Palestine Polytechnic University

College of engineering

Mechanical engineering department

Graduation Project

Design , Building and Testing of Thermoelectric Refrigeration Apparatus Driven By Solar Energy

By

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Submitted to the College of Engineering
In partial fulfillment of the requirements for the
Bachelor degree in Refrigeration and Air Conditioning Engineering

Palestine polytechnic university

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Hebron – Palestine

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Abstract

Refrigeration has become indispensable as it enters into various fields of life such as food preservation and distribution, and production processes . As a result of the increasing and continuous demand for refrigeration has become harmful to the atmosphere due to the emission of gases such as Carbon dioxide (CO_2) caused by the production of the refrigerants.

Thermoelectric refrigeration is a good alternative because it can convert electricity to produce cooling effect without the need for mechanical and traditional components of cooling cycles. It is environmentally friendly and uses electrons as a cooling medium.

This project aims to design and build a portable solar powered thermoelectric refrigerator, which will be used in areas where electricity is not available. The cooling room was set to 5 liters with internal dimensions (22 x 27 x 15.5 cm) and external dimensions (26 x 20 x 20 cm). The 50W solar cell unit was selected based on desired convection, and two TEC 1-12706 addition to the control system.

الملخص

أصبح التبريد لا غنى عنه فهو يدخل في شتى مجالات الحياة مثل حفظ الأغذية وتوزيعها وعمليات الانتاج .ونتيجة للطلب المتزايد والمستمر على التبريد أصبح ضارا للغلاف الجوي بسبب انبعاث الغازات الناجم عن انتاج وتصنيع غازات التبريد. (CO_2)مثل ثاني أكسيد الكربون.

يعتبرالتبريد الكهروحراري بديل جيد لأنه قادرعلى تحويل الطاقة الكهربائية لانتاج تأثيرالتبريد دون الحاجة الى المكونات الميكانيكية و التقليدية لدورات التبريد وهو صديق للبيئة ويستخدم الالكترونات كوسيط تبريد.

يهدف هذا المشروع إلى تصميم وبناء ثلاجة التبريد الكهروحراري باستخدام الطاقة الشمسية; لخدمة المناطق التي لاتصلها امدادات الكهرباء, والبعيدةعن الشبكة العامة. يهدف تم تحديدغرفة التبريد بحجم 5 لتربأبعاد داخلية (22 ×17 × 15.5سم) وأبعادخارجية (26 × 20 × 20سم) ,وتم اختيار وحدةالخلايا الشمسية 50 واط على أساس الحمل الحراري المطلوب , واثنين من المبرد الحراري ,بالإضافة الى نظام التحكم.

Dedication

To

my mother and father

Our Parents

And

Everyone taught me characters

Wisam Shalaldah

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Chapter One

Introduction

1.1 Introduction:

In recent years, with the increasing awareness towards environmental degradation caused by Chlorofluorocarbons (CFCs) andHydrofluorocarbons (HCFCs) from refrigerants in conventional refrigeration systems, it has become a subject of due concern. Besides, rural areas won't have to rely as much on power from the grid for their refrigeration and cooling needs, by harnessing the inexhaustible solar energy to power the thermoelectric refrigeration (TER) system.

Solar thermoelectric refrigerator is type of refrigerator which utilizes solar energy instead of conventional electrical ener-gyto power the thermoelectric module that has been used to cool the refrigeration space.Thermoelectriccooler (TEC) modules that utilize the Peltier effect between the junctions of two semiconductors. Thermoelectric cooling works on the principle of Peltier effect, when a direct current is passed between two electrically dissimilar materials heat is absorbed or liberated at the junction.

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:

Solar refrigeration may be accomplished by using one of thefollowing refrigeration systems: vapor compression,sorption or thermoelectric refrigeration systems. The firsttwo systems need high and low pressure sides of a workingfluid to complete the refrigeration cycle, and are somewhatdifficult to be developed into a portable and light solardevice used outside. The thermoelectric refrigeration system,which has the merits of being light, reliable, noiseless,rugged, and low cost in mass production, uses electronsrather than refrigerant as a heat carrier, and is feasible foroutdoor purposes in cooperation with solar cells, in spite ofthe fact that its coefficient performance is not as high as for a vapor compression cycle . In past years, much work hasbeen reported on thermoelectric cooling . Thethermoelectric refrigeration system is having potentialapplication of storage and transportation of life saving drugsand biological materials at remote areas of our countrywhere electrical power is unavailable. [1], [3]

- **Results and Conclusion:**

Experiment results demonstrated that the system performance is dependent on the temperature difference of hot and cold sides between the thermoelectric modules. the small refrigerator can reduce the temperature from 30 to 8 oC in approximately 2 houre,and has a COP about 0.72 , And the COP dependent on the number of thermoelectriccooler (TEC).

1.3 Scope of theProject:

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 operated using solar cells , 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 to 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 thethermoelectriccooler(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 to cooling the beverage box (5L). The beverage box temperature will be reduced from (30 - 8) ^{o}C in 2 hour.

1.4 Objectives:

The main importance of this project is to design and build a cheap and flexible solar thermal refrigerator that can be transported and does not affect the environment. This project aims to achieve the following objectives:

1. To determine improvements in the of trying to raise coefficient performance.

2. To construct a test on the behavior and specifications of a TEC device operating in a cooler box environment.

3. To investigate the cost and effectiveness of the TEC module.

1.5 Applications:

This project is simple, lightweight, easy to carry, easy to transport, and has no moving parts. This project can be used in many fields. A list would be the following:

1. Indoor space cooling.
2. Outdoor cooling.
3. Cooling in cars and works.
4. In remote and rural areas, when there is no electricity.
5. Can be carried along when travelling outdoors.
6. Can be used in medical field.
7. In the plant field to save wheat seeds at appropriate temperature and humidity.

1.6 Thermoelectric cooling:

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). It can be used either for heating or for cooling, although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools.A Peltier cooler can also be used as a thermoelectric generator. When operated as a cooler, a voltage is applied across the device, and as a result, a difference in temperature will build up between the two sides. When operated as a generator, one side of the device is heated to a temperature greater than the other side, and as a result, a difference in voltage will build up between the two sides (the Seebeck effect).

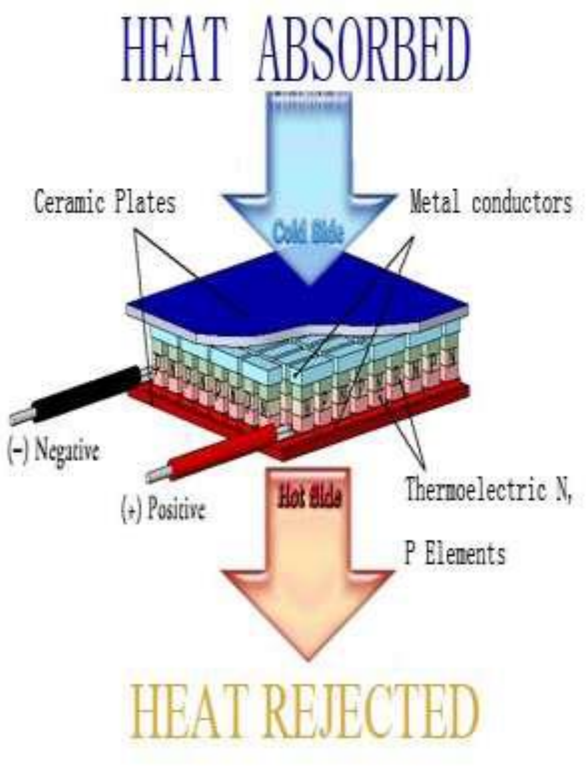

Figure 1.1: working principle of TEC module.

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:

Table1.1: Thermoelectric and Conventional Systems Refrigeration.

Aspect	Thermoelectric System	Conventional System
Moving Parts in The System	No moving part	Includes moving parts which are a compressor,and there may be fans to move air on the evaporator or pumps to move refrigerant to cool the condenser.

COP	Low	Very good
Weight for a certain size	Light weight and can be carried often easily	Relatively heavy
Life	Long life	Is subject to many faults, which makes life short
Areas of use	Private and limited	Wide Of domestic use to commercial use
Maintenance	A few malfunctions and spare Simple, limited and cheap.	Many possible malfunctions and complex and expensive partsprice.
Refrigerant	Available(electrons)	Expensive; ie (HCHs ,HCFCs,CFCs)
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.
The noise	Does not make any noise.	The noise from it may be high.
Cooling energy	low	Ranging to large values sometimes by design
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 technicalproblems. And the thermoelectricmodule requires less electricity compared to traditional cooling thus, solar cells can be utilizedwithout the need for other energy sources to operate them. However, its low efficiency is theonly drawback that makes most of the projects using this system are very small, which makestheir unique advantages outweigh their low efficiency.

1.8 Time Planning for theProject:

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

Table1.2: 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																
Literature Review																
Introduction																
Load Calculation																
Components Selection and Design																
Modification and Coordination																
Preparing and Printing																
Preparation of presentation																

Table1.3: 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																■

1.9 The Budget for the Project:

Table1.4: Actual Budget Table for the Project.

Task	Quantity	Cost (NIS)	Total
Solar Panel	1	250	250
Storage Batteries	1	100	100
Small fan	1	15	15
Large fan	1	25	25
Large Heat sink	1	25	25
Small heat sink	1	20	20
TEC Module	2	25	50
Cooler box	1	45	45
Electronic Pieces	-	400	400
Total			**930**

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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.

2.2Cooling Load:

Cooling load is the rate at which sensible and latent heat must be removed from the space to maintain a constant space dry-bulb air temperature and humidity. Sensible heat into the space causes its air temperature to rise while latent heat is associated with the rise of the moisture content in the space. The building design, internal equipment, occupants, and outdoor weather conditions may affect the cooling load in a building using different heat transfer mechanisms. The cooling load is calculated to select HVAC equipment that has the appropriate cooling capacity to remove heat from the the refrigerated space.

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

1. Active heat load.
2. Passive heat load.
3. Air changing load (Infiltration).

The target temperature in the cooling space is 8 °C, and the ambient temperature is about 31°C based on the Palestinian codes which show the maximum surrounding temperature in Hebron city (Table A-1). The volume of cooler box to be cooled is 5 L and the desired cooling time is 2 hour .

2.2.1 Active Heat Load:

Active cooling load system is one that involves the use of energy to cool something. The active heat load is the heat released by a mass which is kept inside the cabinet during the cooling and is calculated.

$$Q_{active}= \frac{mC_p\Delta T}{\tau} \qquad (2.1)$$

Where:

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

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

Where:

T_i: initial product temperature [30°C].
T_o:outlet product temperature [8°C].

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

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 (cooler box) is:

$$Q_{active} = \frac{(1 * 5)(4.186 * 10^3)(30 - 8)}{2 * 60 * 60} = 63.95\ W.$$

2.2.2Air Changing Load (Infiltration):

Infiltration is the unintentional or accidental introduction of outside air into a cooler box, typically through cracks in the building envelope and through use of doors.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 lid. This is caused by pressure difference between the inlet and outlet area 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. °C].
T_o: outside air temperature [°C].
T_i: inside air temperature [°C].

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

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

V_f = number of air change * volume of refrigeration space.
Number of air change = 1 [time/h].

V_f =1 *0.005 =5*10^{-3}[m^3/h].

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

$$Q_{inf} = 1.25 * \frac{(5 * 10^{-3})}{3600} * 1000 * (31 - 8) = 0.0399W.$$

2.2.3 Passive Heat Load:

Passive heat load refers to cooling technologies that rely solely on the thermo-dynamics of conduction, convection and radiation to complete the heat transfer process.

The heat losses on refrigeration equipment are produced through walls. The body of the refrigerator in this project is cooler box, the refrigerator wall is polyethyleneinsulated , so the heat loss will be by radiation and it is calculated by,

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

Where:
Q_{rad}: the rate of heat transfer by radiation through the wall [W].
$\varepsilon_{s.s}$: emissivity of Plastic =0.95.
σ:Stefan-boltzman constant=5.67 * 10-8 W/m2.K4 .
A: surface area of the inner wall [m^2].
T_{surr} : temperature of the External walls air of cooler box [K].
T_c: temperature within the cabinet of refrigerator [K].

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

$$Q_{rad} = 0.95 * (5.67 * 10^{-8})(0.0374) * [(20 + 273.15)^4 - (8 + 273.15)^4] = 2.29\ W.$$

- So the heat load due to passive load is $2.29\ W$.

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):

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

Table 2.1: Heat Load.

Heat Load	Q_{active} (W)	Q_{inf}(W)	$Q_{passive}$(W)
	63.95	0.0399	2.29
Total (W)	66.27W		

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

$$Q_{c'} = Q_c + (Q_c * 0.1) = 66.27 + (66.27 * 0.1) = 72.89\ W$$

2.3Components of the System:

2.3.1 CoolerBox :

The refrigeration box is selected based on the size of the product to be cooled and prevents the transmission of cold from inside to outside.

2.3.1.1 Geometry:

Two main geometry of the refrigeration box first is 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, 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; the rectangular shape is selected in a refrigeration box design.

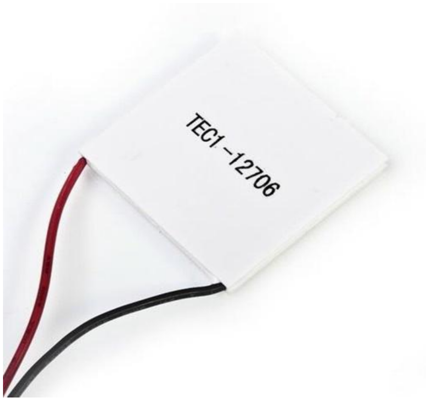
2.3.1.2Materials and Heat Transfer:

One of the best methods used in refrigeration box to prevent heat transfer is to use apolyethylene.Made of plastic, insulation thickness of 25 - 30 mm.heat transfer cannot be conducted by conduction or convection. Radiation heat transfer still occurs though.

Figure 2.1: cooler Box.

2.3.2Thermoelectric (TEC) Module:

Thermoelectric (TE) modules are solid-state devices (no moving parts) that convert electrical energy into a temperature gradient, known as the "Peltier effect. A thermoelectric module consists of an array of p and n-type semiconductor elements that are heavily doped with electrical carriers .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 as a Figure (2.2),(2.3).



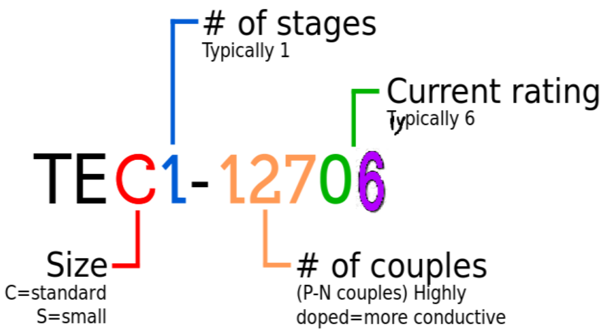


Figure 2.2: TEC1-12706 Module.Figure 2.3: TEC Global Definition Specification

2.3.3Heat Sink:

To complete the thermal system, the hot face of the TE cooler must be attached to a suitable heat sink that is capable of dissipating both the heat pumped by the module and Joule heat created as a result of supplying power to the module**.** A heat sink is an integral part of a thermoelectric cooling system and its importance to total system performance must be emphasized. Since all operational characteristics of TE devices are related to heat sink temperature, heat sink selection and design should be considered carefully. The ideal heat sink will be able to absorb an unlimited amount of heat without showing any increase in temperature. Since this is not feasible, a temperature sink should be selected that has an acceptable temperature rise when handling the total heat flow from a TE device. The definition of theacceptable increase in temperature of the heat sink is necessarily dependent on the specific application, but because of the low heat pump capacity in the TE unit with the increase in the differential temperature, it is strongly recommended to reduce this value.Several types of heat sinks are available including natural convection, forced convection, and liquid-cooled. Natural convection heat sinks may prove satisfactory for very low power applications especially when using small TE devices operating at 2 amperes or less. For the majority of applications, however, natural convection heat sinks will be unable to remove the required amount of heat from the system, and forced convection or liquid-cooled heat sinks will be needed.For solar TEC in this project, it will be used forced convection air-cooled, as in figure (2.4).

Figure 2.4: Heat Sink for hot side .Figure 2.5: Heat Sink for cold side .

2.3.4 Solar Cells:

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a p-n junction.

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

1. The absorption of light, generating either electron-hole pairs or exactions.

2. The separation of charge carriers of opposite types.

3. The separate extraction of those carriers to an external circuit

2.3.4.1 Solar cell type:

Table 2.2: Solar cell type.

Solar Cell Type	Efficiency-Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate; optimised for commercial use; high life-time value	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

2.3.5 Electrical Components:

1. Ardunio Nano: Ardunios were used in this project to control the voltages and the heat, seefigure (2.6).

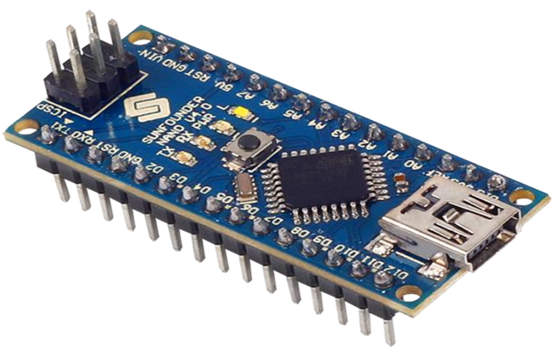


Figure 2.6: Ardunio nano.

2. Relay: relays were used in this project for protection, see figure (2.7).

Figure 2.7: Relay.

3. Temperature Sensor(LM35): It is used in this projectto measure the temperature inside the chamber, see figure (2.8).

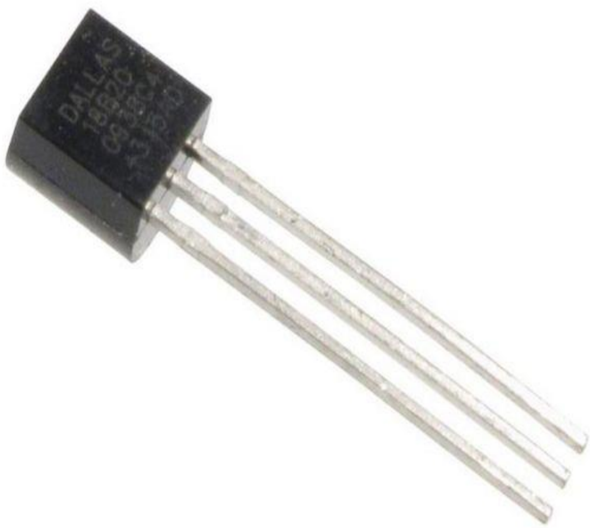


Figure 2.8: Temperature Sensor (lm35).

4.Storage Batteries:Its function is to store electrical energy generated by the panels see figure (2.9).

Figure 2.9: storage batteries .

2.3.6 Secondary Components:

1. The support structures, wiring, storage, etc.
2. 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.
3. A set of electronic pieces: such as boost , Circuit breaker, LEDs, and another.

3

Chapter Three

System Design

3.1 Introduction:

This chapter discusses the selection of system components. The appropriate choice must be based on the required standards and objectives.

3.2Design Option:

3.2.1 cooler Box:

The Refrigeration Box specification selected as in the following table (Table 3.1):

Table (3.1): Cooler box Specifications.

Name	Volume	Insulation	Material	Interior dimensions(cm)	Exterior dimensions (cm)
Cooler Box	5L	polyethylene	plastic	22*17*15.5	26*20*20

3.2.2 Thermoelectric Module Design:

Two thermal units were used to reduce the cooling system temperature. Each thermal power unit comes into contact with the special air cooled heat sink , helping the hot side of the Peltier dish to dissipate more heat in the surrounding areas.To design the thermoelectric module we need to calculate Cooling capacity from the module and temperature differences on both sides of the module.

Temperature differences on both sides of the module, calculated by:

$$\Delta T = Th - Tc \qquad (3.1)$$

Where:

T_{hot}: temperature from hot side module [41°C].
T_{cold}: temperature from cold side module [8°C].

- the temperature from hot side is:

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

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

$$\Delta T = 41 - 8 = 33^oC$$

- Thermoelectric module TEC1-12706 (see spec sheet), has the following parameters, in (Table3.2):

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 °C	Thickness	3.8 mm

- From TEC module performance Figure 3.1, at ΔT=33^oC, Q_c = $72.89W$:
- For each TEC ,Qc= Qc/2 = 36.4 W.
  Voltage=10.5 V and current=4.5 A.

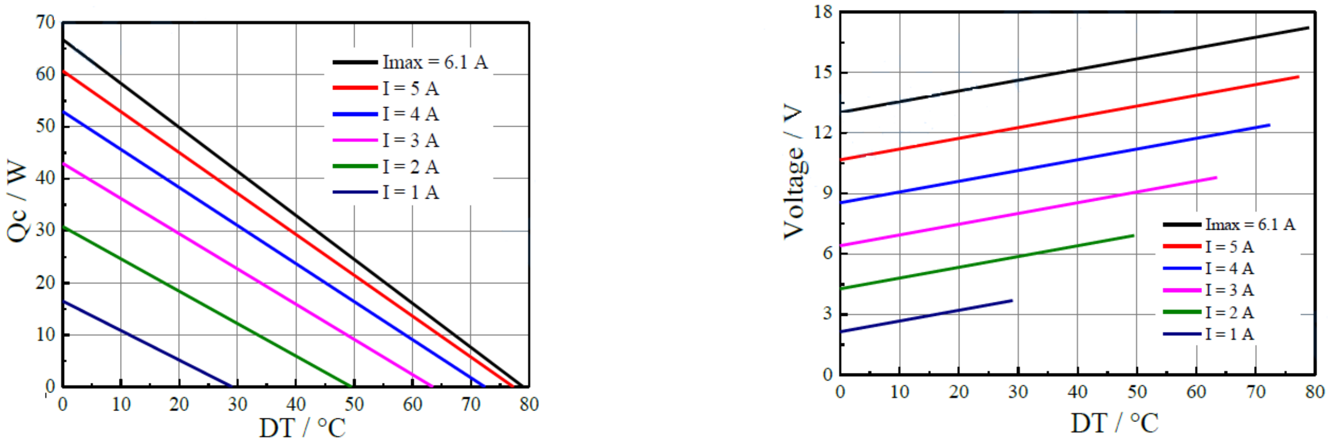


Figure 3.1: TEC Module Performance Graph (Obtained From TEC Module Spec Sheet)

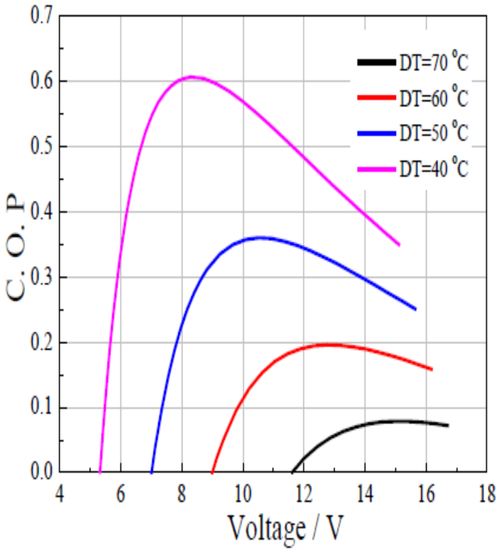


Figure 3.2: (Standard Performance Graph COP = f(V)of ΔT ranged from 40 to 60/70 ˚C)

3.3. Heat Sink Design:

One heat sink will be used for the hot side and two heat sink will be used for the 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:

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

Where:

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

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

Where:

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

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

Where:

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

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

$Q_{tec} = V * I = 10.5 * 4.5 = 47.25\ W$, and

$Q_{tec,tot} = Q_{tec} + Q_c = 47.25 * 2 + 72.89 = 167.39W$.

- Applyingequation (3.2), thermal resistance:

$$R_{th} = \frac{41 - 31}{167.39} = 0.059^{o}C/W.$$

- A heat sink rating $(0.059^{o}C/W)$ or less must were used with TEC module.

Heat sink sizing: Heat sink design parameters (Figure 3.3) 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)	0.002 m
# Of Fins (N_{fin})	20
Material	Aluminum

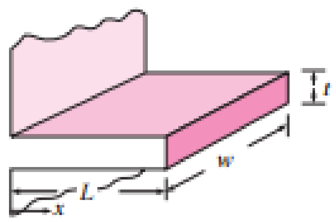


Figure 3.3: Fin Design Parameters.

- For air velocity between fins, we can be calculated it by:

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

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 $v = 30\ CFM = 30 * 4.7194744 * 10^{-3} = 0.01415\ m^3/s$

Applying equation (3.5), air velocity:

$$V = \frac{0.01415}{20 * 1.2 * 10^{-3} * 0.03} = 19.65\ m/s$$

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

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

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).

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

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=1.99956*10^{-5} [kg/m.s].
Pr=0.706.
K=0.0269 [W/m.^{o}C].
ρ=1.1451 [kg/m^3].
Cp=1.0063*10^3 [J/kg.K].

- The Reynolds number is calculated by:

$$R_e = \frac{\rho * V * b}{\mu} = \frac{1.1451 * 19.65 * 1.2 * 10^{-3}}{1.99956 * 10^{-5}} = 1350.5$$

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

$$Nu = 0.683 * (385.87)^{0.466} * (0.706)^{\frac{1}{3}} = \mathbf{17.49}$$

- Average heat transfer co-efficient:

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

Where:

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

Applying equation (3.8), convection heat transfer coefficient:

$$h = \frac{17.49 * 0.0269}{1.2 * 10^{-3}} = 392\ \mathrm{W/m^2.^o\,C}$$

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

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

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

Where:

K_{fin}: Thermal conductivity of aluminum [202 W/m.ºC] from Table (A-6).
L_c: correct length of the fin [m].

(L_c) =L +$\frac{t}{2}$=0.03+$\frac{0.002}{2}$=0.031 m.

Applying equation (3.9) and (3.10):

$$m = \sqrt{\frac{2 * 392}{202 * 0.002}} = 44.05$$

$$\eta_f = \frac{\tanh(44.05 * 0.031)}{44.05 * 0.031} = 0.64$$

- Heat sink thermal resistance is given by:

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

Where:

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

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

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]:

$A_b = (N-1).b.w = (20-1) * 1.2 * 10^{-3} * 0.03 = 0.684 * 10^{-3} m^2$

Area of fin (A_f) =2*0.03*0.031=1.86*10^{-3} m^2.

$A_t = 20 * 1.86 * 10^{-3} + 0.684 * 10^{-3} = 0.0378\, m^2$

Applying equation (3.12):

$$\eta_0 = 1 - \frac{20 * 1.86 * 10^{-3}}{0.0378} (1 - 0.64) = 0.645$$

Applyingequation (3.11), thermal resistance is:

$$R_{hs} = \frac{1}{0.645 * 392 * 0.0378} = 0.104\, {}^oC/W.$$

- Hence:

$0.059^oC/W \ll 0.104C/W$, therefore heat sink design meets requirements.

Specifications of Fan:

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

Voltage	12 V
Power	4 W
Air Volume	30 CFM
Dimension	92*92*25 mm

- **For Coled Side:**

Table(3.5): Fin and Fan Parameters for Cold Side.

Fin Parameters		Fan Parameters	
Dimension	80*50*40 mm	Power	1.56 W
Efficiency	0.6	Air volume	11.5 CFM
# Of Fins (N_{fin})	14	Dimension	40*40*15 mm
Material	Aluminum	Bearing	Ball

3.3.4 Solar Cells Design:

3.3.4.1 Calculation of Solar Panel:

Calculation of the power consumed by the TEC modules and two fans used in the project:

- The TEC module takes a maximum of 4.5A and 10.5V. The power needed to give maximum cooling efficiency= 4.5*10.5= 47.25 W.

- Calculation of the power consumed by the fans:

The first fan is used 4W and the two second fan is used 1.56 W.

power consumed by the fan =4+1.56=5.56W.

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 fans and arduino)= (47.25*2+5.56+0.2) = 100.26 W.

- $\boldsymbol{E\ load = total\ power * time\ operating}$
- E load =100.26*2=200.52W.h/day

- factor of safety as general rule 30% is used:

- E load=200.52*1.3=260.676 W.h/day .
- E load Required = E LOAD/ Rate of solar radiation
- E load = 260.676/5.4=48.27 W.

A solar cells rating $48.27W$ or large must be used .

A LED solar Light 50 W cell was selected in project.

3.3.4.2 Coefficient of Performance (COP):

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

$$\boldsymbol{COP = \frac{Q_{cooling}}{W_{in}}\ (3.13)}$$

Where:

$Q_{cooling}$: Active heat load from beverage box [W].
W_{in}: work done [W].

By applying equation (3.13), Coefficient of Performance (COP) is:

$$COP = \frac{72.89}{100.26} = 0.72$$

3.4 Storage Batteries Design:

Batteries are needed to supply electrical elements and TEC module in the system. considerations that are based on choosing a storage batteries : current and power and operating time(2 houre) in the system.

$\boldsymbol{I = P/V * \eta (3.14)}$
Where:

P: total power in system [W.h].

I: Current in system[A.h].

V:voltage in system[V].

η:Storage Battery efficiency

Applying equations (3.14),Current is:

$I=\frac{100.26}{12}$=8.35A.h.

Storage Batteriescapacity8.35 A.h or large must be used .

Storage Batteries select(9A.h,12V).

4

Chapter Four

Implementation

4.1 Introduction:

This chapter discusses project implementation where mechanical parts and controls will be installed in the system.

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 cooler box, 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.

Figure (4. 1): practical connection of electrical parts.

4.2.2 Electrical Hardware:

The system is turned on and the required temperature is determined. The temperature is then read through the lm35 tempreture sensor and displayed by the lcd screen. After the required temperature is reached, the system turn off automatically.

Boost was used to reduce the voltage from 12V to 8V to suit the Arduino.

Figure (4.2) determine practical connection of electrical parts in this project.

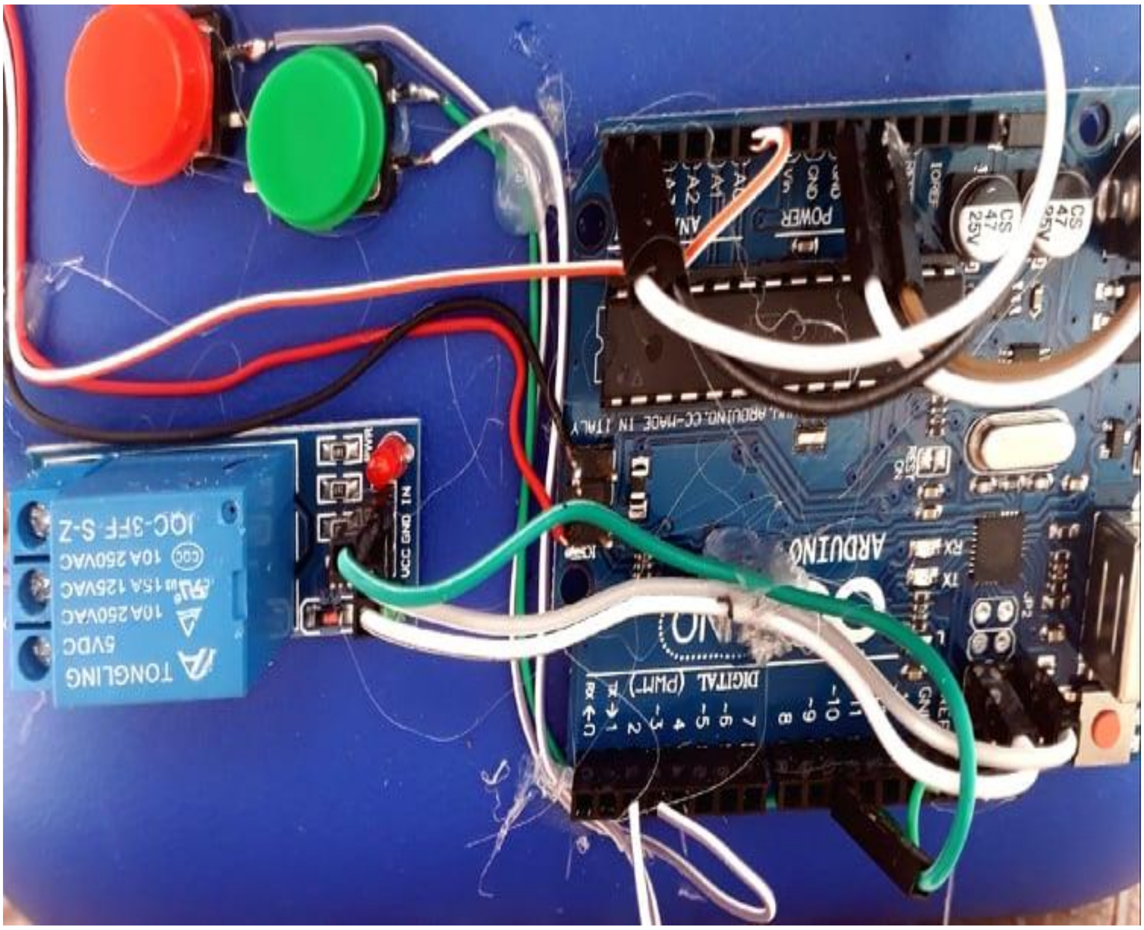


Figure (4. 2): practical connection of electrical parts.

The circuit diagram for the electrical hardware is shown in Figure (4.3) .

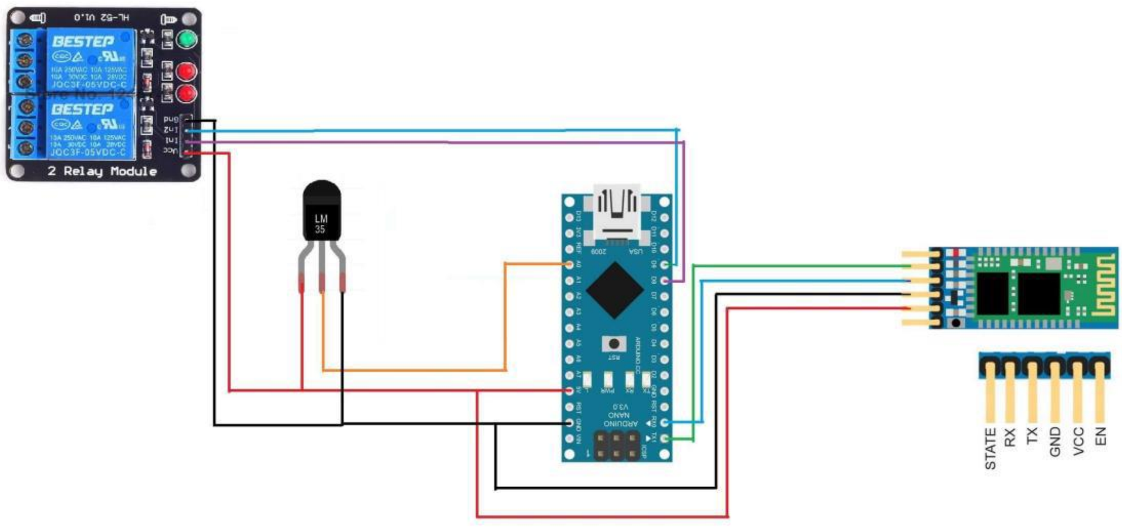


Figure (4.3): Electric circuit control temperature.

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 codes of this system.

4.3.1Microcontrollers Code:

An Arduino UNO was used as a microcontroller. This section will describe the main functions in the Arduino code.
The Arduino code starts by defining the variables that used in the code.
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.

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.

```
 #include <Wire.h>
#include<LiquidCrystal_I2C.h>

//LiquidCrystal_I2C lcd(0x3F, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);  // Set the
LCD I2C address, if it's not working try 0x27.
LiquidCrystal_I2C lcd(0x27,2,1,0,4,5,6,7, 3, POSITIVE); // 0x27 is the
default I2C bus address of the backpack-see article

const int LED_RED=10; //Red LED
const int LED_GREEN=11; //Green LED
const int RELAY=12; //Lock Relay or motor

//Key connections with arduino
const int up_key=3;
const int down_key=2;

int SetPoint=30;
//=================================================================
//                    SETUP
//=================================================================
void setup(){
 pinMode(LED_RED,OUTPUT);
 pinMode(LED_GREEN,OUTPUT);
 pinMode(RELAY,OUTPUT);
 pinMode(up_key,INPUT);
 pinMode(down_key,INPUT);

  //Pull up for setpoint keys
 digitalWrite(up_key,HIGH);
 digitalWrite(down_key,HIGH);

   // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);
  // Print a message to the LCD.
 lcd.print("circuits4you.com");
  lcd.setCursor(0,1); //Move coursor to second Line
  lcd.print("Temp. Controller");
  digitalWrite(LED_GREEN,HIGH);  //Green LED Off
  digitalWrite(LED_RED,LOW);     //Red LED On
  digitalWrite(RELAY,LOW);       //Turn off Relay
  delay(2000);
}
//=================================================================
//                    LOOP
//=================================================================
void loop(){
  double Temperature = ((5.0/1024.0) * analogRead(A0)) * 100;  //10mV per
degree 0.01V/C. Scalling
```

```
  lcd.setCursor(0,0);
  lcd.print("Temperature:");   //Do not display entered keys
  lcd.print(Temperature);

//Get user input for setpoints
 if(digitalRead(down_key)==LOW)
  {
    if(SetPoint>0)
    {
      SetPoint--;
    }
  }
 if(digitalRead(up_key)==LOW)
  {
    if(SetPoint<150)
    {
      SetPoint++;
    }
  }

//Display Set point on LCD
  lcd.setCursor(0,1);
  lcd.print("Set Point:");
  lcd.print(SetPoint);
  lcd.print("C   ");

//Check Temperature is in limit
if(Temperature > SetPoint)
{
   digitalWrite(RELAY,LOW);    //Turn off heater
   digitalWrite(LED_RED,LOW);
   digitalWrite(LED_GREEN,HIGH);  //Turn on Green LED
}
else
{
  digitalWrite(RELAY,HIGH);    //Turn on heater
  digitalWrite(LED_GREEN,LOW);
  digitalWrite(LED_RED,HIGH);  //Turn on RED LED
}

  delay(100); //Update at every 100mSeconds
}
```

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 cooler box insulated, cooling mode, and Coeffecient Performance for the system, these experiences and their results will be explained below:

5.2.1 Tests And Results For Cooling Mode of water:

The curve shows the relationship between the temperature (^0C) and the time in seconds for 5L of water at 17^0C.

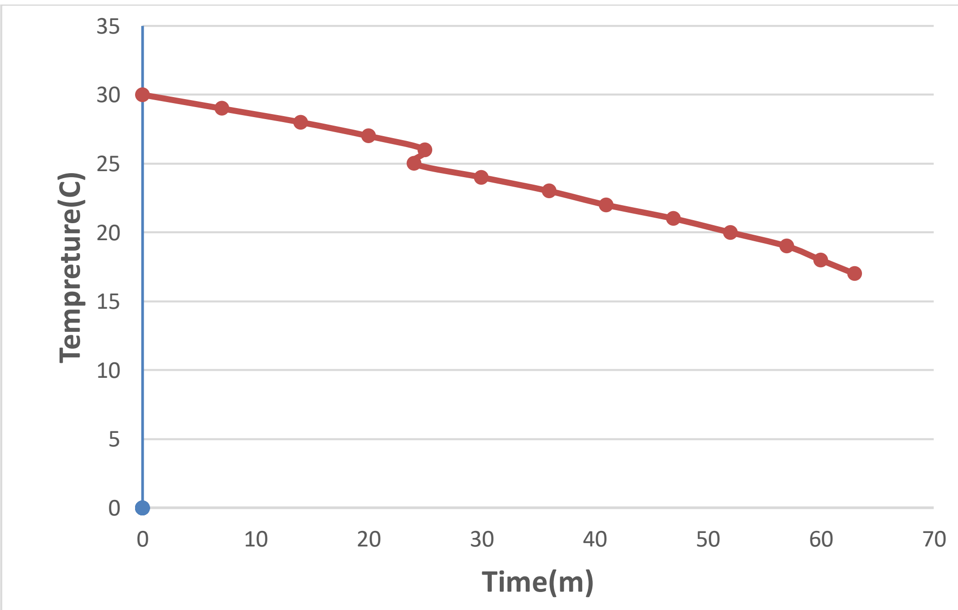


Figure (5.1): Temperature (^0C) v.s Time (m), (Preserving at 17^0C).

The next curve shows the relationship between the temperature ($_{o}$C) and the time in seconds for 5L of water at 8$_{o}$C.

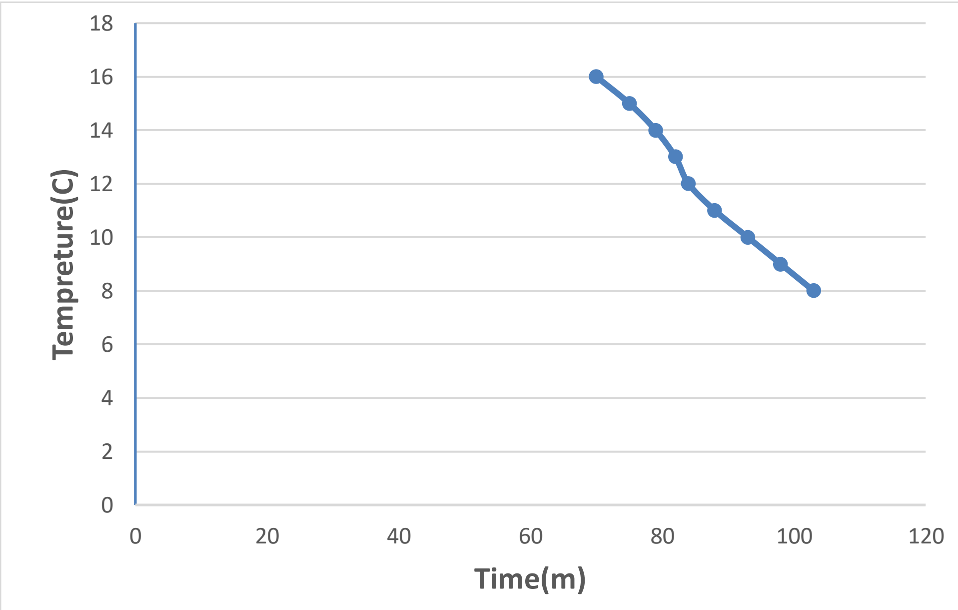


Figure (5.2): Temperature ($_{0}$C) v.s Time (m), (Preserving at 8$_{O}$C).

5.3Coefficient of Performance Experimental (COP):

For Cooling Mode: By applying equation (3.13), the COP from the testing See figure (5.3); determines the decreasing of temperature through 2 hour) is determined as the following:

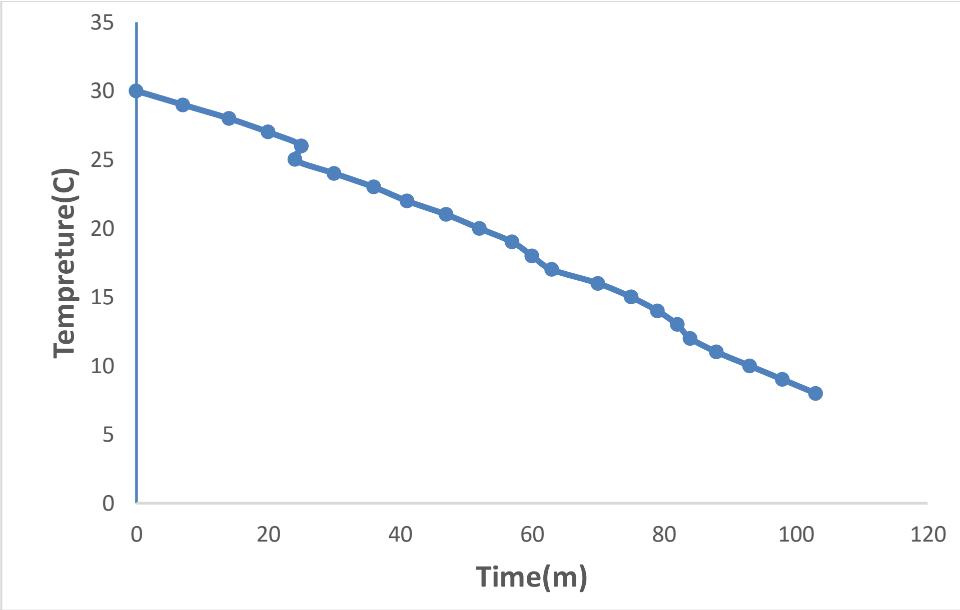


Figure (5.3): Temperature (oC) v.s Time (m).

Slope = 0..21oC/min.

Q_c = m.C_p. Slope =5*4.186*0.21= 69.76 W.

- COP = 69.76/100.26 = 0.69.

5.4 Tests And Results For Cooling Mode of air:

The curve shows the relationship between the temperature (oC) and the time in seconds for 5L of air at 8oC.

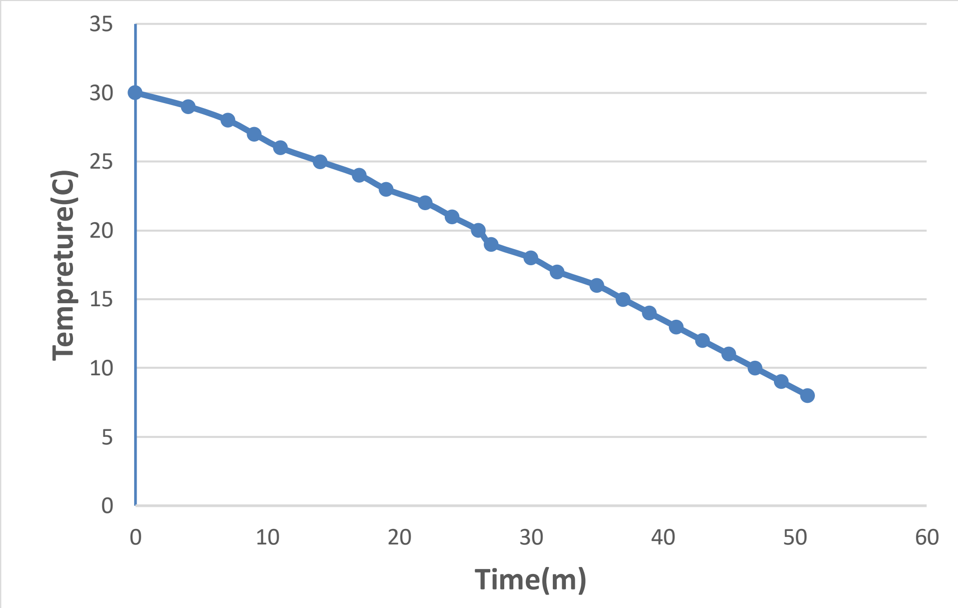


Figure (5.4): Temperature ($_0$C) V.S Time (m).

5.5 Conclusion :

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.

As the number of TEC increases the system becomes more efficient

Reference

[1] M. K. Rawat, P. Sen, H. Chattopadhyay, S. J. I. J. o. E. R. Neogi, and Applications, "Development and experimental study of solar powered Thermoelectric Refrigeration system," vol. 3, no. 4, pp. 2543-2547, 2013.

[2] H. Xi, L. Luo, G. J. R. Fraisse, and S. E. Reviews, "Development and applications of solar-based thermoelectric technologies," vol. 11, no. 5, pp. 923-936, 2007.

[3] H. Kang, "Evaluation of Fin Efficiency and Heat Transfer Coefficient for Fined Tube Heat Exchange," 2012.

[4] U. V. Sangale, P. Jhavar, and G. J. I. j. o. r. i. A. t. Seloskar, "Thermoelectric refrigeration by using solar energy for domestic appliance," vol. 3, no. 1, pp. 72-75, 2015.

[5] R. Sharma *et al.*, "Peltier Effect Based Solar Powered Air Conditioning System," (in No Linguistic Content), pp. 288-292, 2009.

[6] J. P. J. t. Holman, New York, USA, "Heat Transfer, McGraw-Hill Series in Mechanical Engineering," 2009.

[7] W. R. Dai Yanjun and N. J. A. E. S. S. Liang, "EXPERIMENTAL INVESTIGATION AND ANALYSIS ON A SOLAR THERMOELECTRIC REFRIGERATOR [J]," vol. 6, p. 015, 2002.

Appendix

TableA-1: Maximum and Minimum Temperature for Hebron City.

Month	Max.Temp (°C)	Min.Temp (°C)
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

TableA-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

TableA-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

TableA-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

Taple A-5: emissivity of some material

material	emissivity
black body	1
asbestos	0.95
ceramics	0.95
mud	0.95
cement	0.95
paper	0.95
rubber	0.95
plastic	0.95

TableA-6: 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	
	Single pane		6.42

Glass	**Two pane**		**2.61**
	Three pane		**1.65**
	Four pane		**1.19**
Metal	**Stainless steel**	**1 8**	
	Aluminum	**202**	
	Cooper	**386**	
	Galvanized steel	**2 0**	