Palestine Polytechnic University

Design and Building of Solar Powered Thermoelectric Refrigerator

Submitted to the College of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Refrigeration and Air Conditioning Engineering

By

Karama Shahateet

Supervisor:

Dr. Ishaq Sider

May, 2018

Palestine Polytechnic University

Collage of Engineering

Mechanical Engineering Department

Hebron – Palestine

Design and Building of Solar Powered Thermoelectric Refrigerator

Project Team:

Karama Mohammad Shahateet

Submitted to the Collage of Engineering

In partial fulfillment of the requirements for the

Bachelor degree in Mechanical Engineering.

Supervisor Signature

……………………………………………

Testing Committee Signature

……………………………… ……………………………………

Chair of the Department Signature

……………………………………………

May 2018

Abstract

The continuous and increasing demand for refrigeration in various fields such as air conditioning and food preservation can be costly because of maintenance and harmful for the atmosphere due to the emission of gases such as CO_2 caused by the production of the refrigerants and refrigeration cycle components.

Thermoelectric cooling is a strong candidate to replace the traditional refrigeration cycles because of its low maintenance and long life, which can reach up to 200,000 working hours; it transforms electrical energy to produce a cooling effect directly without the need of the traditional refrigeration cycle components. This project aims to design, implement and test an automotive thermoelectric refrigerator, controlled remotely via smartphone application.

The geometry for the refrigeration chamber were determined to have a volume of 0.4 L with an inner volume of 250 mL, then the total heat load was calculated to be 13.815 W and a TEC 1-12706 Peltier module was selected according to that, while the control system consists of a two microcontroller, two channel relay module, Bluetooth module, two voltage sensor and a temperature sensor to achieve the desired outcomes from the project.

الملخص

ان الطلب المستمر والمتزايد على التبريد في مختلف المجالات مثل التكييف وحفظ الأغذية من الممكن أن يكون مكلفاً بسبب الصيانة وضاراً للغلاف الجوي بسبب انبعاث الغازات مثل ثاني أكسيد الكربون الناجم عن انتاج وتصنيع غازات التبريد ومكونات دورات التبريد نفسها.

التبريد الكهرو حراري هو مرشح قوي لاستبدال دورات التبريد التقليدية الحالية نظراً لصيانته المنخفضة وعمره الافتراضي الطويل والذي من الممكن أن يصل الى ٢٠٠٠٠٠ ساعة عمل، التبريد الكهرو حراري يقوم بتحويل الطاقة الكهربائية لإنتاج تأثير التبريد دون الحاجة الى مكونات دورات التبريد التقليدية. يهدف هذا المشروع الى تصميم وتنفيذ ثلاجة كهر وحرارية للسيارات والتي يتم التحكم بها عن بعد بواسطة تطبيق للهواتف الذكية ومتحكم دقيق.

تم تحديد الشكل الهندسي لغرفة التبريد ليكون حجمه 0.4 لتر مع حجم داخلي من 250 مل ، ثم تم حساب الحمل الحراري الإجمالي ليكون 13.815 واط وتم اختيار وحدة TEC 1-12706 بيلتير وفقًا لذلك ، بينما يتكون نظام التحكم من متحكمين اثنين ، وحدة تتابع قناة ، وحدة بلوتوث ، جهازي استشعار للجهد وجهاز استشعار درجة الحرارة لتحقيق النتائج المرجوة من المشروع.

Detected

TO

Our Home Land

Our Parents

Our Brothers & Sisters

Our Friends

And

Every One Who Appreciate The Value Of Science

Karama Shahateet

ACKNOWLEDGEMENT

We would first like to thank our project supervisor Dr. Ishaq Sider. Who always despite his lake of time and his preoccupation with both academic and administrative duties inside and outside the university due to his position as Dean of the College of Applied Professions at Palestine polytechnic university didn’t close the door to his office whenever he managed to make time for us and we ran into a trouble or had a question. He consistently allowed this project to be our own work, but at the same time he steered us in the right directions whenever he thought we needed it.

We would also like to acknowledge all those who helped us in this project from friends and family, especially the colleague Izz Eddine Sobh.

Finally, we must express our very great gratitude to our parents for providing us with support and continuous encouragement throughout our years of study and through the process of researching and writing this project. This accomplishment would not have been possible without them.

Thank you.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

Chapter One

Introduction

1.1 Introduction:

Air conditioning and refrigeration are one of the greatest engineering achievements developed in the 20th century. These achievements have been used in many fields to improve the quality of our lives and make it more comfortable and enjoyable.

Refrigeration may be defined as the process of removing heat. This process may be accomplished by using one of the refrigeration systems; vapor compression, absorption or thermoelectric refrigeration systems. The first two systems need high and low pressure sides of a working fluid to complete the refrigeration cycle. The thermoelectric refrigeration system, however, uses electrons rather than refrigerant as a heat carrier.

In the recent years, electricity crisis becomes the main problem for us. Therefore, the use of renewable sources of the nature is expanding. Therefore, researchers are continuously striving towards the development of thermoelectric refrigeration techniques combined with solar energy as an Eco friendly refrigeration technology. This technique is commonly used in camping, portable coolers, automotive system, for cooling electronic components and small instruments.

1.2 Literature Review:

The principles on which modern thermoelectric coolers are based actually date back to early 1800's [1], although commercial thermoelectric (TE) modules were not available until almost 1960. The first important discovery relating to thermoelectricity occurred in 1821 when a German scientist, Thomas Seebeck, found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals provided that the junctions of the metals were maintained at two different temperatures. In 1834, a French watchmaker and part time physicist, Jean Peltier, while investigating the "Seebeck Effect," discovered the "Peltier Effect" and it is the fundamental principal behind a thermo-electric system. [2]

There are several of experimental and numerical studies that prepared in the performance of TEC heating and cooling systems. Some of there will be displayed in this project, as following:

1. Y.J. Dai et al (2003), [3]**:** in his paper — *"Experimental Investigation and Analysis on A Thermoelectric Refrigerator Driven by Solar Cells"*: Carried an experimental investigation and performance analysis on a portable solar thermoelectric refrigerator for small-scale remote applications or in areas where the electric supply is unavailable. Solar cells are used to supply electric power for thermoelectric module in daytime, and storage battery, as well as AC rectifier is used in night time. Research interest focused on testing the system performance under sunshine.

- **Results and Conclusion:**

Experiment results demonstrated that the system performance is strongly dependent on the intensity of solar insolation and the temperature difference of hot and cold sides between the thermoelectric modules. The studied refrigerator can maintain the temperature in refrigerated space at 5–10 ^{o}C, and has a COP about 0.3.

2. Sabah A. Abdul-Wahab et al. (2009), [4]: in his paper — *"Design and experimental investigation of portable solar thermoelectric refrigerator"*: Conducted a construction for an affordable solar thermoelectric refrigerator for the Bedouin people living in remote parts of Oman where electricity is still not available. The refrigerator could be used to store perishable items and facilitate the transportation of medications as well as biological material that must be stored at low temperatures to maintain effectiveness. The design of the solar-powered refrigerator is based on the principles of a thermoelectric module to create a hot side and a cold side.

- **Results and Conclusion:**

Experiment results demonstrated that the system performance was strongly dependent on the intensity of solar insolation and the temperature difference of hot and cold sides between the thermoelectric modules. The results indicated that the temperature of the refrigeration was reduced from 27 to 5 ^{o}C in approximately 44 min. The (COP) is about 0.16.

3. Adeyanju A. A et al (2010), [5]: in his paper — *" Experimental and theoretical analysis of a beverage chiller"*: Conducted an experimental and theoretical analysis of a fast beverage chiller which based on the principle of thermoelectric refrigeration. Experiments were conducted with different sizes of beverage at different temperatures, and the heat sinks were used to increase cooling efficiency. Comparison were also made between the beverage chillers cooling time with cooling time obtained from the freezer space and cold space of a household refrigerator. All comparison tests were carried out on 325 mL of water in a glass jar.

- **Results and Conclusion:**

It was discovered theoretically that increase in the number of thermoelectric modules and heat sinks increases the cooling rate of beverage. The temperature of beverage decreased exponentially with increase in time. The comparison result shows that for the refrigerator freezer space, the temperature of the water decreased linearly with increasing time. However for the beverage chiller, the water temperature decreased exponentially with increasing time.

4. Manoj Kumar Rawat et al (2013), [6]**:** in his paper — *"Developmental and Experimental Study of Solar Powered Thermoelectric Refrigeration System"*: Explain the Design and developmental methodology of thermoelectric refrigeration that working on solar photo voltaic cells generated DC voltage. The experimental results shows that the performances were optimized for a given operating condition $I=0.5\ I_{maxi}$ and forced air convection heat dissipation. An 11 °C temperature reduction at zero load and 9 °C at 100 ml water inside refrigeration space of developed thermoelectric Refrigeration has been experimentally found with respect to 23 °C ambient temperature in 30 minutes, the COP about 0.1. In addition, in this max work, the developmental thermo-electric refrigeration system gives optimum performance at 2.5A, 8V and the system can continuously work for 15 hours when battery is fully charged by solar panel.

1.3 Scope of the Project:

The design of this project focuses on the principles of a thermoelectric module (i.e., Peltier effect) to create a hot side and a cold side in the refrigerator. The cold side of the thermoelectric module is utilized for refrigeration purposes; provide cooling to the refrigerator space. On the other hand, the heat from the hot side of the module is rejected to the ambient surroundings by using heat sinks.

The refrigeration system will be driven utilizing solar energy (direct energy conversion system ‘PV‘), to offer maximum usage of non-conventional energy sources to enable the use of greener technology. The use of solar energy as a source is considered as a boon for a large number of people in remote areas, or where electric power supply is absent. Also the portability of this system helps in easy transportation.

The problem with this system is the low of the coefficient of performance (COP) for the TEC, and will be improved through the optimum utilization of heat sinks located on the hot and cold sides in order to reduce thermal resistance and by reducing the transfer of heat through the walls of the refrigerator body by using vacuum insulation.

These methods mentioned will be used to design the refrigerator for cooling the beverage box (250 ml). And the volume of the cooling space in the refrigerator will be about (0.4 L). The beverage box temperature will be reduced from (25 - 5) ^{o}C in 50 minute.

1.4 Objectives:

The main significance of this project is to design and building inexpensive and compact solar powered thermoelectric refrigerator for cooling goods placed in insulated chamber. This project aims to achieve the following objectives:

1. To make use of environmentally friendly refrigeration system.
2. To investigate the cost and effectiveness of the TEC module.
3. To identify the improvements on the experiment.
4. To study the results coming out from this project.
5. To compare results with theoretical result.
6. To construct a test on the behavior and specifications of a TEC device operating in a cooler box environment.

1.5 Applications:

This project can be used in many fields. as following:

1. Indoor space cooling.
2. Outdoor cooling, carrying the portable refrigerator along for drinks preservation etc.
3. Cooling in cars and works.
4. In remote and rural areas, in summers when there is no electricity, solar powered thermoelectric cooler comes as a relief.

1.6 Thermoelectric cooling:

A thermoelectric module is a relatively new approach of cooling design to reduce the number of moving parts and to reduce the usage of refrigerants. It is a solid state heat pump that used Peltier effect to create a heat flux between two different kinds of metals. The Peltier effect is a temperature difference created when a direct current is passed between two electrically dissimilar material's heat is absorbed and generated at the junction. This is achieved through small p-n junction semiconductors called thermoelectric modules (See Figure 1.1). The side which generates heat is the “Hot Side”, and the side which absorbs heat is the “Cold Side”. And the direction of the heat flow depends on the direction of applied electric current. [7],[1]

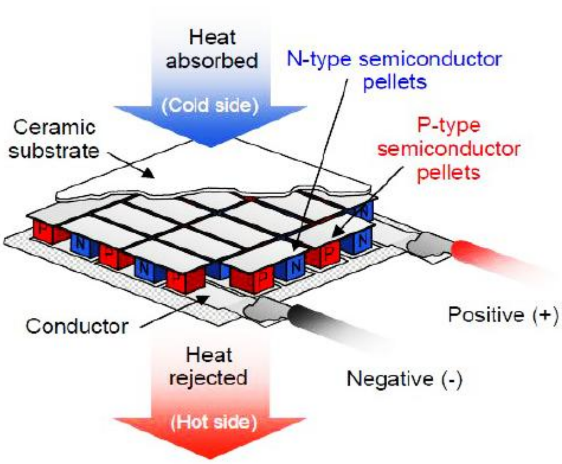


Figure 1.1: Schematic Diagram of Thermoelectric Cooling.

1.7 Problem Statement:

Thermo-electric and conventional refrigeration systems refer to the technology used to cool down the cabinet. Each type of systems has its advantages and disadvantages, Table (1.1) compares among those systems mentioned above, in order to select the most appropriate type to be the subject of study, research, and use in this project:

Table 1.1: Thermoelectric and Conventional Systems Refrigeration. [8]

Aspect	Thermoelectric System	Conventional System
Quality of the Energy Input	Low grade energy sources are more than capable of running a Thermoelectric system. Solar power can also be used for running it.	High grade energy. It needs electrical or mechanical energy for operating compressor which is an essential part of the VC refrigeration system.
Moving Parts in The System	No moving part	The moving part is the compressor which operated by electric motor or engine
COP	Low	Very good
Initial Cost	High	Low
Life	Long life	Is subject to many faults, which makes life short
Maintenance	Rarely	Continuous
Refrigerant	Available(air or sometimes water)	Expensive; ie (HCHs ,HCFCs,CFCs)
Greenhouse Effect	No greenhouse effect	Halocarbon (HCFC) refrigerant produce depletion in Ozone layer

Through the Table (1.1), shows that there are many advantages of Solar Thermoelectric Cooling over the traditional cooling methods in spite of having of economical and technical problems. They are entirely solid-state devices, with no moving parts; this makes them rugged, reliable, and quiet. They use no Ozone depleting chlorofluorocarbons, making it a more environmentally responsible alternative to conventional refrigeration. And the Thermoelectric Module requires less electricity compared to traditional cooling Thus, solar cells can be utilized without the need for other energy sources to operate them. However, Its low efficiency is the only drawback that makes most of the projects using this system are very small, which makes their unique advantages outweigh their low efficiency.

1.8 The Refrigerator Component Selection:

The next chapters will talk about the design and selection of fridge components based on many calculations, and the methodology used in system design will be presented. How to assemble each part of the project and describe the techniques used will be described.

1.9 Time Planning for the Project:

The project plan follows the following time schedule which includes the related tasks of study and system analysis. The following timings plans are for the first and second semesters.

Table 1.2: First Semester Time Plan.

Task/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Identification of on Project Idea	■	■	■	■												
Reading and Collecting Information	■	■	■	■	■	■	■	■	■	■	■	■				
Introduction						■	■	■	■							
Load Calculation							■	■	■	■						
Components Selection and Design							■	■	■	■	■	■	■	■		
Modification and Coordination														■	■	■
Preparing and Printing								■	■	■	■	■	■	■	■	■
Preparation of presentation																■

Table 1.3: Second Semester Time Plan

Task/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Refrigerator Building																
Accessory Selection																
Electrical and Control Building																
System Test																
Comparison																
Conclusion																
Project Documentation																
Preparing and Printing																
Preparation of presentation																

1.10 Project Cost Table:

Table 1.4: Cost Table.

Task	Quantity	Cost (NIS)	Total
Solar Panel	1	200	200
Fin	2	40	80
Fan	1	25	25
TEC Module	1	25	25
Thermos	1	70	70
Electronic Pieces	-	300	300
Total			700

2

Chapter Two

Cooling Load and Project Components

2.1 Introduction:

This chapter will include the calculation of the cooling load required to select the components of the project, and some description of components used in the system.

2.2 Cooling Load:

The total heat required to be removed from the refrigerated space to bring it at the desired temperature and maintain it by the refrigeration equipment is known as cooling load. The purpose of load estimation is to determine the size of the refrigeration equipment that is required to maintain inside design conditions during periods of maximum outside temperature. The design load is based on inside and outside design conditions and its refrigeration equipment capacity to produce and maintain satisfactory inside conditions.

The cooling load is computed in the refrigerator on the basis of:

1. Active Heat Load.
2. Air Changing Load (Infiltration).
3. Passive Heat Load.

The target temperature in the cooling space is 5 °C, and the ambient temperature is about 31^{o}C based on the Palestinian codes which show the maximum surrounding temperature in Hebron city (Table A-1). The volume of beverage box to be cooled is 250 mL and the desired cooling time is 50 minutes.

2.2.1 Active Heat Load:

The active heat load is the heat released from a mass which is kept inside the cabinet during the cooling and is calculated by, [6]

$$\boldsymbol{Q_{active}} = \frac{\boldsymbol{m C_p \Delta T}}{\boldsymbol{\tau}} \qquad (2.1)$$

Where:

Q_{Active}: heat load supplied by beverage box [W].
m: mass product of beverage [kg].
C_p: specific heat capacity of water [4.186 kJ/ kg. ^{o}C].
ΔT: the change in product temperature [^{o}C].
τ: desired cooling time [sec].

$$\Delta T = T_i - T_f \qquad (2.2)$$

Where:

T_i: initial product temperature [25 ^oC].
T_f: outlet product temperature [5 ^oC].

$$m = \rho V \qquad (2.3)$$

Where:
ρ: water density [1 kg/L].
V: volume of product [L].

Applying equations (2.1), (2.2), (2.3), the active load for the product (Beverage box) is:

$$Q_{active} = \frac{(1 * 250 * 10^{-3})(4.186 * 10^{3})(25 - 5)}{50 * 60} = 6.977\, W.$$

2.2.2 Air Changing Load (Infiltration):

In the practical operation of a refrigerated facility, refrigerator must be opened at times in order to move the product in and out. The infiltration load is one of the major loads in the refrigerator. The infiltration air is the air that enters a refrigerated space through cracks and opening of the lid. This is caused by pressure difference between the Internal and external surface and it depends upon temperature difference between the inside and outside air.

The heat losses resulting from air change can be determined by applying the following equation:

$$Q_{inf} = m_f * C_p * (T_0 - T_i) \qquad (2.4)$$

Where:
Q_{inf}: heat losses by air change [W].
m_f: mass product of infiltrated air [kg].
C_p: specific heat capacity of the air [1 kJ/ kg. ^oC].
T_o: outside air temperature [^oC].
T_i: inside air temperature [^oC].

$$m = \rho V_f \qquad (2.5)$$

Where:
ρ: air density [1.25 kg/m^3].
V_f: volumetric flow rate of infiltrating air [m^3/sec].

V_f = number of air change * volume of refrigeration space.
Number of change =0.5 [time/h], (Table A-2).

V_f =0.5 *(0.5) =0.25 [m^3/h].

Appling the equation (2.4), (2.5), the Q_{inf} for the beverage box:

$$Q_{inf} = 1.25 * \frac{(0.25)}{3600} * 1000 * (31 - 5) = 2.257\ W.$$

2.2.3 Passive Heat Load:

The passive heat load is the heat losses due to convection, radiation and conduction of the enclosed thermoelectric cabinet.

The heat losses on refrigeration equipment are produced through walls. The body of the refrigerator in this project is a vacuum flask (Thermos), the refrigerator wall is a dual wall vacuum insulated, as in figure (2.1). So the heat loss will be by radiation and it is calculated by,

$$\boldsymbol{Q_{rad} = \varepsilon_{s.s}.\,\sigma.\,A(T_c^4 - T_{surr}^4)} \qquad (2.6)$$

Where:
Q_{rad}: the rate of heat transfer by radiation through the wall [W].
$\varepsilon_{s.s}$: emissivity of stainless steel=1 (blackbody).
σ: Stefan–Boltzmann constant = 5.67 * 10^{-8} W/m^2.K^4 (blackbody).
A: surface area of the inner wall [m^2].
T_{surr} : temperature of the surrounding air [K].
T_c: temperature within the cabinet of refrigerator [K].

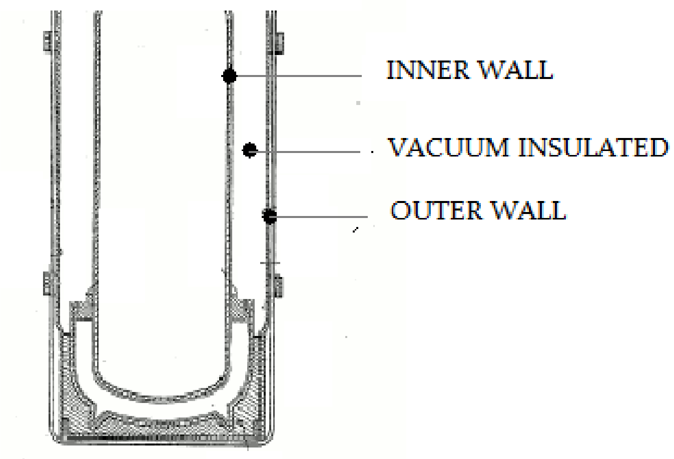


Figure 2.1: Schematic Diagram of Dual Wall Vacuum Insulated.

Applying equation (2.6), the rate of heat transfer through the wall:

$$Q_{rad} = 1 * (5.67 * 10^{-8})(2.28 * 10^{-2}) * [(31 + 273.15)^4 - (5 + 273.15)^4] = 3.325\ W.$$

- So the heat load due to passive load is $3.325\ W$.

2.2.4 Total Cooling Load:

The total cooling load is the summation of heat load due to active, passive and Air changing load (Infiltration), as in Table (2.1):

$$\boldsymbol{Q_c = Q_{active} + Q_{inf} + Q_{passive}} \qquad (2.7)$$

Table 2.1: Heat Load.

Heat Load	**Q_{active} (W)**	**Q_{inf}(W)**	**$Q_{passive}$(W)**
	6.977	2.257	3.325
Total (W)	**12.559 W**		

It is common practice to add 10%-12% as a factor of safety as general rule 10% is used: [9]

$$\boldsymbol{Q_{c1} = Q_c + (Q_c * 0.10) = 12.559 + (12.559 * 0.10) = 13.815\ [W]}.$$

2.3 Components of the System:

2.3.1 Refrigeration Box (Thermos):

There are many considerations that are based on choosing a refrigerator box; the main considerations are heat transfer, geometry and materials.

2.3.1.1 Geometry:

Two main geometry of the refrigeration box first is a rectangle. The advantage of the rectangle is its simplicity to build and insulate. A door can easily be attached to one of the sides. Finally, any insulation, thermo-electric modules or heat sinks are easily fastened to the sides. The second choice is a cylinder. The advantage found in this shape is that it has the largest volume to surface area ratio of the two designs. This is a good property when the objective is to minimize heat loss; this is considered in selecting the thermos.

2.3.1.2 Materials and Heat Transfer:

The Zoie + Chloe vacuum flask (Thermos) is made of durable stainless steel from inside and outside and it has a double wall vacuum insulated as in figure (2.2), that making the heat transfer process very low and takes time.

Figure 2.2: Vacuum Flask (Thermos).

2.3.2 Thermoelectric (TEC) Module:

A thermoelectric (TEC) module is a solid state current device, which, if power is applied, move heat from the cold side to the hot side, acting as a heat exchanger. The amount of cooling produced by the module depends on the Type of the module used and how much power it is supplied. The (TEC1-12706) module was selected based on the amount of total cooling needed as a Figure (2.3).

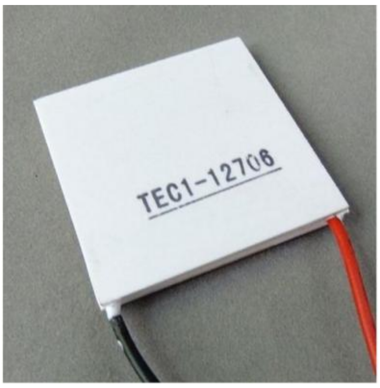


Figure 2.3: TEC1-12706 Module.

2.3.3 Heat Sink:

Selection of a heat sink is crucial to the overall operation of a thermoelectric system. The heat sink should be used to facilitate the transfer of heat from the surface of the thermoelectric. This could be achieved by free convection and forced convection.

1. Free Convection:

In a natural convection air cooled the air comes in contact with the warm fin, it absorbs heat from the TEC and thus the temperature of the air increases. The warm air being lighter, rises up and the cold air from below rises to take away to take away the heat from the fin. This cycle continues in natural convection air cooled fin, since the rate of heat transfer in natural convection is lower, therefore they require a larger surface as compared to forced convection, this is not appropriate for the project.

2. Forced Convection:

In forced convection there are two methods which can be employed to facilitate the transfer of heat from the surface of the thermoelectric, by air-cooled and water-cooled.

In forced convection air cooled, the fan is used to force the air over the TEC fin to increase its heat transfer capacity. But in forced convection water-cooled is used pipe and pump to facilitate the transfer of heat making it difficult to handle, low flexibility and more expensive. For solar TEC, it will be used forced convection air-cooled, as in figure (2.3). Despite its efficiency is low compared with the water-cooled, but the size of the project is small so that it will not be affected by this efficiency.

Figure 2.4: Heat Sink Design.

2.3.4 Solar Cells:

A solar panel is a photovoltaic module which consists of photovoltaic (PV) cells. Photovoltaic cell is manufactured from semiconductor. When this material is exposed to light its produced an electric current, through a physical process is known as the "photovoltaic effect". In which the photons of the sunlight work to dislodge the electrons from the cell atoms the free electrons then move through the cell, creating and filling in holes in the cell, this movement of electrons and holes that generate electricity.

There are several types of solar cells, but the major types of PV systems are available in the marketplace today, flat plate and concentrators. In below will be displayed the types of solar cells available,

2.3.4.1 PV Technologies:

1. **Crystalline Silicon:** (c-Si) modules represent 85-90% of the global annual market today. c-Si modules are subdivided in two main categories:

- Single crystalline (sc-Si).
- Multi crystalline (mc-Si).

2. **Thin Film (TFPV):** currently account for 10-15% of global PV module sales. They are subdivided into three main families:

- Amorphous (a-Si) and micro morph silicon (a-Si/us-Si)
- Cadmium- Telluride (CdTe)
- Copper-Indium-Diselenide (CIS) and copper -Indium-Diselenide (CIGS)

3. **Emerging Technologies:** encompass advanced thin films and organic cells. The latter is about to enter the market via niche application.

4. **Concentrator Technologies (CPV):** use an optical concentrator system which focuses solar radiation, onto a small high-efficiency cell. CPV technology is currently being tested in pilot applications.

5. **Novel (PV) concepts:** aim of achieving ultra-high efficiency solar cells via advanced materials and new conversion concepts and processes. They are currently the subject of basic research.

2.3.4.2 Criteria for Selection of Solar Cells:

Solar cells are selected based on several criteria: efficiency, size, quality, price, availability in local markets and material made, the major types of materials are crystalline and thin film, which vary from other in terms of light absorption efficiency, energy conservation efficiency, manufacturing technology and cost of productions.

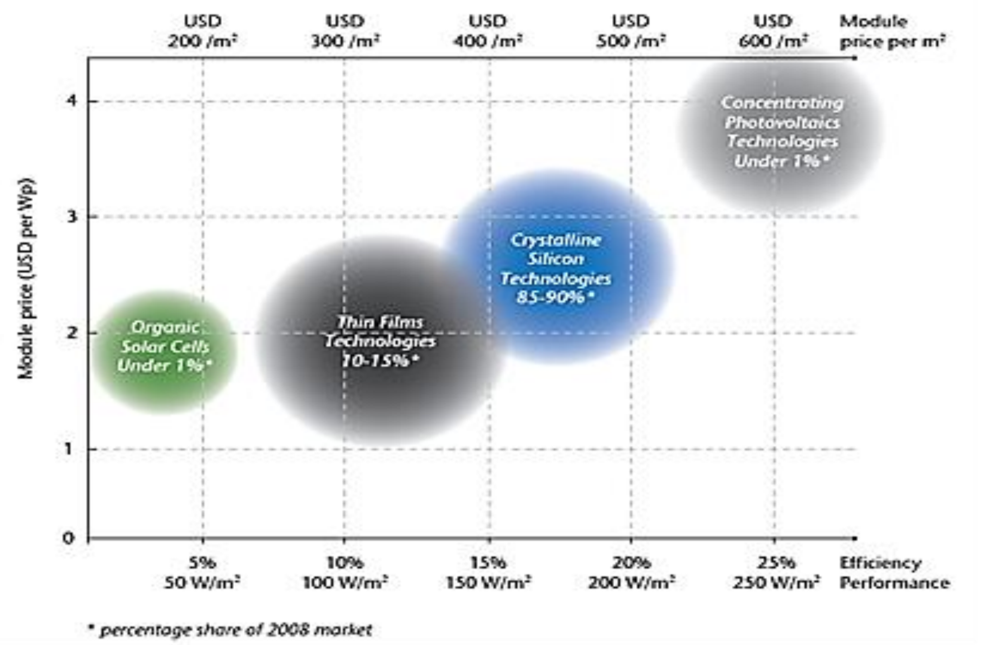


Figure (2.5): Current Performance and Price of Different PV Module Technologies.

Figure (2.5), Shows the current performance of different types of solar cells. We chose amorphous PV cells, with efficiency 10-15%, In spite of their efficiency is lower than others; Because of their light weight, flexibility, durability, sensitivity to light (collects more energy in lower light situations than other technologies) and their ability to resist temperature (all panels become less efficient as they get hotter, Amorphous is less sensitive to high temperatures than crystalline).

2.3.5 Electrical Components:

There are many electrical components which are used in this project to protect and operate a refrigeration cycle. The components are:

1. Bluetooth module (HC05): It sends control signals from the mobile device to the control panel and also receives data sent from the control panel to display on the mobile screen, see figure (2.6).

Figure (2.6): Bluetooth module (HC05).

2. Ardunio Nano: Two Ardunios were used in this project (One to control the voltages and the other to control the heat), see figure (2.7).

Figure (2.7): Ardunio Nano.

3. Relay: Four relays were used in this project for protection, see figure (2.8).

Figure (2.8): Relay.

4. Voltage Sensor: Two voltage sensors were used, see figure (2.9).

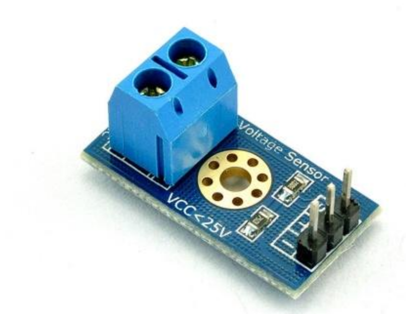


Figure (2.9): Voltage Sensor.

5. Temperature Sensor (LM35): It is used in this project to see the temperature inside the chamber, see figure (2.10).

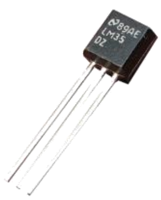


Figure (2.10): Temperature Sensor (LM35).

6. Breadboard: Two of the Breadboard are used to plug the components together, see figure (2.11).

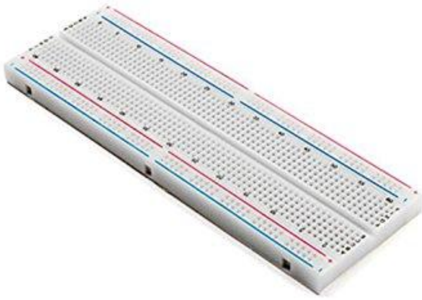


Figure (2.11): Breadboard.

7. Storage Batteries: Two of the Storage Batteries are used in this project, see figure (2.12).

Figure (2.12): Storage Battery.

2.3.6 Secondary Components:

1. Epoxy: is one of the heat sink attachment methods, provides a greater mechanical bond between the heat sink and component, as well as improved thermal conductivity.

2. Cables, Wood and Insulation panel.

3

Chapter Three

System Design

3.1 Introduction:

This chapter discusses the design option of the components of the system and conceptual design of the system such as the work of the components system.

3.2 Brief Description of the System:

The major components of the solar thermoelectric refrigerator include: thermoelectric module, vacuum flask (Thermos), heat sink, and solar cells. Thermoelectric modules are used to provide cooling to the refrigerator space. The electrical power generated by the solar cells is supplied to the thermoelectric refrigerator by means of the photovoltaic effect. In addition, the thermos is used as a body in the refrigerator where the product is to be cooled, in order to inhibit the heat transfer when operating and to evenly distribute the cold for a uniform temperature within the whole refrigerator. They also used to prevent any loss in the performance of the refrigerator to be affected by external heat which is important when the refrigerator is used in hot conditions. The heat sinks are used to enhance and increase the rate of heat transfer from the hot side of the thermoelectric module to the outside of the refrigerator to ambient surroundings, and from the cold side of the thermoelectric module to the inside of the refrigerator to cool the beverage can.

3.3 Design Option:

3.3.1 Thermos Design:

The Thermos specification and dimensions that selected as in the following table (Table 3.1):

Table (3.1): Vacuum Flask (Thermos) Specifications.

Name	Volume	Insulation	Material
Zoie + Chloe Vacuum Insulated Stainless Steel Jar	350 ml	Double wall vacuum insulated	Stainless Steel

3.3.2 Thermoelectric Module Design:

To design the thermoelectric module we need to calculate Cooling capacity from the module and temperature differences on both sides of the module:

1. Cooling capacity from the module is 13.815 W.
2. Temperature differences on both sides of the module, calculated by:

$$\boldsymbol{\Delta T = T_{hot} - T_{cold}} \qquad (3.1)$$

Where:

T_{hot}: temperature from hot side module [^{o}C].
T_{cold}: temperature from cold side module [5 ^{o}C].

- Keeping heat-sink at 15 above ambient temperature, then temperature from hot side is:

  $T_{hot} = T_{surr} + 10^{o}C = 31 + 10 = 41\ ^{o}C.$

- By applying equation (3.1), temperature difference (ΔT):

  $\Delta T = 41 - 5 = 36^{o}C$

- Thermoelectric module TEC1-12706 (see spec sheet), has the following parameters, in (Table 3.2):

Table (3.2): TEC Model Specification

Module: Model TEC1-127-06			
Q_{max}	66.7 W	Dimensions	
I_{max}	6.1 Amp	Width	40 mm
V_{max}	17.2 V	Length	40 mm
T_{max}	79 ^{o}C	Thickness	3.8 mm

- From TEC module performance Figure 3.1, at ΔT=$36^{o}C$, Q_c = 13.815 W:
  Voltage=10 V and current=3.5 A.

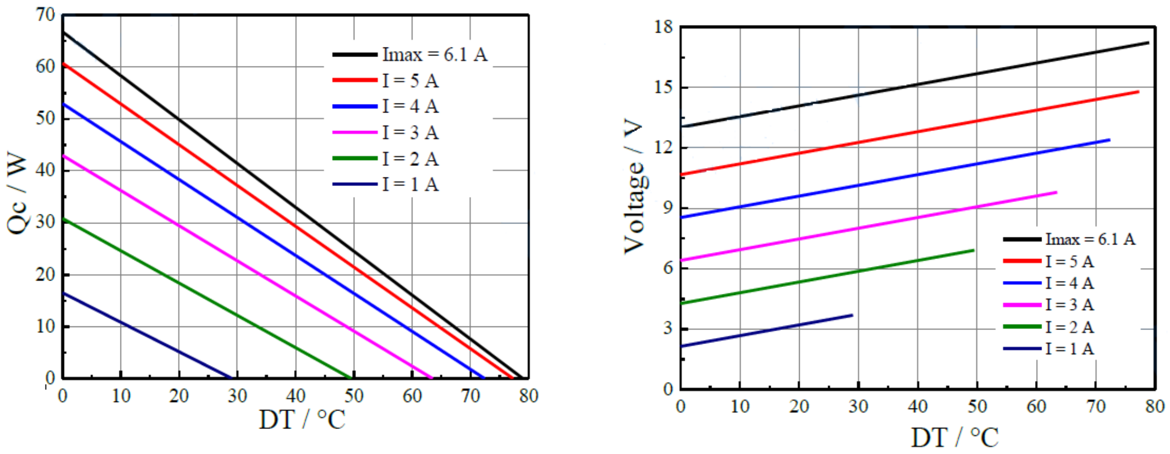


Figure (3.1): TEC Module Performance Graph (Obtained From TEC Module Spec Sheet).

3.3.3 Heat Sink Design:

Two heat sinks will be used for the hot side and the other for cold side.

- **For Hot Side:**

The heat sinks will be selected on the basis thermal resistance. The thermal resistance of a heat sink indicates the heat sink's ability to remove the heat. The lower the rated thermal resistance number is the faster the heat sink is able to draw out the heat from the processor. And we can calculate it by:

$$\boldsymbol{R_{th} = \frac{T_{hot} - T_{surr}}{Q_{tec,tot}}} \qquad (3.2)$$

Where:

R_{th}: Thermal resistance of heat sink [$^oC/W$].
$Q_{tec,tot}$: Total heat that must be dissipated by the hot side heat sink [W], and it is calculated by:

$$\boldsymbol{Q_{tec,tot} = Q_{tec} + Q_c} \qquad (3.3)$$

Where:

Q_c: Cooling load [W].
Q_{tec}: Heat produced internally by TEC module [W], and it is calculated by:

$$\boldsymbol{Q_{tec} = V * I} \qquad (3.4)$$

Where:

V: Voltage TEC module [V].
I: Current TEC module [A].

- By applying equation (3.3) and (3.4):

$Q_{tec} = V * I = 10 * 3.5 = 35\ W$, and

$Q_{tec,tot} = Q_{tec} + Q_c = 35 + 13.815 = 48.815\ W$.

- Applying equation (3.2), thermal resistance:

$$R_{th} = \frac{41 - 31}{48.815} = 0.205\ ^oC/W.$$

- A heat sink rating ($0.205\ ^oC/W$) or less must be used with TEC module.

Heat sink sizing: Heat sink design parameters (Figure 3.2) given as in (Table 3.3):

Table (3.3): Fin Parameters for Hot Side.

Space Between Fins (B)	$1.2*10^{-3}$ m
Fin Length (L)	0.03 m
Heat Sink Depth (W)	0.03 m
Fin Thickness (T)	0.001 m
# Of Fins (N_{fin})	70
Material	Aluminum

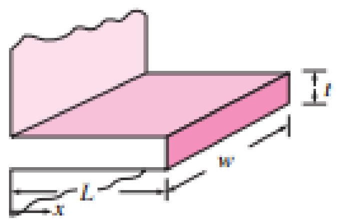


Figure (3.2): Fin Design Parameters.

- For air velocity between fins, we calculate it through:

$$V = \frac{v}{N_{fin} * b * L} \qquad (3.5)$$

Where:

V: Air velocity between fins [m/s].
v: Volumetric flow rate of heat sink fan [30 CFM] from fan parameters.

Volumetric flow rate of heat sink fan $v = 30\ CFM = 0.0142\ m^3/s$

Applying equation (3.5), air velocity:

$$V = \frac{0.0142}{70 * 1.2 * 10^{-3} * 0.03} = 5.635\ m/s$$

- The composite module for forced convection for the plate fin heat sink is given by the equation: [5]

$$Nu = C(Re)^n Pr^{1/3} \qquad (3.6)$$

Where:

Nu: Nusselts number.
R_e: Reynolds number.
Pr: Prandtl number of air at film temperature (T_f).
C,n: constants can be obtained from Table (A-3).

$$T_f = \frac{T_w + T_\infty}{2} \qquad (3.7)$$

Where:

T_f: Film temperature [^oC].
T_w: Wall temperature [^oC].
T_∞: Free temperature [^oC].

The properties of are evaluated at the film temperature, which can calculated by equation (3.7), applying this equation:

$$T_f = \frac{41 + 31}{2} = 36\ ^oC$$

- Using Table (A-4), different properties can be determined at T_f :

μ=1.89*10^{-5} [kg/m.s].
Pr=0.706.
K=0.0273 [W/m.^{o}C].
ρ= 1.1451 [kg/m^3].
Cp=1.0063*10^3 [J/kg.K].

- The Reynolds number is calculated by:

$$R_e = \frac{\rho * V * b}{\mu} = \frac{1.1451 * 5.635 * 1.2 * 10^{-3}}{1.89 * 10^{-5}} = 409.7$$

Applying equation (3.6), Nusselts number at (C=0.683, m=0.466):

$$Nu = 0.683 * (409.7)^{0.466} * (0.706)^{1/3} = 10.03$$

- Average heat transfer co-efficient:

$$\boldsymbol{h = \frac{Nu * K_{air}}{b}} \qquad (\mathbf{3.8})$$

Where:

h: The heat transfer co-efficient that would be obtained through the fins [W/m^2.^{o}C].
K_{air}: Thermal conductivity of air [W/m.^{o}C].

Applying equation (3.8), convection heat transfer coefficient:

$$h = \frac{10.03 * 0.0273}{1.2 * 10^{-3}} = 228.18\ \mathrm{W/m^2.^oC}$$

- Now the fin efficiency is calculated by the following equations:

$$\boldsymbol{\eta_f} = \frac{\mathbf{tanh}\ (\boldsymbol{mL_c})}{\boldsymbol{mL_c}} \qquad (\mathbf{3.9})$$

- $$\boldsymbol{m} = \sqrt{\frac{\mathbf{2}\boldsymbol{h}}{\boldsymbol{K_{fin}} * \boldsymbol{t}}} \qquad (\mathbf{3.10})$$

Where:

K_{fin}: Thermal conductivity of aluminum [202 W/m.^{o}C] from Table (A-5).
L_c: correct length of the fin [m].

Perimeter of the fin (L_c) =L +$\frac{t}{2}$ =0.06+$\frac{0.001}{2}$=0.0605 m.

Applying equation (3.9) and (3.10):

$$m = \sqrt{\frac{2 * 228.18}{202 * 0.001}} = 47.53$$

$$\eta_f = \frac{\tanh\ (47.53*0.0605)}{47.53*0.0605} = 0.5$$

- Heat sink thermal resistance is given by:

$$\boldsymbol{R_{hs}} = \frac{\mathbf{1}}{\boldsymbol{\eta_0 h A_t}} \qquad (\mathbf{3.11})$$

Where:

η_0: overall surface efficiency which characteristic an array of fins and the base to which they are attached [5].

$$\boldsymbol{\eta_0} = \mathbf{1} - \frac{\boldsymbol{NA_f}}{\boldsymbol{A_t}}(\mathbf{1} - \boldsymbol{\eta_f}) \qquad (\mathbf{3.12})$$

Where:

A_f: fin surface area=2wL_c [m^2].
A_t: Area associated with both the fins and exposed surface of the base [m^2].
$A_t = NA_f + A_b$.

A_b: Base area of spaces between fins [m^2]:

$A_b = (N-1).b.w = (70-1)*1.2*10^{-3}*0.03 = 2.484*10^{-3}\ m^2$

Area of fin (A_f) =2*0.03*0.0605=3.63*10^{-3} m^2.

$A_t = 70*3.63*10^{-3} + 2.484*10^{-3} = 0.257\ m^2$

Applying equation (3.12):

$$\eta_0 = 1 - \frac{70*3.63*10^{-3}}{0.257}(1-0.5) = 0.506$$

Applying equation (3.11), thermal resistance is:

$$R_{hs} = \frac{1}{0.506*228.18\ *0.257} = 0.04\ ^oC/W.$$

- Hence:

$0.04\ ^oC/W \ll 0.205\ ^oC/W$, therefore heat sink design meets requirements.

Specifications of Fan:

Table (3.4): Specifications of Fan for Hot Side.

Voltage	12 V
Power	1.2 W
Air Volume	30 CFM
Dimension	90*90*25 cm

- **For Cooled Side:**

Table (3.5): Fin Parameters for Cold Side.

Fin Parameters	
Thermal Resistance	0.5 ^{o}C/W
Dimension	50*50*20 mm
Efficiency	0.6
# Of Fins (N_{fin})	40
Material	Aluminum

3.3.4 Solar Cells Design:

3.3.4.1 Calculation of Solar Panel:

Calculation of the power consumed by the TEC modules, one fan and two Arduino Nano were used in the project:

- The TEC module takes a maximum of 3.5A and 10V. The power needed to give maximum cooling efficiency= 3.5*10 = 35 W.
- The power consumed by the fan is 1.2W.
- Calculation of the power consumed by the Arduino Nano:
  The single Arduino module needs 5 V and 40mA,
  Then the power needed = $5*40*10^{-3}$ = 0.2 W.
- Total power needed from solar cell:

  Total power= power consumed by the module + power Consumed by fan + power Consumed by two Arduinos =35+1.2+2*(0.2) = 36.6 W.
- Efficiency, η_{pv} of solar panel is 10-15%.
- $$\boldsymbol{E_{load} = Total\ Power * Time\ operating} \qquad (3.13)$$

Appling equation (3.13):

$$\boldsymbol{E_{load} = 36.6\ W * \left(\frac{50}{60}\right)\frac{h}{day} = 30.5\ W.h/day.}$$

- $$\boldsymbol{E_{solar\ panel} = \frac{E\ load}{\eta_{pv}}} \qquad (3.14)$$

Appling equation (3.14):

$$\boldsymbol{E_{solar\ panel} = \frac{30.5}{0.1} = 305\ W.h/day.}$$

- Calculate area of solar panel:

$1m^2$ ------------------------ 5400 [W.h/day].

A -------------------------- $E_{solar\ panel}$.

Where:

A: area of solar panel [m^2].
5400 [W.h/day]: annual rate radiation.

$1m^2$ ------------------------- 5400 [W.h/day].

A -------------------------- 305.

- $A = \frac{305}{5400} = 0.056\ [m^2]$.
- The area of solar panel that selected is 0.0629 m^2 (0.0629 > 0.056).

3.3.4.2 Coefficient of Performance (COP):

COP can be defined as, "it is the ratio of cooling effect achieved to the electrical energy consumed" [7], is calculated for 350 ml beverage box inside the cabinet by:

$$\boldsymbol{COP = \frac{Q_{cooling}}{W_{in}}} \qquad (3.15)$$

Where:

$Q_{cooling}$: from beverage box (Active Load) [W].
W_{in}: work done [W].

By applying equation (3.15), Coefficient of Performance (COP) is:

$$COP = \frac{6.977}{36.6} = 0.2$$

3.3.5 Storage Batteries Design:

Batteries are needed to supply TEC module and electrical elements (Fan, Arduino Nano) with suitable electric current in the absence of direct electricity from solar radiation.

Two (12V, 1.3Ah) batteries type MOTOMA1.3Ah vision SLA-MS12V1.3 are needed for operating time (50 min).

4

Chapter Four

Implementation

4.1 Introduction:

This chapter discusses project implementation in terms of hardware and in terms of software. Also shows the connections and application of the project and the block diagram of the project.

4.2 Hardware:

This section will discuss the fabrication and installation of the hardware components and parts, the mechanical hardware will discuss the refrigeration chamber components, while the electrical hardware will discuss the components and the connection circuit.

4.2.1 Mechanical Hardware:

The refrigeration chamber was manufactured as shown in Figure (4.1) and consisted of several fabricated parts: the wooden platform, the stainless steel chamber which was installed at the center of the wooden platform, the insulation plates which that combines the internal fin and the TEC module with the external fin and fan, Where they are fixed together by using an epoxy adhesive and screws as shown in Figure (4.2).

Figure (4. 1): Refrigeration chamber.

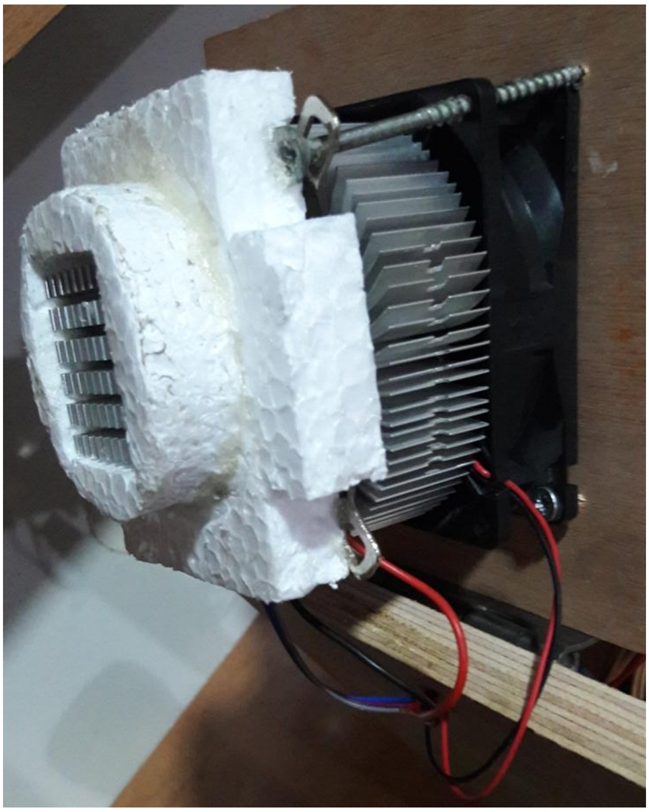


Figure (4. 2): Heat sinks implementation.

4.2.2 Electrical Hardware:

The commands are sent from the Smartphone application to the Bluetooth module, and the Bluetooth module sends the commands to the two control units via a serial port. At the same time, the Bluetooth module receives readings of the voltages of the two batteries and the comparison between them and selects the high-voltage battery to power the system and leave the other to charge, (If both batteries are less than 14 volts, voltages are converted from one battery to another).

Also the Bluetooth module receives temperature readings from the LM-35 sensor and sends them back to the other microcontroller. The microcontroller determines which relay will be operated according to the Smartphone application and will be stopped according to the temperature measurement.

Figure (4.3) determine practical connection of electrical parts in this project.

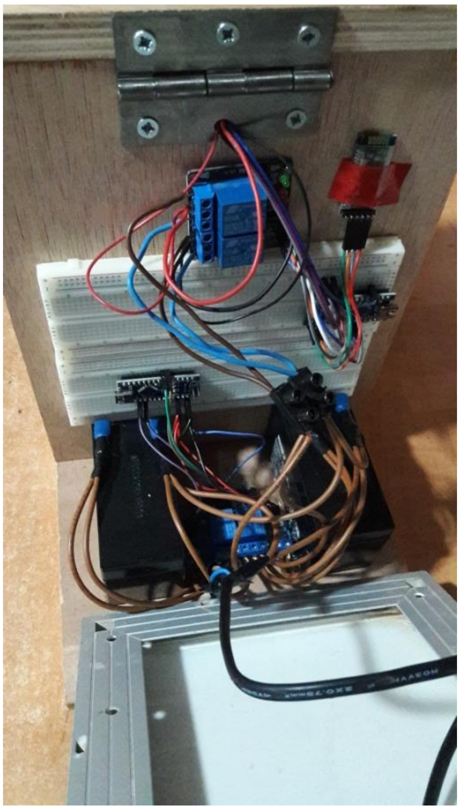


Figure (4. 3): practical connection of electrical parts.

The circuit diagram for the electrical hardware is shown in Figure (4.4a) and (4.4b).

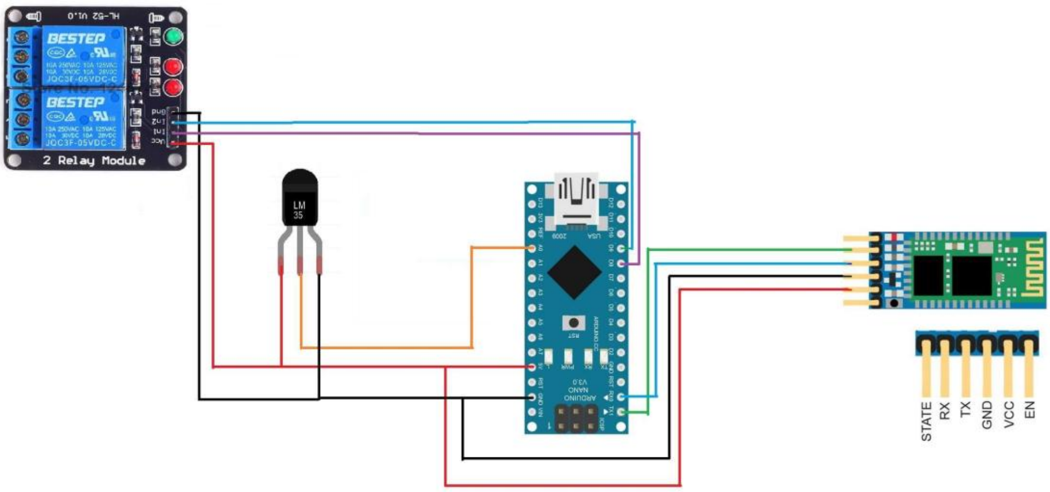


Figure (4.4a): Electric circuit control temperature.

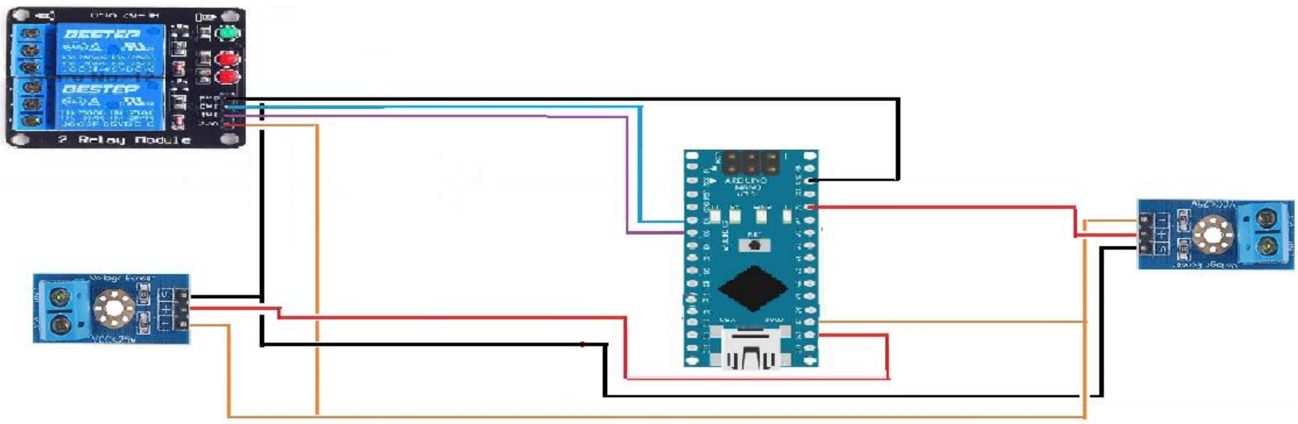


Figure (4.4b): Electric circuit control voltage.

- The block diagram for the electrical hardware as shown in Figure (4.5):

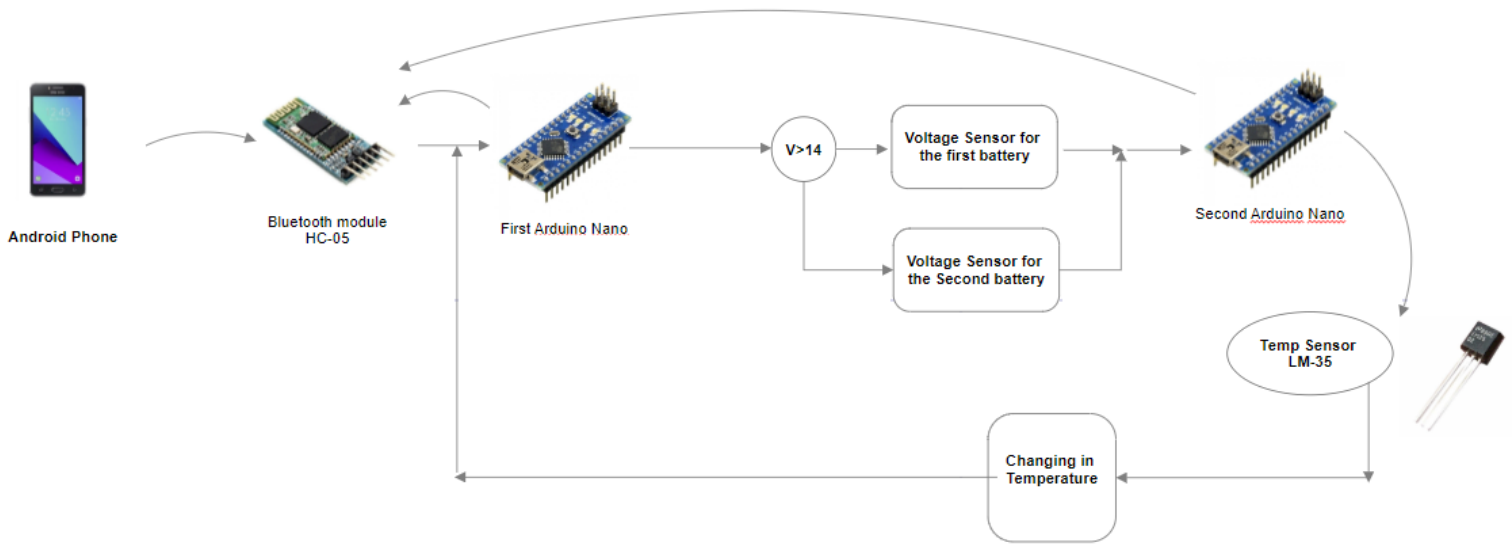


Figure (4. 5): block diagram for the electrical hardware.

4.3 Software:

After understanding the operation of the electrical system, and install all the mechanical and electrical components, it is easy to write the code. This section will describe the main functions in the Arduino and mobile application codes of this robot.

4.3.1 Mobile Application:

The App inventor program was used to design and to write the application's code, Figure (4.6) shows the user interface for the application.

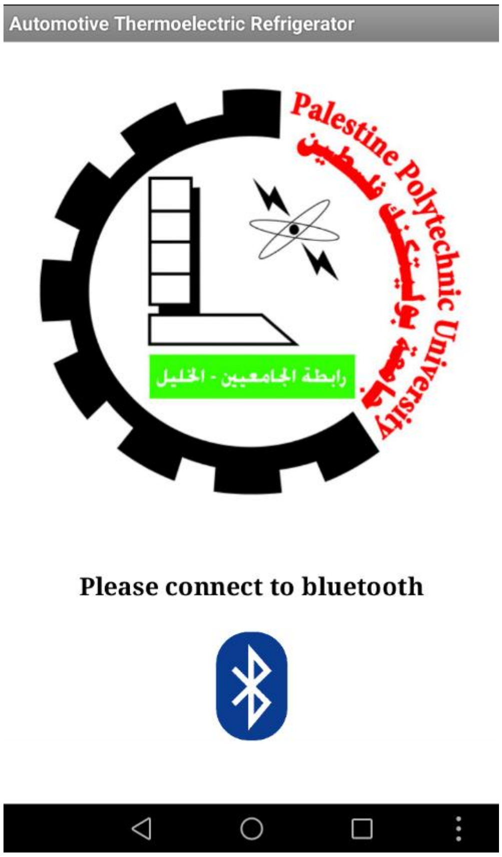


Figure (4.6): Application user interface.

The App inventor uses the block diagram in coding the application, Figure (4.7) show the code for the cooling and heating modes in the application, moreover, the complete code can be found in the Appendix (B).

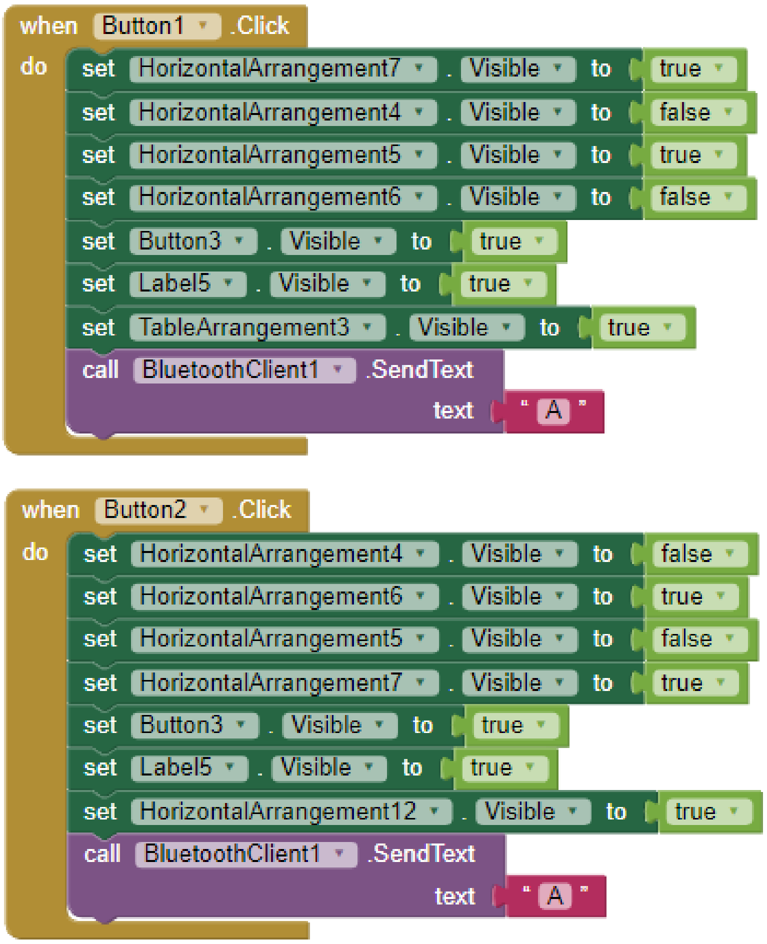


Figure (4.7): Application Code.

4.3.2 Microcontrollers Code:

An Arduino UNO was used as a microcontroller. This section will describe the main functions in the Arduino code. However, Appendix (c) contains the complete code for Arduino.

The Arduino code starts by defining the variables that used in the code.

```
#include <SoftwareSerial.h>
int cooling=13; //define pin 13 for cooling mode relay
int heating=12; //define pin 12 for heating mode relay
float T1; // the refrigerator temperature
```

The next step in the code, is to define the pins set up. This operation was done in void setup because it is done at one time only at the start of the code.

```
char recieve; //the bluetooth command
void setup()
{
 Serial.begin(9600);  //Set rate for communicating with phone
 pinMode(cooling,OUTPUT); //Set relay1 as an output
 pinMode(heating,OUTPUT); //Set relay1 as an output

}
```

After that, the main loop function is defined. This will be executed repeatedly every cycle to receive and send the temperature measurement and set the relays on or off according to the command.

In the void loop for the microcontroller, it measures the temperature measurement and convert it to a voltage, then it receives the command form the application via the Bluetooth module, that contains the mode and desired temperature.

```
void loop()
{
   T1 = analogRead(A0); //getting the voltage reading from the temperature sensor
      T1 = T1 * 0.48828125; // converting that reading to voltage.

      Serial.print("Temperature=");
      Serial.println(T1);
      delay(10000);
  if(Serial.available()>0)//Check if there are available bytes to read
  {
    recieve=Serial.read(); //Conduct a serial read
  }
  {
    if(recieve== 'a')
    {
      digitalWrite(cooling,HIGH);//Switch relay1 on
    }
    if(recieve=='A' || recieve== 'a'&& T1<=0)
    {
      digitalWrite(cooling,LOW);//Switch relay1 off
    }
```

5

Chapter Five

Tests and Results

5.1 Introduction:

This chapter shows the experiments that were tested in the project, discuss these experiments, and identify the results and compare them with what was expected.

5.2 Tests And Results:

Several experiments have been conducted in this project on the vacuum flask insulated, cooling mode, heating mode and Coeffecient Performance for the system, these experiences and their results will be explained below:

5.2.1 Tests And Results For Vacuum Flask Insulated:

An experiment was conducted to determine the rate of heat transfer through the walls of the vacuum flask. The experiment was conducted within a specified period of time as shown in the diagram in Figure (5.1). The figure also shows the temperature changes inside and outside the flask.

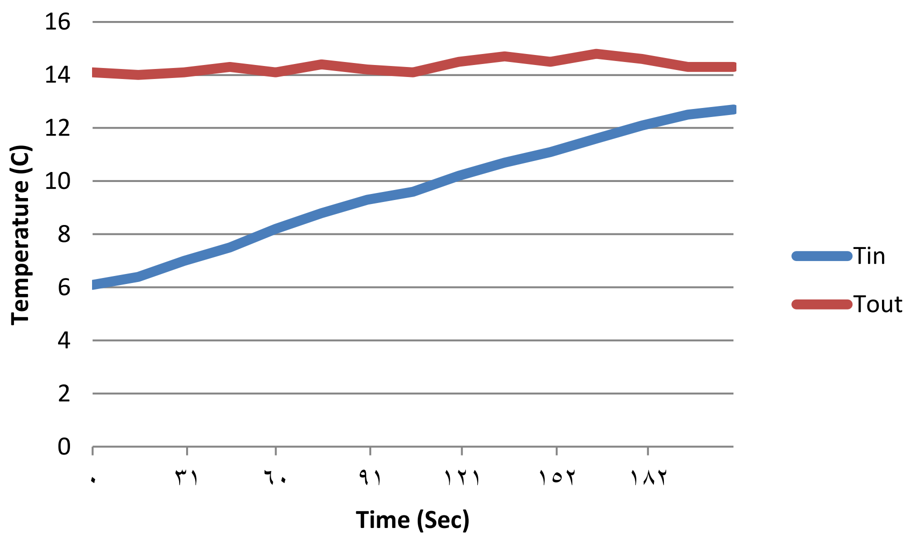


Figure (5.1): Temperature (^{0}C) V.S Time (Sec).

Through these values (change in temperature and time) and knowledge of the vacuum flask area, the value of the heat transfer coefficient was determined, (K = 0.012 W/m^{2}.^{0}C), which is a small value, but larger than the value of heat transfer coefficient in the case of vacuum, However, it is suitable for the project.

5.2.2 Tests And Results For Cooling Mode:

The next curve shows the relationship between the temperature (^{0}C) and the time in seconds for 250 mL of water at 15 ^{0}C.

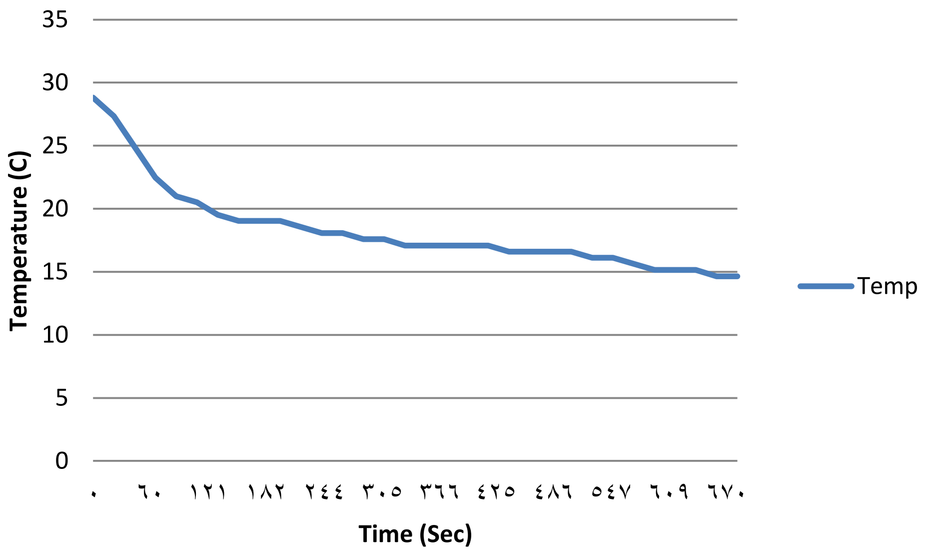


Figure (5.2): Temperature (^{0}C) V.S Time (Sec), (Preserving at 15 ^{O}C).

The next curve shows the relationship between the temperature (^{o}C) and the time in seconds for 250 mL of water at 10 ^{o}C.

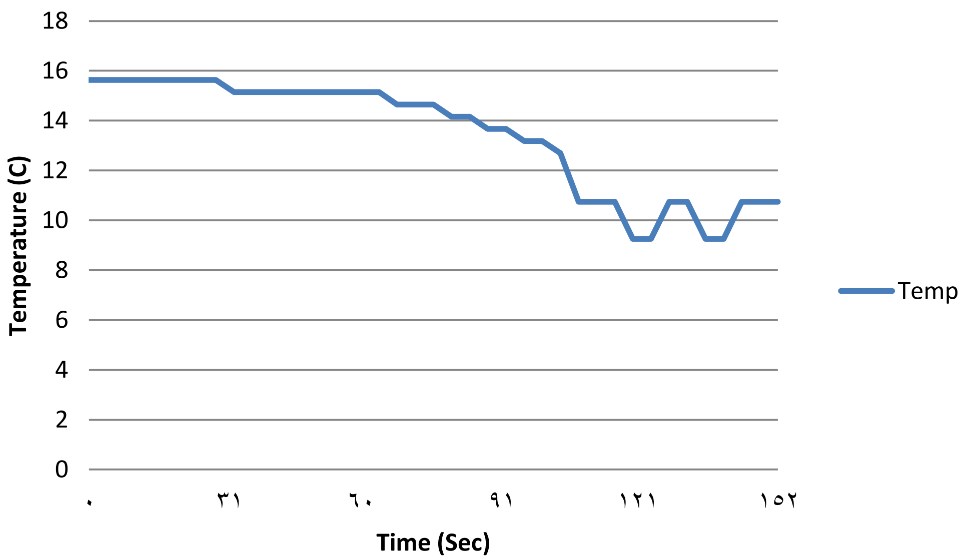


Figure (5.3): Temperature (^{0}C) V.S Time (Sec), (Preserving at 10 ^{O}C).

The next curve shows the relationship between the temperature (^oC) and the time in seconds for 250 mL of water at 5 ^oC.

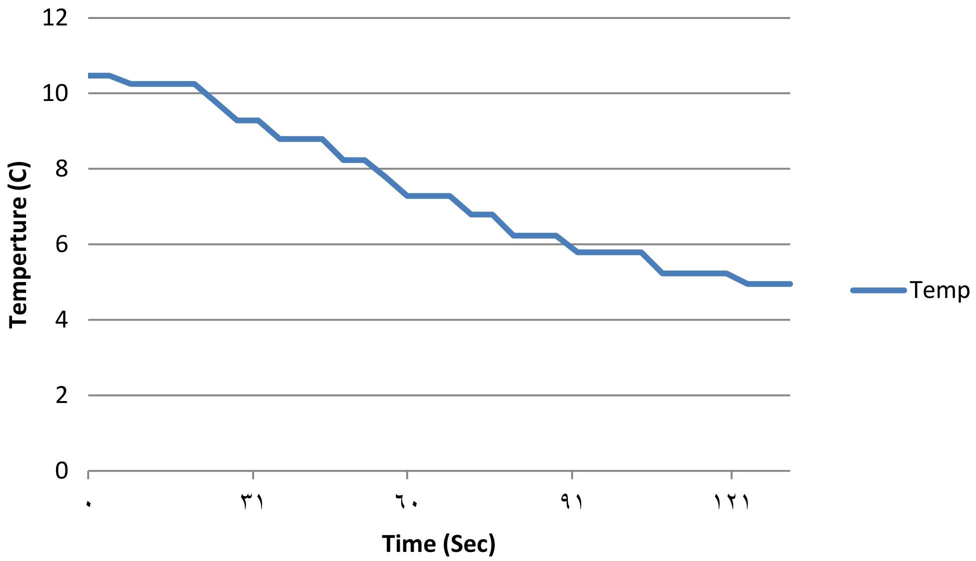


Figure (5.4): Temperature (^0C) V.S Time (Sec), (Preserving at 5 ^OC).

The next curve shows the relationship between the temperature (^oC) and the time in seconds for air sensible cooling.

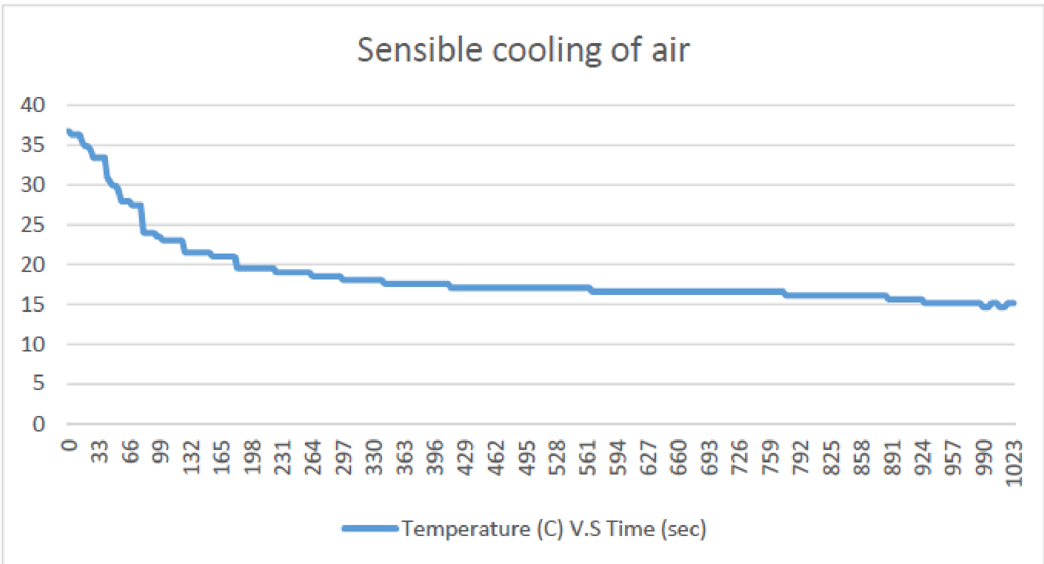


Figure (5.5): Temperature (^0C) V.S Time (Sec).

5.2.3 Tests And Results For Heating Mode:

The following curve shows the relationship between the temperature (^oC) and the time in seconds for air sensible heating.

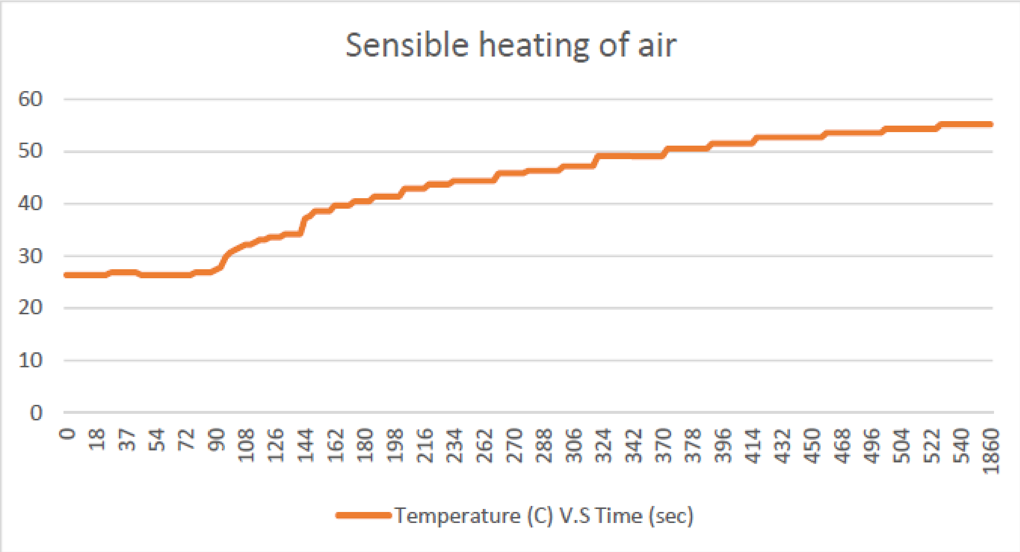


Figure (5.6): Temperature (^0C) V.S Time (Sec).

The following curve shows the relationship between the temdecreasing of temperature through 30 min) is determined as the following:

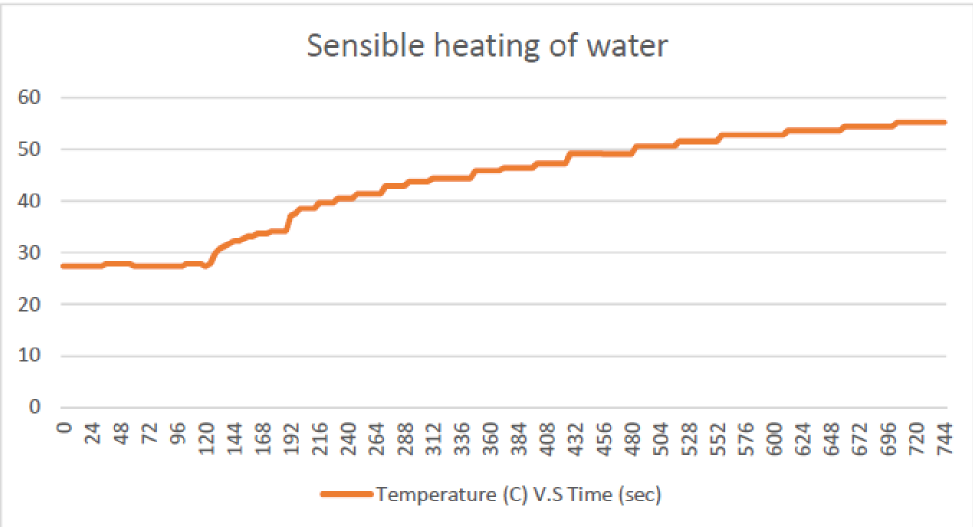


Figure (5.7): Temperature (^0C) V.S Time (Sec).

5.3 Coefficient of Performance (COP):

1- For Cooling Mode:

By applying equation (3.13), the COP from the testing (See figure (5.8); determines the decreasing of temperature through 30 min) is determined as the following:

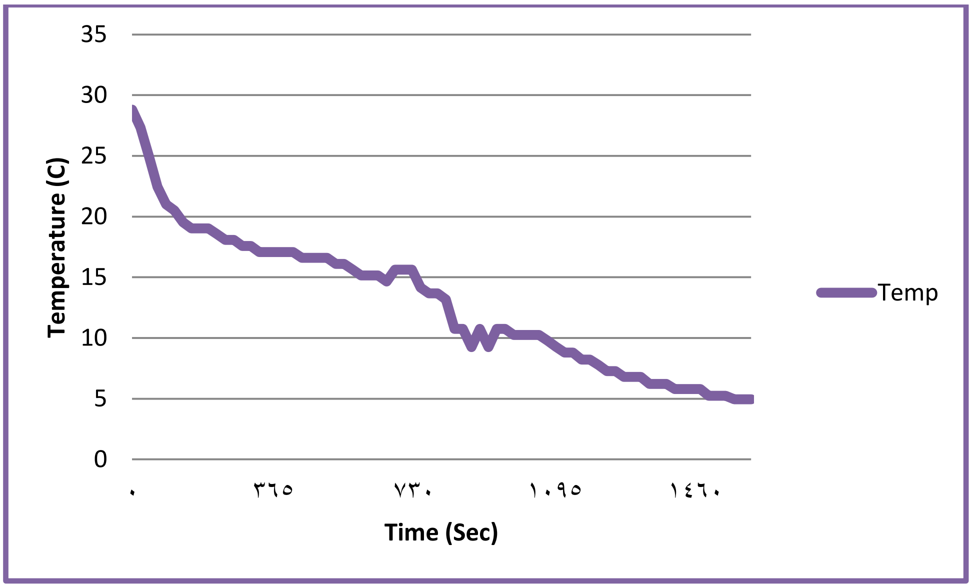


Figure (5.8): Temperature (^{0}C) V.S Time (Sec).

Slope = 0.0149 ^{o}C/sec.

Q_c = m.C_p. Slope =250*4.186*0.0112= 11.7 W.

W_{in} = 48 W.

- COP = 11.7/36.6 = 0.33.

2- For Heating Mode:

From diagram in figure (5.7), the slope = 0.0381 ^{o}C/sec.

COP = 35.9 / 36.6 = 0.98.

5.4 Conclusion & Recommendations:

Conclusion:

The COP for sensible heating is larger than sensible cooling (0.98, 0.33) respectively, however the The COP for cooling in the experiments was higher than the expected value therefore the COP for cooling is 0.33, which is reasonable for Peltier modules.

The results show that the COP for the system is inversely proportional to the temperature difference, moreover the lower the temperature on the hot side means lower temperature on the cold side, so to have a lower temperature on the cold side a larger amount of heat from the Peltier must be removed.

Recommendations:

The LM35 temperature sensor must be changed with a thermocouple for more stable and accurate reading, that means the system needs to microcontrollers on will be master and the other will be a slave, moreover the HC-05 Bluetooth module could be changed to a Wi-Fi module for more options in the application, and finally it is best to use a cell tracking system.

Reference

[1] M. K. Rawat, H. Chattopadhyay, and S. Neogi, "A review on developments of thermoelectric refrigeration and air conditioning systems : a novel potential green refrigeration and air conditioning," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 3, no. 3, pp. 362–367, 2013 .

[2] S. B. Patond, P. G. Bhadake, and C. B. Patond, "Experimental Analysis of Solar Operated Thermo-Electric Heating and Cooling System ISSN : 2231-5381," vol. 20, no. 3, pp. 125–130, 2015.

[3] Y. Dai, R. Wang, and L. Ni, "Experimental investigation and analysis on a solar thermoelectric refrigerator," *Taiyangneng Xuebao/Acta Energiae Solaris Sin.*, vol. 23, no. 6, pp. 377–391, 2002.

[4] S. A. Abdul-Wahab *et al.*, "Design and experimental investigation of portable solar thermoelectric refrigerator," *Renew. Energy*, vol. 34, no. 1, pp. 30–34, 2009.

[5] E. E. and W. C. A.A. Adeyanju, "Experimental and theoretical analysis of a beverage chiller," vol. 5, no. 3, pp. 195–2033, 2010.

[6] M. K. Rawat, P. K. Sen, H. Chattopadhyay, and S. Neogi, "Developmental and Experimental Study of Solar Powered Thermoelectric Refrigeration System," *Int. J. Eng. Res. Appl.*, vol. 3, no. 4, pp. 2543–2547, 2013.

[7] M. B. Dhawade, E. Mourya, A. Yadav, D. Samuel, S. A. Mohod, and V. N. Deshpande, "Review On Portable Solar Thermoelectric Refrigerator Cum Air Cooler," pp. 44–58.

[8] M. Awasthi and K. V Mali, "Design and Development of Thermoelectric Refrigerator," *Int. J. Mech. Eng. Rob. Res*, vol. 1, no. 3, 2012.

[9] Roy J. Dossat, Principles of refregration, Second edition, SI version,University of Houston, Houston, Texas, USA.

Appendix (A):

Table A-1: Maximum and Minimum Temperature for Hebron City.

Month	Max.Temp (^oC)	Min.Temp (^oC)
January	10.3	3
February	11.5	4.7
March	14.6	6.5
April	19.6	9.9
May	23.6	13.2
June	25.9	15.8
July	27.2	17
August	31	18
September	26	15
October	23.2	14
November	17.5	9.9
December	12.1	5.6

Table A-2: Air Change per Hour.

Kind of room building	Air change [time/hr]
Room with no windows or exterior door	0.5
Room with windows or exterior door on one side only	1
Room with windows or exterior door on two side only	1.5
Room with windows or exterior door on three side only	2
Entrance halls	2
Factories, machine shops	1 - 1.5
Recreation room, assembly rooms, gymnasium	1.5
Home, apartment, offices	1 - 2
Class room, dining room, lounges, toilets, hospital room, kitchen, laundries, ballrooms, bathrooms	1 - 2
Stores, public buildings	2 - 3
Toilets, auditorium	3

Table A-3: Constants at Reynolds Number.

Re_{df}	C	N
0.4 – 4	0.989	0.33
4.0 – 40	0.911	0.385
40 – 4000	0.683	0.466
4000 – 40000	0.193	0.618
40000 – 400000	0.0266	0.805

Table A-4: Properties of Air Atmospheric Pressure.

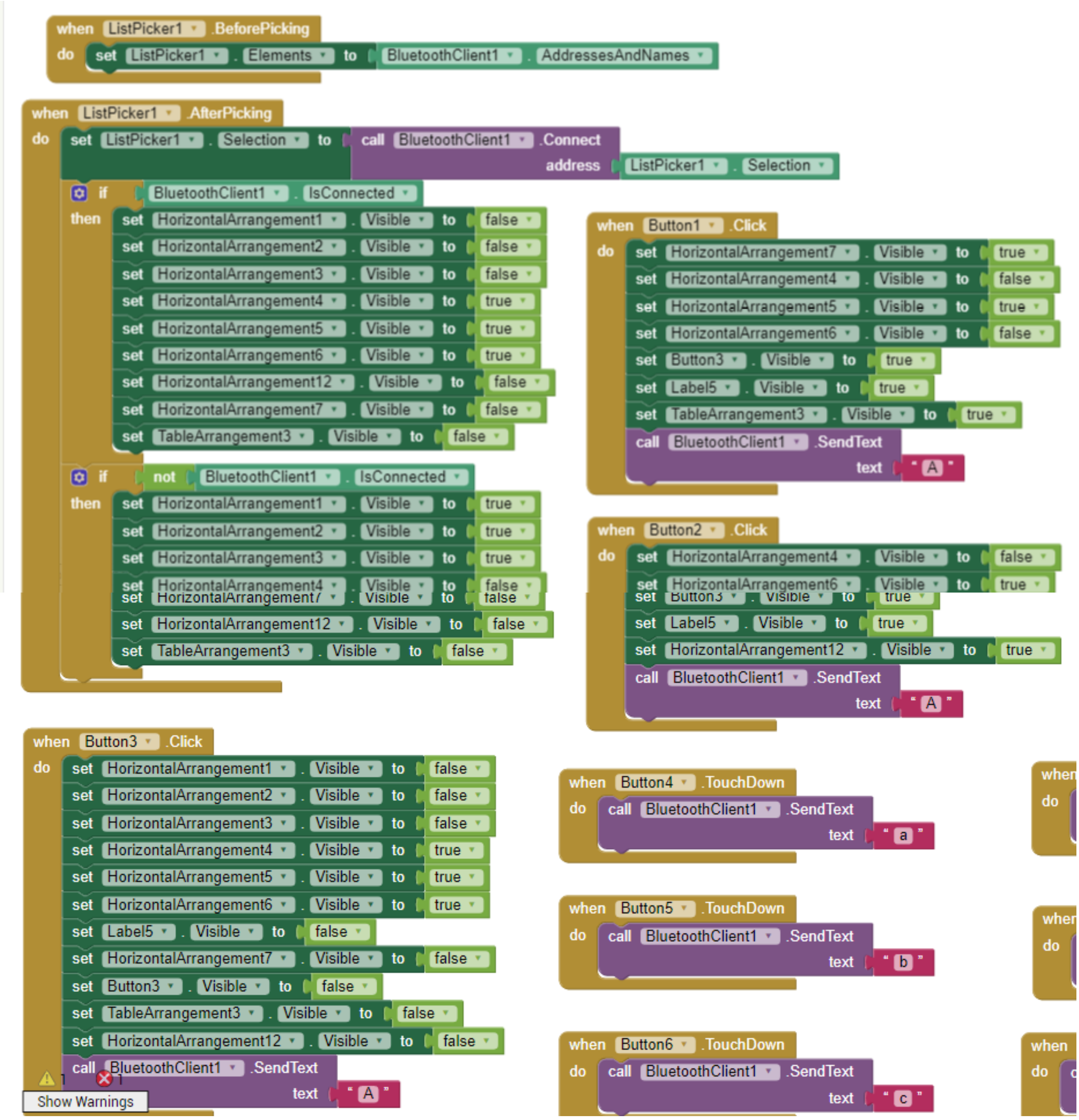
T (K)	ρ (kg/m^3)	c_p (kJ/kg-°C)	μ (kg/m-s) $\times 10^{-5}$	ν (m^2/s) $\times 10^{-6}$	k (W/m-°C)	α (m^2/s) $\times 10^{-4}$	Pr
100	3.6010	1.0266	0.692	1.923	0.00925	0.0250	0.770
150	2.3675	1.0099	1.028	4.343	0.01374	0.0575	0.753
200	1.7684	1.0061	1.329	7.490	0.01809	0.1017	0.739
250	1.4128	1.0053	1.488	9.490	0.02227	0.1316	0.722
300	1.1774	1.0057	1.983	16.84	0.02624	0.2216	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680
550	0.6423	1.0392	2.848	44.34	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.680
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.30	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06225	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702

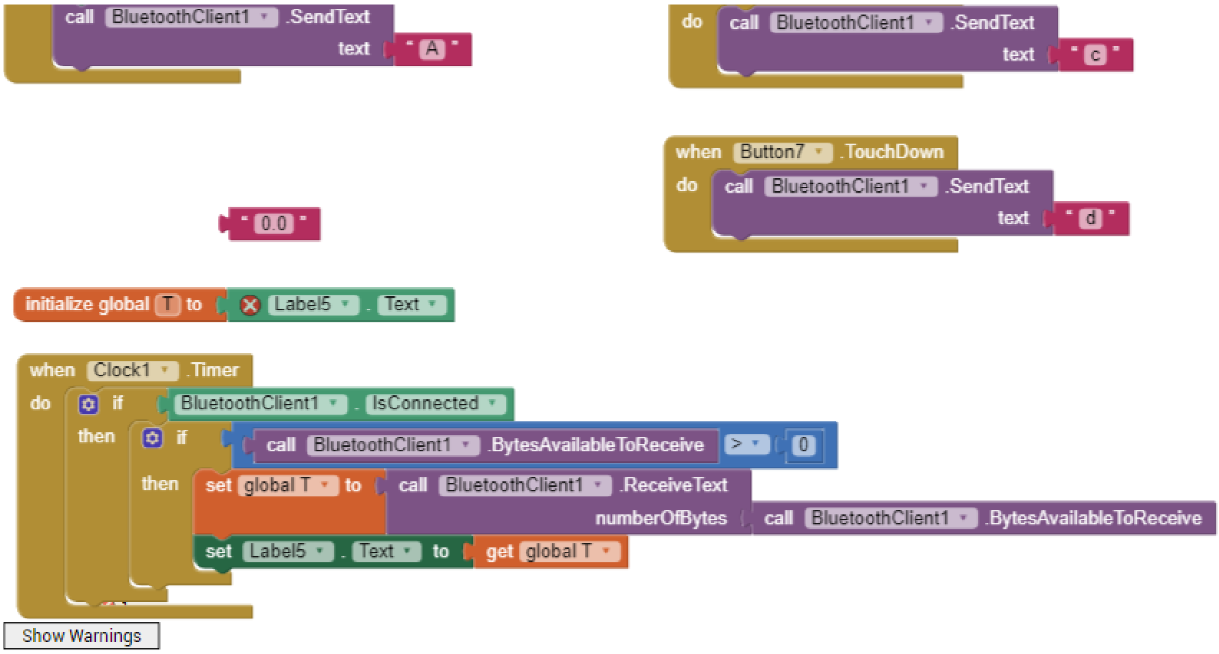
Notes: T = temperature, ρ = density, c_p = specific heat capacity, μ = viscosity, $\nu = \mu/\rho$ = kinetic viscosity, k = thermal conductivity, $\alpha = c_p\rho/k$ = heat (thermal) diffusivity, Pr = Prandtl number

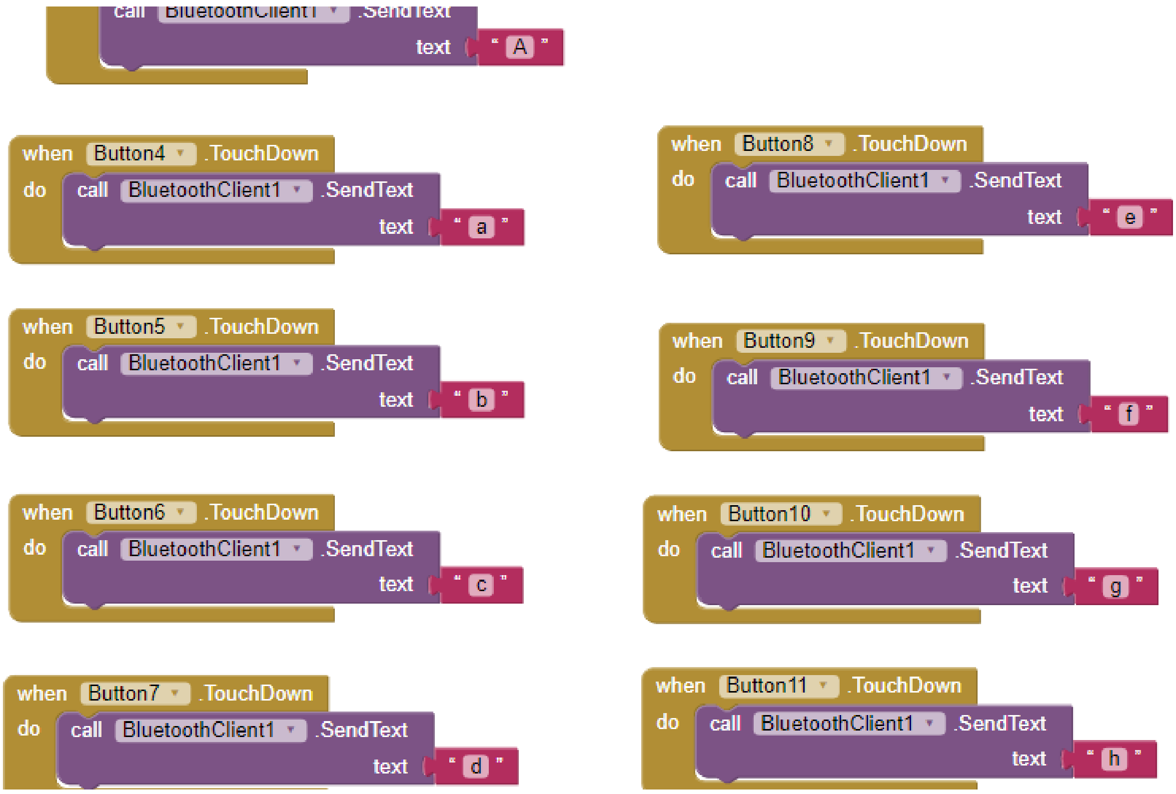
Table A-5: Thermal Conductivity of Materials

Material	Description	Thermal Conductivity (K) W/m2.K	Thermal Conductance (C) W/m2.K
Masonry	Brick, common	0.72	
	Brick face		
	Concrete, mortar or plaster	1.3	
	Concrete, sand aggregate	0.72	
	Concrete block	1.73	
	Sand aggregate 100 mm		7.95
	sand aggregate 200 mm		5.11
	Sand aggregate 300 mm		4.43
Woods	Maple, oak, similar hardwoods	0.16	
	Fir, pine, similar softwoods	0.12	
	Plywood 13 mm		9.09
	Plywood 1.9 mm		6.08
Roofing	Asphalt roll roofing		36.91
	Built-up roofing 9 mm		17.03
Insulating	Blanket or bat, mineral or glass fiber	0.039	
materials	Board or slab		
	Cellular glass	0.058	
	Corkboard	0.043	
	Glass fiber	0.036	
	Expanded polystyrene (smooth)	0.029	
	Expanded polystyrene (cut cell)	0.036	
	Expanded polyurethane	0.025	
Loose fill	Milled paper or wood pulp	0.039	
	Sawdust or shavings	0.065	
	Mineral wool (rock, glass, slag)	0.039	
Glass	Single pane		6.42
	Two pane		2.61
	Three pane		1.65
	Four pane		1.19
Metal	Stainless steel	18	
	Aluminum	202	
	Cooper	386	
	Galvanized steel	20	

Appendix (B):


when ListPicker1 .BeforePicking
do set ListPicker1 . Elements to BluetoothClient1 . AddressesAndNames
when ListPicker1 .AfterPicking
do set ListPicker1 . Selection to call BluetoothClient1 .Connect
address ListPicker1 . Selection
if BluetoothClient1 . IsConnected
then set HorizontalArrangement1 . Visible to false
set HorizontalArrangement2 . Visible to false
set HorizontalArrangement3 . Visible to false
set HorizontalArrangement4 . Visible to true
set HorizontalArrangement5 . Visible to true
set HorizontalArrangement6 . Visible to true
set HorizontalArrangement12 . Visible to false
set HorizontalArrangement7 . Visible to false
set TableArrangement3 . Visible to false
if not BluetoothClient1 . IsConnected
then set HorizontalArrangement1 . Visible to true
set HorizontalArrangement2 . Visible to true
set HorizontalArrangement3 . Visible to true
set HorizontalArrangement4 . Visible to false
set HorizontalArrangement7 . Visible to false
set HorizontalArrangement12 . Visible to false
set TableArrangement3 . Visible to false
when Button1 .Click
do set HorizontalArrangement7 . Visible to true
set HorizontalArrangement4 . Visible to false
set HorizontalArrangement5 . Visible to true
set HorizontalArrangement6 . Visible to false
set Button3 . Visible to true
set Label5 . Visible to true
set TableArrangement3 . Visible to true
call BluetoothClient1 .SendText
text " A "
when Button2 .Click
do set HorizontalArrangement4 . Visible to false
set HorizontalArrangement6 . Visible to true
set Button3 . Visible to true
set Label5 . Visible to true
set HorizontalArrangement12 . Visible to true
call BluetoothClient1 .SendText
text " A "
when Button3 .Click
do set HorizontalArrangement1 . Visible to false
set HorizontalArrangement2 . Visible to false
set HorizontalArrangement3 . Visible to false
set HorizontalArrangement4 . Visible to true
set HorizontalArrangement5 . Visible to true
set HorizontalArrangement6 . Visible to true
set Label5 . Visible to false
set HorizontalArrangement7 . Visible to false
set Button3 . Visible to false
set TableArrangement3 . Visible to false
set HorizontalArrangement12 . Visible to false
call BluetoothClient1 .SendText
text " A "
Show Warnings
when Button4 .TouchDown
do call BluetoothClient1 .SendText
text " a "
when Button5 .TouchDown
do call BluetoothClient1 .SendText
text " b "
when Button6 .TouchDown
do call BluetoothClient1 .SendText
text " c "


call BluetoothClient1 .SendText
text "A"
do call BluetoothClient1 .SendText
text "c"
when Button7 .TouchDown
do call BluetoothClient1 .SendText
text "d"
"0.0"
initialize global T to Label5 . Text
when Clock1 .Timer
do if BluetoothClient1 . IsConnected
then if call BluetoothClient1 .BytesAvailableToReceive > 0
then set global T to call BluetoothClient1 .ReceiveText
numberOfBytes call BluetoothClient1 .BytesAvailableToReceive
set Label5 . Text to get global T
Show Warnings


call BluetoothClient1 .SendText
text "A"
when Button4 .TouchDown
do call BluetoothClient1 .SendText
text "a"
when Button8 .TouchDown
do call BluetoothClient1 .SendText
text "e"
when Button5 .TouchDown
do call BluetoothClient1 .SendText
text "b"
when Button9 .TouchDown
do call BluetoothClient1 .SendText
text "f"
when Button6 .TouchDown
do call BluetoothClient1 .SendText
text "c"
when Button10 .TouchDown
do call BluetoothClient1 .SendText
text "g"
when Button7 .TouchDown
do call BluetoothClient1 .SendText
text "d"
when Button11 .TouchDown
do call BluetoothClient1 .SendText
text "h"

Appendix (C):

Temperature control code:

```
#include <SoftwareSerial.h>
int cooling=13; //define pin 13 for cooling mode relay
int heating=12; //define pin 12 for heating mode relay
float T1; // the refrigerator temperature

SoftwareSerial mySerial(0, 1);    // Rx tx

char recieve; //the bluetooth command
void setup()
{
 Serial.begin(9600);  //Set rate for communicating with phone
 pinMode(cooling,OUTPUT); //Set relay1 as an output
 pinMode(heating,OUTPUT); //Set relay1 as an output

}

void loop()
{
   T1 = analogRead(A0); //getting the voltage reading from the temperature sensor
      T1 = T1 * 0.48828125; // converting that reading to voltage.

      Serial.print("Temperature=");
      Serial.println(T1);
      delay(10000);
  if(Serial.available()>0)//Check if there are available bytes to read
  {
    recieve=Serial.read(); //Conduct a serial read
  }
  {
    if(recieve== 'a')
```

```
{
  digitalWrite(cooling,HIGH);//Switch relay1 on
}
if(recieve=='A' || recieve== 'a'&& T1<=0)
{
  digitalWrite(cooling,LOW);//Switch relay1 off
}

if(recieve== 'b')
{
  digitalWrite(cooling,HIGH);
}
if(recieve=='A'|| recieve== 'b' && T1<=5)
{
  digitalWrite(cooling,LOW);
}
if(recieve== 'c')
{
  digitalWrite(cooling,HIGH);
}
if(recieve=='A'|| recieve== 'c'&& T1<=10)
{
  digitalWrite(cooling,LOW);
}
if(recieve== 'd')
{
  digitalWrite(cooling,HIGH);
}
if(recieve=='A'|| recieve== 'd' && T1<= 15)
{
  digitalWrite(cooling,LOW);
```

```
 if(recieve== 'e')
  {
    digitalWrite(heating,HIGH);
  }
  if(recieve=='A'|| recieve== 'e'&& T1>=40)
  {
    digitalWrite(heating,LOW);
  }
  if(recieve== 'f')
  {
    digitalWrite(heating,HIGH);
  }
  if(recieve=='A'||  recieve== 'f'&& T1>= 45)
  {
    digitalWrite(heating,LOW);
  }
   if(recieve== 'g')
  {
    digitalWrite(heating,HIGH);
  }
  if(recieve=='A'||recieve== 'g'&& T1>= 50)
  {
    digitalWrite(heating,LOW);
  }
  if(recieve== 'h')
  {
    digitalWrite(heating,HIGH);
  }
  if(recieve=='A'||recieve== 'h'&& T1>= 55)
  {
    digitalWrite(heating,LOW);
```

Voltage control code:

```
int offset =0;// set the correction offset value
int B1charge=4; //define pin 8 for battery 1 charging mode relay
int B2charge=3; //define pin 6 for battery 2 charging mode relay

void setup()
{
  Serial.begin(9600);
  pinMode(B1charge,OUTPUT); //Set relay1 as an output
  pinMode(B2charge,OUTPUT); //Set relay2 as an output
}

void loop()
{
  int volt1 = analogRead(A0);// read the input
  double battery1 = map(volt1,0,1023, 0, 2500) + offset;// map 0-1023 to 0-2500 and add correction offset
    battery1 /=100;// divide by 100 to get the decimal values

   int volt2 = analogRead(A1);// read the input
  double battery2 = map(volt2,0,1023, 0, 2500) + offset;// map 0-1023 to 0-2500 and add correction offset
  battery2 /=100;// divide by 100 to get the decimal values
  Serial.print("Battery Voltage: ");
  Serial.print(battery1);//print the voltge
  Serial.print("   ");
  Serial.print(battery2);
  Serial.println("V");
  delay(1000);

 if( battery1 <= 14 && battery1 < battery2)
  {
    digitalWrite(B1charge,HIGH);//Switch relay1 on
    digitalWrite(B2charge,LOW);//Switch relay2 off
  }
    if( battery2 <= 14 && battery2 < battery1)
  {
    digitalWrite(B2charge,HIGH);//Switch relay1 on
    digitalWrite(B1charge,LOW);//Switch relay2 off
  }
 }
```