MARMARA UNIVERSITY
FACULTY OF ENGINEERING

# COOLING DESIGN, EXPERIMENT AND ANALYSIS IN COLD CHAIN BOXES BY MEANS OF THERMOELECTRIC COOLERS

ABDULLAH KARBUZ, HİLMİ KEMAL SATI

**GRADUATION PROJECT REPORT**

Department of Mechanical Engineering

**Supervisor**

Associate. Prof. Dr. Mustafa YILMAZ

ISTANBUL, 2020

MARM A RA U NI VE R SI T Y
F ACU LTY OF EN GI N EERIN G

# COOLING DESIGN, EXPERIMENT AND ANALYSIS IN COLD CHAIN BOXES BY MEANS OF THERMOELECTRIC COOLERS

**by**

**Abdullah Karbuz, H. Kemal Satı**

**July05, 2020, Istanbul**

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

**OF**

**BACHELOR OFSCIENCE**

**AT**

**MARMARA UNIVERSITY**



Signature of Author(s)

..........................................................................................................

Department of Mechanical Engineering

Doç. Dr. Mustafa YILMAZ

CertifiedBy.............................................................................................................................

Project Supervisor, Department of Mechanical Engineering

AcceptedBy.............................................................................................................................

Head of the Department of Mechanical Engineering

# ACKNOWLEDGEMENT

First of all, we would like to thank our supervisor Associate. Prof. Dr. Mustafa YILMAZ, for the valuable guidance and advice on preparing this thesis and giving us moral and material support.

**July, 2020**

**Abdullah KARBUZ, Hilmi Kemal SATI**

Abdullah KARBUZ

Hilmi Kemal SATI

# CONTENTS

# ABSTRACT

Cold storage, cold transport and similar processes that are mandatory to be applied in order to maintain the compliance and properties of the foodstuffs or medical materials that need to be kept in a cold environment from product production to consumption, such as shipment, storage and display, are called Cold Chain. The aim here is that the products put on the market do not pose a risk to the consumer. In the health sector, this stops and is vital. Because these boxes are also used for the transportation of irreversible materials when the structure is broken, such as the human organ.

In this study, it is aimed to cool the cold chain box with peltier which is a thermoelectric material. Two different boxes are designed in the study. The designs were made in the Comsol Multiphysics program which is a computer-aided analysis program. Heat analysis was examined in both designs using the Comsol Multiphysics program. A heat flux is assigned to the peltier in Comsol and the amount of heat flux is associated with a value associated with the temperature value of the box. Thus, control was provided inside the box. The natural heat flux defined in the program was defined outside the designed box. Appropriate materials were selected for the box and peltier materials within the Comsol program. The first design was made with a single peltier and the temperature change in the box was observed by placing a thermostat at the determined points. In the second design, another peltier is added for the same box. Again, temperature changes depending on time were observed by placing a thermostat at determined points. Experiments were repeated with different combinations of mesh and peltier strength, and the results were compared.

In the study, the effect of changes of mesh number and peltier power on the result was observed. As a result, temperature intervals of the box in the given time were found and the suitability of the boxes was determined.

# ÖZET

Soğuk ortamda muhafazası gereken gıda maddelerinin ya da tıbbi malzemelerin üretim aşamasından başlayarak sevkiyat, depolama ve sergileme gibi tüketime kadar olan her aşamada ürün güvenliği kriterlerine uygunluğunu ve özelliklerini koruyabilmesi için uygulanması zorunlu olan soğuk muhafaza, soğuk taşıma ve benzeri işlemlere Soğuk Zincir denir. Burada amaç, piyasaya sürülen ürünlerin tüketici için risk teşkil etmemesidir. Sağlık sektöründe ise bu durum hayati önem taşımaktadır. Çünkü bu kutular insan organı gibi yapısı bozulduğunda geri döndürülemez malzemelerin nakliyatında da kullanılmaktadır.

Bu çalışmada soğuk zincir kutusunun, termoelektrik malzeme olan peltier ile soğutulma amaçlanmıştır. Çalışmada iki farklı kutu tasarlanmıştır. Tasarımlar bilgisayar destekli analiz programı olan Comsol programında yapılmıştır. Comsol programı kullanılarak her iki tasarım için de ısı analizi incelenmiştir. Comsol içerisinde peltier için bir heat flux atanmış ve heat flux miktarı kutunun sıcaklık değeri ile ilişkilendirilen bir değer ile ilişkilendirilmiştir. Böylece kutu içerisinde kontrol sağlanmıştır. Tasarlanan kutunun dışına ise programda tanımlı olan doğal ısı akısı tanımlanmıştır. Kutu ve peltier malzemelerine Comsol programı içerisinde uygun malzemeler seçilmiştir. İlk tasarım tek peltier ile yapılmış ve belirlenen noktalara termostat yerleştirerek kutu içindeki zamana bağlı sıcaklık değişimi gözlemlenmiştir. İkinci tasarımda ise aynı kutu için bir peltier daha ilave edilmiştir. Yine belirlenen noktalara termostat yerleştirilerek zamana bağlı sıcaklık değişiklikleri gözlemlenmiştir. Farklı mesh ve peltier gücü kombinasyonlarıyla deneyler tekrarlanmış ve sonuçlar karşılaştırılmıştır.

Çalışmada mesh sayısı ve peltier gücünün değişimlerinin sonuca etkisi gözlemlenmiştir. Sonuç olarak verilen süredeki kutunun sıcaklık aralıkları bulunmuş ve kutuların uygunluğu saptanmıştır.

# SYMBOLS

℃: Degree Celsius.

$cm$: Centimeter

$cm^2$: Centimeter Square

$cm^3$: Centimeter Cube

$mm$: Millimeter

$dm^3$: Decimeter Cubic

$m^3$: Meter

$ml$: Mililiter

g: Gram

$({}^{W}/_{m * K})$: Watt per Meter Square Kelvin

$K°$: Degree Kelvin

kPa: Kilopascal

# ABBREVIATIONS

COP: Coefficient of Performance.

Max.: Maximum

Min.: Minimum

QH: Heat Supplied to Warm Reservoir

QL: Heat Rejected from Cold Reservoir

R&D: Research & Development.

TL: Temperature of Cold Reservoir

TH: Temperature of Hot Reservoir

T-s: Temperature versus Entropy Diagram

# FIGURES

# TABLES

# 1 INTRODUCTION

The process of lowering the temperature of a system below the temperature of the surrounding environment and keeping it at a low temperature is called cooling. Many different machines have been developed for cooling processes in line with the needs arising from the past to the present. When these machines are classified in general, we see that results. Vapor compression machines with mechanical cooling, absorption and adsorption cooling, air cooling, sterling cooling and the last one is thermoelectric cooling which we are analyzing in our thesis.

Today vapor compression cooling systems are used commonly. The operating principle of these systems is based on the heat transfer of refrigerants with low evaporation temperatures. The aim is to take the heat from the low temperature system and move it to the high temperature environment. However, it causes serious damage to the bard layer due to the reaction of other refrigerants in the atmosphere in the release of refrigerants used in this system. Damage to the bard layer above the atmosphere directly causes global warming and this causes climate change.

The subject of the ozone layer depletion was brought to the agenda in 1976 for the first time in the Management Council of the United Nations Environment Program. Intergovernmental talks against substances damaging the ozone layer began in 1981. As the first concrete step, the Vienna Convention for the Protection of the Ozone Layer was signed in 1985. The convention consists of recommendations that recommend environmental and community health and preventive measures. In the contract, studies have been carried out for a protocol that will provide measures to protect the environmental health by reducing the use of volatile substances that cause the ozone layer to be destroyed and controlling its production. The Montreal agreement was ratified by the states parties for damaging volatile components in 1987. [12]

In the light of these studies, alternative harmless fluids have been produced instead of many harmful refrigerants. And the use of harmful fluids and its production has been prohibited. Another effect of this situation was the increase in the interest of the companies developing cooling technologies to Thermoelectric cooling systems that do not use any fluid and the increase of R&D studies in this field. Thermoelectric cooling systems do not use fluids, have no moving parts, operate silently, have a long life and low production and maintenance costs. Such reasons are various reasons for the increased interest in this type of cooling systems.

Thermoelectric cooling machines, which have many advantages over other cooling machines, are used in many products today. One of these product groups is cold chain boxes. The structure of many pharmaceuticals and biological products deteriorates at temperatures outside 2 ° C and 8 ° C. Cold chain boxes are designed to be shipped without disrupting the structure of these products. The chain boxes used in the health sector occupy the most important place for this group, because the high cost medical supplies are not resistant to room temperature and their structure is irreversibly deteriorated. [13]

Health sector is important for society. Identifying the regions where there is a need for improvement and producing solutions for these regions is important for public health. The increasing population in the world increases the need for health services day by day. The spread of health services, technological changes in the sector, economic growth and increasing the life span of people are another reasons. Therefore, the health sector occupies a serious place in the country's agendas. Accordingly, policies towards improving the health system are important. [9]

One of the basic principles of the health sector is to treat the sick person in a fast and effective figure. The protection of the drugs used during the treatment is easily provided in the cold stores in hospitals. In many cases, there is a need for these drugs to be transferred to another hospital. In this case, cold chain boxes are preferred in addition to many refrigerant dispensing machines.

Examples of the importance of cold chain boxes in the health sector are the transportation of cancer drugs with high costs or the transportation of an organ. The slightest mistake during shipment causes an irreversible structure deterioration for the drug or organ and makes them unusable. It can cause fatal consequences for the patient in need. That's why cold chain boxes are extremely important. For this reason, the risks during shipment are tried to be minimized every year.

Cold chain boxes are freeze-conditioned to keep the desired temperature range of the ice batteries inside for a certain period of time according to the transportation conditions of the drug carried. Then, the drugs are transported by placing them in these highly insulated cold chain boxes. Although this seems to be a useful shipping method, it may not meet the cold space requirement for unexpected shipment time increases or long-term transportation during shipment. In such cases, the medications will deteriorate before they reach the destination, causing serious life risks to the patient.

In order to reduce such risks, when using Thermoelectric materials such as peltier in cold chain boxes, it allows the box to be kept longer in desired temperature ranges.

In this study, it is aimed to keep the cold chain boxes with the help of peltier for a longer time in the desired temperature range. Thus, it will be ensured that the need for urgent medical equipment is carried easily and at less risk over long distances.

Thirdly, for Case 2, when our mesh option was fine, we increased the heat flux value doubles to 1.42 Watt for both Peltier's. All other parameters are identical with chapter 4.2.1. After this change, we run the program in 1440 minutes. When we examined the results, a maximum of about 9 °C minimum -6 °C degrees data was obtained for Thermostat 1. A maximum of 20 °C and a minimum of -2 °C data were obtained for Thermostat 2. The duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 300 minutes. When we look at the results, we saw that our peltier cooled and heated the box quite a lot with 2 times heat flux power. The program did not work properly because the heat transmission power was too high. Therefore, the expected result could not be obtained.

*Table 2: Combinations of solutions.*

| | | | | |
|---|---|---|---|---|
| *Case 1 (Design 1)* | *With Extremely Coarse* | *With Fine mesh* | *With Finer mesh* | *Doubled-Powered Peltier* |
| *Case 2 (Design 2)* | With Extremely Coarse | With Fine mesh | With Finer mesh | Doubled-Powered Peltier |

## 1.1 Studies in This Area

Sidding A. Ömer, S. B. Riffat and Xiaoli Ma did some research on Thermoelectric cooling in 2001. Riffad et al. Tried the Thermoelectric cooling technique in two different variations. In the first one, the connected fin cooler, an old method, was used as the cooler on the cold side of the Thermoelectric material. In the second variation, a phase changing material was used instead of the connected fin cooler. As a result, they proved that the second part, which uses phase changing material, is more efficient. [3]

Another study in this area is the project presented by Suwit Jugsujinda, Athorn Vora-ud and Tosawat Seetawan at the engineering and energy conference. Jugsujinda and his friends compared thermoelectric refrigerator and thermoelectric cooler performances. A cabinet with a volume of approximately $26cm^3$ was cooled. In the experiment, 4 mm thick peltier with an area of 4 $cm^2$was used as thermoelectric coolant. As a result of the result obtained by measuring the temperature from ten different points, a temperature difference of approximately 34.2 was obtained in 1 hour from the thermoelectric cooler, while a temperature difference of 10 °Cwas obtained from the Thermoelectric refrigerator. As a result of the experiments, it was observed that the COP value of the thermoelectric cooler was maximum 3.0 and the COP value for the thermoelectric refrigerator was 0.65. [4]

Another research using thermoelectric cooler is the blood storage and transport box developed by Osman Çiçek, Hüseyin Demirel and Serhat Orkun Tan. Namely, in this project, it is aimed to cool a can with a volume of 3.5 L with the help of TEC1-12703 thermoelectric material. The DC current fan is installed on both cold and hot surfaces of the thermoelectric material, allowing the distribution of cold and hot air to the environment. The temperature in the box was kept constant at 4 °C. [5]

In 2012, Hüseyin Demirel and Oktay Erkol designed a portable water-cooling device using thermoelectric material. Cooling is done by immersing the top of the liquid to be cooled. The control part is also added to the cooling experiment and the measured temperature values are transferred to the computer environment simultaneously thanks to the control mechanism. As a result, when the water of 500 ml volume was cooled for 50 minutes, a cooling of approximately 16°C was found. [6]

Emrah Deniz, Berat Kavak and Kamil Arslan examined the performance of Thermoelectric coolers for different voltage values. In the experiment, in which they connected the Thermoelectric coolers in series, they worked in two different mechanisms as water-cooled and air-cooled. When the thermoelectric material is supplied with a voltage of 5 volts, the COP value of the water-cooled system is 0.12 while the COP of the air-cooled system is measured as 0.57. When the voltage value is removed from 15 voltages, the COP value of the water-cooled system remains at 0.14, while the COP value of the air-cooled system is recorded as 0.35. As a result, in water-cooled systems, the COP value increases proportionally with the voltage supplied to the system, while in air-cooled systems, the voltage and COP value are inversely proportional. In the table below, the voltage value given to thermoelectric material and the COP values were compared. [7]

*Table2: COP values for 5V and 15V in water-cooled and air-cooled systems.*

| | *5 V* | *15 V* |
|---|---|---|
| *Water cooled* | 0,12 | 0,14 |
| *Air cooled* | 0,57 | 0,35 |

## 2 HEAT TRANSFER AND COOLING PRINCIPLE

Materials consists of atoms and molecules and these structures are in motion generally. According to Newton's second law, an object with speed and mass has kinetic energy. For this reason, atoms and molecules in motion supply kinetic energy to that substance. This energy is the inner energy of matter. The average kinetic energy resulting from the movement of all molecules that make up a substance creates the temperature of that substance. In this context, the speed of molecules is directly proportional to its temperature. In order to raise the temperature of the object, it must be given additional energy such as "heat". Heat is a type of energy that flows between a system and its surroundings only due to the temperature difference. The direction of flow of heat energy determines the temperature. Heat temperature flows from high system to low system. Heat is an energy unit. This means that heat can turn into any energy. The behavior of heat to thermodynamic laws (Law 1: Energy remains constant in an isolated system. In other words, energy cannot be destroyed or created and it can be transformed into another form. Law 2: Energy is transferred only from the higher to the lower). A thermal energy created by transferring heat between the systems is called heat transfer. Heat transfer is basically based on two main elements. These are temperature and heat flow. The temperature determines the amount of thermal energy available in the system.

As a result of these findings, the heat transfer between the systems under normal conditions takes place from the system with high energy to the low system. Under normal conditions, when a water at 5 ℃is placed in an environment at room temperature (25℃); water wants to come to an equilibrium temperature. In this example, if we consider the room as a heat well, it will be 25 ℃when the water temperature reaches equilibrium. This situation can only be changed by externally energizing the system. Many machines that do this job have been produced today. These machines are called cooling machines. Cooling machines work with many different methods. Cooling cycles are the most frequently used methods with the help of cooling cycles and Thermoelectric materials. For example, refrigerators are a machine that performs a refrigeration cycle. Peltier is one of the best examples of thermoelectric materials. Thanks to its special structure, when the tension is given, it creates a temperature difference between the two surfaces. Likewise, it can be produced in electricity from the temperature difference between the two surfaces. [11]

## 2.1 Refrigeration Cycles

The fact that heat passes from a high temperature environment to a low temperature environment spontaneously is a known fact according to the second law of thermodynamics. Conversely, if it is desired to transfer heat from a low temperature environment to a high temperature environment, energy must be consumed. The machines that provide this are called cooling machines.

Special liquids with very high heat holding capacity are used in cooling machines. These fluids increase the efficiency of the machine as it will decrease the work force.

Efficiency in cooling machines is calculated with the formula below.

$$COP = \frac{Q_L}{W_{net}} \qquad (1)$$

QL is the effect of cooling Wnet is the difference between the work given to the system and the work done by the system.

### 2.1.1 Reverse Carnot Cycle

When the Carnot cycle works, it acts as a heating machine. This cycle operates in reverse and acts as a cooling machine. In the Carnot cycle, the machine takes heat from the hot source and gives some of this heat as work and throws some of it into the cold source. This event happens spontaneously. Because heat flows from hot system to cold system automatically. Likewise, when you give the system a compression job, the system runs upside down. In other words, it takes heat from the cold system and gives it to the hot system.

Cycle Steps

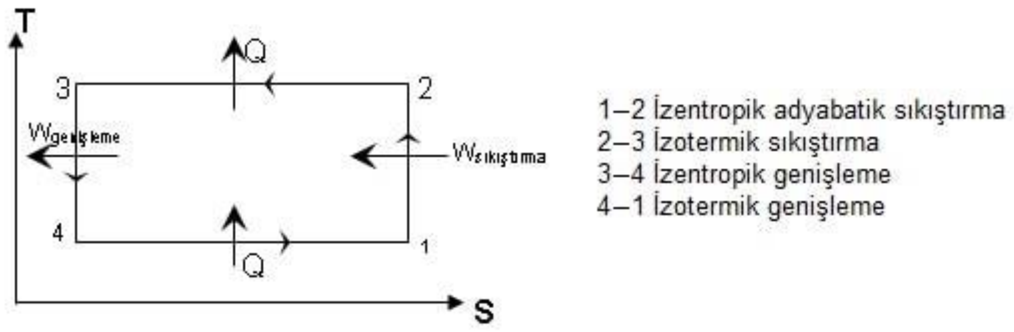


*Figure1: Inverse Carnot Cycle Diagram*

Between stages 4 and 1, a temperature of QL is drawn from the environment where the temperature is desired to be lowered. With the help of a compressor in between steps 1-2, compression is performed in fixed entropy and the temperature of the refrigerant is raised. In the 2-3 steps, a temperature amount of QH from the refrigerant rising in the temperature is thrown into the heat well. In between steps 3-4, the isentropically expanding refrigerant cycle completes the cycle so that a temperature of about QL is drawn in each cycle.

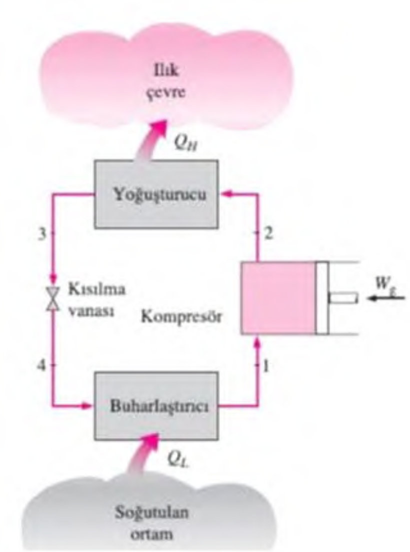


*Figure2: Reverse Carnot Cycle scheme and its elements*

Figure 2 reverses the scheme and elements of the Carnot cycle. In general, the cycle installation can be seen in figure 2. As seen in the figure, the system needs a job entry to work. This is usually achieved with the help of a pump.

The efficiency for Carnot cooling machines is calculated in the following equation.

$$COP_{CARNOT} = \frac{1}{\frac{TH}{TL}-1} (2)$$

TH is the heat source temperature and TL is the temperature of the cold environment.

### 2.1.2 Vapor Compression Cooling Cycle

These are the systems where cooling operation is performed by installing an expansion valve instead of the turbine in the Carnot cycle.

The Cycle can be expressed like this. The low-pressure refrigerant is sent to the condenser after it is removed by the compressor to high pressure. A condensation is created in the condenser and sent to the expansion valve and passed through it to be converted into a low-pressure liquid. From here, cooling is carried out by means of the evaporator.

Cooling Cycle Diagram:

2-3 Condenser

3-4 Expansion Valve (It can also be found as Throttle Valve)

4-1 Evaporator

1-2 Compressor

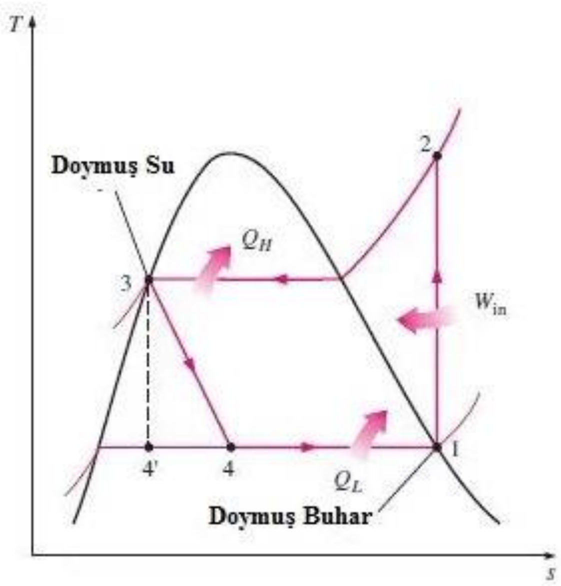


*Figure3: T-s diagram for vapor compression refrigeration cycle.*

In these applications, storage areas or living areas are cooled by sending the heat from the low temperature source to the high temperature environment. Heat normally moves from high temperature to low temperature. Therefore, the importance of insulation is very important in applications. Therefore, insulating materials with low heat transmission coefficient are used. Polyurethane is one of the most frequently used systems in today's systems. Insulation is used to maintain the low temperature in the chilled area and to reduce the energy and power required to reach the low temperature.

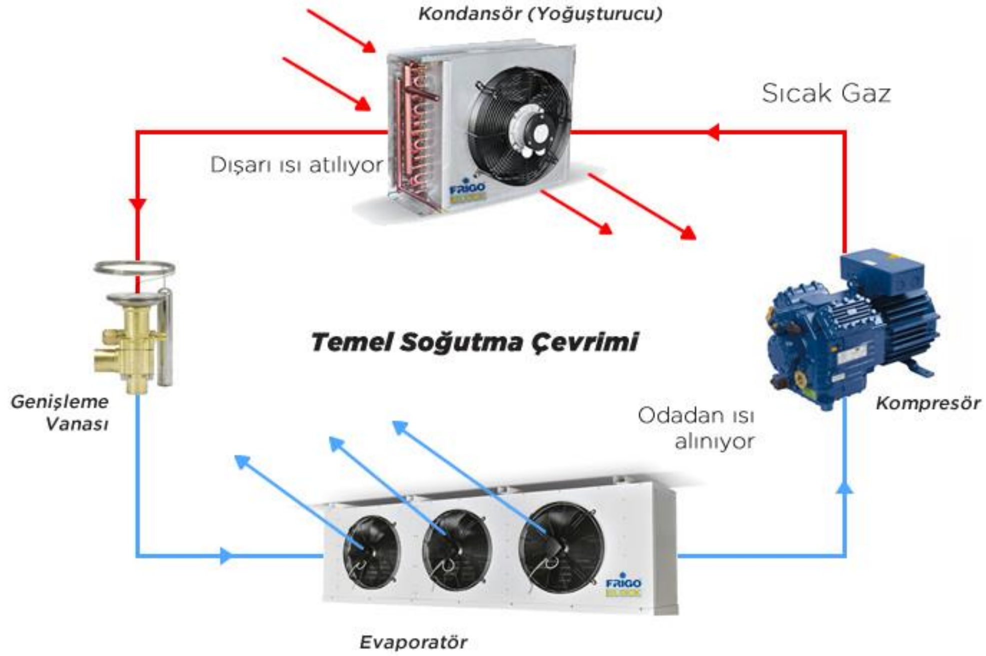


*Figure4: Vapor Compression Refrigeration Cycle Diagram and Elements.*

In the Vapor Compression Refrigeration Cycles, P-h graph is taken into account for COP calculation. (Figure 5)

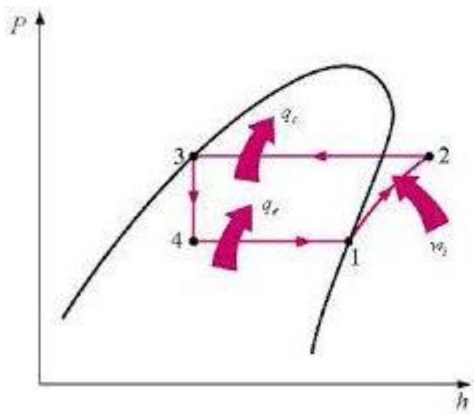


*Figure5: P-h diagram for vapor compression refrigeration cycle.*

Accordingly, COP is calculated in the following equation:

$$\mathrm{COP} = \frac{\mathrm{h1-h4}}{\mathrm{h2-h1}} \quad (3)$$

h1 enthalpy in first step.

h2 enthalpy in the second step.

h4 enthalpy in the fourth step.

### 2.1.3 Real Vapor Compression Cooling Cycle

Ideal Vapor Compression Cooling systems work steps are isentropically and isothermal. In contrast to real vapor compression refrigeration systems, some losses occur at these steps. In this case, the real steam cooling cycle T-s graphic is as follows.

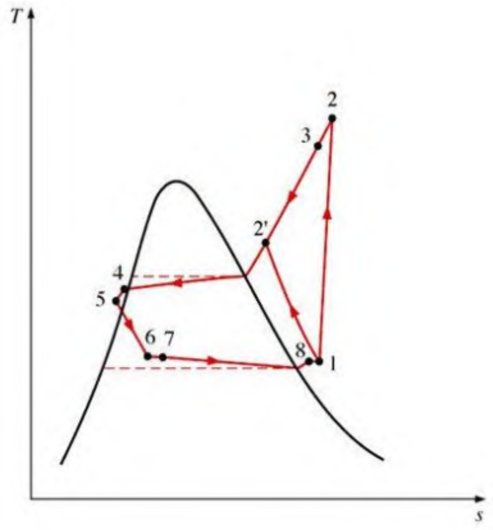


*Figure6: T-s diagram of the ideal vapor compression refrigeration cycle.*

## 2.2 Thermoelectric Cooling

It is the cooling type in which peltier is widely used. Peltier is a thermoelectric cooler consisting of semiconductors that heat one surface while the other surface heats up depending on the direction of the current given to it. The outer surface of the peltier is usually covered with ceramics. Semiconductor materials in the peltier are placed thermally parallel and electrically connected in series. When the peltier is given current, one surface warms and the other surface cools. When the peltier is given current, one surface warms and the other surface cools. Thermoelectric coolers operate on the principle of peltier effect.

### 2.2.1 Thermoelectric Materials

Thermoelectric materials are materials that when a current applied produce temperature difference. Thermoelectric materials mainly consist of semiconductors such as silicon (Si), germanium (Ge) and carbon (C). Thermoelectric coolers do not have dynamic parts so they Works quiet and do not get fail easily. As a result of that they do not need repair a lot. This means cheaper and healthier working. In addition, their sizes are very small and weights are very light. And they have also weaknesses like all devices. Such as their efficiencies are low and they are a little bit expensive.

### 2.2.2 Thermoelectric Effects

As the thermoelectric effect can be understood from its name, it is the conversion of heat and electrical energies to each other. The physicist Johan Seebeck, who took the thermoelectric effect for the first time in history, discovered it in the 1800s. There are 4 different effects in the basic sense between heat and electricity. These; Seebeck effect, Peltier effect, Joule's law and Thomson effect.[14]

#### *2.2.2.1 Seebeck Effect*

Seebeck set up a device to contact two different metal plates and heated them at one end. He observed that with the effects of heat, the nearby magnet moved. Thus, an electric field was formed. Seebeck effect is the process of obtaining electricity by taking advantage of the temperature difference. Direct current occurs when one end of the thermoelectric plate is heated and the other end is cooled. Thus, the Thermoelectric module can be used as a Thermoelectric generator.

Temperature difference between surfaces (℃):

$$\Delta T = T^2 - T^1 \qquad (4)$$

Thermal forces of two different metals due to temperature functions (Seebeck coefficients) ($V$/℃); ($s^2, s^1$)

Voltage generated in the circuit (V):

$$V = (s^2 - s^1) * (T^2 - T^1) \qquad (5)$$

*2.2.2.2 Peltier Effect*

*Figure7: Charles Peltier*

Charles Peltier found that in 1834 the Seebeck effects were two-sided. Peltier effect is basically the process of obtaining a temperature difference from voltage difference. As direct current passes through the intersection of two different conductive or semiconductor materials, heat is absorbed on the one hand and heat is released on the other hand. While the plate that the current passes on get cold and the other plate becomes hot. Cold and hot sides also move in a proportional figure when the direction of the current is changed.

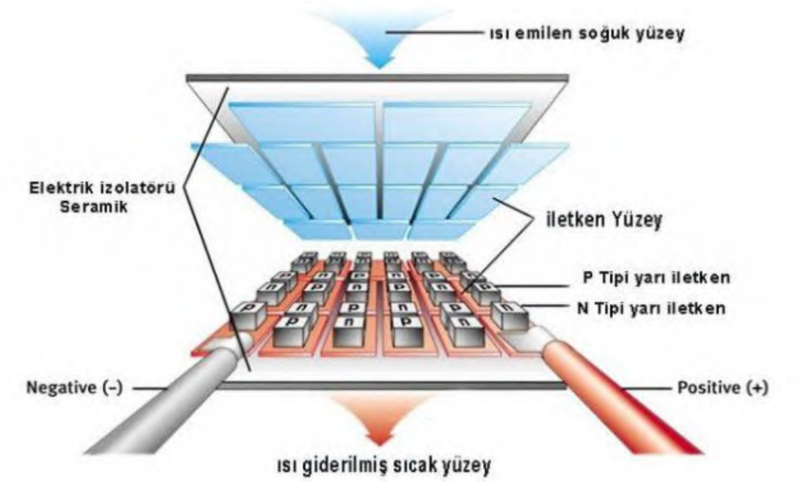


*Figure8: Internal view of the Peltier module.*

Some studies have been done based on Peltier effects. If we talk about a few of them;

In 2005, D. Astrain and colleagues conducted tests on Thermoelectric refrigerators at the University of Publica de Navarra. They have developed a model by simulating the

Thermoelectric performance of the cabinet. Finite methods are used to measure the heat flow, electricity consumption and COP of the refrigerator, which has an internal volume of 55 $dm^3$. Peltier performances in different conditions were investigated in the setup created by using a fan with 2Watt power. The fact that the peltier is quieter and environmentally friendly compared to other older cooling systems has contributed greatly to its use as a cooling system in this project. [1]

Peltier, which was published in the magazine called Technology in 2002, is a water-cooling process. Huseyn USTA and Volkan KIRMACI, who worked in Thermoelectric coolers at Gazi University, tried to cool a 4 mm wide peltier, which is about 50 $m^3$, has a container of 125 g water, and has an area of 4 $cm^2$. It is proportional to the temperature difference between the peltier performances of the current in this experiment and the peltier performances at varying current values.[2]

#### *2.2.2.3 Joule's Law*

*Figure9: James Prescott Joule*

Joule's law is actually two separate laws. James Prescott Joule's first law (Joule effect) formulates the relationship between the heat released when a current is passed through a conductive or semiconductor material and the amount of electric current.

$$Q = I^2 * R * t \tag{6}$$

Here, I (Ampere) represents the current, R (ohms) represents the resistance of the conductor or semiconductor, t (s) represents the time elapsed by, and the heat that the current (I) releases in time t.

#### *2.2.2.4 Thomson effect*

Unlike the heat of William Thomson Joule in 1851, he proposed when he created a heat or absorption. Change in proportion to the two parameters for the amount of heat generated. These are; current density and temperature difference.

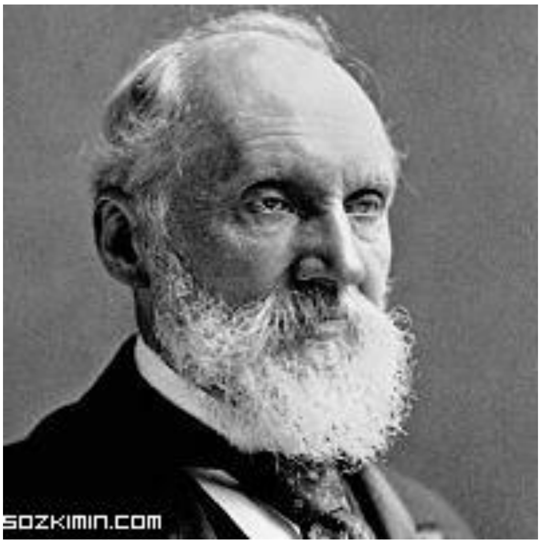


*Figure10: William Thomson.*

### 2.2.3 Insulation Materials

Preventing or reducing heat transfer between surfaces at two different temperatures is called thermal insulation. Materials that reduce heat transfer are called insulation materials. In a cooling or heating process without insulation material, unwanted heat transfer will occur between cold and hot surfaces. This reduces the efficiency of the process. If insulation material is used between the surfaces to be cooled or heated, the process will be more efficient since the heat transfer between the cold and hot surfaces will be controlled.

### 2.2.3.1 Rock Wool

It is obtained by melting volcanic rocks at high temperatures and turning them into fibers. Thermal conductivity coefficient is 0.035 – 0.040 ($W/_{m * K}$).

In addition, it is resistant to heat since high temperature is applied during the production phase and thus provides a good fire safety. It does not contain microorganism due to its non-organic structure. It has the ability to repel water. Its volcanic structure is proof that it is a natural and environmentally friendly insulation material. It is also a good sound insulator.

It is used for building roofs, furnaces, shipbuilding, steel doors, electrical appliances, heat and sound insulation and fire prevention.

*Figure11: Rock wool.*

### 2.2.3.2 Glass Wool

It is made of glass. It has lost its glass feature since it is produced at high temperature. Although it is not as much as stone wool, it is heat resistant (maximum 500 °C). Since its deformation will take many years, its appearance does not deteriorate and meets the production purpose. Heat transmission coefficient is 0.04($W/_{m * K}$).

*Figure12: Glass wool.*

### *2.2.3.3 Polyurethane (PUR)*

It is an artificial, not natural, insulation material such as polyurethane glass and stone wool. It is in fluid form and can be easily applied to many surfaces such as metal, wood and plastic thanks to its spray application. It is antibacterial. It is one of the lowest insulation materials of heat transfer coefficient. Heat transmission coefficient is 0.023 ($^{W}/_{m * K}$).

*Figure13: Application of polyurethane material.*

#### 2.2.3.4 Expanded Polystyrene (EPS)

This material, which is widely used in the insulation industry, is obtained by replacing pentane gas with air. It is made of oil. It is the most economical, light and environmentally friendly insulation material on the market. Also called Styrofoam or foam. It is not advantageous on hot surfaces since it can be used in maximum 100 ℃. It is resistant to cold up to -180 ℃, and it has been used for cold surfaces. Heat transmission coefficient is approximately 0.031 – 0.04 ($\boldsymbol{W}/_{\boldsymbol{m} * \boldsymbol{K}}$).

*Figure14: Expanded polystyrene (EPS).*

*Table3: Comparison of heat transfer coefficient and application temperatures of insulating materials.*

| | *Heat Transmission Coefficient* $(W/m*K)$ | *Minimum Temperature (℃)* | *Maximum Temperature (℃)* |
|---|---|---|---|
| *Rock Wool* | 0.035 | -50 | +750 |
| *Glass Wool* | 0.04 | -50 | +250 |
| *PUR (Polyurethane)* | 0.023 | -200 | +110 |
| *EPS (Expanded Polystyrene)* | 0.031 | -180 | +100 |

### 2.2.4 Fans

Vehicles that create a pressure difference between the two environments, which ensure the air is forced to move from high pressure to low pressure, is called a fan. It can also be called a fan, aspirator or propeller depending on its types. In our project, we will use the fan in two places. The first is on the outer surface of the peltier. Here, we will transfer the air in the heated part of the peltier to the external environment more quickly with the help of a fan by means of forced transport. The second place we will use the fan is the inner surface, which is the cold surface of the peltier. Here, we will transfer the air on the cooling surface to the internal environment in a fast figure again with the help of a fan by means of the forced transport method. The purpose of the fan is to maximize the efficiency of the peltier.

### 2.2.5 Heat Sink

These are the wings that expand the surface area by using the heated or cooled surfaces and allow the heat to spread on the surface. They are generally used together with fan and peltier devices in the form of an active cooling unit. Apart from this, there are usage areas which are called passive cooling units without fan and peltier and which have lower efficiency.

In our project, we will use the heatsink in two places together with the fan and peltier elements for active cooling as in the fan. First, we will spread the hot air on the outer surface with the heatsink to the wide surface and then remove it from the environment with the help of a fan. Secondly, after spreading the cold air on the inner surface to the wide surface with the help of the heatsink, we will be actively cooling by distributing it through the fan.

### 2.2.6 Heat Transfer Mechanisms

When the matter is examined microscopically, the kinetic energy possessed by the speed of the molecules is directly related to thermal energy. The molecules increase in speed to increase the temperature of the substance. Molecules with kinetic energy are transferred. This event is called heat transfer. Heat transfer simply examines in 3 phases: Conduction, convection and radiation.

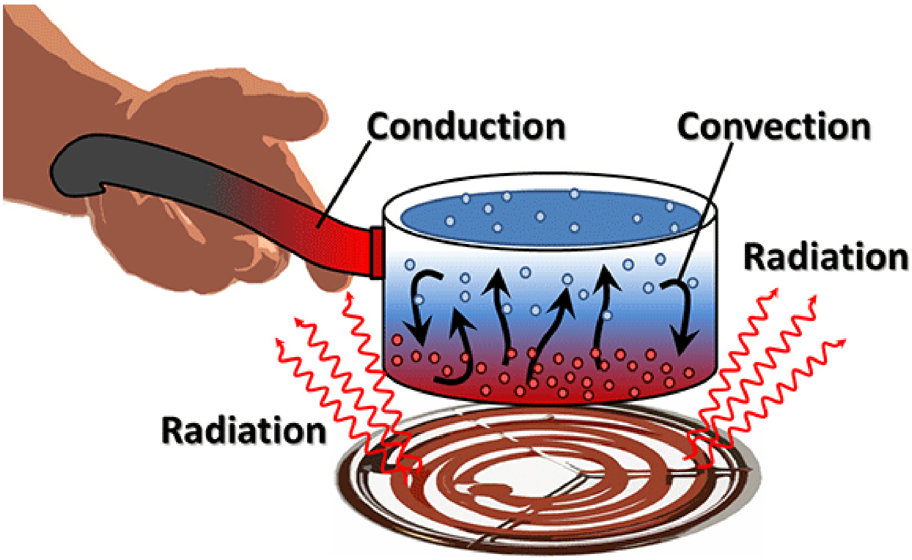


*Figure15: Representation of conduction, convection and radiation.*

The picture above shows how all 3 different heat transfer methods work in the same environment.

#### *2.2.6.1 Conduction*

Conducting heat transfer occurs when the molecules collide directly with each other. A higher energy kinetic energy field transfers energy to a lower kinetic energy field. Higher velocity particles collide with lower velocity particles. However, the kinetic energy of particles at low speed increases. Conduction is the most common method of heat transfer and takes place through physical contact. An example would be to place a metal item over a burning fire.

Heat conduction depends on the following factors: temperature gradient, cross-section of material, length of motion path and properties of the material. The temperature gradient is the physical quantity that defines the direction and rate of movement of heat. The flow of temperature always occurs from the warmest to the coldest, or as we mentioned earlier, from higher kinetic energy to lower kinetic energy. When a thermal balance occurs between two temperature differences (hottest, coldest), heat transfer stops.

The cross-section of material and the length of the travel path play an important role in heat transfer. The larger the size and length of a material, the amount of energy required to heat that material increases accordingly. Also, the larger the surface area exposed to heat, the greater the heat loss. So small objects with small cross sections have minimal heat loss.

Physical properties determine which of the materials transfers heat better. Specifically, the heat conduction coefficient reveals that a metal material will conduct heat better than a fabric. As can be seen in the equation below, the heat transmission coefficient can be calculated as:

$$Q = \frac{k*A*\Delta T}{d} (7)$$

Q= Amount of heat transferred per unit of time.

k= Heat transfer coefficient.

A= Heat transfer surface area.

$\Delta$T= Temperature difference between hot and cold zones

d= Refers to the thickness of the material.

#### 2.2.6.2 Convection

After an air or liquid fluid is heated and then away from the heat source, thermal energy is also carried along with it. This type of heat transfer is called convection. The liquid on a hot surface expands, then condenses and rises.

When examined with a microscope, it is seen that the molecules that take the energy expand. For example, when the temperature of a liquid body increases, the volume of liquid increases in direct proportion to the temperature increase. This effect on fluid causes displacement. The sudden rising hot air suppresses the denser and colder air. As a result of these events, it can be observed how convection currents are formed. The amount of heat transfer achieved per unit time by convection heat conduction can be calculated with the following equation.

$Q = h_c * A * \Delta\mathrm{T}(8)$

Q= Amount of heat transferred per unit of time.

$h_c$= Convection heat transfer coefficient.

A= Heat transfer surface area.

ΔT= The difference between the surface of the substance and the temperatures of the fluid.

### *2.2.6.3 Radiation*

With the propagation of electromagnetic waves, heat transfer occurs. These waves radiate heat. Radiation occurs through a vacuum or any transparent medium (solid or liquid). Thermal radiation is the direct result of random movements of atoms and molecules in matter. The movements of charged protons and electrons cause the propagation of electromagnetic waves.

All substances in nature emit thermal energy according to their temperatures. The amount of energy emitted is directly proportional to their temperature. The sun is an example of heat radiation that radiates heat throughout the solar system. At room temperature, objects propagate as infrared waves. Body temperatures also have an effect on the radiating wavelength and frequency. As the temperature rises, the wavelengths of the emitted radiation decrease, so that shorter wavelengths with higher frequency are emitted. Thermal radiation can be calculated by Stefan-Boltzmann Law:

$\mathbf{P} = \boldsymbol{\varepsilon} * \boldsymbol{\sigma} * \mathbf{A} * (\mathbf{T_r^4} - \mathbf{T_c^4})(9)$

P= Total power.

e= Spread coefficient.

σ= Boltzmann constant.

A= Radiation surface area.

$T_r$= Radiation emitting object temperature.

$T_c$= Environmental temperature.

### 2.2.7 Heat Transfer in One Dimension

Heat transfer in one dimension is calculated in different systems according to the type of surface. In this thesis, since our design is in the form of a plane wall, it will be examined only in this concept.

One dimensional heat transfer on plane wall.

Considering the area constant along the wall in the plane wall, the heat conduction equation is:

In case of variable conductivity:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \grave{e}_{\mathrm{gen}} = \rho c\frac{\partial T}{\partial t} \qquad (10)$$

k= thermal conductivity constant of the material.

In the case of constant conductivity:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\grave{e}_{\mathrm{gen}}}{\mathrm{k}} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (11)$$

In this equation, alpha (α) shows the amount of thermal spread formula:

$$\alpha = \frac{k}{\rho c} \qquad (12)$$

In the case of fixed conductivity, the conditions are reduced to the following forms.

Steady state:

$$\frac{d^2 T}{dx^2} + \frac{\grave{e}_{\mathrm{gen}}}{\mathrm{k}} = 0 \quad (13)$$

When there is no time-dependent heat generation:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (14)$$

When there is no steady heat generation:

$$\frac{\partial^2 T}{\partial x^2} = 0 \qquad (15)$$

### 2.2.8 Boundary and Initial Conditions

#### *2.2.8.1 Heat Flux Boundary Condition*

To calculate the heat flux between the two systems, the boundary conditions of the systems and the properties of the materials used must be known.

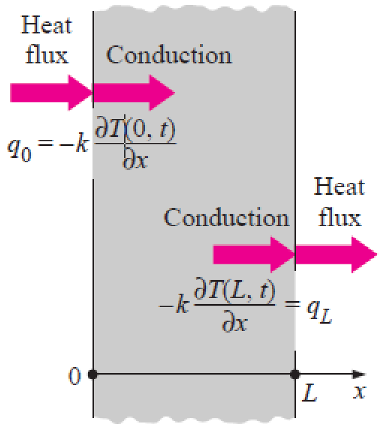


*Figure16: Convection boundary conditions on two surfaces of the plane wall.*

Fourier's heat conduction law and heat flux formula are as follows:

$$q = -k\frac{\partial T(0,t)}{\partial x} \quad (W/m^2) \quad (16)$$

#### *2.2.8.2 Convection Boundary Condition*

This boundary condition is the most common boundary condition. This is because many systems are exposed to a different temperature environment. The formula extracted from the heat balance is as follows:

$$-k\frac{\partial T(0,t)}{\partial x} = h_1[T_{\infty 1} - T(0,t)] \qquad (17)$$

$$-k\frac{\partial T(L,t)}{\partial x} = h_1[T(L,t) - T_{\infty 1}] \qquad (18)$$

where $h_1$ and $h_2$ are convection heat transfer coefficients and $T_1$ and $T_2$ are the temperatures of the surrounding environments on both sides of the plate.

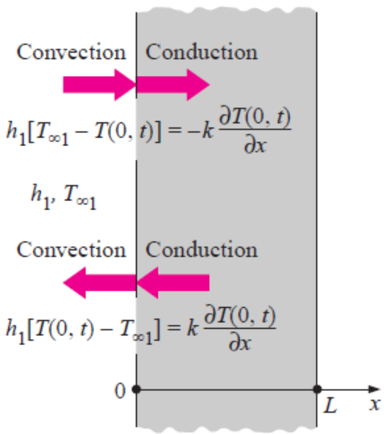


*Figure 17: The default direction of heat transfer at a boundary has no effect on the boundary condition*

### 2.2.8.3 Radiation Heat Transfer Boundary Condition

For one-dimensional heat transfer in the x direction of a L-thick plate, the radiation boundary conditions on both surfaces can be expressed in the figure below:

$$-k\frac{\partial T(0,t)}{\partial x} = \varepsilon_1\sigma[T_{s1}^4 - T(0,t)^4] \qquad (19)$$

$$-k\frac{\partial T(L,t)}{\partial x} = \varepsilon_2\sigma[T(L,t)^4 - T_{s2}^4] \qquad (20)$$

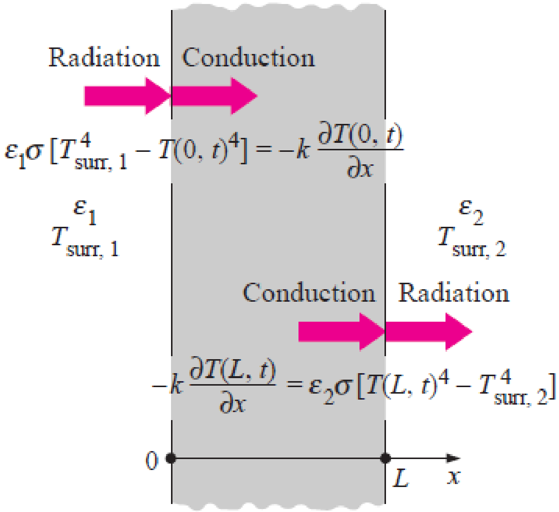


*Figure18: Radiation boundary conditions on both surfaces of the plane wall.*

### 2.2.8.4 Boundary Condition Between Solid-Solid Surfaces

It is the boundary condition that occurs when two solid objects contact each other. As an example, we can consider a house wall. When a section is taken from the wall, layers of solid material such as paint, plaster, insulation material, brick are seen in the section. These solid materials each had separate conduction coefficients and thicknesses, so the boundary condition between solid-solid surfaces should be used to calculate the heat flux.

The formula for this type of boundary condition is:

Boundary condition for the interlocking surface of solid surfaces

$T_A(x0,t) = T_B(x0,t)$ (21)

Heat transfer between two surfaces:

$-(k_A\,\partial T_A(x0,t))/\partial x = -(k_B\,\partial T_B(x0,t))/\partial x$ (22)

# 3 METHOD

## 3.1 Comsol Multiphysics Program and Working Principle

In our age where almost no scientific work can be done without a computer, Comsol Multiphysics is basically a computer-aided analysis program. In 1986, Svante Littmarck and Farhad Saeid founded the company in Sweden, which will become Comsol Multiphysics today. In 1996, the software with the simulation package was launched. Comsol Multiphysics was released in 2016 with Comsol Multiphysics version 5.2. Comsol Multiphysics has the capacity to design and analyze in many fields, especially in basic physics. [8]

### 3.1.1 Main Screen

There are four main windows on the Comsol Multiphysics program home page. The first is the Model Builder, where the applied processes take place step by step, the second is the Settings part, which, as the name suggests, is the setting window, the third is the notification screen showing the error messages and the progress, the fourth part is the Graphics part, which is the most important part. Here is the model studied. Physical studies such as views of the model from different angles and axes are included in the Graphics section.

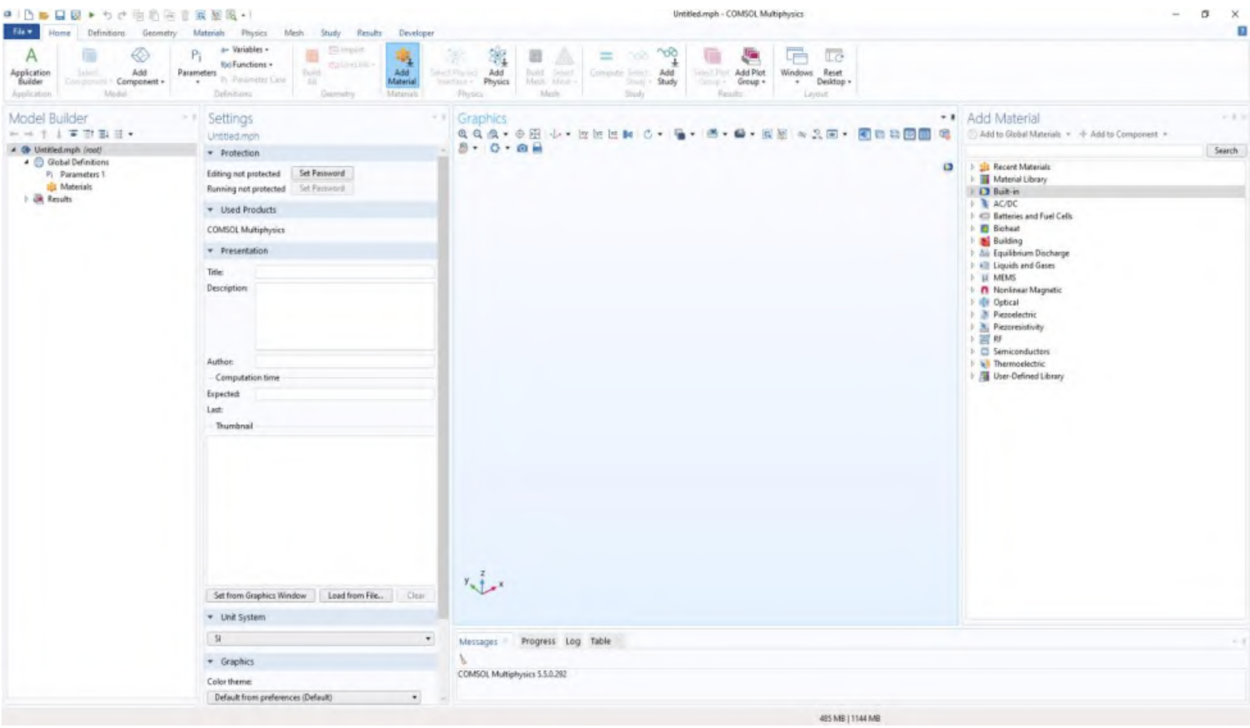


*Figure19: Main screen in Comsol Multiphysics program.*

### 3.1.2 Physics Choice Screen

In the Comsol program, it is possible to work in different branches of physics such as electrochemistry, fluid analysis, heat transfer, chemistry, acoustics, electricity etc. We have worked in the field of heat transfer in our project. When we click on the heat transfer tab, there are different heat transfer mechanisms. We modeled our design by choosing the heat transfer mechanism between solid and liquid materials.

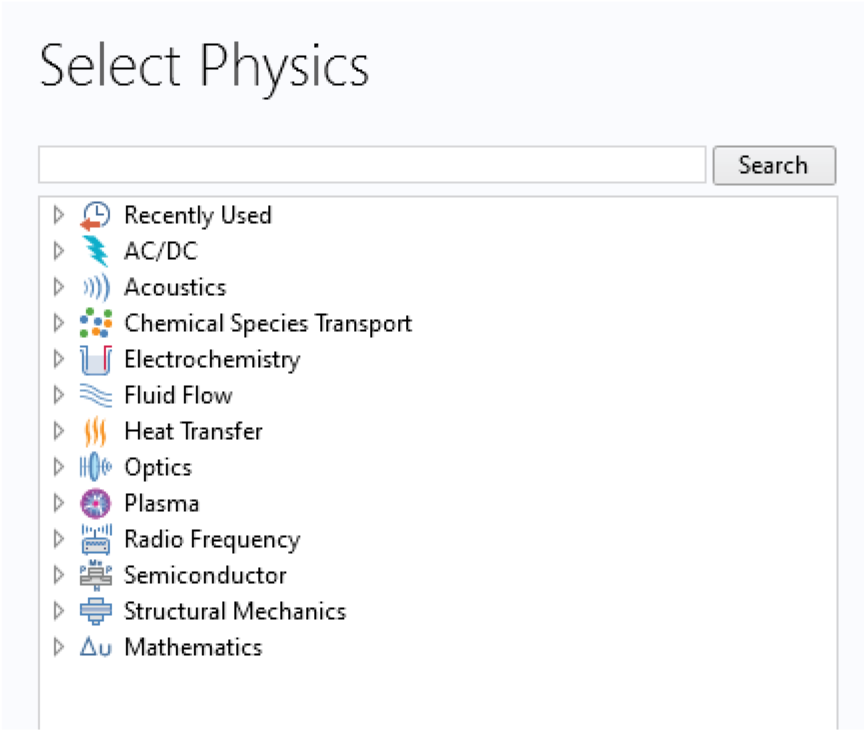


*Figure20: Physics addition screen in Comsol Multiphysics program.*

### 3.1.3 Material Library

Comsol also has its own material library. Here, material is selected for the product to be analyzed. Comsol's material library has a wide range of elements such as building materials, different fluids, conductive and insulating materials, magnetic materials, biological materials, organic& inorganic materials and Thermoelectric materials.

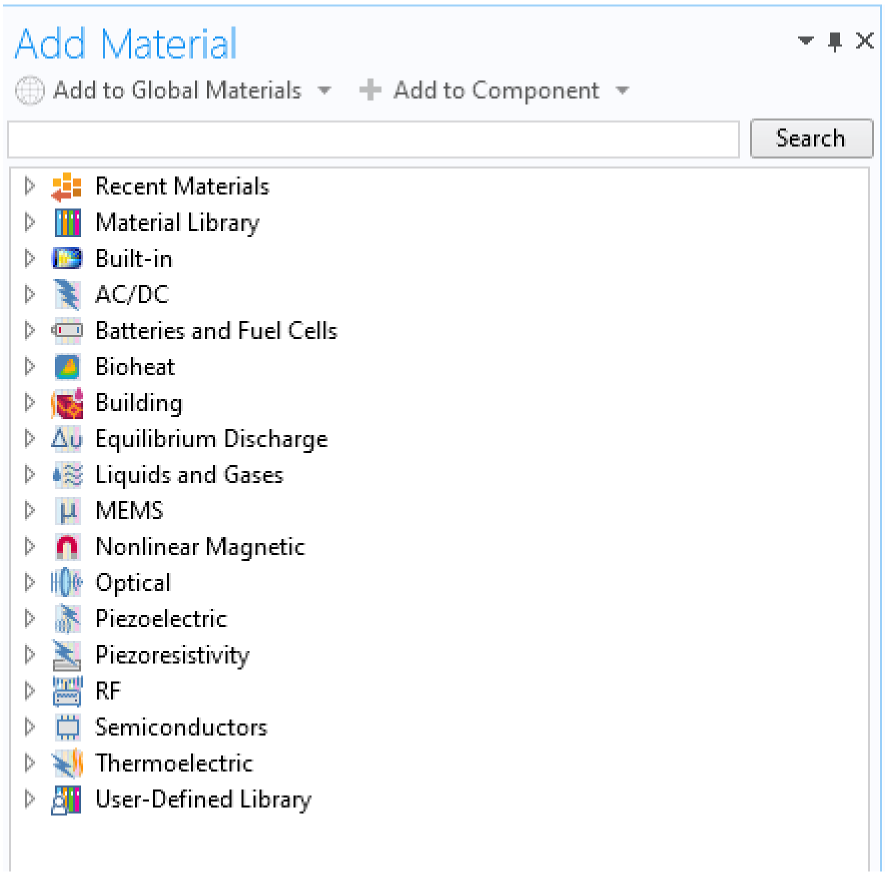


*Figure21: Material addition screen in Comsol Multiphysics program.*

### 3.1.4 Mesh Logic and Working System in Analysis Programs

Mesh means the network structure of the word Turkish. In fact, the basic logic of the mesh system is to simplify and speed up the process by dividing the part to be analyzed into smaller pieces than itself. Namely, by the method named as finite element method, it is the process of placing control points on each piece by dividing the material into infinitely small pieces. And it is to make a measurement from a single point and to provide a solution throughout the material thanks to the network system.

#### *3.1.4.1 Mesh Dependency*

There are two important points to consider when choosing mesh in any analysis. The first one is the correct mesh selection, and the second one is the number of mesh. In the basic sense, three-dimensional mesh types are; tetrahedron, hexahedron, pyramid and wedge types. In this case, in order to get more accurate results, the mesh type in which the material to be meshed is geometrically close must be selected. There are totally nine mesh options in the Comsol program, four of which are sensitive, which we call 'fine', four of which are called 'coarse', and the middle of the two is 'normal' mesh options.

If we come to the number of mesh, the analysis will not be sensitive if the number of mesh is chosen low, in the opposite case, if the number of mesh is selected more than necessary, the process will take too long. If a normal number of mesh needs to be done and a finer result is desired, the number of mesh should be increased. After a while, it is understood that the increasing number of mesh has no effect on the solution. Here the number of mesh at this point is the most accurate mesh number.

In our study we prefer two mesh options. One of them is fine mesh option and the other one is extremely coarse mesh option. We will mention about the temperature values for the fine mesh and extremely coarse mesh options in the table 4 in the results chapter.

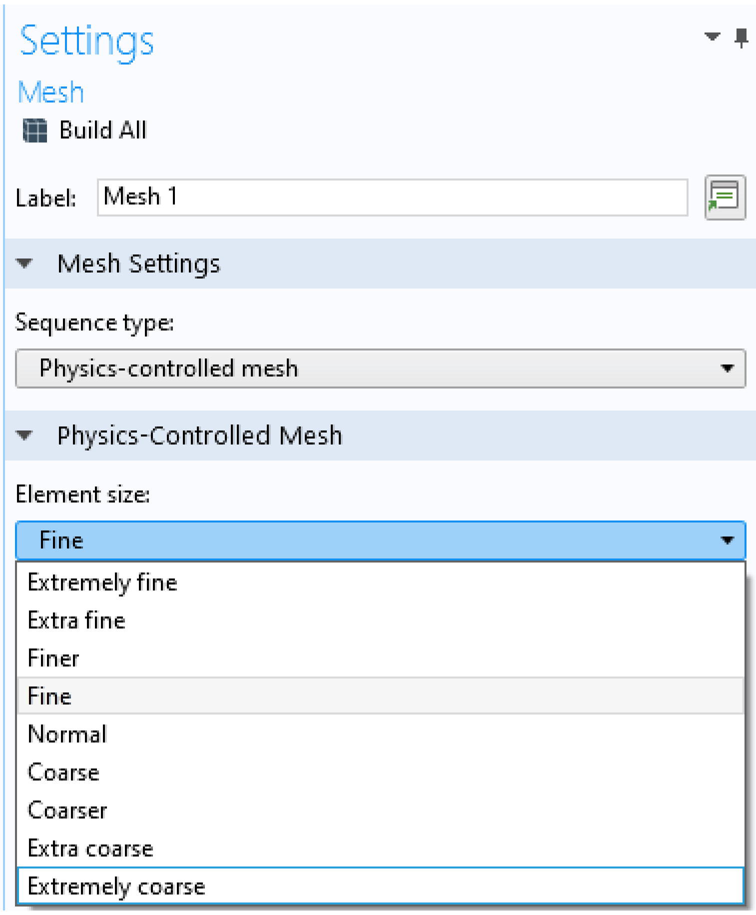


*Figure 22: Mesh selection screen in Comsol Multiphysics program.*

## 3.2 Comsol Program Working Principle

### 3.2.1 Case 1

#### *3.2.1.1 Geometry*

In the program, we first created the geometry that we will analyze. Our geometry consists of 4 blocks. The first block consists of a $30 * 30 * 30$ cm cube that we determined beforehand. Our 2nd block is the air environment on the surface for the box. Since we determined the box thickness by 3 cm, we determined the dimensions as $27 * 27 * 24$ cm. Our third block is the lid of the box. The dimensions of the lid we have determined in thickness are $3 * 3 * 30$ cm. Our last block is the space we have reserved for peltier. In this, the dimensions are determined in the figure that will be $3 * 4 * 4$cm. Our system is formed when we place our 4 blocks on the 3-dimensional axis.

The geometry of our system is as shown in the picture below.

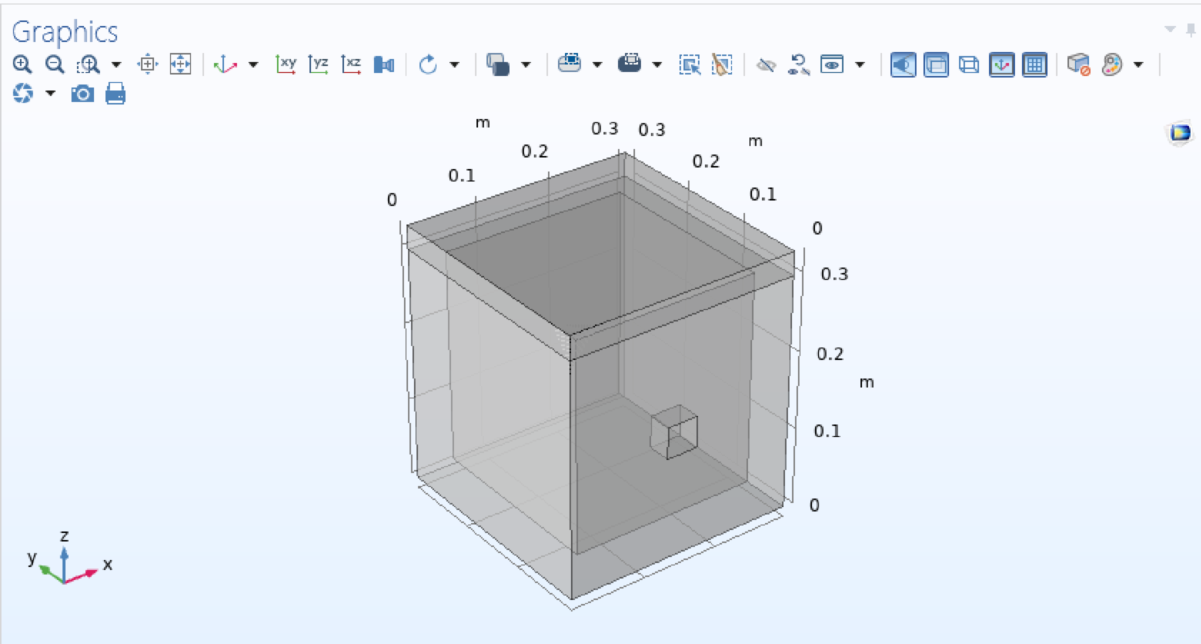


*Figure 23: View of Cooling Cup in Comsol program.*

### 3.2.1.2 Thermostat

In this section, we have positioned the thermostats that allow us to control the system over the temperature values. We placed the thermostats near the box lid where the heat loss was highest and in the furthest part from our cooler kit peltier. We placed another thermostat at the point where the product will be placed to observe the point temperature change for the box.

The positions of the thermostats in the coordinate plane are:

For first thermostat: x; 0.25 m y; 0.25 m z; 0.25 m

For second thermostat: x; 0.15 m y; 0.20 m z; 0.10 m

The positions of the thermostats are shown with red dots in the two images below.

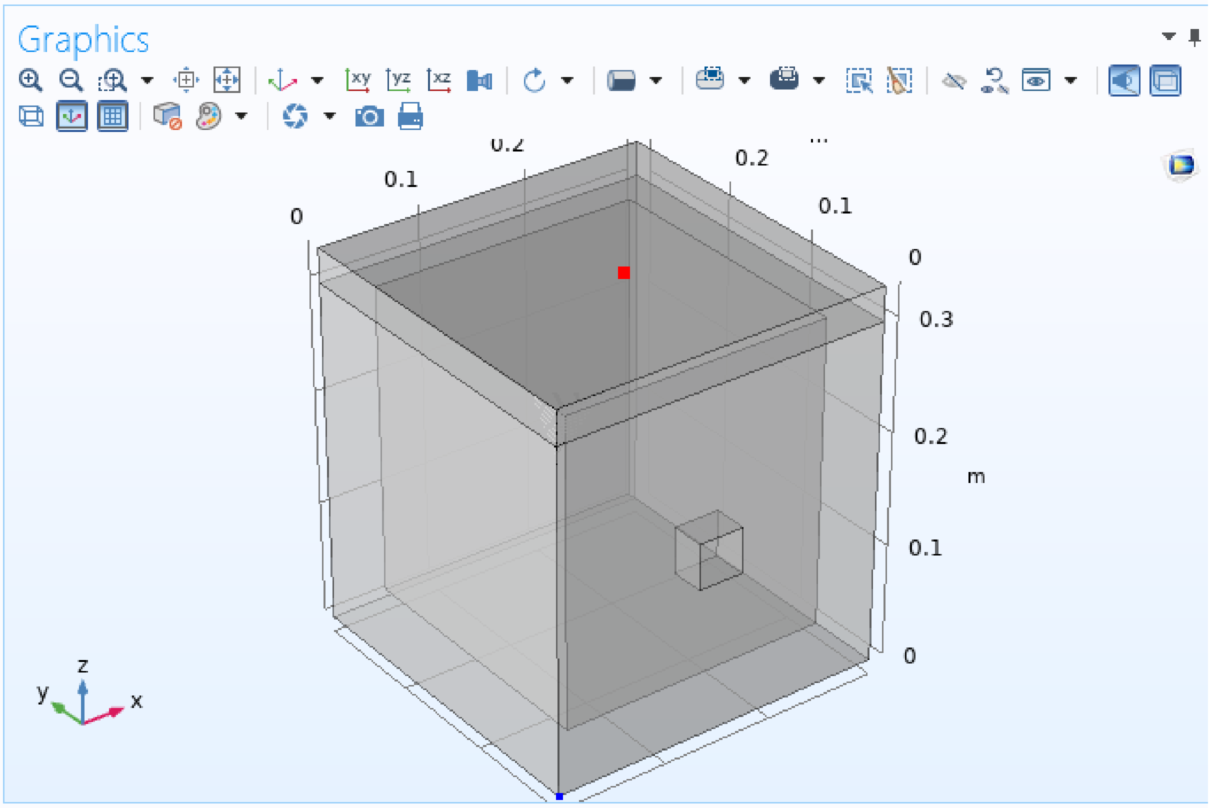


*Figure 24: Position of the first thermostat.*

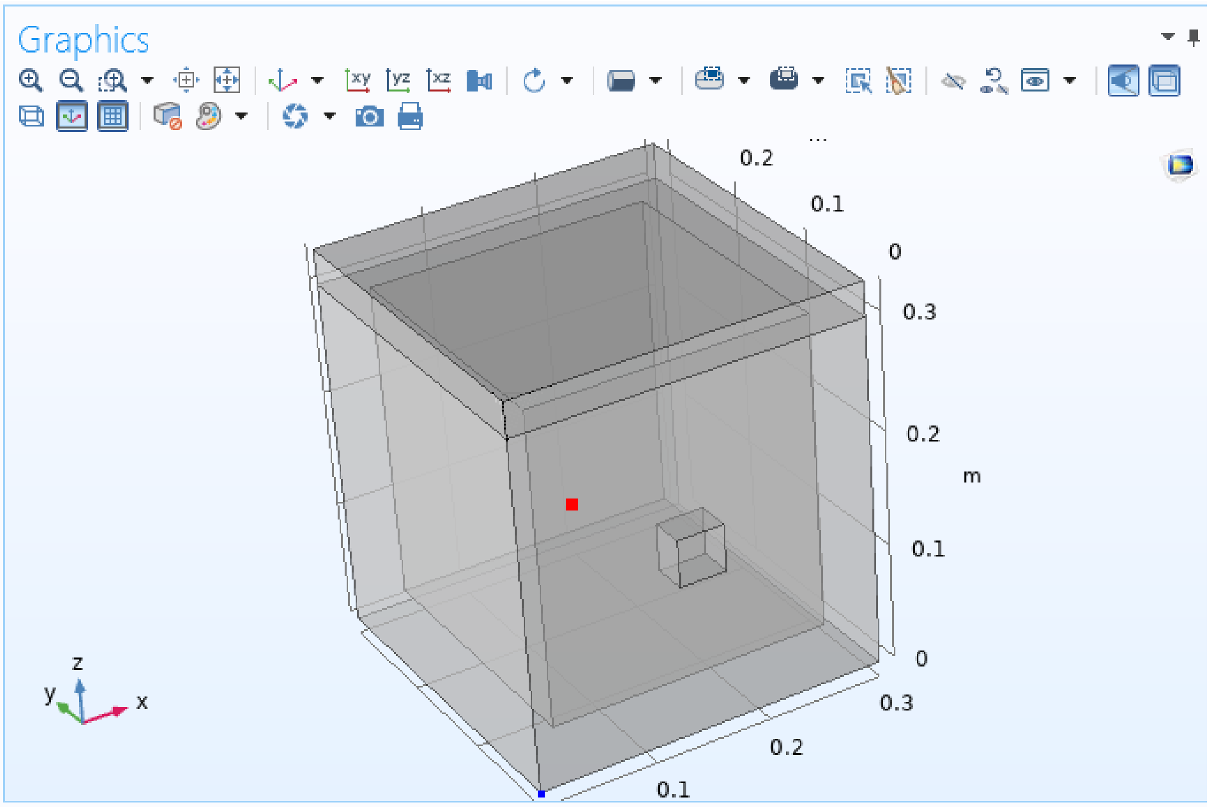


*Figure 25: Position of the second thermostat.*

### 3.2.1.3 Material Selection

We determined our materials by assigning predefined materials in the program.

We used Foam [solid, 101 kPa] coded material, which is an insulation material for the outer material of our box 1 and 3 blocks.

Material properties are shown in figure 26.

| | Property | Variable | Value | Unit | Property group |
|---|---|---|---|---|---|
| ☑ | Thermal conductivity | k_iso ; kii =... | k_solid_101_kPa_1(T[1/K])[W/(m*K)] | W/(m·K) | Basic |
| ☑ | Heat capacity at constant pressure | Cp | C_solid_101_kPa_1(T[1/K])[J/(kg*K)] | J/(kg·K) | Basic |
| ☑ | Density | rho | rho(T[1/K])[kg/m^3] | kg/m³ | Basic |
| | Local property TD | TD | TD_solid_101_kPa_1(T[1/K])[m^2/s] | m²/s | Local properties |

*Figure 26: Heat transfer properties of our insulation material.*

For the second block, we chose the Air as a material defined in the program.

Material properties are shown in figure 27.

| | Property | Variable | Value | Unit | Property group |
|---|---|---|---|---|---|
| ☑ | Heat capacity at constant pressure | Cp | 154[J/(kg*K)] | J/(kg·K) | Basic |
| ☑ | Density | rho | 7700[kg/m^3] | kg/m³ | Basic |
| ☑ | Thermal conductivity | k_iso ; kii =... | k(T) | W/(m·K) | Basic |
| | Seebeck coefficient | S_iso ; Sii =... | S(T) | V/K | Basic |
| | Electrical conductivity | sigma_iso ;... | sigma(T) | S/m | Basic |
| | Relative permittivity | epsilonr_iso... | 1 | 1 | Basic |

*Figure 27: Thermal insulation properties for air.*

We used Bismuth Telluride - Bi2Te3 coded material, which is also a semiconductor for the fourth block, the peltier material. When choosing this material, it is based on the properties of the peltier material.

Material properties are shown in figure 28.

| | Property | Variable | Value | Unit | Property group |
|---|---|---|---|---|---|
| ☑ | Heat capacity at constant pressure | Cp | 154[J/(kg*K)] | J/(kg·K) | Basic |
| ☑ | Density | rho | 7700[kg/m^3] | kg/m³ | Basic |
| ☑ | Thermal conductivity | k_iso ; kii =... | k(T) | W/(m·K) | Basic |
| | Seebeck coefficient | S_iso ; Sii =... | S(T) | V/K | Basic |
| | Electrical conductivity | sigma_iso ;... | sigma(T) | S/m | Basic |
| | Relative permittivity | epsilonr_iso... | 1 | 1 | Basic |

*Figure 28: Heat conduction properties for Bismuth Telluride.*

### 3.2.1.4 Heat Transfer Part in Comsol

In this section, we aimed to make the block five act like the same peltier and to make the natural transmission of the box outside the 5th block external surfaces. First, we have defined the solid, initial values, thermal insulation part on the program. In this section, we only set 275.15 $K°$ (2℃) as the first temperature. Then, by adding 4 heat fluxes, we completed the heat transfer part of our design.

#### 3.2.1.4.1 Heat flux 1

We first added a heat flux to its outer surface to transform the block into the working principle of the peltier.

We wrote the Power for Peltier at 0.71 W according to the Heat rate and multiplied it with a variable called Heat State to control it. Heat State variable will be explained in detail in the control section.

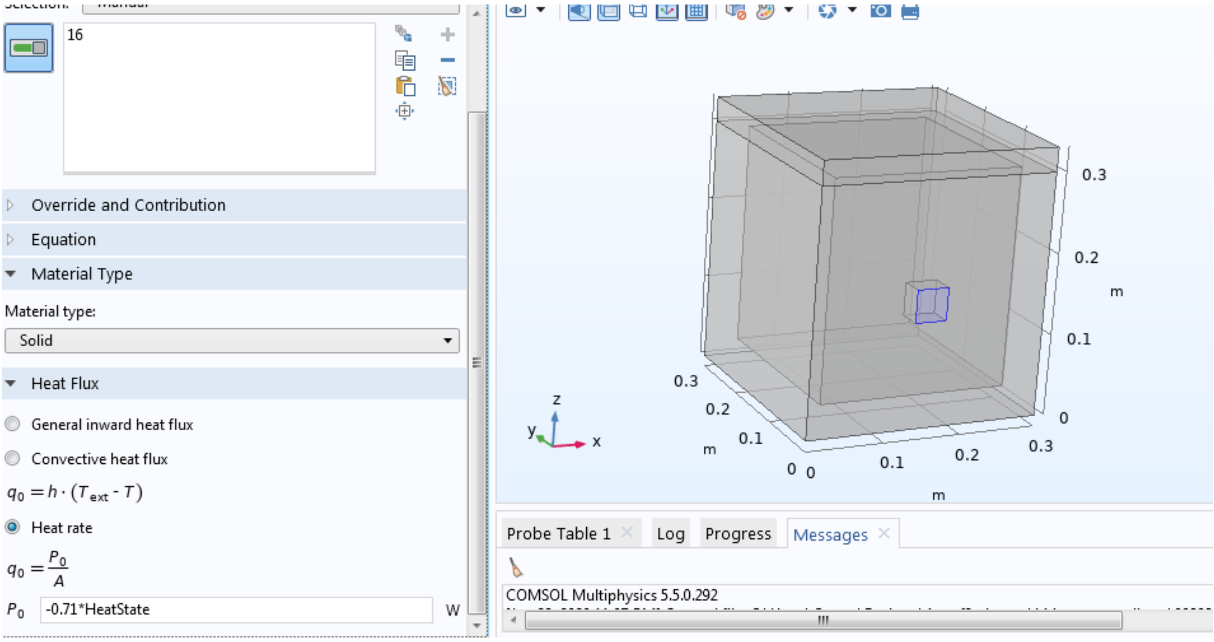


*Figure 29: Technical characteristics of heat flux 1.*

### 3.2.1.4.2 Heat Flux 2

In this section, we have determined the natural heat conduction between the exterior and interior environment from the side walls. After selecting the side wall areas, we entered heat flux, convective heat flux, external natural convection, vertical wall, and then we entered height (L) as 33cm (0.33m). The following picture shows this process.

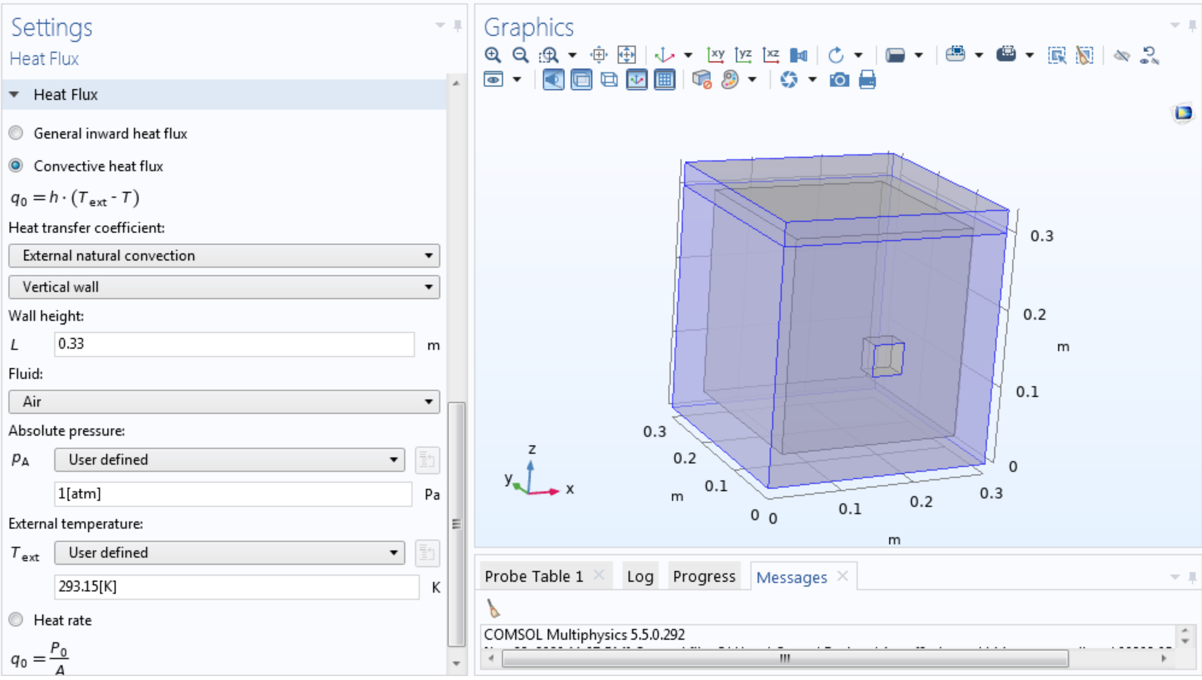


*Figure 30: Technical characteristics of heat flux 2.*

### 3.2.1.4.3 Heat Flux 3

In this section, we have determined the natural heat conduction between the inside and outside of the lid on the box. After selecting heat flux, convective heat flux, external natural convection, horizontal plate upside, we entered the characteristic length (area per circumference ratio (L)) as 0.075 m. The following picture shows this process.

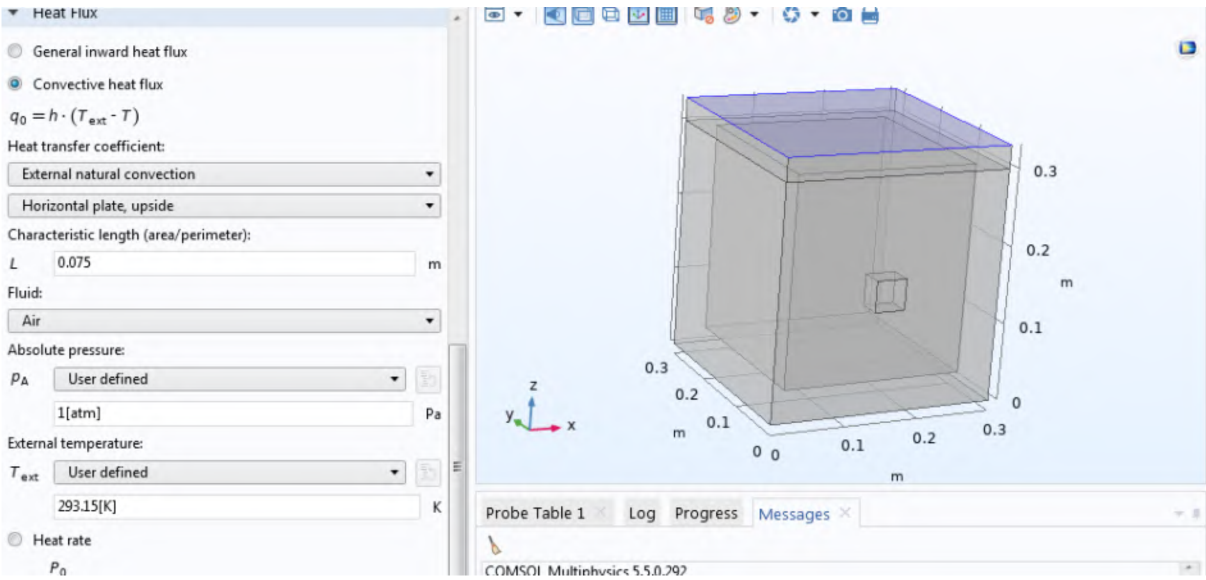


*Figure 31: Technical features of heat flux 3.*

### 3.2.1.4.4 Heat Flux 4

In this section, we determined the natural heat conduction between the inner and outer environment of the bottom of the box. After selecting heat flux, convective heat flux, external natural convection, horizontal plate downside respectively, we entered the characteristic length (area per circumference ratio (L)) as 0.075 m. The picture below shows this process.

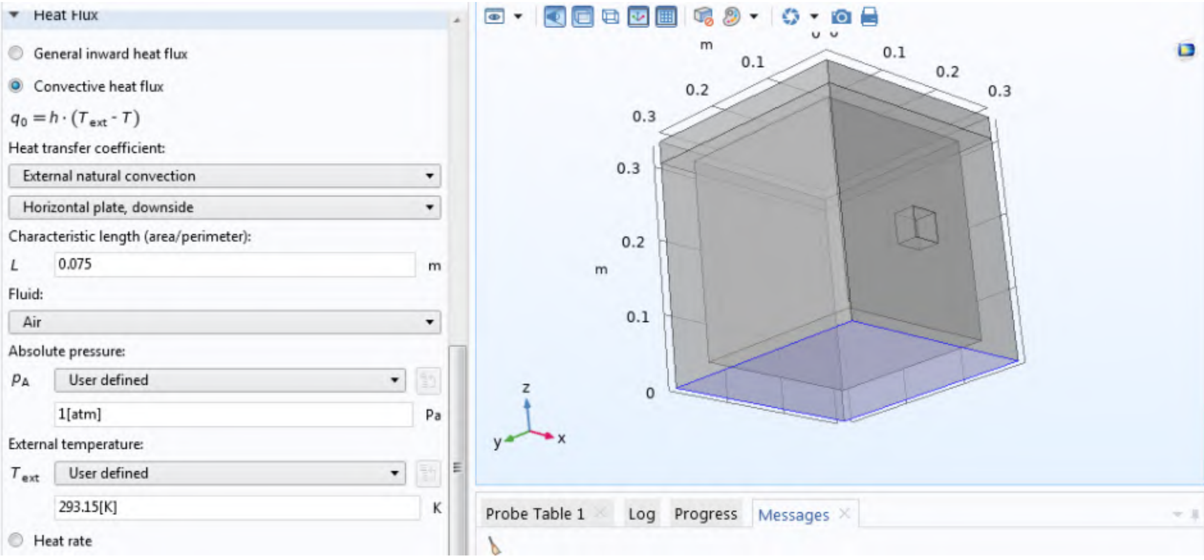


*Figure 32: Technical characteristics of heat flux 4.*

### *3.2.1.5 Mesh*

In this section, we completed by selecting the 'fine' option pre-defined in the program. The particle size that our box will be examined after the mesh analysis is as shown in the picture.

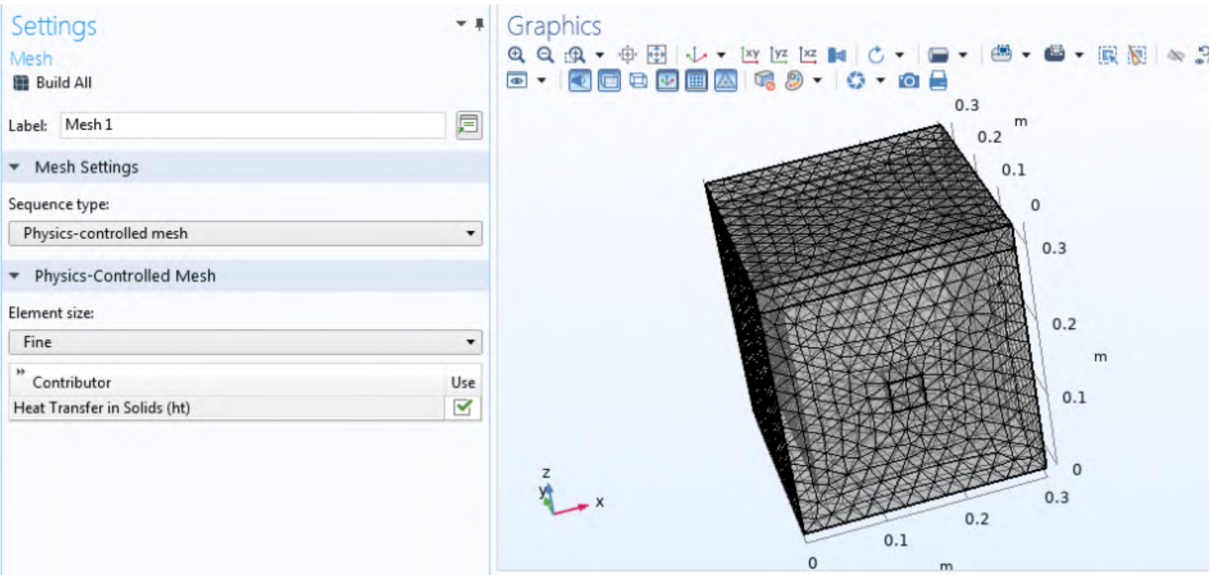


*Figure 35: Mesh analysis in Comsol.*

### 3.2.1.6 Control

In this section, we first identified a one-dimensional component. We defined the component2 under the name Tmeasured to define the temperature measured in the thermostat1. In this section, we associate Tmeasured with comp1.pp1, that is, thermostat1 in component1.

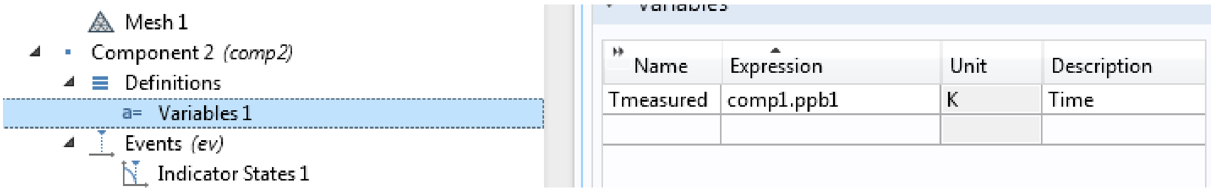


*Figure 34: Defining the Tmeasured value.*

Then we wrote the plot required for the working behavior of Heat Flux 1 in the Events section.

In the event section, we first associated low temperature and high temperature with the T set we determined in the measured temperature and parameter.

$$lowtemp = (Tset - 17) - Tmeasured$$

$$hightemp = Tmeasured - (Tset - 15)$$

We calculated this value at the first temperature values and entered it as the initial value.

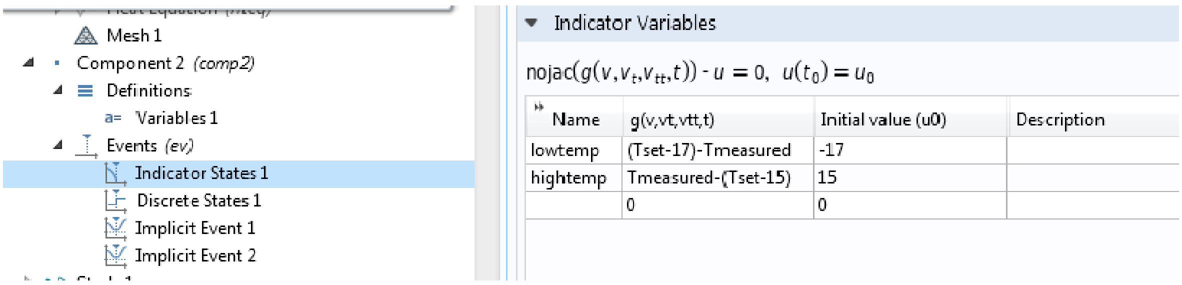


*Figure 35: Defining Indicator variables.*

Then we added the part of the relay that will serve as a key in the discrete states section and set the relay in the figure to be 1 or 0 according to the measured value.

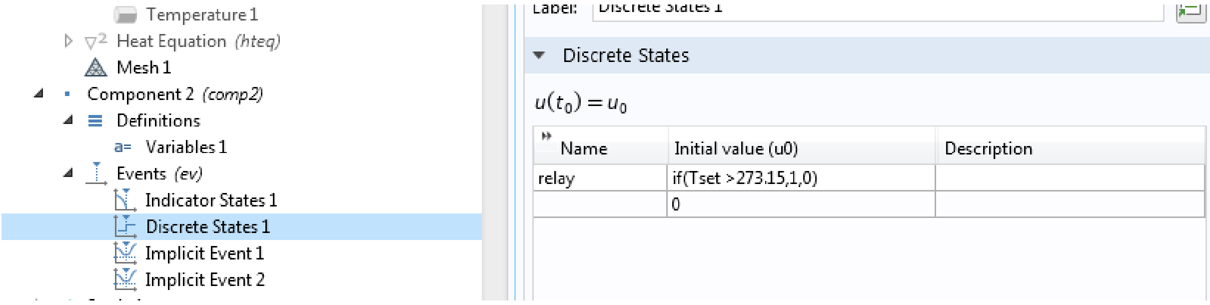


*Figure 36: Discrete States 1.*

Then, in the Implicit event 1 and Implicit event 2 section, we wrote the control part of our switch that commands the Tmeasured to turn off when it reaches 2 °C and the Tmeasured opens again when it reaches 4 °C.

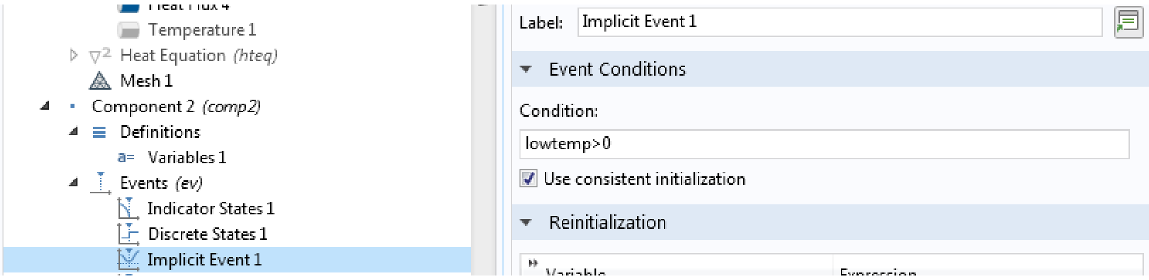


*Figure 37: Implicit Event 1.*

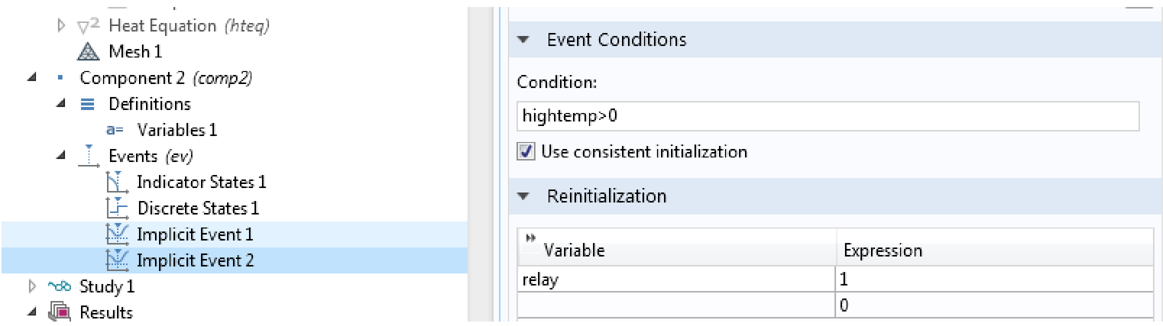


*Figure 38: Implicit Event 2.*

After completing this section, we associated our key with a new parameter under the name Heat State in the Reduced-order modeling section to be able to associate it with Heatflux1. Then we associated the Heat State parameter and a power of Heat Flux.

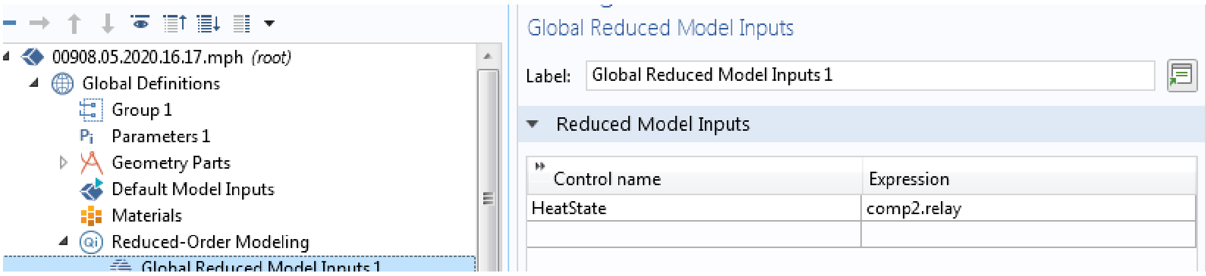


*Figure 39: Global Reduced Model Inputs 1.*

### *3.2.1.7 Study*

After defining all batches, we solved our model in the figure that will receive data and control every 500 minutes in the study section.

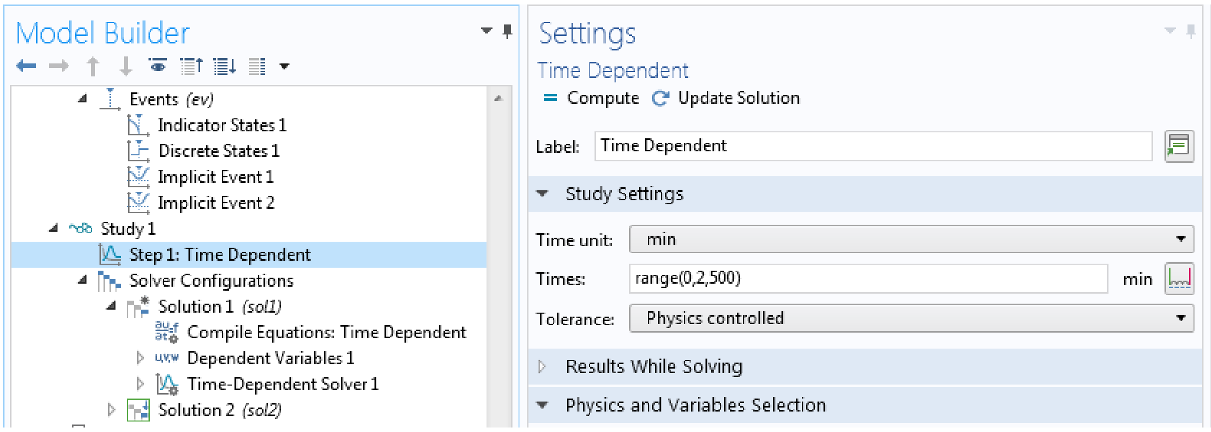


*Figure 40: Study screen in Comsol program.*

## 3.2.2 Case 2

### *3.2.2.1 Geometry*

This section was created by adding a 5th block in 4 * 4 * 3 cm dimensions in addition to case 1. We positioned the 5th block (peltiyer2) in the position opposite the 4th block (peltiyer1) as shown in Figure 41.

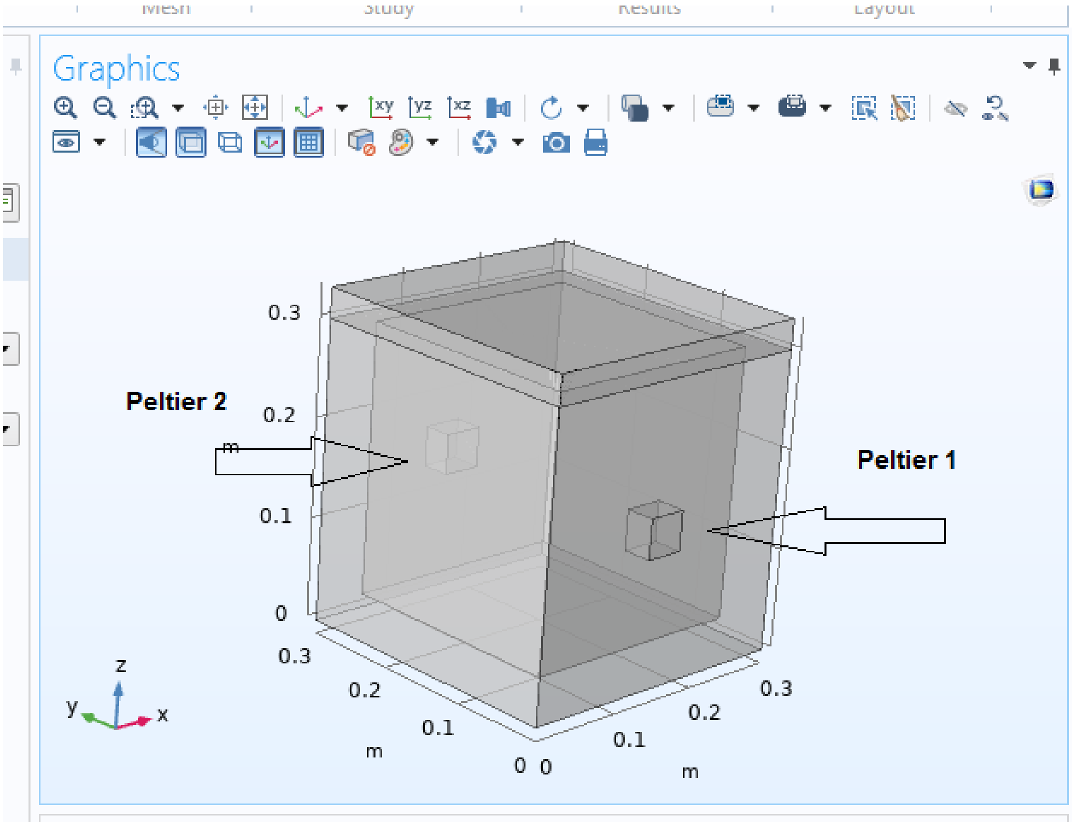


*Figure 41: View of two Peltier's in Case 2.*

### 3.2.1.2 Thermostat

In this section, the location of the thermostat 2 is in memory with case 1. We just placed the thermostat 1 centered on the two Peltier's and close to the lid. The reason for this is that the place where our box gains the highest amount of heat is close to the box wall and cover.

New location coordinates for Thermostat 1: x; 0.25 m y; 0.15 m z; 0.25 m

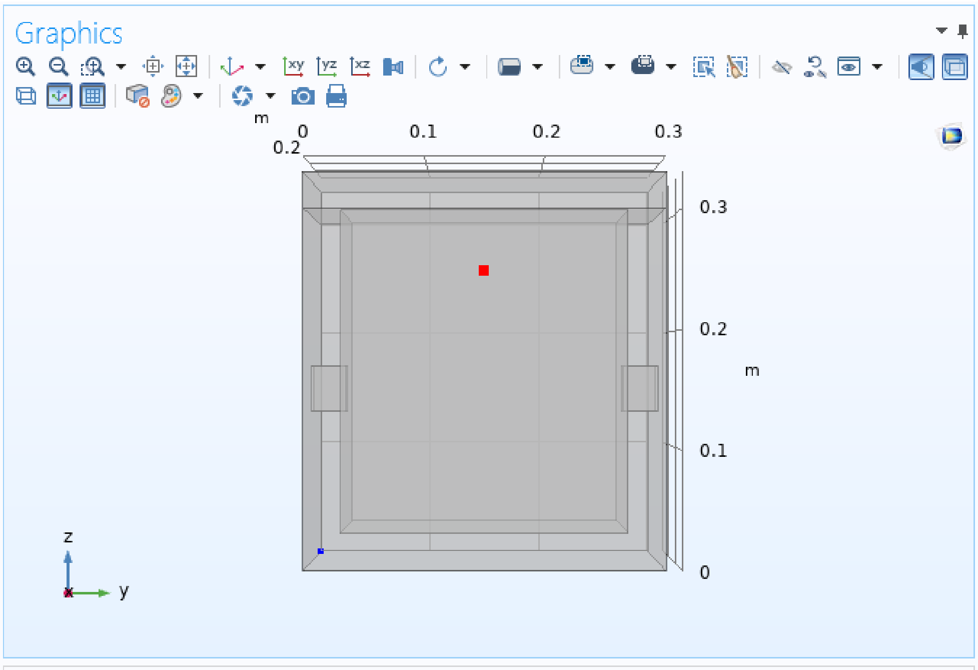


*Figure 42: View of thermostat 2 which position changed in Case 2.*

All the other properties are the same with Case 1.

## 4. RESULTS

In this section, we will show the analysis results we made with different mesh numbers and different peltier powers for case 1 and case 2 with the data we received from the Comsol program. We tested the fine and finer mesh options for both cases.

### 4.1 Analysis Results for Case 1

For Case 1, we analyzed the single peltier box model by choosing three different meshes. We choose Finer mesh option, Fine mesh option and Extremely mesh option. In the study section, we determined the analysis time of our box as one day means 1440 minutes. We have adjusted our data to take one data in every minute in order to provide ease of control and healthy data. As a result, we obtained the temperature dependent graph of the thermostats in the result part as shown in figure 41.

### 4.1.1 Extremely Coarse Mesh Option

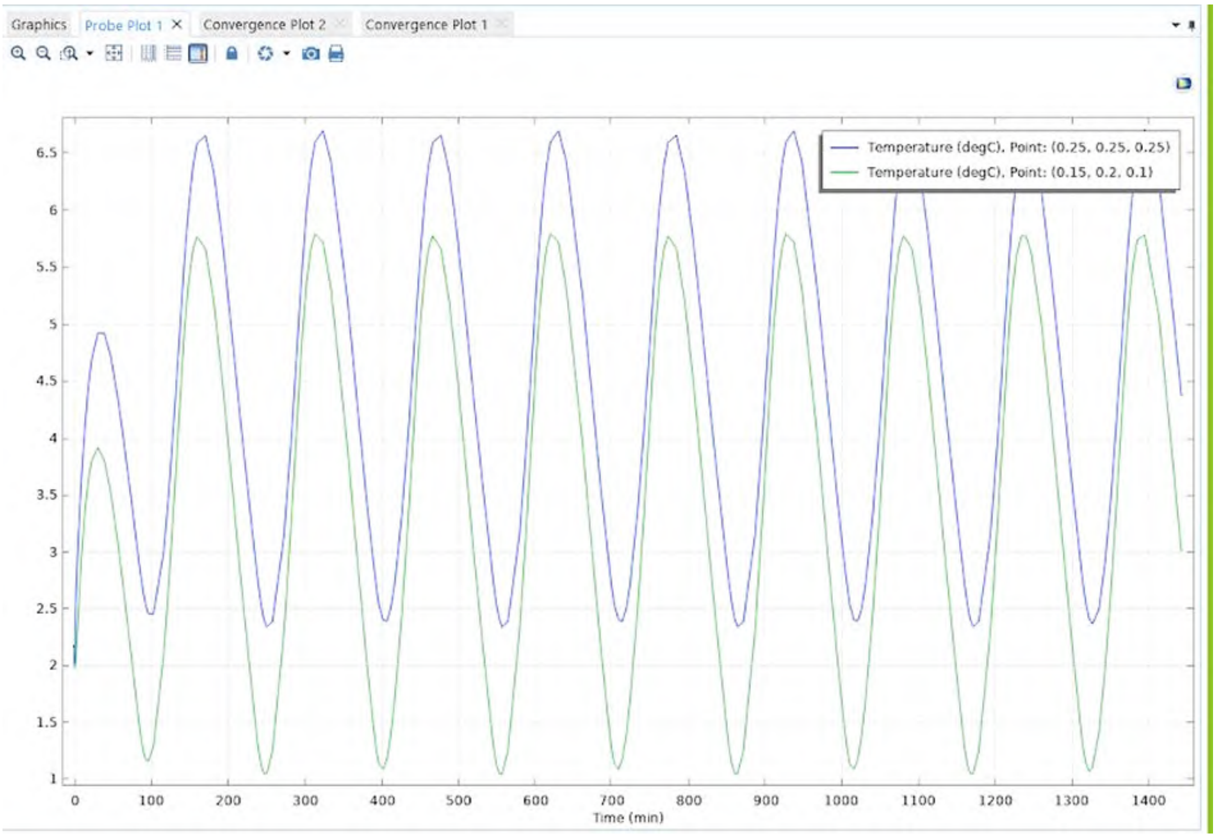


*Figure 43: Probe graphic for Case 1 de extremely coarse.*

Firstly, we got the solution by choosing Extremely coarse by lowering our Mesh number for Case 1. In this section, where the control section is identical according to Peltier power box geometry and thermostat degree, we obtained the result of thermostat temperatures for 1440 minutes as in figure 44. Similarly, data was taken at 1-minute intervals and control was achieved. When we examine the results, the maximum temperature value for thermostat 1 is approximately 7 C, and the minimum temperature value is measured as 2.3 degrees. The temperature value for thermostat 2 was maximum 5.8 and minimum 1.3 C. Looking at these results, when we reduce our mesh count, we can say that we achieve higher temperature ranges under identical conditions. The duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 70 minutes. It can be said that peltier (heat flux1) has a sudden and distinct effect in the low mesh option. Although the range we have obtained is still suitable for medical equipment, it is far from actual measurements.

### 4.1.2 Fine Mesh Option

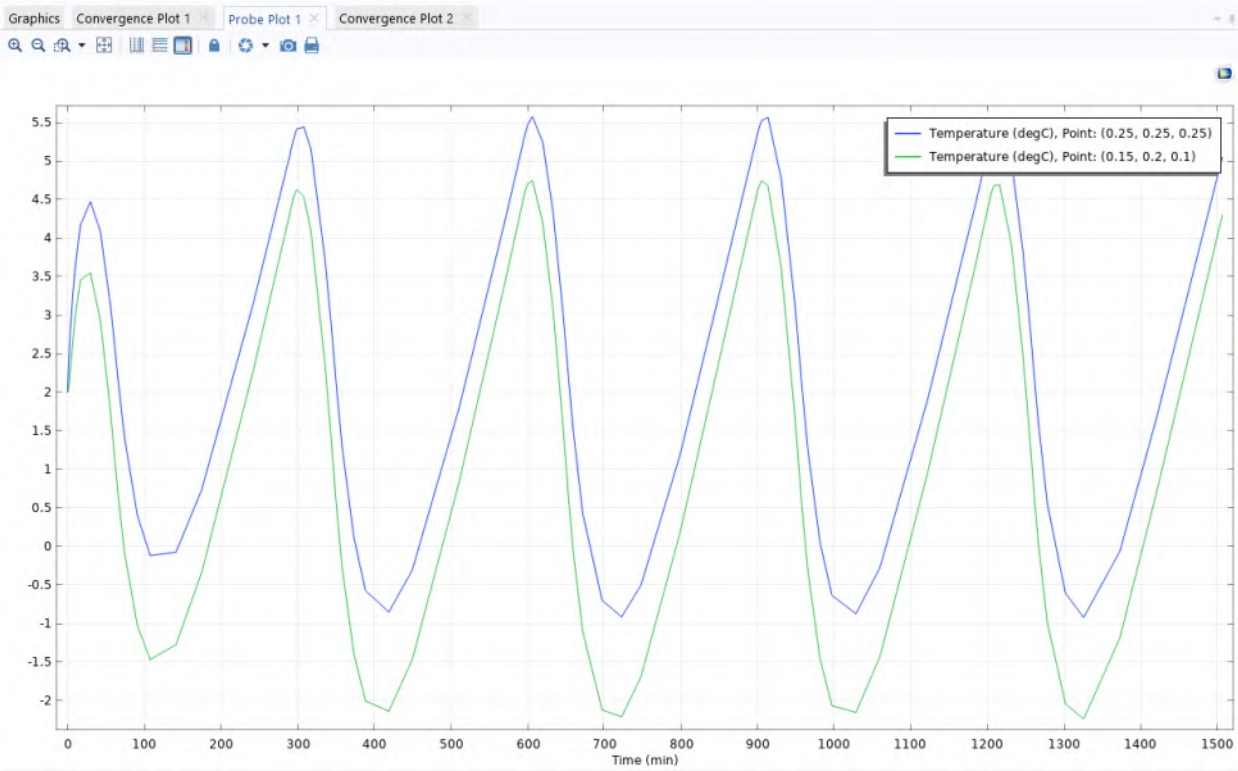


*Figure 44: Probe graphic for fine mesh in Case 1.*

Figure 43 shows the temperature change values for each thermostat on a separate day. With the temperature change on the first Thermostat (blue one), we ensured the temperature control of the peltier. The location of the second thermostat (green one) was estimated as the place where the medical equipment would be placed. When we examine the results, it is planned to have a peltier of 4 * 4 * 0.2 cm with a power of 0.71 watts on this box between 2 °Cand 4 °C values. At the end of the analysis we run with this software, the maximum temperature of the first thermostat was 5.56°C, the minimum temperature was -0.6°C, while the maximum temperature value of the second thermostat was 4.6°C and the minimum temperature value was -2.1 °C. As predicted, the first thermostat was more affected by the outdoor environment. In the second thermostat, we observed that the temperature values were less affected by the outdoor environment since it is closer to the center of the box and the peltier. In addition, the duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 110 minutes. Temperature changes of thermostats are sufficient for medical material transportation for fine mesh option.

### 4.1.3 Finer Mesh Option

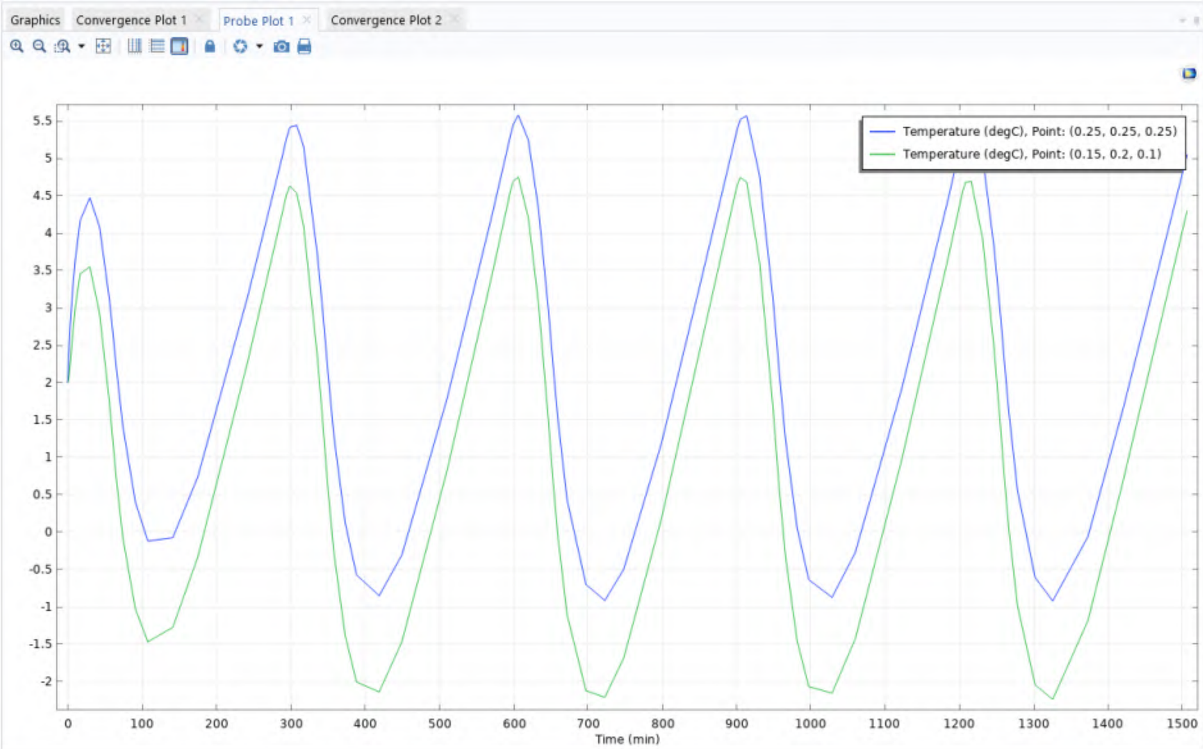


*Figure 45: Probe graphic for finer mesh in Case 1.*

Thirdly, we choose the Finer mesh option and analyzed our model according to finer mesh option. All the other parameters are the same with the other mesh options. In this section, where the control section is identical according to Peltier power, box geometry and thermostat degree, we obtained the result of the thermostat temperatures as shown in Figure 45 for 1440 minutes. Likewise, data was taken at 1-minute intervals and control was achieved. We observed that the maximum temperature of thermostat 1 is approximately 5.5 ℃ and the minimum temperature value of it is equal to -0.9 ℃. For thermostat 2, the maximum temperature value is approximately 4.7 ℃ and the minimum temperature is about -2.2 ℃.

*Table 4: Comparison of Extremely Coarse mesh, Fine mesh and Finer mesh options.*

| | *Termostat1 (Extremely Coarse)* | *Termostat 2 (Extremely Coarse)* | *Termostat 1 (Fine)* | *Termostat 2 (Fine)* | *Termostat 1 (Finer)* | *Termostat 2 (Finer)* |
|---|---|---|---|---|---|---|
| *Max. Value* | 7 °C | 5.8 °C | 5.56 °C | 4.6 °C | 5.5 °C | 4.7 °C |
| *Min. Value* | 2.3 °C | 1.3 °C | -0.6 °C | -2.1 °C | -0.9 °C | -2.2 °C |

### 4.1.4 Double-Powered Peltier

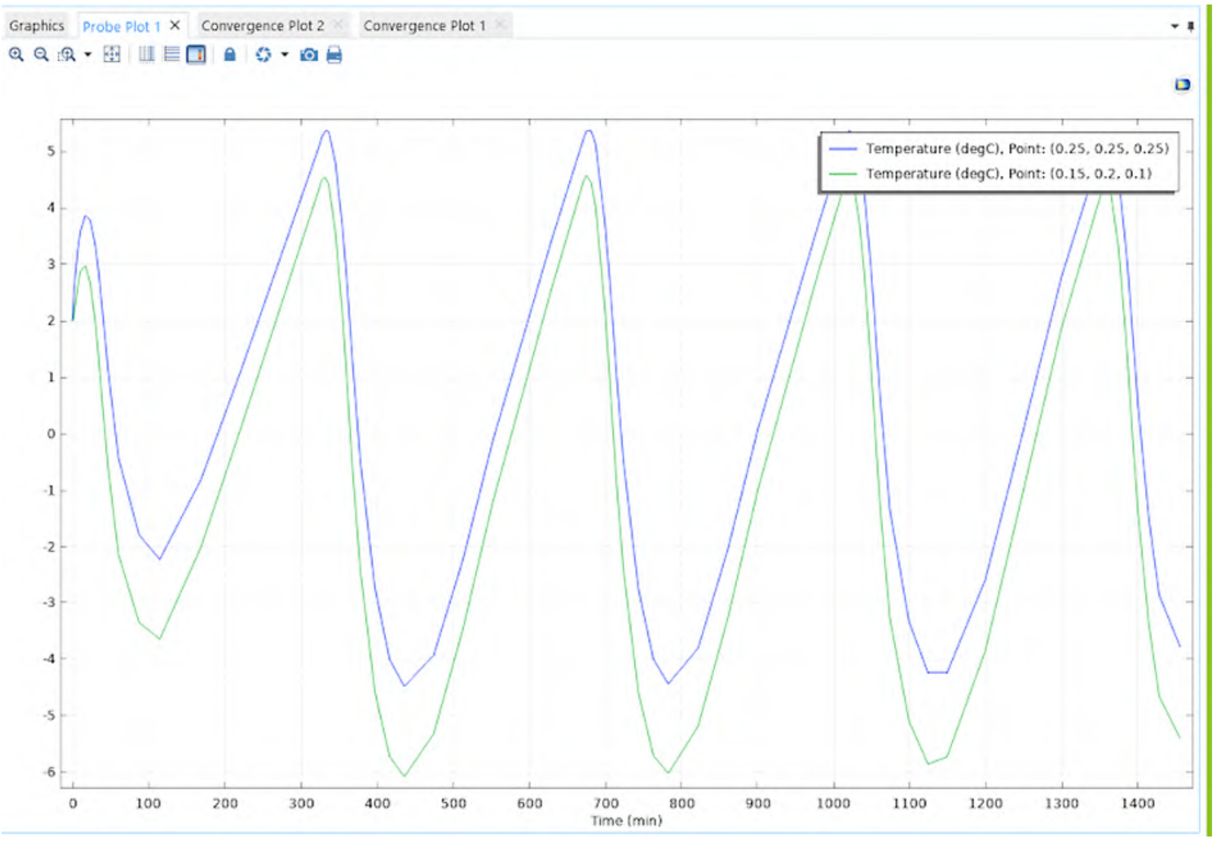


*Figure 46: Probe graphic for Case 1 which has double-powered peltier.*

Lastly, for Case 1, when our mesh option was Fine, we doubled the power of the heat axis to 1.42 W for peltier. All other parameters are identical with chapter 4.1.1. After this change, we run the program in 1440 minutes. When we examined the results, the maximum temperature value for thermostat 1 was approximately 5.5 °C, while the minimum temperature value was around -4.5 °C. The maximum temperature value is 4.5 °C and the minimum temperature value is -6 °C for Thermostat 2. The duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 100 minutes. When we look at the results, we saw that our peltier cooled the box pretty much with 2 times the heat flux power. However, when excessive current is given to the pelvis under normal conditions, the peltier performance will decrease due to the high temperature of the hot section. This is the ideal behavior of a peltier working with heat flux at 1.41W. This can be approached only by quickly removing heat from the high temperature surface of the peltier. Today, there are studies to increase the efficiency of the peltier by removing heat from the high temperature surface of the peltier with the heat sink and fan.

## 4.2 Analysis Results for Case 2

In this section, we made analysis by changing the number of peltier. In addition to the existing case, we have added another peltier. We have added a second peltier opposite to Peltier 1. We added a heat flux to the second peltier in the Heat State controller and solved it with the study command. Other data are identical to case 1.

### 4.2.1 Fine Mesh Option

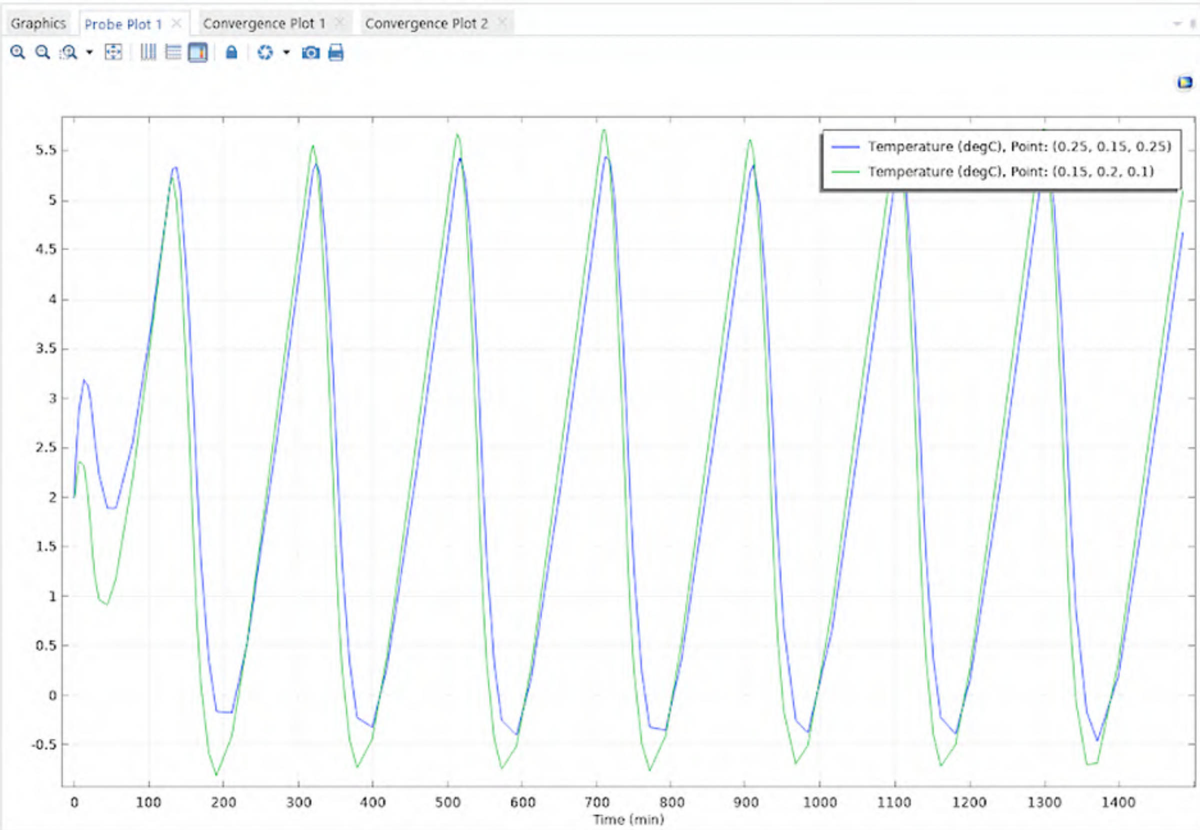


*Figure 47: Probe graphic for Case 2 which has fine mesh.*

In this Chapter, we have solved our box with two-peltier design with the Fine mesh option and obtained the temperature dependent graph of the thermostat (Figure 44). When we examined the results, approximately the maximum temperature was 5.4 °C and the minimum temperature was -0.3 °C for thermostat 1 and the maximum temperature was 5.7 °Cand the minimum temperature was -0.7°C for thermostat 2. The duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 100 minutes. When our two-peltier design was operated under the same conditions (4.1.1 Fine Mesh option) compared to case one, a more controlled temperature change was observed when we look at the figure 44. The reason for this is that when the reference temperature is exceeded, cold heat flux comes from two different directions simultaneously. Ideally, using two-sided identical peltier improves the safety of the material to be transported.

*Table 5: Comparison of fine mesh options in Case 1 and Case 2.*

| | *Termostat 1 (Case1)* | *Termostat 2 (Case1)* | *Termostat 1 (Case 2)* | *Termostat 2 (Case 2)* |
|---|---|---|---|---|
| *Max. Value* | 5.56 °C | 4.6 °C | 5.4 °C | 5.7 °C |
| *Min. Value* | -0.6 °C | -2.1 °C | -0.3 °C | -0.7 °C |

Table 5 shows us the comparison of fine mesh solutions in Case 1 and Case 2. According to these results, adding another Peltier to our box increases efficiency and gives us closer solutions to our temperature range of 2 °C and 8 °C.

### 4.2.3 Double-Powered Peltier

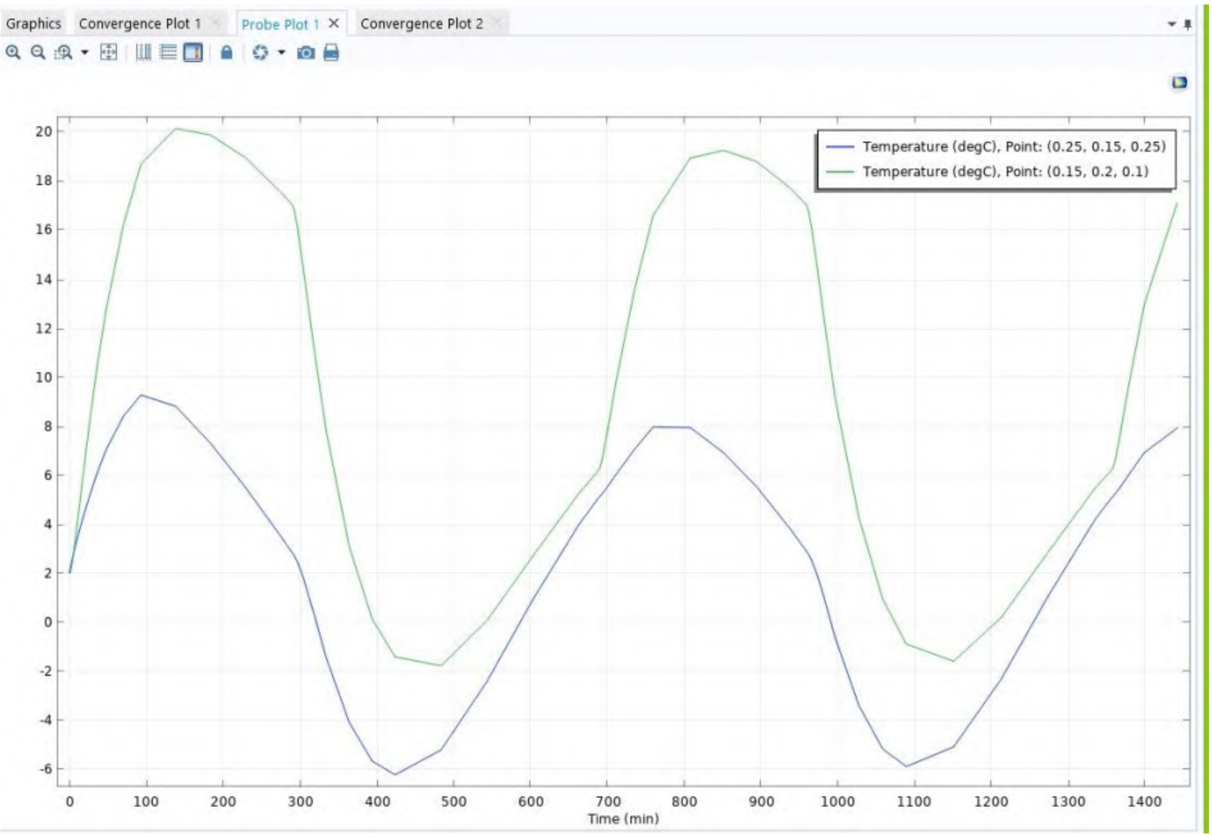


*Figure 48: Probe graphic for Case 2 which has double-powered peltier.*

Thirdly, for Case 2, when our mesh option was in Fine state, we doubled the heat flux power for both Peltier's, 1.42 W. All other parameters are identical to 4.2.1. After this change, we run the program in 1440 minutes. When we examined the results, a maximum of about 9 ℃, minimum -6℃data was obtained from Thermostat 1. A maximum of 20 °Cand a minimum of -2 ℃ data were obtained from Thermostat 2. The duration of the thermostat from minimum temperature to maximum temperature was observed as approximately 300 minutes. When we look at the results, we saw that our peltier cooled and heated the box quite a lot with 2 times heat flux power. The program did not work properly because the heat transmission power was too high. Therefore, the expected result could not be obtained.

*Table 6: Comparison of Double-Peltier Power in Case 1 and Case 2.*

| | *Termostat 1* ( *Case 1)* | *Termostat 2* *(Case 1)* | *Termostat 1* *(Case 2)* | *Termostat 2* *(Case 2)* |
|---|---|---|---|---|
| *Max. Value* | 5.5 ℃ | 4.5 ℃ | 9.0 ℃ | 20 ℃ |
| *Min. Value* | -4.5 ℃ | -6.0 ℃ | -6.0 ℃ | -2.0 ℃ |

Table 6 shows us the comparison of maximum and minimum temperature values of thermostat 1 and thermostat 2 in Double-Peltier Power option for each of case1 and case 2. We conclude that the results were worse in Case 2 when we doubled the Peltier power.

## 5 DISCUSSION & FUTURE WORKS

In this study, it was to make a heat analysis by adding a peltier module to the cold chain boxes used in the delivery of medical materials. Our aim was to take temperature values from certain points at certain time intervals with different mesh numbers and two different designs suitable for peltier powers. We decided on the Comsol program for our analysis and created two different designs within the program, as shown in case 1 and case 2. For the start, we took our temperature in the box 2 ℃ and determined the outdoor environment as 20 ℃ and 101 kPa (atmospheric pressure). After choosing the suitable materials for the box and peltier, we determined a natural conduction (heat loss to the outside) to the outer surface of the box in the program. And we wrote our code to operate the peltier we determined to control in the 3-5 C range. When we look at the results, we decided that it is the right choice to have our mesh number as the Fine option. In our analysis with fewer mesh counts, we found that the temperature ranges were very high and the result was actually getting farther away. When we set the Fine option and run our box for 1440 minutes, we compared the two cases. As a result of the comparisons, we found that our second design had a lower temperature range and that the Peltier's worked better by responding to the indoor temperature. Of course, the disadvantage of this situation is that since it is 2 cooling units, the cost increases and naturally increases the energy consumption. Secondly, we compared the results when we increased the power of the Peltier's for both cases. In this case, when the graphics of Case 1 were examined, a positive change was observed, the temperature intervals and the cooling time of the box shortened. When the graphics of Case 2 were examined, we determined that the program was not working properly and we accepted this experiment as unsuccessful. With these analyzes, we found that the design of the cooler boxes directly affects the results and we saw the thermal effect of the change of the peltier power on the box. As a result, we found that a cold chain box with 2 pelts gives better results and it is inconvenient to increase the peltier power. The results obtained in each experiment were obtained as a step in cooling the main cold chain box, which is the next study.

For future studies, a fan and heat sink module can be added to our box in order to dissipate the hot and cold air temperature inside and outside the peltier module. In this way, the air inside the box diffuses faster and more homogeneously. Hot air outside the Peltier module is easily diffused.

## 6 REFERANCES

[1] Astrain, D., Vian, J.G. and Albizua, J., (2005), “Computational model for refrigerators based on Peltier effect application”, Applied Thermal Engineering 25, 3149-3162.

[2] TERMOELEKTRİK ETKİLER VE SOĞUTMA ETKİNLİĞİNİN UYGULANMASI

[3] A novel thermoelectric refrigeration system employing heat pipes and a phase change material: An experimental investigation

[4] Jugsujinda, S., Vora-ud, A. and Seetawan, T., (2011), “Analyzing of Thermoelectric Refrigerator Performance”, Procedia Engineering 8, 154–159.

[5] O.Çiçek, H.Demirel, S. Tan, (2011), “TermoelektrikModüllü Kan NakilKabıTasarımı”, Technology, 14(4), 115-121.z<

[6] O. Erkol, H. Demirel, (2012), “TermoelektrikMalzemelerileSeyyarSuSoğutucuUygulaması”, TUBAV BilimDergisi, Cilt:5, Sayı:1, 16-20.

[7] E. Deniz, B. B. Kavak, K. Arslan, (2015), “Seri BağlıArdışıkTermoelektrikSoğutucularınSoğutmaPerformanslarınınDeneyselİncelenmesi”, NWSA-Engineering Sciences, 10.03.1A0357

[8] https://books.google.com.tr/books?id=Zs9TDwAAQBAJ&pg=PA145&lpg=PA145&dq=comsol+program%C4%B1+ve+i%C5%9Fleyi%C5%9Fi&source=bl&ots=IsZ2J5ZdWd&sig=ACfU3U117zdrzCfxyOct5Lkrk3WrmzUwvQ&hl=tr&sa=X&ved=2ahUKEwjz0oOr5KnqAhUEy6YKHagsAE8Q6AEwC3oECAoQAQ#v=onepage&q&f=false

[9] http://www.uis.gov.tr/media/1488/saglik.pdf

[10] ZHAO, DONGLIANG (MAY 2014). "A REVIEW OF THERMOELECTRIC COOLING: MATERIALS, MODELING AND APPLICATIONS". APPLIED THERMAL ENGINEERING. 66 (1–2): 15–24.

[11] yunuscengel Heat and Mass Transfer Fundamentals & Applications. ( Fifth edition)

[12] https://iklim.csb.gov.tr/viyana-sozlesmesi-i-4399

[13] https://www.journalagent.com/turkhijyen/pdfs/THDBD_75_3_305_322.pdf

[14] https://en.wikipedia.org/wiki/Thermoelectric_effect