DESIGN AND FABRICATION OF A THERMOELECTRIC REFRIGERATING SYSTEM

A Project & Thesis

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DEPARTMENT OF MECHANICAL ENGINEERING

SONARGAON UNIVERSITY

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DECLARATION

We hereby declare that the project titled "Design and Fabrication of a Thermoelectric Refrigerating System" is the result of our own research, conducted under the supervision of **Md. Mahfujul Islam (Sajeeb),** Lecturer, Department of Mechanical Engineering, Sonargaon University (SU). This work has not been submitted elsewhere for any degree.

It is submitted in fulfillment of the requirements for the Bachelor of Science in Mechanical Engineering.

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All praise and gratitude are due to Almighty Allah, the Most Gracious and the Most Merciful, for granting us the strength, patience, and determination to undertake and successfully complete this project. Without His blessings, this endeavor would not have been possible.

We would like to express our profound appreciation to our honorable supervisor, **Md. Mahfujul Islam (Sajeeb)**, Lecturer, Faculty of Science & Engineering, Department of Mechanical Engineering, Sonargaon University, for his invaluable guidance, continuous support, and thoughtful encouragement throughout the duration of this project. His expertise, constructive feedback, and insightful suggestions have played a pivotal role in shaping the outcome of our work and in enhancing the depth and quality of our learning.

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We are especially grateful to our family members for their unconditional love, patience, and encouragement during every step of this journey. Their moral support has been a constant source of strength, particularly during challenging times.

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ABSTRACT

Thermoelectric refrigeration has long been explored, but previous attempts to develop practical refrigerators were hindered by the lack of suitable thermocouple materials. In this project, semiconductor-based thermoelectric modules are proposed, with selection criteria based on high mean atomic weights and thermoelectric power between 200 and 300 μV/°C.

Advancements in thermoelectric technologies have led to the development of systems capable of both heating and cooling, with one prominent application being the portable preservation of insulin. In such systems, thermoelectric modules replace traditional compressors, enhancing portability while ensuring effective thermal regulation based on the Peltier effect, which generates both hot and cold sides.

The developed thermoelectric refrigerator prototype utilizes commercially available components and offers several advantages: compact design, no moving parts, and absence of CFCs, silent operation, and minimal maintenance. A performance evaluation was conducted by cooling 500 mL of water from 30°C to 13.5°C within 12 minutes, achieving an experimental Coefficient of Performance (COP) of **0.27**. In addition, a no-load test conducted over 9 minutes resulted in a COP of **0.004**, demonstrating the impact of thermal mass on system performance.

These findings demonstrate the practical viability of thermoelectric refrigeration for small-scale and portable cooling applications, with room for performance improvements through optimization of design and material properties.

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CHAPTER 1

INTRODUCTION

1.1 Brief History of Thermoelectric

The manufacturing or process industry consumes vast amount of energy and around its half eventually lost as waste heat to the environment in the form of flue gases and radiant heat energy. There is a clear need to improve the situation by capturing at least some of the waste heat (harvesting) and converting it back into useful energy such as electricity to supply for instance small sensing electronic devices of the plant system, to increase the efficiency of system. Also, recuperating it, helps to reduce the emission which contributes to global warming. There are a lot of technologies which are being used to capture the waste heat; these different methods which are normally used to recover waste heat, differ each other with respect to the intensity of waste heat, for instance some of them are not adequate for low temperature, others require moving part to converts waste heat into useful energy, and others are not environmental friendly. This study is focusing on thermoelectric generators, which use thermoelectric effects to produce power. This technology is an interesting one, for direct heat to power conversion. Thermoelectric generators present potential applications in the conversion of low level thermal energy into electrical power. Especially in the case of waste heat recovery, it is unnecessary to consider the cost of the thermal energy input, and there are additional advantages, such as energy saving and emission reduction, so the low efficiency problem is no longer the most important issue that we have to take into account [1] Thermoelectric generators work even at low temperature applications, there are a renewable energy sources and do not produce noise. This project is focusing on the design, modelling and manufacturing thermoelectric generator for waste heat recovery applicable in local industries, by using comsol Multiphysics software as the tool. The design is based on the shape of the chimney, environment and cost of manufacturing, cost is found by considering all materials used in process, this helps to give conclusion weather the system should be adopted in local processing industries. Energy consumption is an important parameter which reflects the influence of a certain sector on the economic growth and environmental pollution of a region. Existing reports from different energy statistics agencies and show that both industrial activities and energy sectors (power stations, oil refineries, coke ovens, etc) are the most energy consuming sectors worldwide and, consequently, the responsible for the release of large quantities of industrial waste heat (IWH) to the environment by means of hot exhaust gases, cooling media and heat lost from hot equipment surfaces and heated products. Recovering and reusing IWH would provide an attractive opportunity for a low-carbon and less costly energy resource. Moreover, reducing the environmental impact and costs could, at the same time, improve the competitiveness of the sector [2]. Nowadays, energy problems have become worldwide focuses. Several national problems, such as, energy security, energy prices, increasingly competitive global markets and stringent environmental emission regulations, are primary driving forces in the search for efficient, sustainable and economically viable technologies for energy conversion and utilization. The process industries of the chemicals, food and drinks, steels and iron, pulps and paper are substantial energy users, which represent more than 50% of the industrial energy usage. Hendricks and Choate reported that 33% of

the manufacturing industrial energy was discharged directly to the atmosphere or cooling systems as waste heat, due to the fact that most industries were incapable of recycling excessive waste heat. Moreover, the global energy demand will increase by almost 35% by 2030 compared with the 2005s level or by up to 95% without the use of energy efficient technologies. Great efforts have been made in improving the energy conversion efficiency, but a considerable amount of energy is still wasted in forms of gas, liquid and solid, which requires large scope of waste energy recovery [3] In the French industry, 75% of the final energy is used for thermal purposes such as furnaces, reactors, boilers and dryers. However, around 30% of this heat is assumed to be wasted in the form of discharged hot exhaust gas, cooling water and heated product. In metal and non-metallic mineral product manufacturing in the United States, 20-50% of the energy is lost as waste heat. In Turkey, in cement plants 51% of the overall heat of the process is unfortunately lost. The combustion of fossil fuels, which generates carbon dioxide emissions, is considered as the primary source of heat production in the industry [4]. More than 80% of the total energy use in the Dutch industry involves the need for heat, either in fired furnaces or in the form of steam at different pressure levels, see Figure 1. Most of this heat is eventually released to the ambient atmosphere through cooling water, cooling towers, flue gasses, and other heat losses. We call this heat loss 'Industrial waste heat'. Large energy savings are possible, if this waste heat could be reused. The total industrial waste heat in the Netherlands is estimated at more than 250 PJ (PJ Petajoule = 1*1015J) per year [5].

For all the above-mentioned reasons, it is necessary to recover waste heat via capturing and reusing for heating or generating electrical or mechanical power in industrial processes. That way, the process efficiency will be increased, less fuel will be consumed and therefore less carbon dioxide will be emitted [4], The high and intermediate temperature waste can be directly utilized by driving steam turbine and gas turbine to generate electricity, but there are still difficultiesin the utilization of waste heat in low-temperature range [3]. Thermoelectricity (TE), which is directly generated electric energy from waste heat sources shows promising results in making vital contributions to reducing greenhouse gas emissions and providing cleaner forms of energy [6]. The Thermoelectric Generator (TEG) can be used to convert heat to electricity through the Seebeck effect as illustrated

Thermoelectric Effects Early study of Thermoelectricity 1820-1920 In the 100 years before the world wars thermoelectricity was discovered and developed in Western Europe by academic scientists, with much of the activity centered in Berlin.

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely when a voltage is applied to it, it creates a temperature difference (known as the Peltier effect). At atomic scale (specifically, charge carriers), an applied temperature gradient causes charged carriers in the material, whether they are electrons or electron holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence, the thermally induced current.

This effect can be used to generate electricity, to measure temperature, to cool objects, or to heat them or cook them. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices make very convenient temperature controllers.

Traditionally, the term thermoelectric effect or thermoelectricity encompasses three separately identified effects, the Seebeck effect, the Peltier effect, and the Thomson effect. In many textbooks, thermoelectric effect may also be called the Peltier-Seebeck effect. This separation derives from the independent discoveries of French physicist Jean Charles Athanase Peltier and Estonian-German physicist Thomas Johann Seebeck. Joule heating, the heat that is generated whenever a voltage is applied across a resistive material, is somewhat related, though it is not generally termed a thermoelectric effect (and it is usually

regarded as being a loss mechanism due to non-ideality in thermoelectric devices). The Peltier-Seebeck and Thomson effects can in principle be thermodynamically reversible, whereas Joule heating is not.

Seebeck Effect:

In 1821-3 Thomas Johann Seebeck found that a circuit made from two dissimilar metals, with junctions at different temperatures would deflect a compass magnet [1]. Seebeck initially believed this was due to magnetism induced by the temperature difference and thought it might be related to the Earth's magnetic field. However, it was quickly realized that a "Thermoelectric Force" induced an electrical current, which by Ampree's law deflects the magnet. More specifically, the temperature difference produces and electric potential (voltage) which can drive an electric current in a closed circuit. Today, this is known as the Seebeck effect.

Thermoelectric Refrigeration:

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments.

Magnetic Refrigeration:

Magnetic refrigeration, or adiabatic demagnetization, is a cooling technology based on the magnetocaloric effect, an intrinsic property of magnetic solids. The refrigerant is often a paramagnetic salt, such as cerium magnesium nitrate. The active magnetic dipoles in this case are those of the electron shells of the paramagnetic atoms. A strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. A heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off. This increases the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. Because few materials exhibit the required properties at room temperature, applications have so far been limited to cryogenics and research.

Other methods:

Other methods of refrigeration include the air cycle machine used in aircraft; the vortex tube used for spot cooling, when compressed air is available; and thermos-acoustic refrigeration using sound waves in a pressurized gas to drive heat transfer and heat exchange. Many Stirling cycle heat engines can be run backwards to act as a refrigerator, and therefore these engines have a niche use in cryogenics.

1.2 Aim

Our main aim was to build electro-thermal refrigerator to get the proper cooling facility through peltier modules without compressor and refrigerant.

The existence of non-metallic inclusions in the ingots or billets has harmful effects on steel products. High gas concentration in steel products will cause internal defects (microcracks, porosities, vacancies) which harm the mechanical properties of products, as well as affect other properties like magnetic permeability and electrical conductivity. The demands for steels with insignificant quantities of gases, non-metallic inclusions, micro-porosity, and homogeneity in properties are increasing to produce different kinds of industrial materials. These requirements for steel products cannot be carried out without using advanced techniques, like vacuum furnaces or inert gas blowing.

1.3 Objectives

The objective of this thesis is to design and modeling a thermoelectric generator for waste heat recovery (module and heat exchanger) and calculate the optimum power with respect to optimum materials, by means of Consul Multiphasic software. Input data are real waste heat values, from local industry which is 3B Fiberglass Company. Figure 3 shows purpose in the details, where the electricity can be produced when there is heat at one side and cold at the other side. The following points were considered to full fill the task:

1. To build electro-thermal refrigerator to get the proper cooling facility.
2. To develop thermoelectric cooling system.
3. To calculate the Coefficient of Performance (COP).

Thermoelectricity is based upon following basic principles:

1. See beck Effect, 2. Peltier Effect, 3. Thomson Effect.

See Beck Effect: In 1821, Thomas See beck found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, if the junctions of the metals were maintained at two different temperatures.

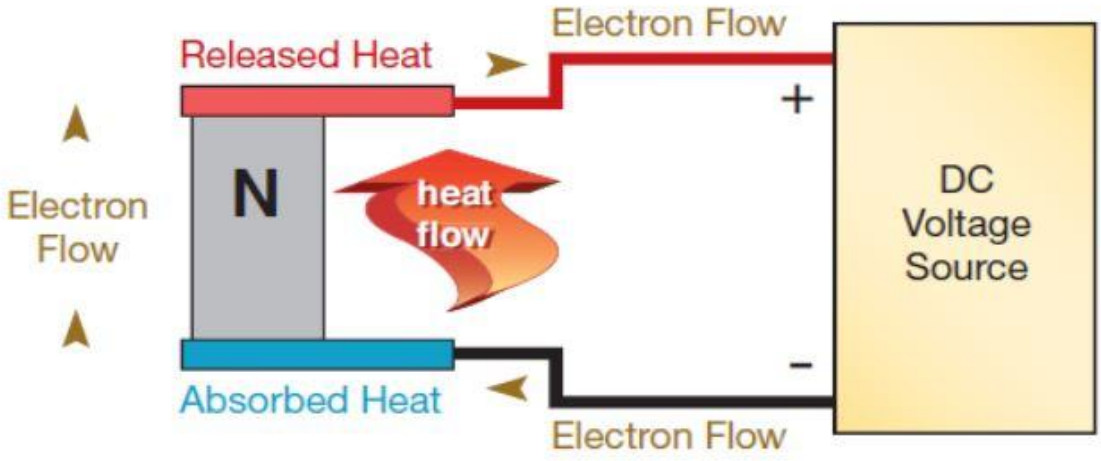


Figure 1.1: Peltier Cooling System with Semiconductor

Thermoelectric power supply generators are based on the Seebeck effect which is based on voltage generation along a conductor subjected to a gradient of temperature. When a temperature gradient is applied to a conductor, an electromotive force is produced. The voltage difference generated is proportional to the temperature difference across the thermoelectric module between the two junctions, the hot and the cold one. AV a AT See Beck Effect: See Beck Coefficient: The See beck coefficient is defined as the ratio of the voltage difference to the temperature gradient. If the temperature difference AT between the two ends of a material is small, then the Seebeck coefficient of a material is defined as: aab = AV /AT aab = aa - ab aa & ab is the Seebeck Co-efficient with units of Volts per Kelvin for metals A & B or P & N Peltier Effect: In 1834, a French watchmaker and part time physicist, Jean Peltier found that an electrical current would produce a temperature gradient at the junction of two dissimilar metals. The Peltier effect is the main contributor to all thermoelectric cooling applications. It is responsible for heat removal and heat absorbance. It states that when an electric current flows across two dissimilar conductors, the junction of the conductors will either absorb or emit heat depending on the flow of the electric current. The heat absorbed or released at the junction is proportional to the input electric current. The constant of proportionality is called the Peltier coefficient.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Review of literature shows that although many studies exist on the design and development of thermoelectric refrigerating systems operating without compressors and refrigerants in various countries, such studies in Bangladesh are rare. Some previous studies are summarized here.

This study reviews recent advances in thermoelectric materials, modeling approaches, and applications. Thermoelectric cooling systems have advantages over conventional devices, including compact size, light weight, high reliability, no moving parts, no working fluid, DC power, and easy switching between cooling and heating modes. The study first introduces the historical development of thermoelectric cooling, followed by advancements in thermoelectric materials and achievements over the past decade. Modeling techniques to improve system performance are described for thermoelement and thermoelectric cooler (TEC) modeling, including simplified energy equilibrium models, 1D and 3D models, and numerical compact models. Finally, applications are reviewed in domestic refrigeration, electronic cooling, scientific uses, and automobile air conditioning and seat temperature control, along with summaries of commercially available thermoelectric modules and refrigerators. This study aims to aid thermoelectric cooling system design, simulation, and analysis.

Another paper reviews key research on parameters defining thermoelectric cooling device characteristics and performance, focusing on practical aspects such as figure of merit, cooling capacity, and coefficient of performance (COP). It categorizes recent review topics, noting that many focus broadly and lack specific details on thermoelectric cooling parameters and performance.

2.2 Previous work and how they performed:

Jincan Chena et al. [11]: -
According to non-equilibrium thermodynamics, cycle models of single-stage and two-stage semiconductor thermoelectric refrigeration were experimentally investigated. By using the three important parameters which governs performance of thermoelectric refrigerator i.e. coefficient of performance (COP), the rate of refrigeration, and the power input, development of general expressions performances of the two-stage thermoelectric refrigeration system took placed. It was concluded that performance of thermoelectric refrigerator depends on temperature ratio of heat sink to cooled space. When this ratio is small, the maximum value of COP of a two-stage thermoelectric refrigeration system is larger than COP of a single-

stage thermoelectric refrigeration system; however maximum rate of refrigeration is smaller than that of a single stage thermoelectric refrigeration system. Hence it is convenient to use single stage thermoelectric refrigerator when ratio is small. When temperature ratio is large two stage thermoelectric refrigerator is observed to be superior to single stage by both parameters i.e. maximum value of COP and maximum rate of refrigeration.

X.C. Xuan et al. [12]: -

In this paper Two stage thermoelectric refrigerator was investigated with two design configurations. Two configurations were pyramid style and cuboid style as shown in respective figures. In pyramid style configuration top side is being coldest as current is unidirectional. In cuboid style configuration current can be alternated causing top and bottom side to be switched between heating and cooling mode. To obtain optimization methods other multi stage designs can be used. The point of maximum cooling capacity and maximum COP both were taken into consideration while investigation for optimization for the two-stage TE coolers. It was concluded that value lies between 2.5-3 for both parameters that is optimum limit of ratio of number of thermoelectric modules of two stages in pyramid style TE cooler and optimum limit of ratio of electric current between stages of cuboid style TE cooler. Maximum temperature difference of pyramid-style cooler is greater than single stage cooler

Jun Luo et al., [13]: -

Using finite time Thermodynamics theory performance of a thermoelectric refrigeration system, with multi elements was analyses. To improve and maximize the cooling load and coefficient of performance (COP) optimization of the ratio of the heat transfer surface area of the high temperature side to the total heat transfer surface area of the heat exchangers was done. The analysis of number of parameters which affects optimum performance of Thermoelectric system was done parameters were number of thermoelectric refrigerating elements, the Seeback coefficients, internal heat conductance, the heat source temperature and internal electrical resistance. As well as the analysis of other parameters like influences of total heat transfer surface area and working electrical current on the optimum performance was done. They concluded that the cooling load and coefficient of performance (COP) of TE system is greatly influenced by total heat transfer surface area and working electrical current. These results can be used for designing and manufacturing of practical thermoelectric refrigerators.

D. Astrain et al. [14]: -

In this paper a device using phase change material based on Thermosyphon principle was developed. This device was used and tested as a heat dissipater for hot side of TE cooler. Performance of TE cooler with this device was compared with TE cooler with conventional heat dissipater made up of fins. It was concluded that with the help of developed phase changing device it is possible to reduce thermal resistance between hot side of TE cooler and atmosphere up to 23.8% at 293 K ambient temperature and 51.4% at 308 K ambient temperature, compared to commercial finned heat sink. Decrease in thermal resistance ultimately causes heat to dissipate more effectively from heat sink of TE cooler, therefore improving the COP of TE cooler. At the same values of temperatures, it was observed that COP increases by 26% and 35% respectively.

Yuzhuo Pan, et al, [15]: -

Author of this paper designed and analyzed an Irreversible multi-couple thermoelectric refrigerator, which operates between two reservoirs maintained at constant temperature. Effect of other factors like external and internal irreversibility of thermoelectric refrigerator on performance was also studied. They have specified many important parameters which affects coefficient of performance (COP) of system. Results of obtained from experiments leads to knowledge of information about performance characteristics of real multi couple thermoelectric refrigerator. This information may be used to manufacture and design thermoelectric refrigerator which will perform at its optimum level.

Hongxia Xi.et al, [16]: -

In this paper Author done survey on solar based driven thermoelectric technology. A brief history of development of solar based driven thermoelectric technology was presented. It's today's status and drawbacks present in current Technologies were reviewed. Applications, future scope, advantages over conventional technology where also discussed. In this paper they have discussed about two main mode that are solar based thermoelectric power generation and refrigeration. Current status of both Technologies was described. Problems related to this technology and their possible solutions were presented. Ultimately these Technologies with some more development may lead to solve demand of Environment protection and energy conservation.

Suwit Jugsujinda et al, [17]: -

In this paper they have fabricated thermoelectric refrigerator using thermoelectric cooler. Thermoelectric refrigerator (25× 25 × 35 cm^3) and thermoelectric cooler (4×4 cm^2). This system was applied to 40 W electric power without any cooling fan as heat dissipater at heat sink. They have measured temperature of this system at ten different points. It was concluded that these experiments result into temperature of cold side of thermoelectric cooler to be decreased from 30℃ to - 4.2℃ for 1 hour and decreased to -7.4℃ for 24 hours with heat plate temperature being 50℃ Temperature of cold side of thermoelectric refrigerator decreased from 30℃ to 20℃ for 1 hour and decreased further in 24 hours. 3 and 2.5 are the maximum value of coefficient of performance (COP) of thermoelectric cooler and thermoelectric refrigerator respectively.

S.A.Omer et al, [18]:-

This paper presents some results of thermoelectric refrigeration system using phase change materials (PCM) integrated with thermosyphones. They investigated two models of thermoelectric refrigeration system, one with conventional finned devices. As heat dissipater and other with phase change material (PCM) as heat dissipater. After results they have concluded that coefficient of performance (COP) and effectiveness of thermoelectric refrigeration system with Phase Change Material (PCM) is higher than conventional one. They have also compared thermoelectric refrigeration system of two kinds, one is using phase change materials (PCM) without thermal diode and other integrated with thermal diode (Thermosyphones). Results shows that thermosyphones used prevent leakage of heat during power off. Overall they have concluded system can be work with the help of renewable energies like solar energy producing electricity. It is suited for medicine and food storage.

Sujith G. et al.(2016), [19]:-
In this paper author design and fabricated the Thermoelectrical Refrigeration to cool a volume of 40L using principle of Peltier effect to cool and maintain temperature range of 5°C to 25°C and the project is used only for light heat load to lower its temperature to particular temperature. One of the advantage of this project is it takes low power to drive the refrigerator.

Bharat M. Jibhakate et al. (2016), [20]: -
The study show that a Thermoelectric Refrigeration model is design and fabricated in place of compressor and it is based on principle of Peltier effect to maintain effectiveness of both heating and cooling side also the simulation is done to on thermoelectric refrigeration to maintain it at 40°C. The designed is environmental friendly also it has various applications in medical and pharmaceutical equipment's.

Sivakumar.N.et al. (2018), [21]: -
In the literature the author designed the Thermoelectric Refrigeration in place of prime movers, compressor or any type of refrigerant as this designed is applicable in such areas where the electricity not available and also environmental friendly as CFC, CO2 etc. produce in other refrigeration system. As per the experimental result on thermoelectric refrigeration the minimum temperature 15°C for cooling and maximum temperature 65°C for heating was obtained. Also comparisons of results done on effect of cooling on AC and DC supply and COP of systems.

Mr. Swapnil B. Patond et al. (2015), [22]: -
In this research a thermoelectric module is designed to analysis the heating and cooling system by using solar energy and which is based on Peltier effect. This system is different from other refrigeration system where heating and cooling is done with the help of mechanical devices and by using refrigerants. Experimental study is done for small scale solar operated thermoelectric heating and cooling, the graph is plotted from obtained results from experiment for different metals, fruits & water to analyses the heating and cooling rates in various modes. This system is free from Maintenance. In the literature the author fabricated a prototype of solar operated thermoelectric cooling system based on Peltier effect and its working on solar photo voltage cell generated DC voltage. Through the experiments the performance parameter (heat absorption, energy supply and coefficient of friction) are analyses the result show that the COP of the system increases with time interval. Through the system high COP on low cost obtained. It also having applications in Military and medical equipment.

Abhijith Raju et al. (2016) [23]: -
In this paper the authors objective is to design and develop solar operated thermoelectric refrigeration to produce small amount of refrigerating effect using solar energy this system is working on the principle of Peltier effect. Its results from experiments shows that the COP about 0.17 when the atmosphere temperature was 27°C and 500ml water kept inside the refrigerated space for 50 minutes it shows that the reduction of temperature from 27°C to 15°C. and through the results of experiment shows that the system work continuously if we full charged it with solar panel for 15 hours.

Recent development and application of thermoelectric generator and cooler Wei He, Gan Zhang, Xingxing Zhang, Jie Ji, Guiqiang Li, Xudong Zhao applied energy 143, 1-25, 2015 energy crisis and environment deterioration are two major problems for 21st century. Thermoelectric device is a promising solution for those two problems. This review begins with the basic concepts of the thermoelectric and discusses its recent material researches about the figure of merit. It also reports the recent applications of the thermoelectric generator, including the structure optimization which significantly affects the thermoelectric generator, the low temperature recovery, the heat resource and its application area. Then it reports the recent application of the thermoelectric cooler including the thermoelectric model and its application area. It ends with the discussion of the further research direction.

Thermoelectric cooler and thermoelectric generator devices: A review of present and potential applications, modeling and materials Seyed Mohsen Pourkiaei, Mohammad Hossein Ahmadi, Milad Sadeghzadeh, Soroush Moosavi, Fathollah Pourfayaz, Lingen Chen, Mohammad Arab Pour Yazdi, Ravinder Kumar Energy 186, 115849, 2019

Increasing the production of energy in line with industry development, transportation, and life quality improvement is an interesting topic needs to be addressed. Energy policymakers and researchers have aimed at energy management, particularly by improving energy systems performance. This review paper explains the rising interest of thermoelectric technology and applications. Nowadays, thermoelectric technology such as thermoelectric generators (TEGs) and thermoelectric cooling systems (TECs) provide heat loss recovery of thermodynamic units for power production of remote areas. Unlimited solar energy can also be employed for thermoelectric power production. This paper describes the principles of thermoelectricity and presents an explanation of current and upcoming materials. Developed models and various performed optimization of thermoelectric applications by using non-equilibrium thermodynamics and finite time thermodynamics are discussed as well. Additionally, a number of topical applications and energy resources are introduced. The main goal of this study is to give a clear overview of thermoelectric technology and applications.

Thermoelectric cooling technology applied in the field of electronic devices: Updated review on the parametric investigations and model developments Yang Cai, Yu Wang, Di Liu, Fu-Yun Zhao Applied Thermal Engineering 148, 238-255, 2019. In recent years, thermoelectric cooling technology (TECT) has emerged as one of high efficiency and low energy consumption methodologies for electronic cooling. This paper presented a comprehensive survey of TECT to show a complete foundation on the thermoelectric applications in electronic cooling. Thermoelectric physical parameters, consisting of Seebeck coefficient S, thermal conductivity K, and electric resistance R, are highly dependent on temperatures of thermoelectric heating and cooling sides and they have been simplified into constants when the thermoelectric cooling model was theoretically established. Furthermore, two systematical solution methodologies were proposed, i.e., the thermal resistance network and the effectiveness-number of transfer units, to describe the coefficient of performance (COP). Effects of cooling load, air temperature and all thermal conductance in heating side on the cooling performance have been attempted, regarding surface temperature of electronic devices and COP as evaluation indexes. Our analysis reveals that thermal control for electronics of high heat flux could be achieved by enhancing heat transfer in the hot side of thermoelectric system and increasing the numbers of thermoelectric coolers. Overall, the governing parameters and modeling for practical applications have been presented, and the cooling potential of thermoelectric technology for electronic devices can be further enhanced.

Increasing the production of energy in line with industry development, transportation, and life quality improvement is an interesting topic needs to be addressed. Energy policymakers and researchers have aimed at energy management, particularly by improving energy systems performance. This review paper explains the rising interest of thermoelectric technology and applications. Nowadays, thermoelectric technology such as thermoelectric generators (TEGs) and thermoelectric cooling systems (TECs) provide heat loss recovery of Thermodynamic units for power production of remote areas. Unlimited solar energy can also be employed for thermoelectric power production. This paper describes the principles of thermoelectricity and presents an explanation of current and upcoming materials. Developed models and various performed optimization of thermoelectric applications by using non-equilibrium thermodynamics and finite time thermodynamics are discussed as well. Additionally, a number of topical applications and energy resources are introduced. The main goal of this study is to give a clear overview of thermoelectric technology and applications.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Thermoelectric refrigeration technology is an electronic refrigeration technology with high efficiency and low energy consumption. Thermoelectric elements are characterized by compact structure, fast response, and integration of refrigeration and heating. The thermoelectric elements can be divided into two categories, one is a thermoelectric generator (TEG) based on Seebeck effect, which converts heat into electricity and uses waste heat as energy. The other is a thermoelectric cooler (TEC) based on Peltier effect, which converts electricity into heat for cooling and heating. The most direct representative is semiconductor refrigeration,

Based on the thermoelectric elements characteristics, a large number of experiments and simulations have been done to prove feasibility of thermoelectric elements in BTMS. Alaoui [176] studied a BTMS based on Peltier thermoelectric elements, and measured discharge efficiency of a 60-Ah prismatic lithium ion battery at different rates and temperatures. It was found that thermal response and energy consumption of the BTMS can meet the design requirements. Zhang [177] designed a BTMS using semiconductor refrigeration, simulated and analyzed it. The results showed that the BTMS had a good cooling effect under high temperature conditions.

At present, the research progress of thermoelectric elements refrigeration used for BTMS is still in its infancy, and there are still many problems to be solved in the development of this technology. Thermoelectric elements are used for BTMS, and there is still a lot of room to improve battery pack cooling performance. How to further optimize the thermoelectric elements-based BTMS is a problem that researchers need to solve. Low conversion efficiency and high material cost of thermoelectric elements are the major factors restricting their popularization. Optimizing TEC, and improving cooling performance of thermoelectric elements is the key of thermoelectric elements-based BTMS in the future development.

3.2 Heat Transfer Methods

Geometry and materials. Heat transfer methods there are several methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric to the surrounding. These methods are described in the following three sections.

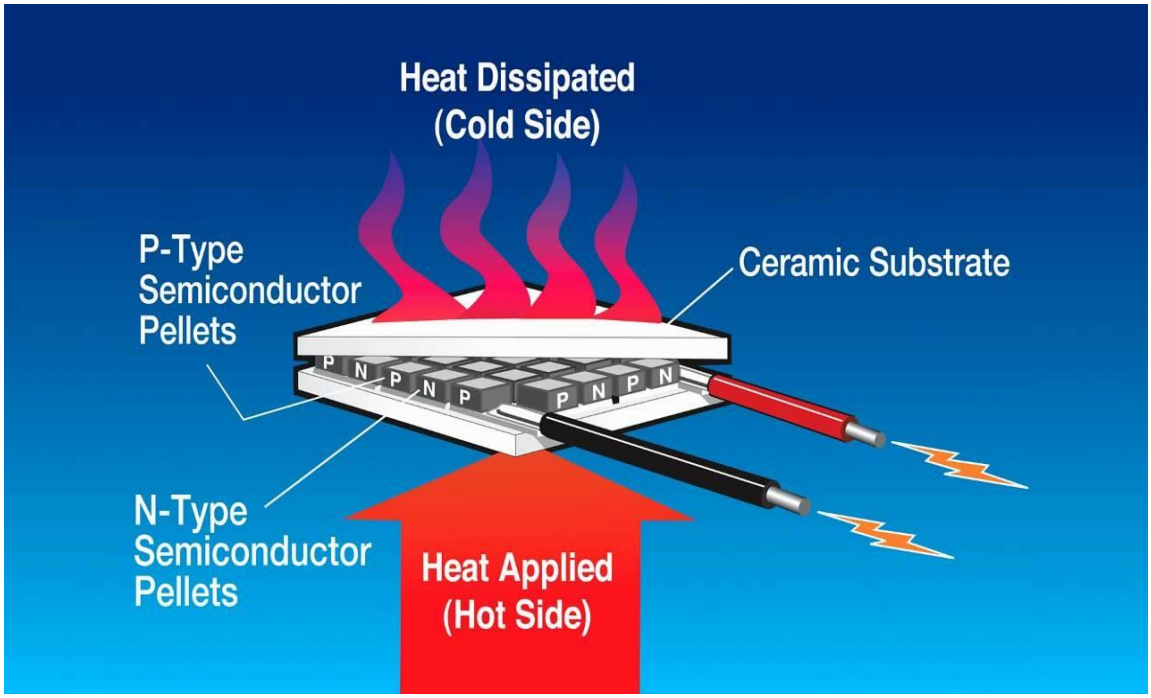


Figure 3.1: Thermoelectric Elements

Natural convection, Liquid cooled, forced convection when the co-efficient of thermal transfer (K) was investigated, the K for natural convection was approximately 25 W/mK. This value compared to 100W/mK for forced convection. Clearly the size of the heat sink for a natural convection apparatus would need to be 4 times that for a forced convection set-up.

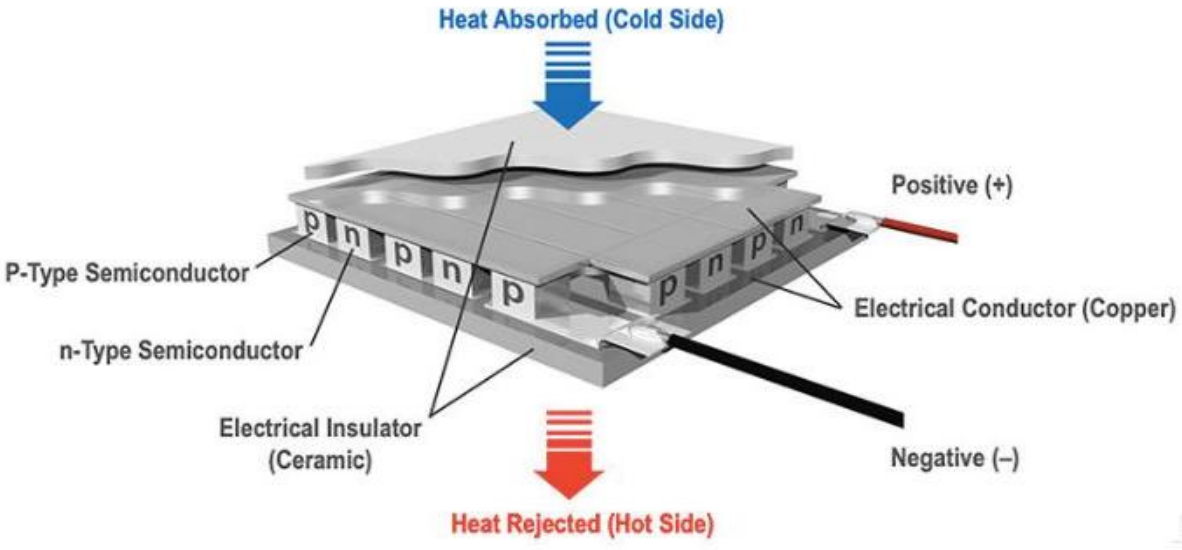


Figure 3.2: Thermoelectric Cooler

3.3 Geometry

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

3.4 Material

We explored three different materials for the construction of the outer casing and frame of the device. These were aluminum, stainless steel and Hips. High impact polystyrene is desirable as it has a low thermal conductivity. Building the device out of would make it very light, portable while maintaining rigidity is readily available and reasonably priced, is easy to cut and drill. The outer casing and container would be made by first making a positive mold and applying a cloth coated with resin. Thermoelectric coolers operate according to the Peltier effect. The effect creates a temperature difference by transferring heat between two electrical junctions. A voltage is applied across joined conductors to create an electric current.

3.5 Principle of thermoelectric refrigerator

Thermoelectric coolers operate according to the Peltier effect. The effect creates a temperature difference by transferring heat between two electrical junctions. A voltage is applied across joined conductors to create an electric current.

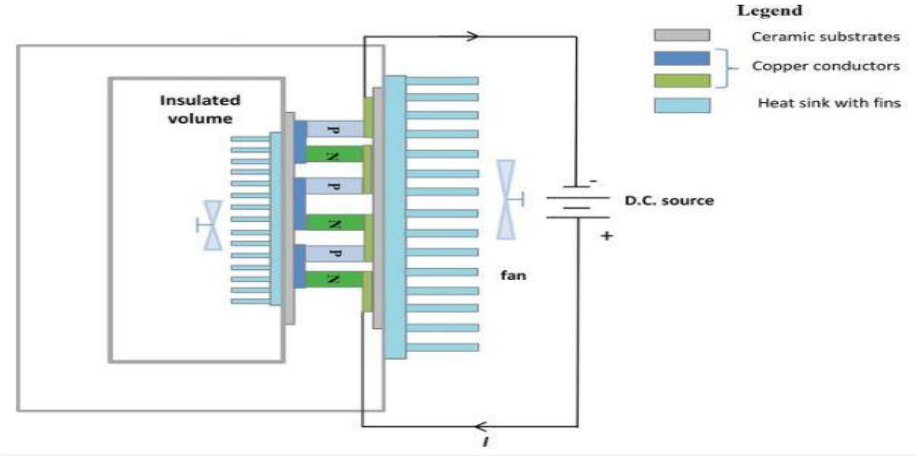


Figure 3.3: Thermoelectric Refrigerator Working

3.6 Components of Thermoelectric Refrigerator Project

01	Peltier Module
02	Dc Power Supply 12 Volt
03	Heat Sink
04	Thermal Paste
05	Cooling Fan
06	PU Foam
07	Temperature Sensor
08	Relay Module (1 CH, 5V)
09	Arduino UNO

Table 3.1: Necessary Component for Thermoelectric Refrigerator Project

1. **Peltier Module:**
   Peltier module (thermoelectric module) is a thermal control module that has both "warming" and "cooling" effects. By passing an electric current through the module, it is possible to change the surface temperature and keep it at the target temperature.



Figure 3.4: Peltier Module

2. **Dc Power Supply:**
   The AC current runs through a coil, which creates a magnetic field. A second coil, with fewer turns of wire, is placed next to it. The magnetic field from the first coil creates an electric current in the second coil. Because there are fewer turns in the second coil, it creates lower-voltage AC electricity.



Figure 3.5: SMPS DC Power Supply (12V/20A)

3. Heat Sink:

A heat sink is an electronic device made of good thermal conducting material and usually attached to an electronic device to dissipate the unwanted heat. It is used to cool the circuit components by dissipating the excess heat to prevent overheating, premature failure, and improve the reliability and performance of the components.

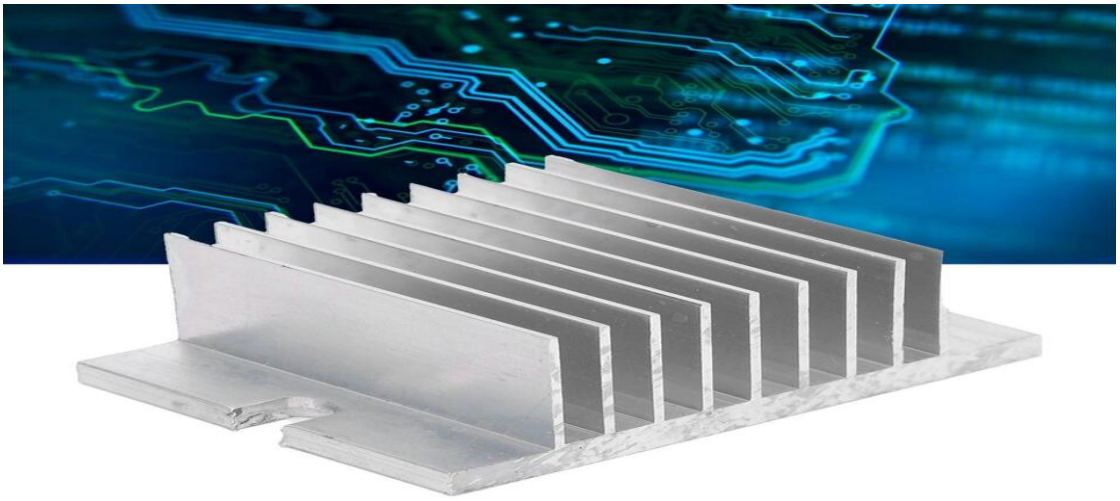


Figure 3.6: Heat Sink

The heat sink operation is based on Fourier's law of heat. Whenever a temperature gradient exists in a body, heat transfers from the high temperature sections to the lower temperature areas. The three different ways in which the heat can be transferred are through radiation, convention or by conduction.

Thermal conduction occurs whenever two objects at different temperatures are in contact. This involves the collisions between the fast molecules of the hotter object with the slow moving molecules of the colder object. This leads to the energy transfer from the hot object to the cooler object. A heat sink thus transfers the heat from the high temperature component such as a transistor

to the low-temperature medium such as air, oil, water or any other suitable medium through conduction and then convection.

4. **Thermal Paste:**

Thermal Paste - A silvery-gray substance that you apply to a processor before installing a cooling solution. It allows for an efficient transfer of heat from the IHS of the processor to the base plate or water block of the CPU cooler that is designed to dissipate that heat.

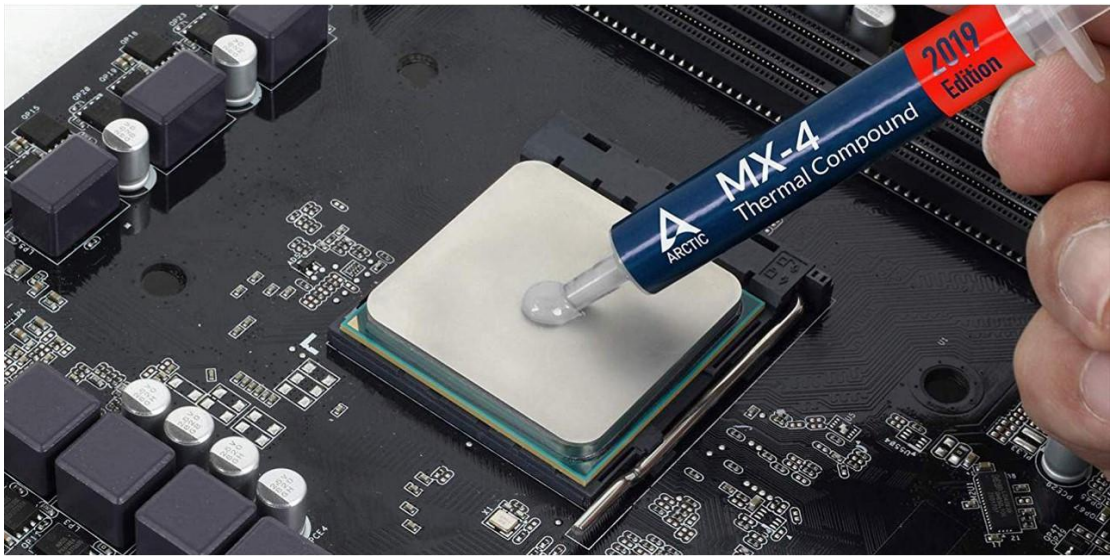


Figure 3.7: Thermal Paste

5. **Cooling Fan:**

A DC ceiling fan works pretty much on the same principle as the DC motor. A DC motor uses an internal arrangement of magnets with opposing polarity. As current passes through the coil around this arrangement, a strong magnetic field is produced. This magnetic field then creates a torque that causes the motor to rotate



Figure 3.8: Cooling Fan

6. **PU foam:**

PU foams are formed by the reaction between an isocyanate prepolymer and a polyol in the presence of a blowing agent and an amine catalyst. The isocyanate is typically a diisocyanate such as methylene diphenyl diisocyanate (MDI) or toluene diisocyanate (TDI).



Figure 3.9: PU Foam

7. **Temperature Sensor:**

How do temperature sensors work? They are devices to measure temperature readings through electrical signals. The sensor is made up of two metals, which generate electrical voltage or resistance once it notices a change in temperature.



Figure 3.10: Temperature Sensor

8. **Relay Module (1 CH, 5V):**

A relay module serves as an electronic switch that allows to automatically control the power to components like the Peltier module or cooling fans based on temperature conditions. Acts as a bridge between low-power (Arduino) and high-power (Peltier, fans) circuits.



Figure 3.11: Relay Module

9. **Arduino UNO:**

The Arduino UNO is the central control unit of our project. It acts as a programmable microcontroller that reads data from sensors (like temperature sensors) and makes decisions based on the programmed logic. It controls components such as relay modules, Peltier units, and cooling fans. It serves as the brain of the system, sending low-power signals to control high-power devices through the relay. Acts as a decision-maker and signal sender between input sensors and output devices in temperature-regulated systems.

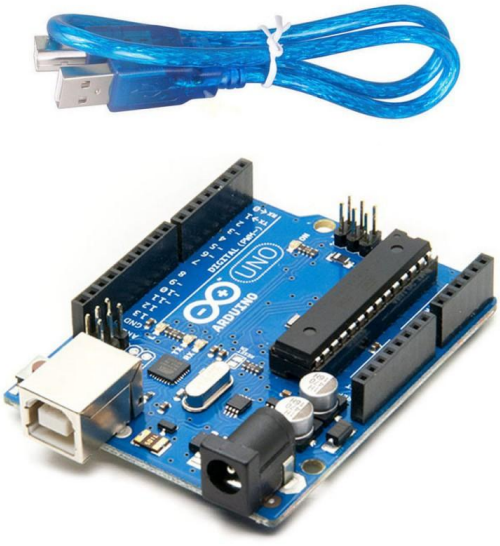


Figure 3.12: Arduino UNO

CHAPTER 4

DESIGN OF THE PROJECT

4.1 Introduction

The design progressed through a series of steps. These steps were identification of the problem, analyze problem, brainstorm ideas, decide upon a design selection, and implement design.

4.2 Concept Design

The conceptual design of the Thermoelectric Cooler (TEC) was developed and rendered using Solidworks CAD software prior to the start of fabrication. This design phase was crucial for visualizing the system's overall structure and verifying component compatibility. The CAD model incorporated all essential components, including the thermoelectric module, heat sink, and cooling fans, and enabled early identification of design challenges.



Figure 4.1: Conceptual Design Visualization of the TEC

The finalized conceptual design features external dimensions of 300 mm (height) × 200 mm (width) × 245 mm (depth), with an additional 86 mm rear extension for the heat dissipation assembly.

As shown in Figure 4.1, high-quality rendered views were generated to provide a clear visualization of both the internal and external aspects of the TEC unit.

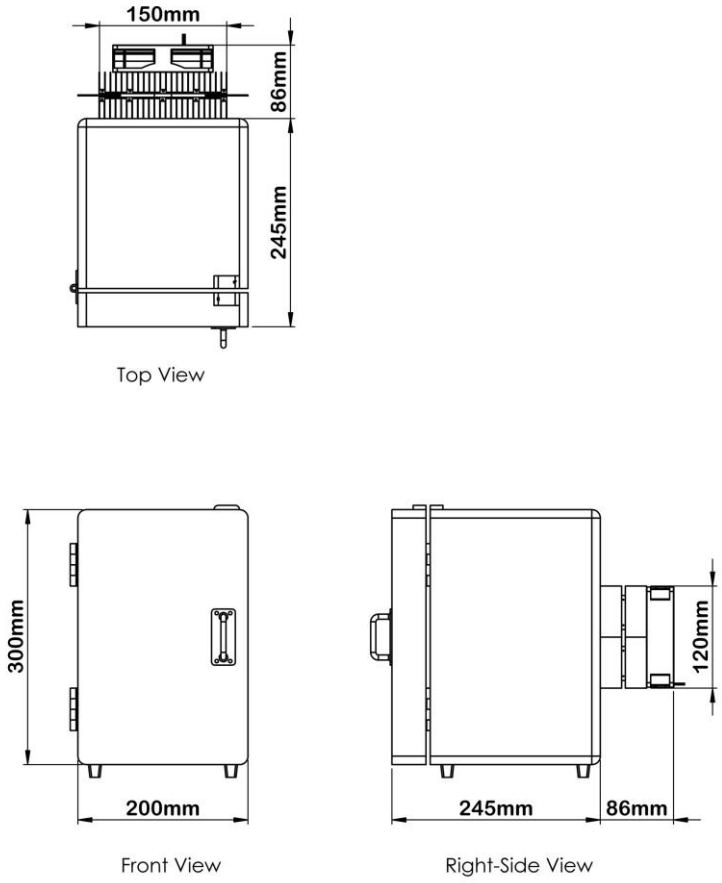


Figure 4.2: Technical Views & Dimensions of the Conceptual TEC Design

Figure 4.2 presents the corresponding technical drawing, including top, front, and right-side views with labeled dimensions. Together, these visual outputs served as a critical reference throughout the project, assembly procedures, and thermal design validation.

4.3 Actual Design

The final construction of the Thermoelectric Cooler (TEC) was executed in accordance with the initial conceptual model, integrating both mechanical and electrical components into a compact and functional structure. Minor adaptations were made during fabrication to accommodate component fit and optimize thermal performance.

Final Dimensions:

Outer Dimensions (Figure 4.3)*:*

- Height: 43 cm
- Width: 35 cm
- Depth: 43 cm (excluding 5 cm mounted components)
- Door Thickness: 10 cm
- Main Body Depth: 33 cm

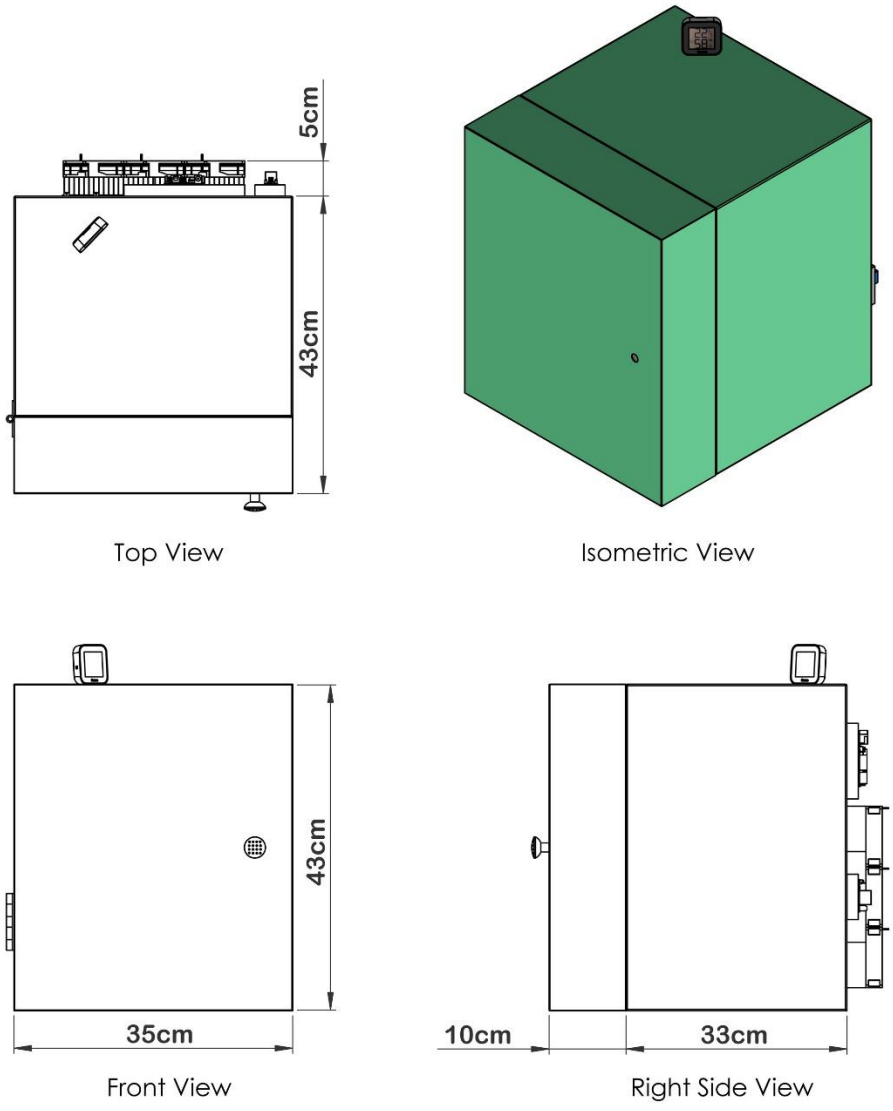


Figure 4.3: Outer Dimensions of TEC Refrigerator

These views were rendered and dimensioned using CAD software to provide accurate physical references for construction and thermal analysis

Inner Dimensions (Figure 4.4):

- Height: 30 cm
- Width: 27 cm
- Depth: 26 cm
- Internal Volume: ≈ 0.02106 m³.

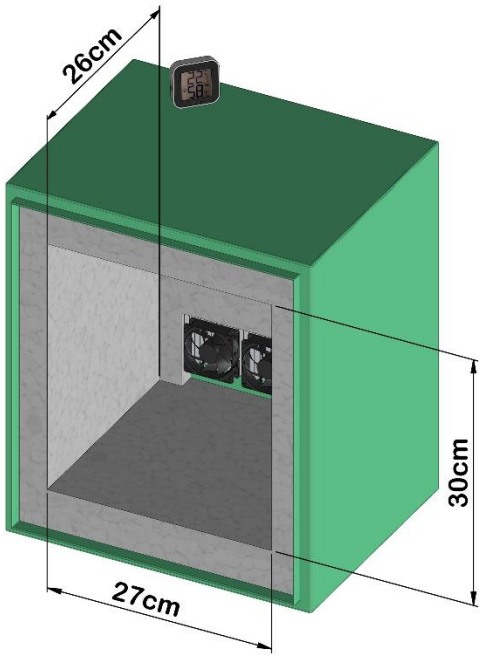


Figure 4.4: Inner Dimensions of TEC Refrigerator

Figure 4.5 shows the final CAD-rendered assembly of the Thermoelectric Cooler (TEC). The model illustrates the complete design—including internal insulation, fan placement, and external control units—and confirms that the fabricated prototype aligns accurately with the planned specifications.



Figure 4.5: Visualization of Final CAD Model

4.4 TEC Refrigerator Assembly (With Pictures)

This section presents the fully assembled Thermoelectric Cooler (TEC) prototype through a series of actual images, showcasing the final integration of components and the physical realization of the conceptual CAD model.



Figure 4.6: Assembled Thermoelectric Refrigerator

Figure 4.6 presents a combined view of the front and back sides of the fully assembled Thermoelectric Cooler (TEC) unit. The front view highlights the clean metallic enclosure and the top-mounted HTC-2 digital temperature-humidity sensor, used for real-time monitoring of internal and external environmental conditions. The rear view shows the full integration of key electronic components including the Arduino UNO, relay module, and DC SMPS power supply (12V, 20A). The nine-fan array, mounted on a large aluminum heat sink, ensures efficient dissipation of heat from the Peltier modules.

The internal chamber, as shown in Figure 4.7, is constructed with layered PU (Polyurethane) foam and thermocol sheets, which serve to reduce heat transfer from the external environment. PU foam acts as an effective thermal insulator, helping to maintain the internal temperature by limiting conduction through the chamber walls. To support uniform air distribution, three internal circulation fans are installed at the rear wall of the chamber. These fans circulate the cooled air throughout the space, promoting thermal consistency during operation.



Figure 4.7: Inner Section of Thermoelectric Refrigerator

The following key components were used in the construction of the TEC refrigerator:

- Peltier Modules (TEC1-12706) – Three modules were used to generate the cooling effect via the thermoelectric principle.
- Heat Sinks – Attached to both sides of each Peltier module to manage heat flow efficiently.
- Cooling Fans – A total of nine external cooling fans for the hot side and three internal fans for circulation within the cooling chamber.
- Relay Module (5V, 1 Channel) – Acts as a switching mechanism controlled by the Arduino to turn off the TEC once the desired temperature is reached.
- DC SMPS Power Supply (12V, 20A) – Powers all electrical components including Peltier modules and fans.
- HTC-2 Digital Temperature and Humidity Sensor – Displays both internal and external temperatures along with relative humidity.
- Arduino UNO – Functions as the central controller, processing temperature data and controlling the relay based on predefined thresholds.
- PU (Polyurethane) Foam – Used for insulation inside the chamber to reduce heat transfer and maintain temperature.

4.5 Functionality of the Thermoelectric Refrigeration System

The system operates based on the Peltier effect, where electrical energy is converted into a temperature difference across a thermoelectric module. When a DC voltage is applied to the TEC1-12706 Peltier modules, one side becomes cold while the opposite side becomes hot.

The cold side is oriented toward the internal chamber, while the hot side is attached to a heat sink and cooled by a bank of nine external fans. These fans continuously extract and dissipate the heat to the surrounding air, preventing heat buildup and allowing the cold side to maintain a lower temperature.

Inside the chamber, PU foam and thermo-cool insulation minimize heat transfer from the environment, helping to retain the cold temperature. Three internal circulation fans evenly distribute the cooled air throughout the chamber, maintaining uniform thermal conditions.

A digital temperature and humidity sensor (HTC-2) measures both the internal and external conditions and displays them in real time. The Arduino UNO microcontroller continuously monitors the temperature through a connected sensor. When the internal temperature drops below a pre-set threshold, the Arduino sends a signal to a 5V relay module, which disconnects the power to the Peltier modules and fans, preventing overcooling and saving energy.

When the temperature rises above the threshold again, the relay reactivates the system. This closed-loop control mechanism allows the TEC unit to function automatically and efficiently without manual intervention.

CHAPTER 5

RESULT ANALYSIS

5.1 Introduction

This section presents the experimental evaluation of the thermoelectric refrigerator's performance. It includes temperature measurements over time, supported by data tables and a graphical representation, to assess the system's cooling behavior. The Coefficient of Performance (COP) is calculated based on practical results and compared to theoretical expectations. This analysis provides insight into the system's thermal response during both operation and shutdown, helping to validate the design and identify areas for improvement.

5.2 Data Table

The following data was recorded during the experiment with a 500 mL water bottle placed inside the chamber. Temperature readings were taken at regular intervals while the system was operating and after it was turned off;

SL.	Condition	Time(Minutes)	Temperature (°C)
1	When System Run	0	30
2		3	17.3
3		6	14
4		9	13.6
5		12	13.5
6		15	13.5
7		18	13.6
8		21	13.6
9		24	13.7
10		27	13.7
11		30	13.9
12	When System Stop	33	14
13		36	18
14		39	22

Table 5.1: Temperature Variation with Time

5.3 Design Graph

Figure 5.1 shows the temperature change over time in the thermoelectric refrigerator during both active cooling and after it was turned off, with a 500 mL water bottle inside the chamber. During the cooling period (0–30 minutes), the temperature dropped quickly from 30°C to about 13.5°C, showing effective cooling. From 12 to 30 minutes, the temperature stayed mostly steady, which means the system reached a balance and kept the water cold. After turning off the system at 30 minutes, the temperature slowly increased, reaching 22°C by the 39th minute. This rise happened because heat entered the chamber from the outside, showing how well the chamber is insulated. Overall, the temperature trend proves the system can lower and keep temperatures low under real conditions.

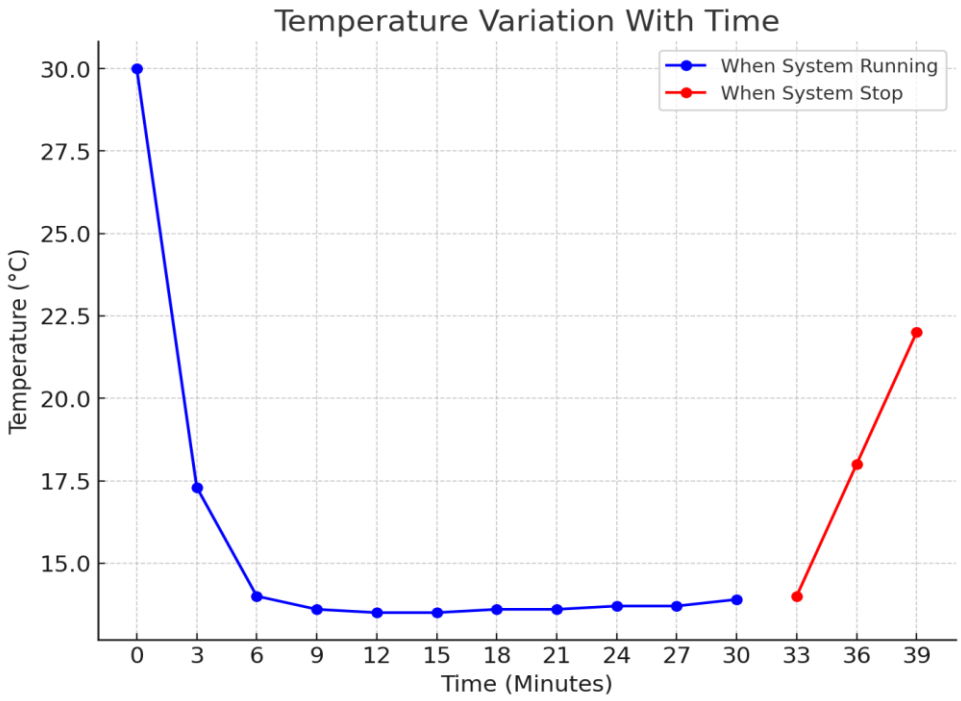


Figure 5.1: A Graphs of Temperature Variation Against Time

5.4 Analysis of The Result

Refrigerator Dimensions:

Outer Dimensions (Figure 4.3):

- Height = 43 cm
- Width = 35 cm
- Depth (including mounted parts) = 43 cm
- Main Body Depth = 33 cm

Inner Dimensions (Figure 4.4):

- Height = 30 cm
- Width = 27 cm
- Depth = 26 cm
- Internal Volume = 0.02106 m^3

Experimental Condition:

To evaluate the performance of a thermoelectric refrigerator, experiments were conducted under three different conditions: with a 500 mL water bottle inside the chamber, under no-load (air-only) conditions, and through theoretical modeling based on the module's thermal and electrical properties. In the water-loaded test, the system was operated for 12 minutes, while the no-load condition was run for 9 minutes. These tests aimed to simulate both practical use and idle operation, providing a basis for comparison with ideal theoretical performance.

Using 500mL Water Bottle:

Given the following experimental parameters:

- Water Volume (500 mL) = 0.5 L = 0.0005 m^3
- Density of Water (ρ) = 1000 kg/m^3
- Mass of Water (M_w) = ρ v = 1000 × 0.0005 = 0.5 kg
- Sp. Heat Capacity of Water: C_p = 4.20 kJ/kg·K
- Initial Temperature (T_1) = 30°C = 303.15 K
- Final Temperature (T_2) = 13.5°C = 286.65 K
- ΔT = (303.15 − 286.65) = 16.5 K

Input Data:

- Voltage = 12V
- Current = 5A
- Power = 12 × 5 = 60 W
- Time = 12 minutes = 720 seconds

Cooling Effect (Q):

$Q = M_w \times C_p \times \Delta T$

$Q = 0.5 \times 4.2 \times 16.5$

$Q = 34.65$ kJ

$Q = 34650$ J

Work Input (W):

W = Power × Time × No. of Peltier

W = 60W × 720 sec × 3

W = 129600 J

Coefficient of Performance (COP):

$$COP = \frac{\text{Cooling Effect (Q)}}{\text{Work Input (W)}}$$

$$COP = \frac{34650}{129600}$$

COP = 0.27

<u>For No Load Condition (Air):</u>

Given the following experimental parameters:

- Inner chamber volume = 0.02106 m^3
- Density of air (ρ) ≈ 1.225 kg/m^3
- Specific heat capacity of air (C_p) ≈ 1.005 kJ/kg·K
- Initial temperature (T_1) = 29.5°C = 302.5 K
- Final temperature (T_2) = 13.3°C = 286.3 K
- ΔT = (302.5 − 286.3) = 16.2 K
- Mass of air (M_{air}) = ρ × V = 1.225 × 0.02106 = 0.0258kg

Input Data:

- Voltage = 12V
- Current = 5A
- Power = 12 × 5 = 60 W
- Time = 9 minutes = 540 seconds

Cooling Effect (Q):

- $Q = M_{air} \times C_p \times \Delta T$
- Q = 0.0258 × 1.005 × 16.2
- Q = 0.42 kJ
- Q = 420 J

Work Input (W):

- W = Power × Time × No. of Peltier = 60W × 540 sec × 3
- W = 97200 J

Coefficient of Performance (COP):

- $\text{COP} = \frac{\text{Cooling Effect (Q)}}{\text{Work Input (W)}}$
- $\text{COP} = \frac{420}{97200}$
- COP = 0.004

<u>For Considering TEC Module Thermal Conductivity (Theoretical):</u>

- Seebeck Coefficient: S = 0.0129 V/K
- Thermal Conductivity: K = 0.1815 W/K
- Resistance: R = 4 Ω
- Voltage: V = 12 V
- Current: I = 5 A
- Hot Side Temp: T_{hot} = 30°C = 303.15 K,
- Cold Side Temp: T_{cold} = 13.5°C = 286.65K
- ΔT = (303.15 − 286.65) = 16.5 K

Cooling Effect (Q_L):

$$Q_L = -[S \cdot I \cdot T_{cold} - \frac{1}{2}(I^2 R) - K(T_{hot} - T_{cold})]$$

$$Q_L = -[(0.0129 \times 5 \times 286.65) - \frac{1}{2}(5^2 \times 4) - 0.1815(16.5)]$$

$$Q_L = 34.51 \text{ W}$$

Heat Rejection (Q_h):

$$Q_h = S \cdot I \cdot T_{hot} + \frac{1}{2}(I^2 R) - K(T_{hot} - T_{cold})]$$

$$Q_h = (0.0129 \times 5 \times 303.15) + \frac{1}{2}(5^2 \times 4) - 0.1815(16.5)$$

$$Q_h = 65.56 \text{ W}$$

Coefficient of Performance (COP):

$$\text{COP} = \frac{Q_L}{Q_H - Q_L}$$

$$\text{COP} = \frac{34.51}{65.55 - 34.51}$$

COP = 1.11

5.5 Comparison of COP

The Coefficient of Performance (COP) of the developed thermoelectric refrigerator was measured under three different conditions: with a 500 mL water load, under no-load (air only), and based on theoretical calculations.

In the water load test, the system achieved a COP of 0.27 after cooling the water from 30°C to 13.5°C over a 12-minute period. This reflects the system's practical cooling ability under typical usage conditions. The no-load condition, conducted over a 9-minute interval with only air inside the chamber, resulted in a much lower COP of 0.004, which is expected due to the significantly lower thermal mass and heat capacity of air compared to water.

A similar study reported a higher experimental COP of 0.66 for a thermoelectric refrigerator [16]. While this value is greater than the COP obtained in our setup, differences in performance can be attributed to variations in insulation quality, heat sink configuration, system size, and ambient conditions. The comparison suggests that while our system performs reasonably under basic conditions, there is potential for improvement through design optimization.

Both experimental COP values are below the theoretical COP of 1.11, which assumes ideal conditions. This highlights the common gap between theoretical expectations and real-world results in thermoelectric systems.

CHAPTER 6

RECOMMENDATION AND CONCLUSION

6.1 Introduction

Refrigeration involves removing heat from a substance or space to lower its temperature below that of the surroundings. Thermoelectric refrigeration (TER) achieves this using the Peltier effect, where a constant voltage applied across two dissimilar conductors or semiconductors creates a cooling effect—unlike conventional vapor or gas compression systems. TER is widely used in electronics to cool sensitive components like power amplifiers and microprocessors, as well as in space applications to manage extreme temperatures. In scientific equipment like digital cameras and CCDs, TER minimizes thermal noise, enhancing sensitivity and image quality. For low-capacity refrigeration, where the COP of compression systems drops, TER offers superior temperature control and is ideal for preserving food and pharmaceuticals. Thermoelectric modules (TEMs) are compact, vibration-free, and silent, but their efficiency is limited by thermal and electrical contact resistances. This work extends existing 1D models to include these resistances, particularly for air-cooled systems. Optimization of pellet geometry under various conditions shows that a tenfold decrease in thermal conductance reduces peak heat removal by 10%, while increased electrical interconnect resistance can cut maximum heat removal by 20% and reduce COP by 50%.

6.2 Limitation

Our project was so small that it was not for big commercial operations. And also low coefficient of performance. We cannot decrease less than 12 temperatures. Utilizing thermoelectric refrigerator system is increasing in many industrial applications due to its advantages. Heat rejection from cold side of a pettier module is a substantial parameter to improve conversion efficiency of the module. One of the easy-to-use cooling approaches is using direct current (DC) fans. This study investigates a self-cooling (TER) system, where the cooling fans consume a fraction of power generated by the TERs. Critical design parameters are studied to reach maximum net power by utilizing suitable operating conditions of the cooling fans. Moreover, performance of the TER system, supplying electrical power required for both external user and the cooling fans, is explored experimentally. This paper studies, for the first time, effect of electrical input power of the cooling fans, coupled with the TERs, on performance of the self-powered energy harvesting system. Results of this work demonstrate that, feasibility of utilization of the cooling fans is strongly related to thermal boundary conditions and electrical load resistance applied on the coupled electric circuit of the TERs. Moreover, the results show a minimum inlet water flow temperature and a minimum external load resistance are required in self-cooling system to provide a net power more than without using the cooling fans.

6.3 Future Recommendation

With recent development taking place in field of thermoelectric and Nano science different thermoelectric material with figure of merit ZT more than 1 with high temperature difference to be explored this will further help to reduce the temperature, current below and can also perform better at higher ambient conditions.

To improve the power retention in this thermoelectric cooler sandwich heater needs to be explored with quick switching mechanism from thermoelectric cell off state of heater to on state, so that temperature drop in thermoelectric cell can be reduced.

6.4 Conclusion

This study demonstrates the potential of Thermoelectric Refrigeration (TER) systems as alternatives to traditional vapor compression systems. A thorough review of past research, advancements in thermoelectric materials, system configurations, and hybrid technologies has been provided. The application of TER in portable and domestic cooling devices offers notable benefits such as compactness, environmental sustainability, and simplicity of operation.

Experimental results from this project, which involved three different test conditions, confirm the effectiveness of the thermoelectric refrigerator in lowering temperatures. Under the water load test, where 500 mL of water was cooled from 30°C to 13.5°C over 12 minutes, the system achieved a COP of **0.27**. In the no-load test, conducted over 9 minutes with air inside the chamber, the COP dropped significantly to **0.004**, highlighting the impact of thermal mass and heat capacity on system performance. Additionally, the theoretical COP, calculated based on ideal module parameters, was **1.11**, demonstrating the potential for much higher performance under optimized conditions.

CHAPTER 7

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