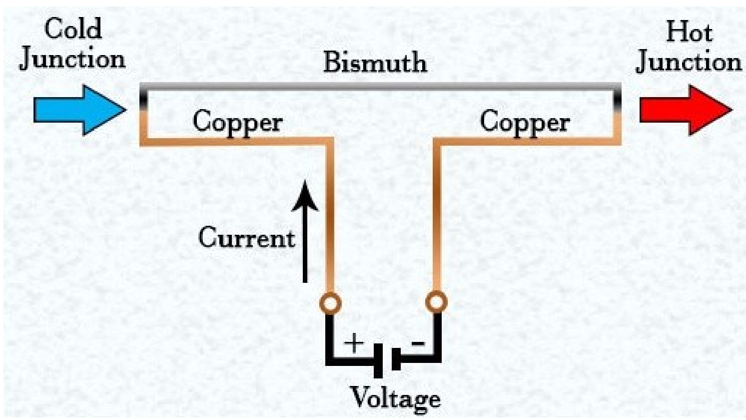

Figure1.4: Peltier effect

1.1.4.2 Seebeck Effect

The Seebeck effect is defined as a phenomenon where emf is produced across the junction of two different materials connected electrically and having a temperature difference. German physicist Thomas Johann Seebeck discovered this phenomenon in 1821. This is just the opposite case of that of the Peltier effect. This is a reversible process. If we interchange the hot and cold junctions then it will change the current direction as well. This phenomenon is used to determine temperature with high sensitivity and accuracy and is useful in thermoelectric generators to utilize residual heat in the industry and harness it into electricity.

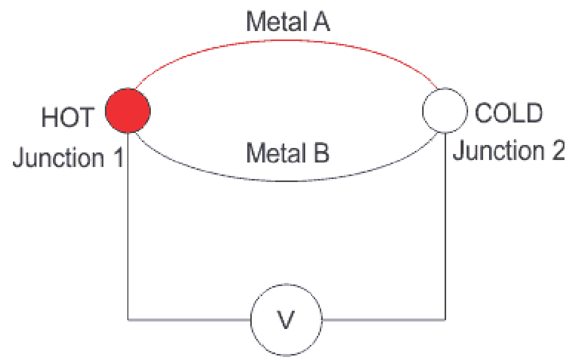

Figure 1.5: Seebeck Effect

1.2 Background and the invention of Peltier Module:

Arrays of thermoelectric pairs made of n-type and p-type semiconductor materials are used in thermoelectric coolers. The electrical and thermal connections of thermocouples are in series and parallel, respectively. Between two ceramic plates is an implanted thermoelectric component.

The cold or hot sides are defined by two ceramic plates depending on how the DC power is connected. The cold side temperature decreases as heat is absorbed when a positive DC voltage is provided to an n-type thermocouple. Electrons travel from the p-type to the n-type thermocouple during this process. When electrons move from the low energy level of p-type thermocouples to the high energy level of n-type thermocouples, cooling takes place. Cooling is proportional to the current and the number of thermocouples. Heat is then conducted through the thermocouple to the hot side and released when the electrons return to the lower energy level of the p-type thermocouple. The heat released on the hot side must be dissipated to keep the device running. A heatsink is attached to the hot side for heat dissipation. The thermo elements of the module are referred to as legs.

Early thermoelectric coolers were made using flat conductive strips stamped from conductive metal strips, preferably copper. Each tab is large enough to accommodate the spaced ends of a pair of legs.

By placing the tabs on a grid, brushing the grid to align the tabs, and receiving the grid, the tabs are arranged in a grid-like shape. Then the screen prints the solder paste onto the ceramic plate. Then press the tabbed grid onto the solder paste area of the board. The grid is taken off after gluing a tab to the ceramic plate. After that, the ceramic plate with tabs is put in an oven where the solder is reheated to essentially permanently secure the tabs. It employs two grids. Both the first and second types of grids feature hot side patterns and cold side patterns, respectively. The tabs of the ceramic tile are then treated with solder flux. The legs are then vibrated inside a leg matrix mold and added there. The full mold is then placed in the soldering flux, aligned with the first (hot side or cold side) solder permeated tab of the tab-patterned ceramic. The legs are then permanently joined to the tabs by reflowing the solder after removing the leg mold. The other end of the leg is similarly fastened to a second (cold or hot, as appropriate) ceramic patterned tab that supports the tab to complete the thermocouple.

A problem with existing thermoelectric coolers is their cost. Due to the complexity of the elements of the thermoelectric cooler components, considerable manual labor must be expended in the process of assembling engine coupling components into components and assembling engine coupling components into thermoelectric coolers.

1.3 Comparison between different refrigeration systems

Vapor compression refrigeration systems have a high cooling capacity, high efficiency, long life expectancy, and affordable price, making them a popular and versatile option for many applications. Absorption refrigeration systems are more energy-efficient and suitable for certain industrial applications but are generally more expensive and have a shorter life expectancy. Thermoelectric refrigeration systems have the advantage of being quiet, reliable, and portable, but have a lower cooling capacity, lower efficiency, and higher cost compared to the other two systems.

	Type	VCAC	AAC (single effect)	TEAC
Cooling	Cooling capacity, W	2500–4500	15–2x104 KW	15–560
	Input electric power, W	750–1670	1.8–54 KW	36–1495
	COPc	2.6–3.0	0.6–0.7	0.38–0.45
	Work permit temperature range, °C	18–45	N/A	0–70
Noise, Db		35–48 Indoor	N/A	N/A
Size		Medium	Big	Small
Life expectancy, years		10–12	≈ 15	≈ 23
Price		Low	High	High

1.4 Problem Statement

Considering the applications of the Refrigeration system, it has become a part of our life. Food processing and preservation, storage applications, medical applications, and scientific applications are some of the areas where refrigeration is widely used. This can be achieved by using a conventional refrigeration system. But the use of compression refrigeration systems has been linked to several environmental concerns. These include:

- **Ozone depletion:** Many refrigerants used in compression refrigeration systems, such as chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs), have been found to contribute to the depletion of the ozone layer.
- **Global warming:** Some refrigerants used in compression refrigeration systems, such as hydro fluorocarbons (HFCs), have a high global warming potential (GWP), which means they have a significant impact on climate change.
- **Energy consumption:** Compression refrigeration systems require a lot of energy to operate, which contributes to greenhouse gas emissions.

Overall, there is a need to replace compression refrigeration systems with more sustainable alternatives in order to mitigate their impact on the environment and reduce energy consumption.

Similarly, Vapor Compression Refrigeration System is less portable and more expensive as well. The farmers in the remote areas could not afford it. Also, lack of electricity is another issue in many places in the country. So, large quantities of fruits and vegetables go wasted because of the lack of a refrigerated storage system which results in economic loss. Vaccines and medicines are needed to store in refrigerators even while we transport them from one place to another. So a portable and clean refrigeration system is in high demand at the present time.

Therefore, Thermoelectric Refrigerators being compact, noiseless, lacking moving parts, portable, and cheaper, can be a better alternative to conventional refrigeration systems. The only problem with this system is its efficiency and Coefficient of Performance (COP). The actual COP value of this system is very low. Several research and experiments are going on to improve the performance of the system. Developing the best heat exchange system is the main challenging task of the present time.

1.5 Objectives

The main and specific objectives of this project are mentioned below:

1.5.1 Main objective

- To study and fabricate a prototype thermoelectric refrigeration system using the Peltier module.

1.5.2 Specific objectives

i. To optimize the performance of the thermoelectric refrigeration system by selecting appropriate materials and heat sink assembly.

ii. To conduct experimental tests and evaluate the performance of the thermoelectric refrigeration system in terms of power consumption, cabin temperature, and overall efficiency.

iii. To compare the cabin temperature by changing different parameters such as layer of insulation, types of fins and air circulation arrangement.

iv. To perform the comparative analysis of different cooling systems such as air cooling system and fan enhanced cooling system.

v. To explore potential applications of the thermoelectric refrigeration system in various fields, such as food storage and preservation, medical equipment, environmental pollution control and electronics cooling.

CHAPTER TWO: LITERATURE REVIEW

2.1 History of thermoelectric refrigeration

The history of thermoelectric refrigeration dates back to the early 19th century, when French physicist Jean Charles Athanase Peltier discovered the thermoelectric effect in 1834. The thermoelectric effect is a phenomenon where an electric current flowing through two different types of metals or semiconductors generates a temperature difference between them. The effect is reversible, meaning that a temperature difference can also generate an electric current.

The discovery of the thermoelectric effect led to the development of the Peltier effect, which is the basis of thermoelectric cooling. The Peltier effect is a process where a temperature difference is created across a junction of two dissimilar materials when an electric current is passed through them. This effect was later used to develop thermoelectric cooling devices.

In 1836, another French physicist, Jean Baptiste Fourier, suggested that the Peltier effect could be used to create a refrigeration cycle. However, it wasn't until the 20th century that practical thermoelectric refrigeration devices were developed.

In the 1930s, researchers began exploring the use of thermoelectric cooling for military applications, such as cooling infrared detectors and electronic equipment. During World War II, thermoelectric cooling devices were used to cool electronics on board aircraft and ships.

In the 1950s and 1960s, researchers began developing thermoelectric cooling devices for commercial applications, such as refrigeration for medical and scientific equipment. However, these early devices were not very efficient, and their cooling capacity was limited.

In the 1970s and 1980s, advances in materials science and semiconductor technology led to the development of more efficient thermoelectric materials, such as bismuth telluride and lead telluride. These materials allowed for the development of more efficient thermoelectric cooling devices with greater cooling capacity.

Today, thermoelectric cooling devices are used in a wide range of applications, including refrigeration for medical and scientific equipment, cooling for electronic devices, and air conditioning for automobiles and other vehicles. The technology continues to evolve, with researchers exploring new materials and designs to improve the efficiency and performance of thermoelectric cooling devices.

The thermoelectric refrigeration device is a utility of the Peltier effect, and good overall performance is dependent on powerful heat dissipation. Thermoelectric refrigerators usually contain a series of small metal cubes called thermopiles. The cool end is inside the cooler and keeps the food cold. The hot end is on the outside, which releases heat into the air. Awasthi M. et al.(2012) explain the design and development of a thermoelectric Refrigerator using the single-stage 12V Peltier module for cooling. The designed refrigerator has a cooling volume of 5L that utilizes the Peltier effect to refrigerate and maintain a selected temperature from 5 °C to 25 °C.

Krishpersad M. et al. (2014) studied the comparison between a commercial vapor compression refrigerator and the laboratory-built thermoelectric refrigerator over 325 ml of water in a glass jar to reduce the temperature from 32ºC to 6 ºC. It shows that temperature reduces linearly in commercial refrigeration whereas it reduces exponentially in thermoelectric refrigeration. The look additionally suggests that withinside the freezer compartment of the industrial fridge, the water took 61 min to chill to 6°C the same time as the thermoelectric beverage cooler took 69 min.

Jugsujinda S. et al. (2010) analyzed the performance of thermoelectric refrigerators based on current, differential temperature, time, and COP. The Peltier module operated at 3.5A where the cold side of the Peltier module is maintained at -4.2ºC for 1 hr which maintains the overall temperature of the refrigerator to 20ºC. The COP obtained by the refrigerator is 0.65 using fins for heat dissipation.

Amankwah A.K. et al.(2017) studied and fabricated the thermoelectric refrigeration system for rural medical applications where the heat load is calculated to remove heat from the medical items(equipment, medicines) to cool them using solar PV cells for 80 minutes. The heat sink is used to extract the heat from the hot side of the Peltier module and its COP was found to be 0.87.

Thermoelectric refrigerator boxes were used to cool air inside the box for different purposes such as medical, and keeping beverages and foods cool and fresh (Zhao and Tan, 2014; Zheng et al., 2014). A portable TE medical cooling box controlled by a microprocessor was developed for preserving human blood during transportation (Güler and Ahiska, 2002).

Welling et al. (1997) reported an experiment that evaluated the effects of thermoelectric module location on cooling efficiency. It was concluded that it is important to optimize module location so as to increase the system efficiency and reduce operating costs.

Darshan et al. (2016) performed an experiment to check the performance of thermoelectric refrigeration systems for load and no load conditions. The theoretical COP of the system was obtained to be 0.5481. For no load condition, it was found that it took 4 minutes to achieve 20 degrees celsius temperature on the cold side where the ambient temperature was 32 degrees Celsius. The COP was calculated for a no-load condition which was obtained to be 0.1939. For load conditions, 0.273 liters of water was kept for cooling. The system nearly took 21 minutes to cool down the temperature of the water to 23 degrees celsius from the initial temperature of 31 degrees Celsius. The calculated COP was 0.03.

Numerous studies have shown how the size of the thermoelement affects the COP and heat pumping capacity of thermoelectric modules. While a relatively short thermoelement is preferable for having a higher heat pumping capacity, a comparatively long thermoelement is necessary to attain higher COP. Therefore, a compromise between the module's required COP and heat pumping capability must be made. It was discovered that water-cooled forced convection heat exchangers outperform other heat exchanger types utilized in thermoelectric cooling systems. However, because of their convenience to use, air-cooled heat exchanger systems are used most of the time. For large temperature difference applications, multistage thermoelectric modules give the best performance with COP value increased significantly. According to obtained data, at a 100-degree Celsius temperature difference, the use of cascade heat exchanger modules increased the COP by 54%.

2.2 Research Gap:

One potential research gap in thermoelectric refrigeration is the development of more efficient and cost-effective materials for thermoelectric cooling. Currently, the performance of thermoelectric materials is limited by their low conversion efficiency, which makes it challenging to achieve significant cooling with small-scale devices. Researchers are exploring ways to improve the performance of thermoelectric materials, such as by developing new materials with higher conversion efficiencies or by enhancing existing materials through Nano structuring, doping, or other techniques.

Another potential research gap is the optimization of thermoelectric refrigeration systems for specific applications. While thermoelectric refrigeration has advantages over other refrigeration technologies, it may not be the best option for all applications. We can explore ways to optimize the design of thermoelectric refrigeration systems for specific applications, such as portable cooling devices, automotive air conditioning, or refrigeration in remote or off-grid locations.

Additionally, there is a need for more research on the environmental impact of thermoelectric refrigeration. While thermoelectric refrigeration systems have advantages in terms of energy efficiency and reduced greenhouse gas emissions compared to traditional refrigeration systems, there may be other environmental impacts associated with the production, use, and disposal of thermoelectric materials and devices. We can explore ways to reduce the environmental impact of thermoelectric refrigeration, such as by developing more sustainable materials or by improving the end-of-life management of thermoelectric devices.

2.3 Development of thermoelectric Materials:

A material must have a combination of a high Seebeck coefficient, a low heat conductivity, and a high electrical conductivity in order to have a high thermoelectric performance. A reduction in one property could result from an improvement in another, though. For instance, increasing the number of carriers will improve the electrical conductivity while simultaneously lowering the Seebeck coefficient, which increases the contribution of electrons to the thermal conductivity. Therefore, it is essential to balance these features in order to optimize a material for its ZT, a measurement of thermoelectric efficiency. For many years, this challenge has limited the highest attainable ZT to 1, resulting in thermoelectric devices with low power conversion efficiency of only 4-5%.

Bulk alloys like Bi2Te3, PbTe, SiGe, and CoSb3 are common examples of traditional thermoelectric materials. It has been found that alloy semiconductors with a high carrier concentration are the most effective bulk thermoelectric materials. Good electrical conductivity is produced by this high charge carrier concentration, although it can be improved by changing the charge carrier concentration. By alloying, it is possible to interfere with the quantized lattice vibrations known as phonons that transmit heat and reduce thermal conductivity. While phonons cannot transport heat at the atomic level, high mobility electrons may carry charge and heat freely in phonon glass electron crystal materials, which are good thermoelectric materials. Reducing the material's thermal conductivity is a popular trend right now to improve thermoelectric materials' performance.

The development of extremely effective photonic electro crystalline liquid crystal thermoelectric materials is proposed using a unique technique that involves a crystalline sub-lattice for electronic conduction encircled by ions that resemble liquid. According to experimental findings, copper ions surrounding the crystalline sub-lattice of se in Cu2xSe behave like liquids, resulting in extremely low lattice thermal conductivity and raising the ZT value for this straightforward semiconductor. Nanostructure engineering, which may be explored using two major approaches: bulk materials incorporating nano-scale components and nano-scale materials themselves, can increase the efficiency of thermoelectric devices even more. Nanostructures have enabled the ZT to be lowered to about 1.7, leading to power conversion efficiencies of 11–15%.

The development of thermoelectric materials, both in bulk and low-dimensional forms, has been covered in a number of reviews. Quantum confinement effects on electron carriers are present in low-dimensional materials such as 2-D quantum wells, 1-D quantum wires, and 0-D quantum dots. These effects raise the Seebeck coefficient and, as a result, power factor. There is also a bigger drop in thermal conductivity than in electrical conductivity as a result of the fact that different interfaces scatter phonons rather than electrons more effectively.

Recent studies have shown that two-dimensional nanostructures made of Bi2Te3 can significantly increase ZT by enhancing thermopower, with estimated values much higher than those of bulk materials. In particular, Bi2Te3-Sb2Te3 quantum well superlattices with a periodicity of 6 nm have exhibited the highest observed ZT value of 2.4, whereas bulk Bi2Te3 only reaches 1.1. Similarly, quantum-dot super lattices in PbTe-PbSeTe systems designed under quantum confinement have shown potential for increasing Seebeck coefficients and resulting in higher ZT values. For instance, embedding PbSe nanodots in a PbTe matrix led to a ZT of 1.6. A special nanostructure in the cereal compound Ag1–xPb18SbTe20 has also been shown to achieve a high ZT value of 2.2 at 800 K, making it a highly promising TE material and the subject of much research. These emerging technologies are expected to further improve ZT to 2.4 and enhance device conversion efficiency to 15-20%.

2.4 Applications using thermoelectric Coolers:

Commercial TE coolers are utilized in applications that require precise temperature control, intrinsic safety against hazardous electrical conditions, and high dependability in cooling system design. When low COP is not a clear disadvantage, TE coolers are better suited for unusual applications like space missions, medical, and scientific equipment.
Portable and home refrigerators, portable ice boxes, and beverage can coolers with moderate cooling needs are examples of small-capacity cooling applications for TE coolers. When the temperature difference between indoors and outdoors is between 20 and 25 °C, the COP is often less than 0.5 for both household and portable thermoelectric refrigerators.

When operating, electronic gadgets like computer processors produce a lot of heat. Due to this, it will be difficult to keep these electronic gadgets' working temperatures consistent. When conventional passive cooling methods fall short of heat dissipation requirements, TE's cooling devices reduce thermal noise and leakage currents in scientific and laboratory equipment for laser diodes and integrated circuit chips. For instance, lowering the temperature of this CdZnTe detector for X-ray astronomy to 30–40°C lowers leakage currents. It enables the use of lengthy pulse shaping durations and pulse-reset preamplifiers, greatly enhancing energy resolution. Micromachining techniques are used to integrate thin-film TE coolers and microelectronics. TE coolers appear to be particularly beneficial for automotive applications. In addition to car air conditioners and car mini-fridges, the researcher used his TE device to cool or heat the temperature of car seats.

To compete with the vapor compression devices already in use, some researchers are working to develop residential thermoelectric air conditioners. They investigated this TE cooling system for indoor small-space cooling applications. A TE cooling unit was put up to have a maximum cooling capacity of 220W and a maximum coefficient of performance (COP) of 0.46 at an input current of 4.8A per module.

PV modules may be directly connected to TE systems. Since TE's products are low-voltage, they may directly absorb power from solar panels without converting it. The devices from TE are appealing for building air conditioning applications because of this benefit. The energy consumption and environmental effects of conventional refrigeration and air conditioning can be reduced by using this solar cooling technique. In addition to providing DC electrical energy when there is no sunlight, the battery can also be utilized to store DC voltage when sunlight is present. To prevent the battery from being overcharged, a battery charge controller is necessary. In chilled sealing applications, solar thermoelectric components can be employed to reduce the majority of the sensible cooling load.

2.5 Different cooling methods for cooling the heat exchanger on the hot side are

1. Fan-enhanced heat pipe cooling
2. Water cooling
3. Air cooling

1. Fan-enhanced heat pipe cooling:

A heat pipe is an efficient heat exchanger that uses two-phase fluid flow to transfer heat. A working fluid, wick structure, and a casing make up this sealed device. The evaporator section's wick's liquid working fluid evaporates due to the heat source. The resulting saturated vapor condenses and releases its latent heat in the cooler condenser portion after it flows there. As long as there is a temperature difference, the condensed liquid will eventually return to the evaporator through the wick structure through capillary action. Deionized water is frequently employed as the working fluid because of its high latent heat capacity, low surface tension, high thermal conductivity, and high boiling point. At lower temperatures than typical, the vacuum inside the heat pipes causes the water to boil and transform into steam.

Many different goods, including air conditioners, freezers, heat exchangers, transistors, and condensers, employ heat pipes. In order to lower operating temperatures and boost performance, heat pipes are also employed in desktops and laptops. Since the middle of the 1960s, commercial heat pipes have been available. Heat pipes are a recently developed, dependable, and affordable cooling technology from electronic cooling. Yang Liu and Yan Su's experiment revealed that the thermoelectric cooler module's average coefficient of performance (COP) is approximately 0.31.

Astrain D. et al. (2003) explain the increase of COP of the thermoelectric refrigerator by optimization of heat dissipation. A thermosyphon and phase-change device will reduce thermal resistance and, as a result, a slight temperature decrease between the hot side of the Peltier pellet and the environment, increasing the efficiency of the system.

in the thermoelectric refrigerator's COP. The largest thermal drop was achieved at 19°C in his subsequent study, published in 2009, on the development of thermoelectric refrigerators with two-phase thermosyphons and capillary lift. The created refrigerator uses only 1.08 kWh of electricity each day and has no noise or vibration because there are no exterior fans. Its COP value for the nominal situation is 0.45, and experimental evidence shows that utilizing Thermosyphon increases the refrigerator's COP by 66%.

Figure 2.1: Fan-enhanced heat pipe

2. Water cooling:

Water cooling is the method of removal of heat from the object using the convection technique as the heat transfer mode. Convection is a heat transfer process in which a fluid comes in contact with a warmer surface and removes heat from it. When water is used as a medium of heat transfer it is simply called the water cooling method. When external means such as pumps or fans are utilized to increase the flow rate, it’s called “forced convection”. External means like a water block are used to circulate the liquid with the external power supply. This system is widely applied in cooling the electronics system.

In a study conducted by Murat G. et al, it was found that water-cooled thermoelectric refrigerators have a higher coefficient of performance (COP) compared to fins-and-fans-cooled thermoelectric refrigerators. The study showed that the internal temperature of the water-cooled refrigerator could reach around 2°C at a flow rate of 0.8 L/min, and -0.1°C at a flow rate of 1.5 L/min after a 2-hour experiment. The COP for a flow rate of 1.5 L/min was 0.23, while for 0.8 L/min, it was 0.19. In an 8V system with a flow rate of 1.5 L/min, the COP was 0.41. However, to improve the energy consumption, the temperature difference between the hot and cold sides of the thermoelectric refrigerator needs to be reduced. For a temperature difference of 19°C, the total electrical energy consumption was 2.3kWh/day, with a COP of 0.19.

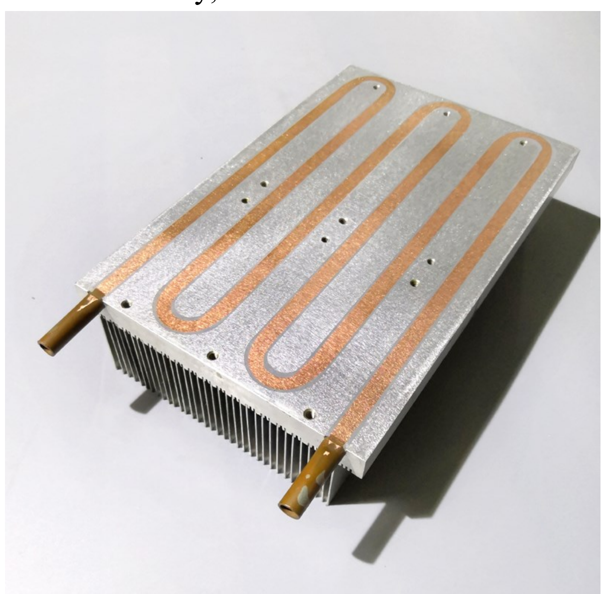

Figure 2.2: Water cooling system

3. Air cooling:

Air cooling is a process that involves increasing the surface area or airflow over an object to dissipate heat. One way to achieve this is by adding fins to the surface of the object, which can be attached directly or made integral to it to maximize heat transfer efficiency. Another approach is to use a fan to blow air onto the object, which further increases airflow. The addition of fins to a heat sink is an effective way to increase its surface area and improve cooling performance. There are two types of cooling pads available for air cooling, namely honeycomb and excelsior designs. However, for air cooling to work, the air temperature must be cooler than the object being cooled, as heat will only move from hot to cold according to the second law of thermodynamics.

According to Daniel C. et al., Air cooling is an innovative technology for cooling thermoelectric refrigeration. There are no heavy moving parts to achieve the cooling effect, resulting in less violent vibration compared to traditional cooling systems. In addition, it is an environment-friendly system that does not use harmful refrigerants and does not generate harmful components such as Freon. Thermoelectric modules operate with direct current (DC), heating, and cooling phenomena, depending on the direction of current flow. Air passes through the cold side and water is used to reduce heat on the hot side. The system reached 25°C within 300 seconds and took 700 seconds to reach ambient temperature from 30°C to 15°C. This TEACS novelty has a COP of 1.13 obtained by carefully tuning the electrical parameters, a cooling capacity of 648W, and is designed using environmentally friendly materials.

Figure 2.3: Air cooling system

CHAPTER THREE: METHODOLOGY

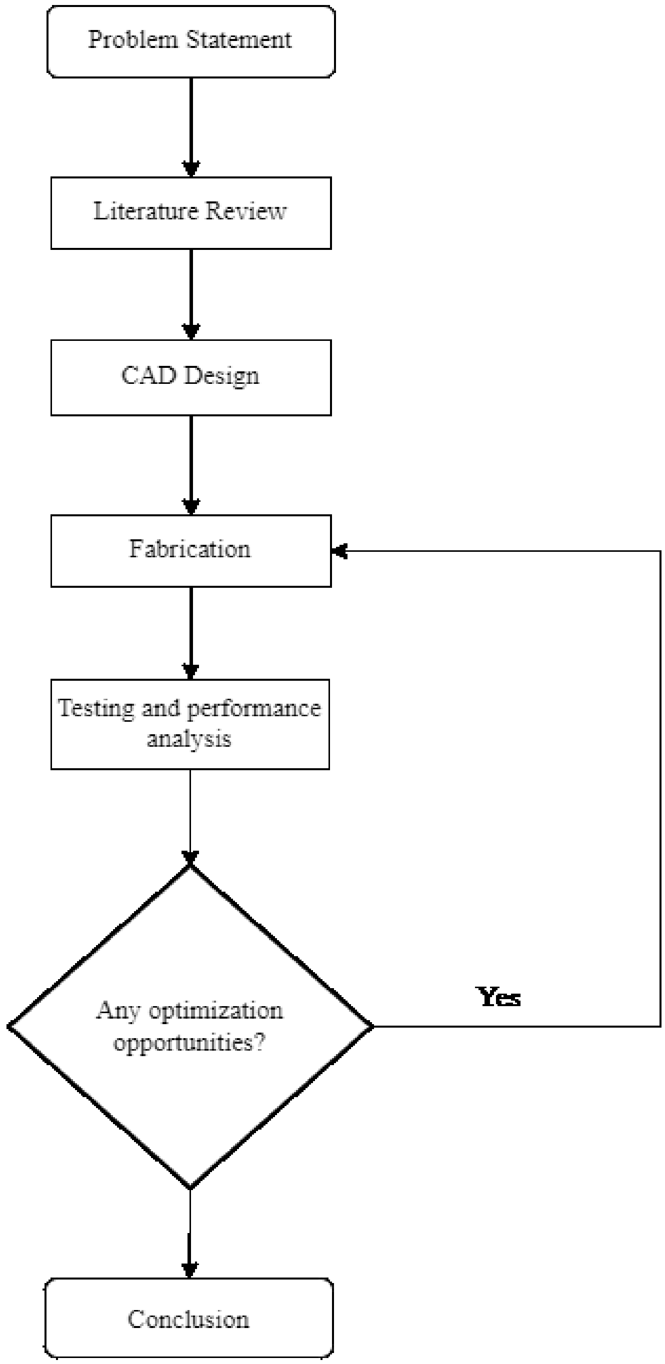

Figure: Methodology

3.1 CAD design

CAD stands for Computer-Aided Design, which uses computer software to create, modify, analyze, or optimize designs for a variety of applications. CAD design is widely used in various industries such as architecture, engineering, manufacturing, and construction to create detailed models and drawings that can be used to visualize and simulate real-world objects, structures, and systems.

CAD software typically includes a variety of tools for creating 2D and 3D models. This includes drawing and annotation tools, modeling and sculpting tools, rendering and visualization tools, and analysis and simulation tools. CAD software also facilitates collaboration and sharing of design data across teams and organizations.

CAD design is a powerful tool that has revolutionized the way designs are created and developed. This allows designers to quickly create and iterate designs, simulate and test their performance, and optimize them for specific applications. CAD design also helped reduce design errors and improve product quality while reducing development time and costs.

After the design is finalized, the next step is to fabricate a prototype of the box. This can be done using various methods such as 3D printing, CNC machining, or traditional fabrication techniques. The designer may also need to source the materials and components required to assemble the box, such as hinges, latches, and insulation material.

During the fabrication process, it is important to ensure that the dimensions and specifications of the box are accurately replicated in the prototype. This can be achieved through careful measurement and quality control checks. Since the prototype is fabricated, it can be tested and evaluated to ensure that it meets the desired specifications and functions as intended. Any necessary modifications or improvements can then be made to the design before the final product is produced.

CAD design plays a critical role in the development of modern products and systems. It allows designers to create complex and detailed models that can be used to optimize and refine designs, reduce development time and costs, and improve the overall quality and performance of the final product. The length*breadth*height of the other box is 30*30*25 cm. and the inner casing is insulated with 13 mm insulating material.

Figure 3.1: CAD Design

3.2 Material selection

Once the 3D model is complete, the designer can use rendering and visualization tools to create a realistic representation of the final product. This can help to identify any potential design issues or areas for improvement before the unit is fabricated. The outer casing of the Refrigerator can be fabricated using a variety of materials such as metal, plastic, or a combination of both. The choice of materials will depend on factors such as cost, durability, and aesthetic considerations.

Overall, designing the outer casing of a thermoelectric refrigerator using CAD software allows for greater customization and flexibility in the design process. It also helps to ensure that the final product meets the desired specifications and functions as intended.

3.2.1 Outer Casing:

Plywood is a type of engineered wood made from thin layers of wood veneer that are glued together in alternating directions to create a strong and durable material. It is commonly used in a variety of applications including furniture, cabinetry, and construction. Using plywood for the fabrication of a thermoelectric refrigerator can be a cost-effective and practical choice. Plywood is a lightweight and versatile material that can be easily cut, shaped, and assembled into the desired form. It also offers good structural strength and stability, making it suitable for use in a variety of applications.

After the design is complete, the plywood sheets can be cut and shaped using a variety of tools such as saws, drills, and routers. The pieces can then be assembled using glue, screws, or other fasteners to create the final product. To ensure that the thermoelectric refrigerator is properly insulated, the interior of the unit can be lined with a layer of insulation material such as Nitrile Rubber or foam. This will help to maintain a consistent temperature inside the refrigerator and improve energy efficiency. Compared to substances like metals, marble, glass, and concrete, it has a low thermal conductivity (high heat-insulating ability). Light, dry woods are superior insulators because thermal conductivity is highest in the axial direction and increases with density and moisture content. A 6 mm thickness plywood is used for making the 250*300*300 cubic mm box.

Reason for selection of Plywood:

- Low thermal conductivity
- High strength and stability
- High impact resistance
- Easily available and cheap in cost.

3.2.2 Insulation:

To improve the efficiency of thermoelectric refrigeration, it is important to use effective insulation materials inside the refrigerator. The insulation helps to prevent heat from entering the refrigerator and affecting the cooling performance of the thermoelectric modules.

There are several types of insulation materials that can be used inside a thermoelectric refrigerator, including foam, fiberglass, and Nitrile Rubber. Foam insulation is a common choice due to its low cost and ease of installation. It is typically made from polyurethane foam or polystyrene foam, which are both effective at reducing heat transfer. However, foam insulation can be less effective at very low temperatures, such as those required for freezing.

Fiberglass insulation is another option that is commonly used in thermoelectric refrigeration. It is made from fine fibers of glass that are woven together to create a mat. Fiberglass insulation is lightweight and offers good thermal insulation properties, making it effective for use in refrigeration applications. Effective insulation is an important consideration in the design of thermoelectric refrigeration. Foam, fiberglass, and Nitrile rubber are all effective insulation materials that can be used to reduce heat transfer and improve the cooling performance of thermoelectric refrigerators. The choice of insulation material will depend on factors such as cost, temperature requirements, and overall performance requirements.

Nitrile rubber insulation is a type of synthetic rubber material that is commonly used for thermal insulation in various applications. The thermal conductivity of nitrile rubber insulation can vary depending on a number of factors such as its thickness, density, and temperature. The thermal conductivity of nitrile rubber insulation is typically in the range of 0.032 to 0.036 W/mK (Watts per meter Kelvin) at room temperature. This means that nitrile rubber insulation is a relatively good insulator and can effectively resist the transfer of heat energy.

One of the advantages of using nitrile rubber insulation is its ability to maintain its insulating properties even at low temperatures. This makes it suitable for use in refrigeration and other low-temperature applications where maintaining a consistent temperature is important. Another advantage of nitrile rubber insulation is its ability to resist moisture and water vapor. This helps to prevent the buildup of condensation inside the insulation layer, which can reduce its effectiveness and potentially lead to damage or corrosion of the underlying materials.

Nitrile Rubber insulation with aluminum foil is used as an insulating material in the fabricated Thermoelectric Refrigerator. Nitrile rubber insulation is a very versatile and flexible insulation. Widely used in industrial insulation, air conditioning, plumbing, and HVAC industries. It is a closed-cell elastomeric insulation that is resistant to water vapor, oil, and most acids. Two layers of 13 mm thickness insulation are attached with heat-resistant adhesive on the inner side of the box.

Figure 3.2: Insulating material

Properties of insulating material used:

- Durable and Erosion Resistant
- Easy To Apply

- General Thermal Insulation
- Easy availability

3.2.3 Heat sink:

As we know the Peltier module has both cold side and hot side that's why we need two heat sinks which are connected at both ends. Attaching heat sinks to both sides of a Peltier module is a common method of improving the performance and reliability of a thermoelectric cooling system. This module uses the Peltier effect to transfer heat from one side of the module to the other when an electric current is passed through it. One side of the module gets cold, while the other side gets hot. When a Peltier module is used for cooling, heat is absorbed from the cold side of the module and dissipated to the hot side of the module. To ensure efficient heat transfer and prevent overheating, it is important to attach heat sinks to both sides of the module. Heat sinks are designed to increase the surface area available for heat transfer, allowing more heat to be dissipated from the module.

The heat sinks used on the cold side of the module typically have fins or other features to increase the surface area and promote convective cooling. The heat sinks on the hot side of the module may use similar features, but may also incorporate a fan or other forced-air cooling method to increase heat dissipation.

By attaching heat sinks to both sides of the Peltier module, the cooling performance of the system can be improved, and the risk of overheating and failure can be reduced. The size, design, and material of the heat sinks used will depend on the specific requirements of the application, including the power output of the Peltier module, the desired cooling performance, and the available space and airflow for the heat sinks. Proper thermal management is critical for the reliable and effective operation of a thermoelectric cooling system, and the use of heat sinks on both sides of the Peltier module is an important part of this.

At cold side:

The cold side of a Peltier module is the side that is intended to be used for cooling. This side is typically attached to a heat sink or fins to increase its cooling efficiency. Aluminium fins are a common material used for this purpose due to their high thermal conductivity and lightweight. By attaching aluminium fins to the cold side of the Peltier module, heat is transferred away from the module more efficiently. This allows the module to maintain a lower temperature, which in turn enhances its cooling performance. Additionally, the fins increase the surface area of the cold side, which allows for greater heat dissipation.

Aluminium is a highly conductive metal with excellent thermal conductivity. Its thermal conductivity is around 237 W/(m*K) at room temperature, which means that it is an efficient conductor of heat. This high thermal conductivity makes aluminum a popular material for use in heat sinks and other thermal management applications, as it can quickly and effectively transfer heat away from the source.

Aluminium's thermal conductivity is significantly higher than many other common metals and materials, such as copper, brass, and stainless steel. For example, copper has a thermal conductivity of around 401 W/ (m*K), which is higher than aluminium, but aluminium is much lighter and less expensive, making it a more practical choice in many applications.

Attaching two fans with high RPM (revolutions per minute) to a heat sink is a practical way to enhance the rate of cooling in the surrounding area. When the fans are turned on, they generate a forced convection effect that helps to move air over the surface of the heat sink more quickly. Forced convection is a process in which a fluid (such as air) is moved by an external force, such as a fan or pump. In this case, the fans generate a flow of air over the heat sink, which helps to increase the rate of heat transfer away from the heat sink and into the surrounding environment. The high RPM of the fans allows them to move a larger volume of air in a shorter period of time, which can help to reduce the temperature of the heat sink and the surrounding area more quickly.

At Hot side:

When a Peltier module is used for cooling, the hot side of the module generates heat that needs to be dissipated to the surrounding environment. One way to dissipate this heat is by attaching a fan-enhanced heat pipe to the hot side of the module. A heat pipe is a passive heat transfer device that uses a sealed, hollow tube to transfer heat from one point to another. The heat pipe contains a working fluid that evaporates at the hot end and condenses at the cool end, creating a continuous cycle of heat transfer. By adding a fan to the heat pipe, the heat transfer rate can be increased, which helps to dissipate heat from the hot side of the Peltier module more effectively.

A fan-enhanced heat pipe is a type of heat pipe that uses a fan to increase the rate of heat transfer between the heat source and the heat sink. They consist of a sealed tube filled with a working fluid that evaporates at the heat source, moves through the tube via capillary action, and condenses at the heat sink, releasing heat in the process. In a fan-enhanced heat pipe, a fan is attached to one end of the heat pipe to increase the rate of airflow over the heat sink, thereby enhancing the rate of heat transfer. The fan creates a forced convection effect that helps to remove heat from the heat sink more quickly than would be possible with a passive heat pipe alone. Fan-enhanced heat pipes are commonly used in electronic cooling applications, where high heat fluxes need to be dissipated quickly and efficiently.

Attaching a fan-enhanced heat pipe to the hot side of the Peltier module has several benefits. Firstly, it increases the surface area available for heat dissipation, allowing for more efficient heat transfer. Secondly, it increases the heat transfer rate through the use of the working fluid and the fan, which helps to reduce the temperature of the hot side of the module. This can help to prevent damage to the module and ensure that it operates at peak efficiency.

The effectiveness of fan-enhanced heat pipes depends on several factors, including the size and speed of the fan, the design and orientation of the heat pipe, and the thermal properties of the working fluid. The performance of fan-enhanced heat pipes can be optimized through careful design and testing, taking into account the specific requirements of the application. Compared to other cooling technologies, fan-enhanced heat pipes offer several advantages, including high efficiency, low noise, and low maintenance requirements. They are also environmentally friendly, as they do not require any refrigerants or other harmful chemicals. However, they may not be suitable for applications where space is limited, or where the use of a fan is not feasible due to noise or power consumption constraints.

Specifications of Fan Enhanced Heat pipe:

- Heatsink Material: 2 Heat pipes/Aluminium fins/ Direct contact
- Dimensions: 90*90*25 mm
- Weight: 405 g
- Speed: 1700+- 200 RPM
- Air flow: 25.9 CFM (Max)
- Power connector: 3-Pin
- Rated Voltage: 12 VDC
- Rated current: 0.16 A
- Safety current: 0.18 A
- Power Consumption: 1.92 W

3.2.4 Power supply:

The Peltier module is an electronic device that works by transferring heat from one side of the module to the other when a voltage is applied to it. This process requires energy, and therefore, power is needed to operate the module. Similarly, the fan attached to the heat sinks helps to dissipate the heat generated by the Peltier module, and it also requires power to operate. The amount of power required by the fan depends on its size, speed, and the amount of heat that needs to be dissipated.

It's important to ensure that the power supply used to operate the Peltier module and fan is adequate to meet their power requirements. Study shows that only 2.7 A current is only drawn by the peltier module and 0.18 A is the requirement of fan both devices require 12 V voltage. When a 12V and 4A adapter is used for power supply, it should be sufficient to power both the Peltier module and the fan attached to the heat sinks, as long as their power requirements do not exceed 4A.

It's always a good idea to ensure that the power supply is rated higher than the total power consumption of the components to provide some margin for error and ensure reliable operation.

3.2.5 Thermal Paste:

Thermal paste, also known as thermal grease is a substance used to improve the thermal conductivity between two surfaces, usually a heat source (such as a CPU or GPU) and a heatsink. The purpose of thermal paste is to fill in the microscopic gaps and imperfections between the two surfaces, allowing for more efficient transfer of heat from the heat source to the heatsink. The most common type of thermal paste is a silicone-based compound that is filled with tiny particles of metals such as aluminum, zinc, or silver. These metal particles are highly conductive and its thermal conductivity is nearly 2 W/m.K which helps to bridge the gaps between the two surfaces. Other types of thermal paste may use different materials, such as ceramic or carbon-based compounds.

When applying thermal paste, it is important to use only a small amount, as using too much can actually decrease the effectiveness of the paste by creating a barrier between the two surfaces. Most manufacturers recommend applying a small, pea-sized amount of paste to the center of the heat source before attaching the heatsink. It is also important to ensure that the surfaces are clean and free of debris before applying the paste.

3.3 Experimental Setup

An experimental setup refers to the collection of equipment, tools, and procedures used to conduct an experiment. The design of an experimental setup is critical to ensuring that the experiment is conducted accurately and produces reliable results. The setup should be constructed in a way that minimizes the possibility of errors and ensures that the data collected is representative of the phenomenon being studied.

This presents detailed information about the thermoelectric cooler's devices, working procedures, and operating parameters. It includes the specifications of the Peltier module used along with the design and measuring temperature with a constant value required in the calculation of COP of the thermoelectric refrigeration.

3.3.1 Peltier Module Specification

A Peltier module, sometimes referred to as a thermoelectric cooler or TEC, is a compact electronic device that transfers heat from one side of the module to the other using the Peltier effect. A thermoelectric phenomena known as the Peltier effect occurs when an electrical current is carried through two materials that are not comparable to one another, resulting in a difference in temperature at the junctions of the materials.

Two ceramic plates are placed together with a number of thermoelectric elements to form the Peltier module. These thermoelectric elements are commonly composed of semiconductors like bismuth telluride. The thermoelectric elements in the module produce a temperature differential between the plates when an electric current is supplied, making one side of the plates hot and the other side cold. Peltier modules are efficient, reliable, and can be easily integrated into existing systems. However, they do have some limitations, including limited cooling capacity, high power consumption, and the need for a heatsink to dissipate the heat generated during operation.

In this project, we use the TEC1-12706 L model Peltier module having the following specifications:

Table 3.1: Peltier Module specification

Module: TEC1-12706 L			
Q_{max}	72 Watts	**Dimensions**	
I_{max}	6 Amp	Width	40 mm
V_{max}	12 V	Length	40mm
T_{max}	90ºC	Thickness	3.5 mm
Number of the thermocouple	127		

3.3.2 Design and measurement of temperature

For thermoelectric refrigeration, different objects like the Peltier module, heat sinks are set up to have the optimized result. Every experiment where the Peltier module is used for refrigeration purposes is characterized by a set of operation parameters, which dictate the necessity and accurate selection of the optional thermoelectric cooler as a single-stage method.

The thermoelectric Cooler (Peltier) module material chosen is Bismuth telluride. The properties of a 127 couple i.e p-n junction, with 6A current and 12V voltage supply, are:

Seebeck coefficient (S) = 0.01229 V/K
Module thermal conductance (K) = 0.1815 W/K
Module resistance = 4.44 ohms

Here we run a thermal resistance network for analysis. A-TEC produces Joule heat, so the heat release, called Q_H, from the hot side of the TEC is greater than the heat gain, called Q_L, to the cold side of the TEC. According to the literature, common forms of heat absorption and heat release are listed below. Heat transferred into the cold side when neglected the temperature drop through TEC is given by,

$$Q_L = -[\,SIT_C - \tfrac{1}{2}(I^2R) - K(T_h - T_C)] \quad \{-\text{ sign for heat rejection}\}$$

While the heat transferred out of the hot side into the heat sink is given by,

$$Q_H = SIT_h + \tfrac{1}{2}(I^2R) - K(T_h - T_C)$$

Seebeck coefficient (S) and the electrical Resistance (R) in ohms are dependent on the materials used within the TEC, but also on the geometry of the device, given by the number and dimensions of the individual N and P-type semiconductor elements.

3.4 Testing and Data collection

Testing and data collection are critical components of the scientific method and are essential for conducting experiments and gathering evidence to support hypotheses or theories. The following are some key considerations for testing and data collection:

Planning: Before conducting any tests or collecting data, it is important to carefully plan the experiment. This includes defining the research question, identifying the variables that will be tested or measured, selecting appropriate instruments or equipment, and determining the procedures for conducting the experiment.

Control: To ensure that the results of the experiment are valid and reliable, it is important to control as many variables as possible. This may involve using a control group, standardizing the testing conditions, and implementing blinding techniques to reduce bias.

Data collection: Data should be collected using reliable and valid instruments, and procedures should be followed consistently. It is important to record data accurately and completely and to identify any potential sources of error or bias.

Analysis: After the data is collected, it must be analyzed to determine whether there are any statistically significant differences between the groups being tested or measured. The analysis should be conducted using appropriate statistical methods, and the results should be reported clearly and accurately.

Replication: To ensure that the results of the experiment are valid and reliable, it is important to replicate the experiment and collect data multiple times. This can help to identify any potential sources of error or bias and to verify the results.

After the experimental setup, it is operated with different input parameters. The performance of the Peltier module fluctuates highly with the input power value. So, current and voltage are varied and different data are collected. Time-based data is obtained to find the time required to create a distinct temperature difference.

3.5 COP calculation

The coefficient of performance (COP) of a thermoelectric refrigeration system is a measure of its cooling efficiency. The COP is defined as the ratio of the heat removed from the cold side of the thermoelectric module to the electrical power supplied to the module. In other words, it is a measure of how much cooling is achieved for each unit of electrical energy input.

The COP of a thermoelectric refrigeration system is typically lower than that of a traditional refrigeration system, such as a vapor compression refrigeration system. This is because thermoelectric modules have a relatively low cooling capacity and a high electrical power consumption. The COP of a thermoelectric refrigeration system is also affected by the temperature difference between the hot and cold sides of the module, with higher temperature differences resulting in higher COPs.

The COP of a thermoelectric refrigeration system can be improved by optimizing the design of the module, such as increasing the number of thermoelectric elements or improving the thermal conductivity of the module materials. It can also be improved by reducing the thermal resistance between the hot and cold sides of the module, such as by using high-performance thermal interface materials.

For the calculation of COP, the following formula is used.

COP = Q_L/Energy supplied (W)
Where,
Energy supplied = Q_H - Q_L
Heat released (Q_H) = $SIT_h + 0.5I^2R - k(T_h - T_c)$
Heat absorbed (Q_L) = $-[SIT_c - 0.5I^2R - k(T_h - T_c)]$
S = Seebeck coefficient (0.01229 V/k)
I = Current
k= Module Thermal conductance (0.1815 W/k)
R= Module Resistance (4 ohms)
T_h = Temperature at hot side
T_c = Temperature at cold side

Source: (Patel, 2016, p.74)

3.6 Optimization:

Optimization refers to the process of making something as effective or efficient as possible. In the context of a project or experiment, optimization involves identifying the key parameters that impact the performance or outcome of the project, and adjusting them to maximize the desired result.

Optimization in the experiment done with thermoelectric refrigeration involves identifying the key parameters that affect the performance of the prototype and adjusting them to maximize the cooling efficiency and minimize power consumption.
Some of the key parameters that can be optimized in a thermoelectric refrigeration experiment include:

1. **Peltier module selection:** The Peltier module is the heart of the thermoelectric refrigeration system and is responsible for generating the cooling effect. By selecting a Peltier module with a high coefficient of performance (COP), the cooling efficiency can be maximized while minimizing power consumption.

2. **Heat sink selection and design:** The heat sinks are responsible for dissipating heat from the Peltier module and the surrounding components. By selecting or designing heat sinks that are optimized for maximum heat dissipation, the cooling efficiency of the prototype can be improved.

3. **Fan selection and positioning:** The fans are used to facilitate heat transfer from the heat sinks to the surrounding air. By selecting fans with high air flow rates and positioning them in strategic locations, cooling efficiency can be improved.

4. **Insulation and sealing:** Insulating the prototype and sealing it from the surrounding environment can help minimize heat transfer and improve cooling efficiency.

5. **Temperature control and regulation:** Accurately controlling and regulating the temperature of the prototype can help optimize its performance and prevent overheating.

By optimizing these key parameters, it is possible to improve the cooling efficiency and reduce the power consumption of the thermoelectric refrigeration prototype. It is important to perform experiments and collect data to evaluate the effectiveness of the optimizations and make further adjustments as needed.

3.7 Cost Analysis of Prototype:

To perform a cost analysis of a thermoelectric refrigeration prototype, we need to consider various factors, including the cost of materials, labor, and any additional expenses associated with the manufacturing process. Here is an overview of the cost components that should be considered:

Materials: The cost of materials required for building a thermoelectric refrigeration prototype can vary depending on the specific components used. Some of the key materials include the Peltier module, heat sinks, fans, temperature sensors, and a power supply. Cost of different material used in the prototype fabrication are mentioned in the table below:

S.N	Items	Quantity	Cost
1.	Peltier Module	4	Rs. 4,000
2.	Cooler master T20	1	Rs. 2,000
3.	Cooler fan (Air cooling)	1	Rs. 500
4.	Adapter	1	Rs. 500
5.	Temperature sensor	2	Rs. 500
6.	Thermal paste	3	Rs. 450

6.	Plywood and insulation	-	Rs. 1,000
7.	Fans	2	Rs. 500
8.	Wiring and connections		Rs. 500
9.	Miscellaneous	-	Rs. 1,000
	Total		**Rs. 10950**

Labor: The labor cost will depend on the time required to design and assemble the prototype. This includes the time required to select and order the materials, assemble the components, and test the system. The labor cost will depend on the skill level of the person doing the work and the time required to complete the project. In this project context, all the group members had only worked for the development of the prototype so there is no any labor cost involved.

Additional expenses: There may be additional expenses associated with the manufacturing process, such as the cost of renting a workspace, purchasing tools and equipment, and shipping costs for components. For our project, we worked in the carpentry and robotics club on the Pulchowk campus. Also, we used the tools and equipment that were there so we didn't have to pay any additional costs.

Once the cost components have been identified, we can calculate the total cost of the thermoelectric refrigeration prototype by adding up the cost of materials, labor, and any additional expenses. It's important to note that the cost of the prototype will depend on the level of complexity and performance required. A simple prototype with basic components may cost a few hundred dollars, while a more advanced prototype with higher quality components and advanced features could cost several thousand dollars. Additionally, the cost of a prototype is likely to decrease with mass production and economies of scale.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Dimensions of fabricated prototype:

The dimensions of a thermoelectric refrigeration prototype will depend on various factors, including the specific components used, the desired cooling capacity, and the space available for the prototype. The cooling capacity of the prototype will depend on the size and performance of the Peltier module and the heat sinks. A larger Peltier module and heat sink will generally provide more cooling capacity but will also require more space. The power supply required for the prototype will depend on the power requirements of the components used. A larger power supply may require additional space. The available space for the prototype may be limited, especially if it needs to fit into a specific location or device. In this case, the dimensions of the prototype may need to be adjusted accordingly.

Parameters	calculations	Results
Length	-	30 cm
width	-	30 cm
Height	-	25 cm
Total outer volume	30*30*25	22.5*10^3 cm^3
Insulation thickness	2*1.3	2.6 cm
Total internal volume	24.8*27.4*19.8	13.45*10^3 cm^3
% of volume utilized by air	(13.45/22.5)*100	59.77 %

4.2 Observed Data:

The experimental data collected during our investigation of the thermoelectric refrigeration prototype are noted below. The results of this experiment demonstrate that the thermoelectric refrigerator is capable of providing cooling for small volumes, but has a lower COP than traditional refrigeration systems. The lower COP is due to the relatively low cooling capacity and high electrical power consumption of the thermoelectric module. Different results are obtained by changing the parameters of the system and the comparative analysis is done for two different methods of the cooling system.

1. **Single layer Insulation with single Module**

Time (Mins)	Cabin Temperature(T_c)(°C)	Decrement(°C)
0	25	-
4	22.9	2.1
8	21.7	1.2
12	20.8	0.9
16	19.9	0.9
20	19.1	0.8
24	18.5	0.6
28	17.9	0.5
32	17.4	0.5
36	17	0.4
40	16.6	0.4
44	16.3	0.3
48	16	0.3
56	15.8	0.2
60	15.7	0.1
1 hr 12 mins	15.6	0.1
1 hr 20 mins	15.6	0.0
1 hr 30 mins	15.6	0.0

Calculation:

Given,

T_h= 48ºC

T_C= 15.6ºC

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K
Module resistance = 4.44 ohms

$Q_L = -[\ SIT_C - \frac{1}{2}(I^2R) - K(T_h - T_C)]$

$= -23.7213$

$Q_H = SIT_h + \frac{1}{2}(I^2R) - K(T_h - T_C)$

$= 12.022$

Energy supplied (W) = $Q_H - Q_L$

.

$= 12.022 + 23.7213$

$= 35.7433$

COP = Q_L/Energy supplied (W)

=23.7213/35.7433

= 0.6636

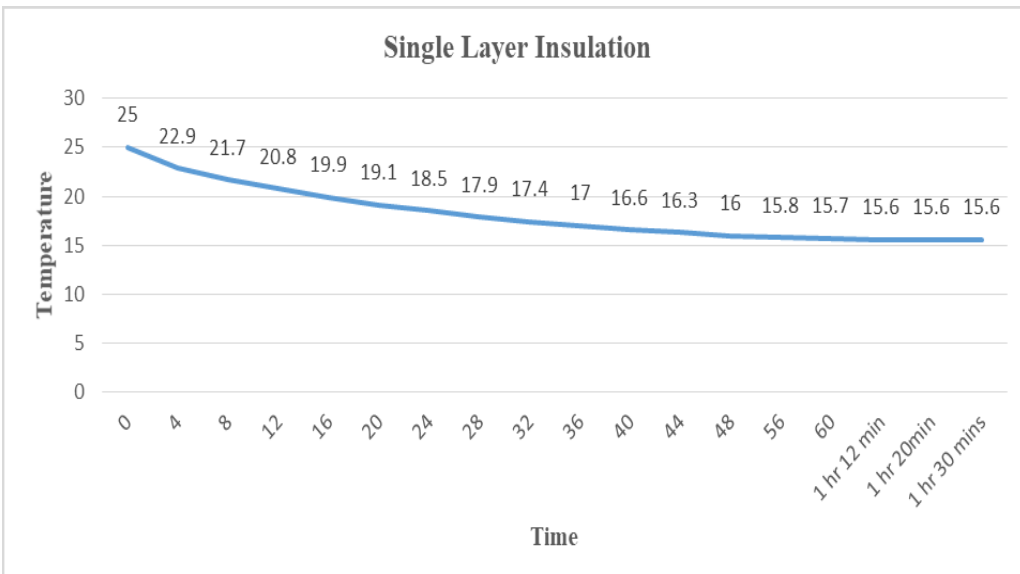

Figure4.1: Graph-1

2. Double insulation with single module

Time(mins)	Cold side temperature(T_C) (°C)	Decrement(°C)
0	24	-
4	20.3	3.7
8	18.3	2
12	17.2	1.1

16	16.6	0.6
20	16.2	0.4
24	15.9	0.3
28	15.6	0.3
32	15.4	0.2
36	15.2	0.2
40	15.0	0.2
44	14.8	0.2
48	14.6	0.2
52	14.4	0.2
56	14.3	0.1
60	14.2	0.1
1 hr 15 mins	14	0.2
1 hr 30 mins	14	0.0

Calculation:

Given,

T_h= 48°C

T_C= 14.2°C

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = -[\, SIT_C - ½(I^2R) - K(T_h - T_C)]$

$= -24.065$

$Q_H = SIT_h + ½(I^2R) - K(T_h - T_C)$

$= 11.7316$

Energy supplied (W) = $Q_H - Q_L$

$=11.7316+ 24.065$

$= 35.7966$

COP = Q_L/Energy supplied (W)

= 24.065/35.7966

= 0.6722

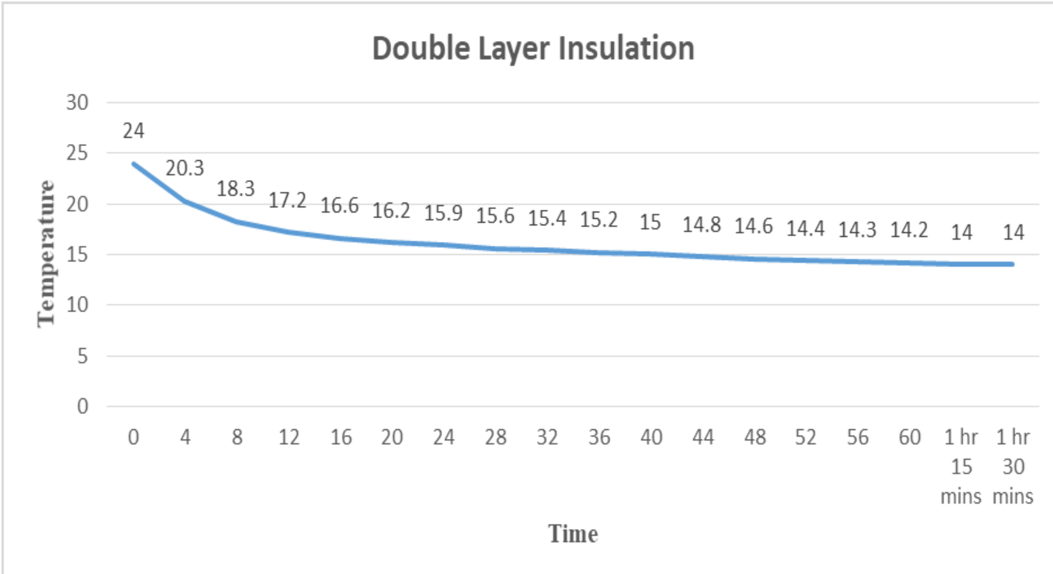

Figure4.2: Graph-2

In the experiment with single layer insulation, the lowest temperature of the cabin reached 15. 6°C in a one and half hour time period. But in the second table we can see, by doubling the insulation layer we were able to achieve 14°C in the same time period. So, just by improving insulation, the cold side temperature was further reduced by 1.6°C and COP was increased by 1.29%.

3. Double module (Using single cooling system)

Time(mins)	Cold side temperature(T_C) (°C)	Decrement(°C)
0	24	-
4	21.2	2.8
8	19.8	1.4

12	19.0	0.8
16	18.4	0.6
20	18.1	0.3
24	17.9	0.2
28	17.8	0.1
32	17.7	0.1
36	17.6	0.1
40	17.5	0.1
44	17.5	0.0
48	17.4	0.1
52	17.4	0.0
56	17.3	0.1
60	17.3	0.0

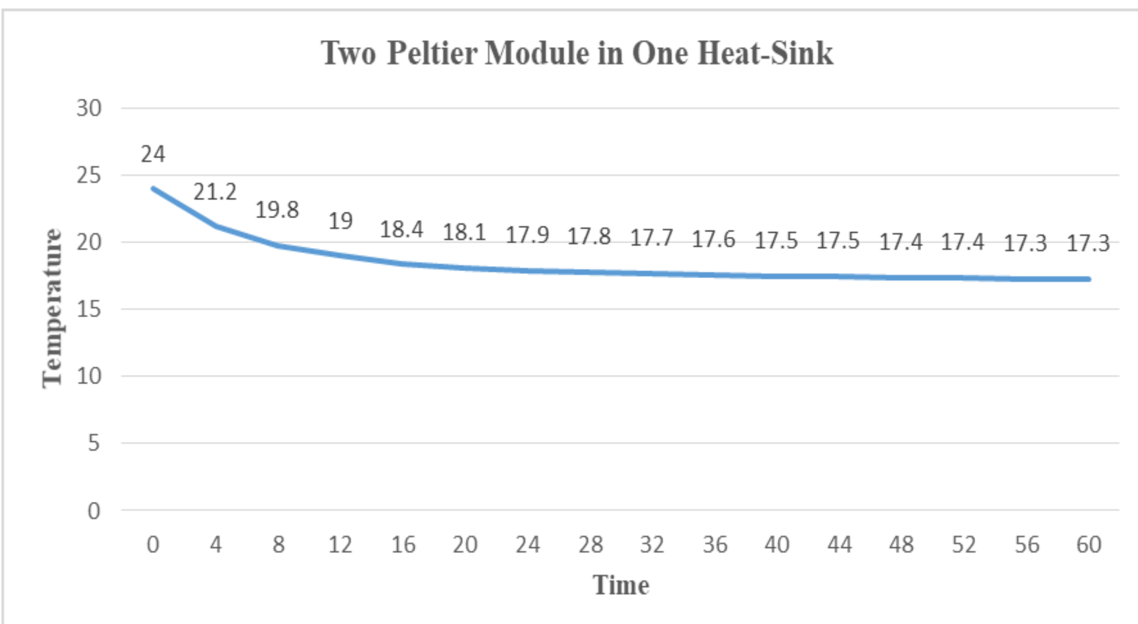

Figure4.2: Graph-3

The sink used for the thermoelectric refrigerator was unable to cool the hot side of the peltier module at the rate at which heat is produced from two modules simultaneously.

Due to this, the hot side temperature of the refrigerator increased rapidly leading to higher cold side temperature.

4. Double Insulation with single module after Improvements

Time (mins)	Cabin Temperature(T_C)(°C)	Decrement(°C)
0	25	-
4	21.6	3.4
8	19.4	2.2
12	17.6	1.8
16	16.3	1.3
20	15.4	0.9
24	14.7	0.7
28	14.2	0.5
32	13.8	0.4
36	13.4	0.4
40	13.1	0.3
44	12.9	0.2
48	12.6	0.3
56	12.3	0.3
60	12.3	0.0
1 hr 5 mins	12.1	0.2
1 hr 13 mins	12	0.1
1 hr 25 mins	11.9	0.1
1 hr 40 mins	11.8	0.1
2 hrs	11.8	0.0

Calculation:

Given,

$T_h = 48.2^oC$

$T_C = 11.8^oC$

$V_{max}=12V$

$I_{max}= 2.71A$

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = –[\ SIT_C – ½(I^2R) – K(T_h – T_C)$

$= –24.5738$

$Q_H = SIT_h + ½(I^2R) – K(T_h – T_C)$

$= 11.3026$

Energy supplied (W) = $Q_H - Q_L$

. = 11.3026+ 24.5738

= 35.8765

COP = Q_L/Energy supplied (W)

= 24.5738/35.8765

= 0.6849

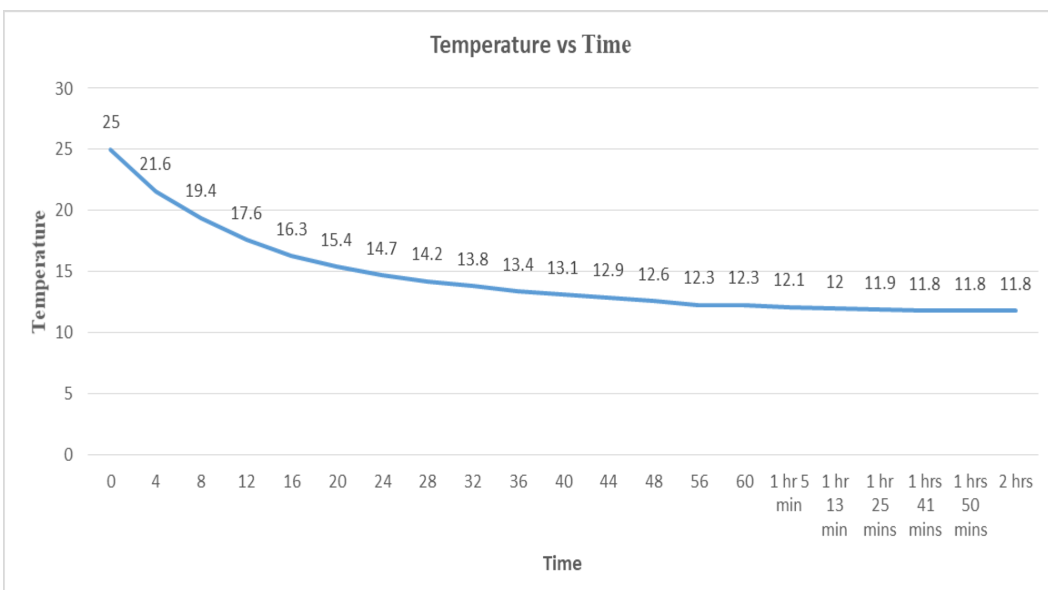

Figure4.4: Graph-4

For this optimized condition, a single layer Peltier module was used to cool the cabin temperature which was insulated with the double layer of insulation. The insulation of the system was improved and the cold side heat sink was provided with a tunnel like structure for better air circulation. And the above mentioned data were obtained during the experiment. It was observed that the cabin temperature reached 11.8ºC and outside hot side reached upto 48.2ºC. The Peltier module had drawn only 2.7A current and its temperature was stable after 1hr 15mins. Using the COP formula its COP was calculated about 0.6192.

5. Heat pipe-based sink vs Air Cooling (Single module)

a) Heat pipe-based sink

Time (mins)	Cold Side Temperature(T_C)(°C)	Decrement
0	25	-
4	21.6	3.4
8	19.4	2.2
12	17.6	1.8
16	16.3	1.3
20	15.4	0.9
24	14.7	0.7
28	14.2	0.5
32	13.8	0.4
36	13.4	0.4
40	13.1	0.3
44	12.9	0.2
48	12.6	0.3
56	12.3	0.3
60	12.3	0.0
1 hr 5 mins	12.1	0.2

1 hr 13 mins	12	0.1
1 hr 25 mins	11.9	0.1
1 hr 40 mins	11.8	0.1
2 hrs	11.8	0.0

Calculation:

Given,

T_h= 48.2°C

T_C= 11.8°C

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = -[\ SIT_C - ½(I^2R) - K(T_h - T_C$

$= -24.5738$

$Q_H = SIT_h + ½(I^2R) - K(T_h - T_C)$

$= 11.3026$

Energy supplied (W) = $Q_H - Q_L$

.

$= 11.3026 + 24.5738$

$= 35.8765$

COP = Q_L/Energy supplied (W)

$= 24.5738/35.8765$

$= 0.6849$

b) Air cooling

Time(mins)	Cold side temperature (°C)	Decrement(°C)
0	25	-
4	22.1	2.9
8	20.3	1.2
12	19.4	0.9

16	18.7	0.7
20	18.2	0.5
24	17.9	0.3
28	17.9	0.0
32	17.8	0.1
36	17.8	0.0
40	17.8	0.0
44	17.7	0.1
48	17.7	0.0
52	17.7	0.0
56	17.6	0.1
60	17.6	0.0
1 hr 15 mins	17.5	0.1
1 hr 30 mins	17.4	0.1
1 hr 45 mins	17.4	0.0
2 hrs	17.4	0.0

Calculation:
Given,
T_h= 47.6°C
T_C= 17.4ºC
V_{max}=12V
I_{max}= 2.71A
Seebeck coefficient (S) = 0.01229 V/K
Module thermal conductance (K) = 0.1815 W/K
Module resistance = 4.44 ohms

$Q_L = –[SIT_C – ½(I^2R) – K(T_h – T_C$
= -23.262

$Q_H = SIT_h + ½(I^2R) – K(T_h – T_C)$

= 12.408

Energy supplied (W) = Q_H - Q_L

. = 12.408+ 23.262

= 35.67

COP = Q_L/Energy supplied (W)

= 23.262/35.67

= 0.6521

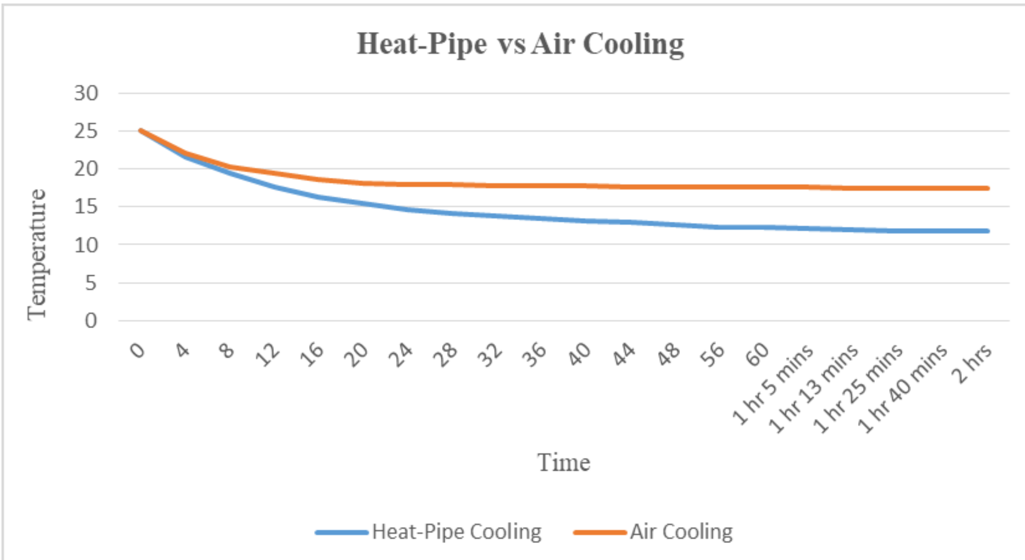

Figure4.5: Heatpipe Vs Air Cooling

The performance of the thermoelectric refrigerator was found to be better with the heat pipe based sink in comparison to the normal air cooling system. The heat pipe based sink was able to cool the hot side of the peltier module with higher rate in comparison to normal air cooling due to which, the cold side temperature was further reduced by 5.8°C with a COP increase by 5%.

6. Rectangular Vs circular fins

a) Rectangular fins (Surface area = 655.0912cm^2)

Time (mins)	Cold Side Temperature(T_C)(°C)	Decrement(°C)
0	25	-
4	21.6	3.4
8	19.4	2.2

12	17.6	1.8
16	16.3	1.3
20	15.4	0.9
24	14.7	0.7
28	14.2	0.5
32	13.8	0.4
36	13.4	0.4
40	13.1	0.3
44	12.9	0.2
48	12.6	0.3
56	12.3	0.3
60	12.3	0.0
1 hr 5 mins	12.1	0.2
1 hr 13 mins	12	0.1
1 hr 25 mins	11.9	0.1
1 hr 40 mins	11.8	0.1
2 hrs	11.8	0.0

Calculation:

Given,

T_h= 48.2ºC

T_C= 11.8ºC

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = –[\ SIT_C – ½(I^2R) – K(T_h – T_C$

$= –24.5738$

$Q_H = SIT_h + ½(I^2R) – K(T_h – T_C)$
$= 11.3026$

Energy supplied (W) = Q_H - Q_L
.
$= 11.3026 + 24.5738$
$= 35.8765$

COP = Q_L/Energy supplied (W)
$= 24.5738/35.8765$
$= 0.6849$

b) Circular fins (Surface area = 673.92cm²)

Time(mins)	Cold side temperature(T_C) (°C)	Decrement(°C)
0	24	
4	20.5	3.5
8	18.6	1.9
12	17.5	1.1
16	16.8	0.7
20	16.3	0.5
24	15.8	0.5
28	15.3	0.5
32	14.9	0.4
36	14.5	0.4
40	14.1	0.4
44	13.8	0.3
48	13.5	0.3
52	13.2	0.3
56	12.9	0.3
60	12.6	0.3

1hr 15mins	12.4	0.2
1hr 30mins	12.3	0.1
1hr 45mins	12.3	0.0
2hrs	12.3	0.0

Calculation:

Given,

T_h= 47.9ºC

T_C= 12.3ºC

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = –[\ SIT_C – ½(I^2R) – K(T_h – T_C$

$= – 24.412$

$Q_H = SIT_h + ½(I^2R) – K(T_h – T_C)$

$= 11.4379$

Energy supplied (W) = $Q_H - Q_L$

.

= 11.4379+ 24.412

= 35.8498

COP = Q_L/Energy supplied (W)

= 24.412/35.8498

= 0.6809

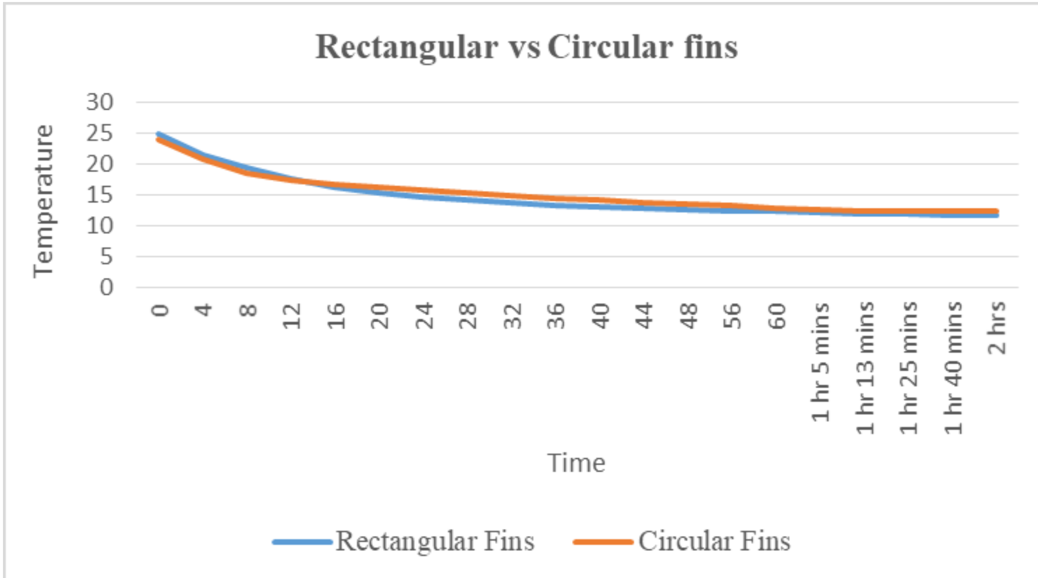

Figure 4.6: Rectangular fins Vs Circular fins

The performance of the thermoelectric refrigerator was found similar under both types of fins. The circular sink was able to perform better than the rectangular fins when air dissipating fans were attached on top of the rectangular fins. But the performance of circular sink and tunnel type rectangular fins was found almost similar when tunnel type rectangular fins were used.

7. Different air circulation system through cold side fins (Rectangular fins)

a) Tunnel system

Time (mins)	Cold Side Temperature(T_C)(°C)	Decrement(°C)
0	25	-
4	21.6	3.4
8	19.4	2.2
12	17.6	1.8
16	16.3	1.3
20	15.4	0.9
24	14.7	0.7

28	14.2	0.5
32	13.8	0.4
36	13.4	0.4
40	13.1	0.3
44	12.9	0.2
48	12.6	0.3
56	12.3	0.3
60	12.3	0.0
1 hr 5 mins	12.1	0.2
1 hr 13 mins	12	0.1
1 hr 25 mins	11.9	0.1
1 hr 40 mins	11.8	0.1
2 hrs	11.8	0.0

Calculation:

Given,

T_h= 48.2°C

T_C= 11.8°C

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = -[\ SIT_C - ½(I^2R) - K(T_h - T_C$

$= -24.5738$

$Q_H = SIT_h + ½(I^2R) - K(T_h - T_C)$

$= 11.3026$

Energy supplied (W) = $Q_H - Q_L$

. $= 11.3026 + 24.5738$

$= 35.8765$

$COP = Q_L/\text{Energy supplied (W)}$

$= 24.5738/35.8765$

$= 0.6849$

b) Two fans on top of fins

Time(mins)	Cold side temperature(T_C) (°C)	Decrement(°C)
0	24	-
4	20.5	3.5
8	18.7	1.8
2	17.8	0.9
16	17.3	0.5
20	16.9	0.4
24	16.5	0.4
28	16.1	0.4
32	15.7	0.4
36	15.4	0.3
40	15.1	0.3
44	14.8	0.3
48	14.5	0.3
52	14.2	0.3
56	13.9	0.3
60	13.7	0.2
1hr 15min	13.4	0.2
1hr 30min	13.3	0.1
1hr 45min	13.2	0.1
2hr	13.2	0.0

Calculation:

Given,

T_h= 47.2ºC

T_C= 13.2ºC

V_{max}=12V

I_{max}= 2.71A

Seebeck coefficient (S) = 0.01229 V/K

Module thermal conductance (K) = 0.1815 W/K

Module resistance = 4.44 ohms

$Q_L = –[SIT_C – ½(I^2R) – K(T_h – T_C$

$= – 24.0916$

$Q_H = SIT_h + ½(I^2R) – K(T_h – T_C)$

$= 11.7049$

Energy supplied (W) = $Q_H - Q_L$

.

$= 11.7049+ 24.0916$

$= 35.7966$

COP = Q_L/Energy supplied (W)

= 24.0916/35.7966

= 0.6730

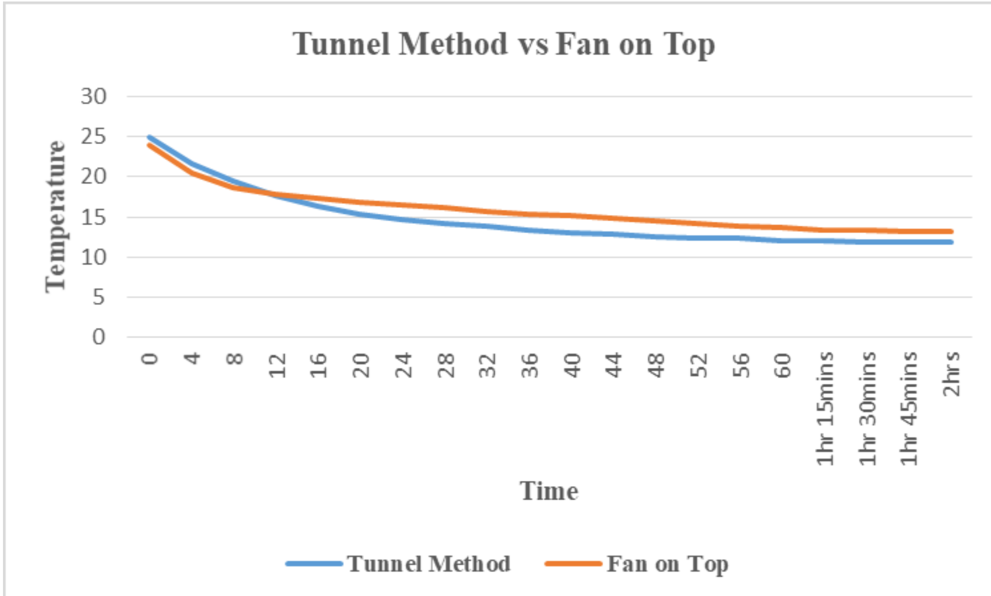

Figure 4.7: Tunnel Method Vs Fan on top

The tunnel structure of rectangular fins was found to be more efficient. It improved air circulation inside the cabin and air improved air contact with the surface of fins. The temperature was further reduced by 1.4°C and COP was increased by 1.76%.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study and fabrication of the thermoelectric refrigerator with its performance analysis was done using the Peltier effect and the fan-enhanced heat pipe was used for heat dissipation from the hot side. From our work, we concluded that:

- Cabin temperature of the thermoelectric refrigeration system is maintained at 11.8°C with a theoretical COP of 0.6197.

- Fan-enhanced Heat pipe is comparatively better than the air cooling Method used for the heat dissipation at the hot side of the Peltier module.

- Current drawn by the Peltier module is constant during the experiment which means that the amount of electrical power being supplied to the module is constant over time.

- Double insulation is more efficient and it helps to improve the COP of thermal refrigeration.

- Tunnel arrangement through the heat sink (fins) at the cold side of the peltier module is better than the fans attached to the top of the heat sinks.

- Rectangular sink is slightly better than the circular fins for heat dissipation from the cold side of the Peltier module.

Thermoelectric refrigeration systems offer several advantages over conventional refrigeration systems, including their compact size, low maintenance requirements, and lack of refrigerants, which can be harmful to the environment. However, they also have some limitations, such as lower efficiency compared to vapor-compression systems and a limited cooling capacity. Its suitability of a thermoelectric refrigeration system will depend on the specific application and its requirements. For low-power applications or for cooling small volumes, a thermoelectric system may be a good choice due to its simplicity and ease of use. For high-power or high-capacity applications, however, a vapor-compression system may be more suitable due to its higher efficiency and greater cooling capacity.

In conclusion, thermoelectric refrigeration systems can be a viable alternative to conventional refrigeration systems in certain applications, but their use should be carefully evaluated based on the specific requirements of the application in question.

5.2 Recommendations:

Our main goal of doing the project in the thermoelectric refrigeration system is to find the alternative of vapor compression refrigeration for the low power applications. We aim to study and fabricate the best cooling system for the system so that the cabin temperature can be minimized with good COP. For the more efficient output following points are recommended:

- Efficiency of thermoelectric refrigeration systems can be improved by considering the new material of the peltier module with better thermoelectric properties.

- Using a more efficient Peltier module with low thermal resistance can help to improve the COP of the system.

- Efficient Cooling system can be used which help to lower the temperature of the hot will side as well as cabin temperature.

- Instead of aluminium fins, copper fins can be used as its thermal conductivity is higher than aluminium.

- High RPM fans help to increase the rate of force convection inside the cabin which will increase the rate of heat transfer.

- Insulation material having high thermal resistance can be used to have more efficient results.

- Air leakage should be minimized for better results.

- Multistages of the thermoelectric module should be used to get better results.

- Number of modules can be increased with increasing the heat sink capacity to obtain the lower temperature of the Cabin.

3.3 Limitations

Following limitations are the observed during our project:

1. The low quality and performance of peltier modules available in the market.
2. Lower conductivity of the thermal grease affects the performance rate of the system.
3. The limited accuracy and relatively slow response time of the probe-type temperature sensor.
4. Lack of good contact between the interconnected components of the system.

3.4 Applications:

With the increasing demand for more energy-efficient and environmentally friendly refrigeration technologies, thermoelectric refrigeration has the potential to be an attractive option for various applications, including food storage.

The prototype of the thermoelectric refrigerator can give a stable temperature of around 11.8ºC when atmospheric temperature is around 25°C. Here is the list of items which can be suitably stored in our refrigerator.

Items	**Storage Temperature (°C)**
Chocolates	15-17
Papayas	10-12
Pineapples	10-12
Tomatoes	12-14
Watermelon	12-14
Lemons	10-12
Sweet potatoes	13-15
Cucumbers	10-12
Canned and Dry foods	10-21

REFERENCES

Astrain, D., Vian J.G. & Domınguez M. (2003). *Increase of COP in thermoelectric refrigeration by the optimization of heat dissipation*, Department of Mechanical Engineering, Universidad Pública de Navarra, Madrid, Spain.

Xia, A., Zhao H. et al. (2022). *Study on Performance of the Thermoelectric Cooling Device with Novel Subchannel Finned Heat Sink.* Energies. https://doi.org/10.3390/en15010145

Jugsujinda, S. et al. (2010). *Analyzing Thermoelectric Refrigerator Performance.* Thermoelectric Research Center and Program of Physics, Faculty of Science and Technology, Sakon Nakhon Rajabhat University. Thailand.

Zhao, D. & Tan, G. (2014). *A review of thermoelectric cooling: Materials, Modeling, and Applications.* Department of Civil and Architectural Engineering, University of Wyoming.

Awasthi, M. & Mali, K.V. (2012). *Design and development of thermoelectric refrigerators.* International journal of mechanical engineering and Robotics Research, India.

Manohar, K., Adeyanju, A.A. (2014). *Comparison of the experimental performance of a thermoelectric refrigerator with a vapor compression refrigerator.* International Journal of Technical Research and Applications. Nigeria.

Dhakal, S., et al. (2020). *Experimental analysis of free-surface single jet impingement on the performance of the thermoelectric cooler.* Department of Mechanical and Aerospace Engineering, Tribhuvan University, Nepal.

Riffat S.B., et al. (2004). *Improving the coefficient of performance of thermoelectric cooling systems: a review*. International Journal of Energy Research.

Irshad K. (2021). *Performance improvement of thermoelectric air cooler system by using variable-pulse current for building applications*. Sustainability 2021.

Ahmad S. (2019). *Design and investigation on portable thermoelectric air chillers.* International Journal of Engineering Trends and Technology (IJETT).

Hongbin M. (2018). *An investigation into thermoelectric coolers.* Faculty of Graduate School at the University of Missouri.

Chen L., et al. (2019). *Thermodynamic modeling and analysis of an air-cooled small space thermoelectric cooler*. The European physical journal plus.
Gokcek M, Sahin F. (2017). *Experimental performance investigation of mini channel water cooled-thermoelectric refrigerator*. Case studies in thermal engineering.

Suryawanshi, D. et al. (2016). *Design and Fabrication of Thermoelectric Refrigerator for Liquid Cooling by Automatic Temperature Microcontroller.* International Journal of Science Technology & Engineering. Narhe.

Arora, D. R. (2008). *Refrigeration and Air Conditioning*, Eighth ed. Dhanpat Rai & Co.(P) LTD. India.

Goktun, S. et al. (1995*). Design considerations for a thermoelectric refrigerator. Energy Conversion and Management*.

Riffat, SB et al. (2001). *A novel thermoelectric refrigeration system employing heat pipes and a phase change material: an experimental investigation*. Renewable Energy

Patel, J. et al. (2016). *Improvement in the COP of thermoelectric Cooler,* International Journal of Scientific & Technology Research Volume 5.

Daniel, C. et al. (2022). Journal of Physics: Conference Series.

Y. Liu, Y. Su, (2018) *Experimental investigations on COPs of thermoelectric module frosting systems with various hot side cooling methods*, Applied Thermal Engineering.

B. K., R. et al.(2016). *Study, analysis and fabrication of thermoelectrci cooling system,*international Journal of scientific Development and Research. volume1, Issue 5.

APPENDIX

Description	Notation (*)	Note
operating temperature up to 120 °C, max assembly temperature = 130 °C**	HT(120)	assembly solder with Tm = 139 °C
operating temperature up to 150 °C, max assembly temperature = 170 °C**	HT(150)***	assembly solder Pb-Sn with Tm = 183 °C***
operating temperature up to 200 °C, max assembly temperature = 220 °C**	HT(200)	assembly solder with Tm = 232 °C
special version for operation under conditions of temperature cycling	C	> 10^5 cycles +40C/+90 °C
height tolerance = ± 0.025 mm; parallelism 0.02 mm; flatness 0.015 mm.	L2	
height tolerance = ± 0.015 mm; parallelism 0.01 mm; flatness 0.01 mm.	L3	
metallization of cold (mc) and (or) hot side of cooler with solder tinning (melting temperature = 95 °C, 117 °C, 139 °C, 183 °C)	mc95, mh95, mm117 etc.	
gold plating	mcAu, mhAu, mmAu	0.2-1 micron
substrate material – aluminium nitride (AlN)	N	heat conductivity > 180 W/mK
sealant: epoxy, silicon	E, S	
non-standard pin orientation		
type and length of wires by customer's requirement		
assembling into arrays		
connectors crimping		
soldering on cold or hot heatsink, packaging or cold block		

(*) - the notations shown are used to notate additional options in cooler name;
(**) - the maximum assembly temperature influence on the module must not exceed 2 minutes;
(***) - Important! TEC with this option does not satisfy ROHS requirements.

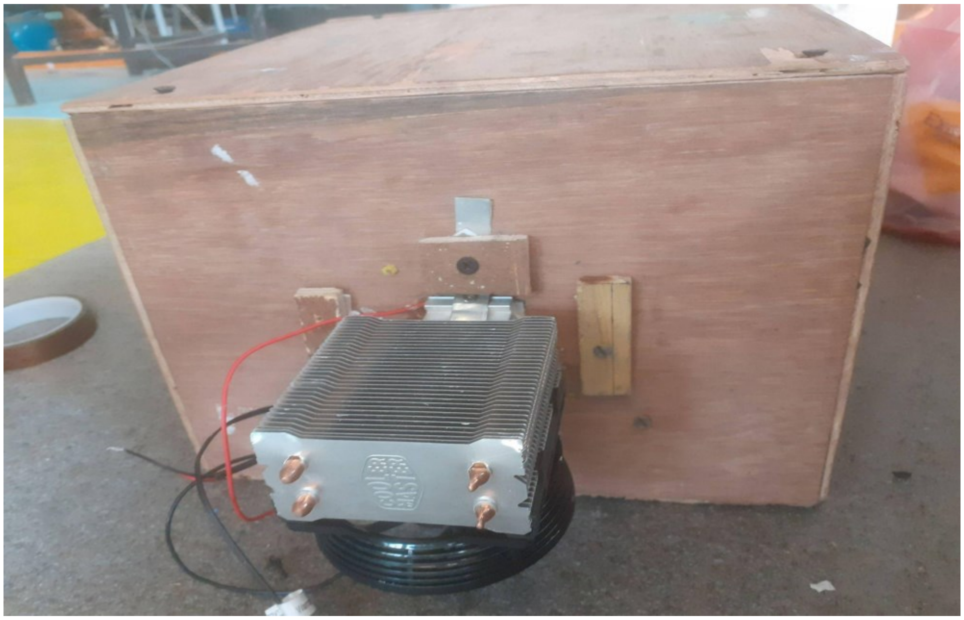

Figure: Fan-Enhanced heat pipe

Figure: Thermoelectric Cabin

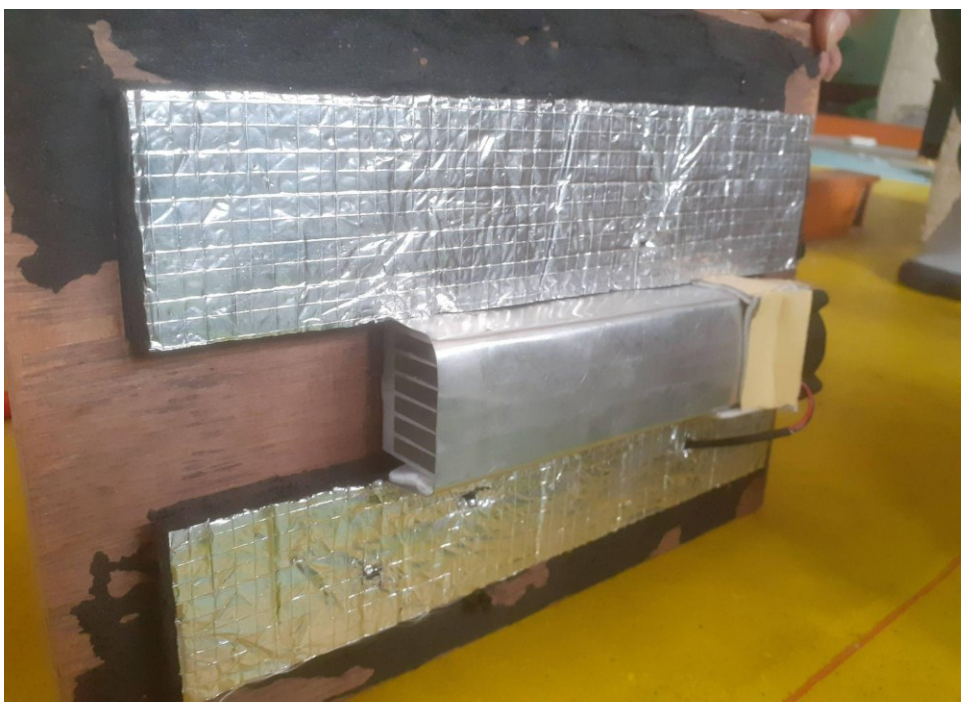

Figure: Tunnel Circulation of cold side air

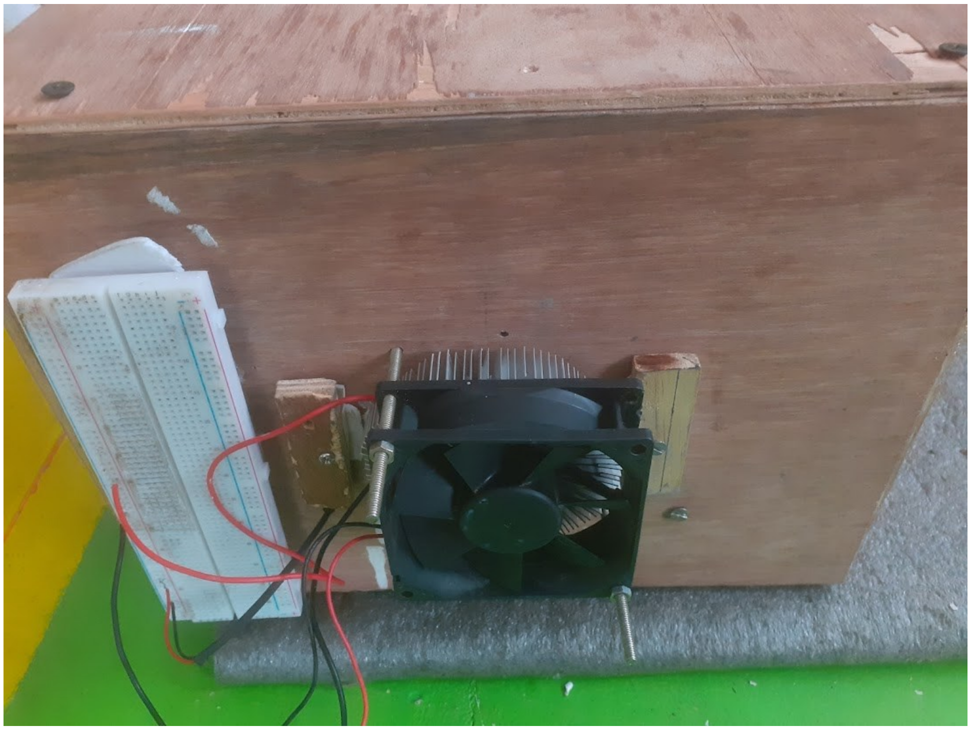

Figure: Air- Cooling