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Design and Development of HVAC Sleeping Bag

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A Final Year Project

ReportPresented to

**SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING**

Department of Mechanical

EngineeringNUST

ISLAMABAD, PAKISTAN

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In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Mechanical Engineering

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by

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*The Project is Proposed & Sponsored by:* ***Techy Tech***

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Titled: "DESIGN AND DEVELOPMENT OF HVAC SLEEPING BAG" proposed & sponsored by Techy Tech, be accepted in partial fulfillment of the requirements for the award of BE Mechanical Engineering degree with grade ___

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# ABSTRACT

This project is aimed at providing an industry solution to the lack of HVAC enabled sleeping bags that have the capability of cooling in addition to the heating feature. The idea is originally proposed by Techy Tech to engage young minds to work on providing a solution that is both economical and consumer friendly. The sleeping bags, mostly having predominated in cold markets, have long been enabled with heating feature but relatively few solutions have been proposed for ones with a feasible cooling feature as well, owing to their growing popularity and utility in warmer regions. Thus, the students have set out to conceive, design and fabricate such a sleeping bag, which comes with HVAC features of both cooling and heating. As this would be an initial prototype for the market, the specific bag being designed is being designed for the conditions of Pakistan's specific climate region of Islamabad and Lahore.

***About Techy Tech:***

Techy Tech is a technical sales & consultancy organization based in Lahore, Pakistan. From past few years, Techy Tech is playing its utmost role in developing young minds to work on innovative ideas in mutual collaboration with educational institutions in Pakistan. Its aim is to groom young engineers to cater the challenges of current economy and to give them exposure to the real-world applications.

# ACKNOWLEDGMENTS

We would like to extend our gratitude to Sir Waqas Khalid for guiding us through the meticulous research process. We would also express immense gratitude to Techy Tech company for the sponsorship, also Mr. Mohammad Ali (CEO) & Mr. Arslan Saeed (Technical Specialist Engineer) for their utmost guidance throughout the course of this project. We would also express immense gratitude to Sir Adnan Munir, and his student Mr. Umer Farooq for their cooperation in certain aspects of the project related to conjugate heat transfer simulations. In this respect, we would also acknowledge the efforts of Mr.Rashaeel, who has separately provided guidance and help in the simulations process.

# ORIGINALITY REPORT

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# ABBREVIATIONS

| Abbreviation | Meaning |
|---|---|
| HVAC | Heating, Ventilation, and Air Conditioning System |
| TEC | Thermoelectric Coolers |
| TEG | Thermoelectric Generators |

# NOMENCLATURE

| Term | Meaning |
|---|---|
| $q_{\square}$ | Heat transfer rate of fin. |
| $m$ | Dimensionless parameter |
| $\varepsilon_{\square}$ | Fin effectiveness |
| $\eta_{\square}$ | Fin efficiency |
| Q | Total heat transfer rate |

# CHAPTER 1: INTRODUCTION

The project of HVAC sleeping bags with the capability of heating as well as cooling is an ambitious one undertaken by students keeping in view the burgeoning market for sleeping bags as well as the humid and hot climate of the region making it not very suitable for most of the year for potential customers to utilize such a commodity. Due to the same reason the purchasing perception of such a product is being hampered mainly due to the climate factor. These bags have been traditionally in use in cold climate regions where only heating feature has been needed for such products to be commercially successful. Therefore, not much has been offered in the way of providing for comfort in conditions of sweltering heat and humidity.

This paired with the fact that many people nowadays prefer to go for localized solutions in cooling/air conditioning, not necessarily the larger air conditioning units that need to be installed on a somewhat permanent basis, gives a market gap for such products existing that can provide thermal comfort to customers in a localized and economized way, such that they may even use when travelling and having no electricity whatsoever.

The students realized this opportunity and decided to bring about a concept of such a sleeping bag which is just offering the cooling feature in addition to a normal/traditional sleeping bag (i.e. the one which also has a heating capability) to tap into the market. This seems a vernacular yet effective solution, especially for lower end economy countries, where people prefer having smaller localized cooling solutions.

## 1.1 Scope:

The scope of the project encompasses catering to the climatic region of Pakistan, i.e. subtropical. As already mentioned, sleeping bags have traditionally been designed and equipped for colder climatic regions. This project aims to cater to the customer base of regions like Pakistan where ambient summer temperatures can be expected to shoot as high as 40 degrees Celsius. For the purpose of this project, the winter conditions to b catered are as low as 10 degrees Celsius. The project encompasses both heating and cooling aspects. For the purposes of this project, the external/ambient temperature being considered is the dry bulb temperature. The heat exchanger that would be designed for such a purpose would serve air conditioning for a limited space such as a bag, or any other conceivable space or enclosure that is single occupancy only. Since the heat exchanger is aimed to be portable, it has to be DC powered. This heating and cooling solution is not just confined to campers and trekkers, but also for students and those who cannot afford a full-fledge air conditioning system (i.e. split AC etcetera) and want a localized and affordable option.

## 1.2 Objectives:

The objectives have been clearly listed below:

- Workable in the temperature ranges of 10 to 40 degrees Celsius.
- Attain a comfort temperature within the range of 22-25 degrees Celsius in the bag.
- Achieve the targets in the climatic conditions of Pakistan.
- Having a detachable heat exchanger from the bag, so that in mild conditions (when the heat exchanger is not in operation) the user does not have to carry around the heat exchanger as well.
- Making the heat exchanger as portable and compact as possible.
- DC powered system to enable portability.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Human Heat Load Studies:

The first few articles reviewed were pertaining to the human heat load and the heat emanating from human body and the certain factors related to it. For this purpose, the "Prediction Of Air Temperature For Thermal Comfort Of People Using Sleeping Bags: A Review"[4] paper was read which gave various models according to which the per meter heat dissipation from human body can be determined. There were about 5 different models, viz a viz, Goldman model, KSU model, European model, Holand model and TNO model (Huang J.[4]). These are various models that have been empirically determined to various extents by inclusivity of populations of larger samples, varied conditions, both genders and over extended periods of time. The average value suggested by all of these models was around 45 W/m2. The paper "Relationship between Human Heat Load and Sleep (2019)"[5] was also reviewed which used Debois Formula (1913) for calculation of heat load and provided a value of 0.65 to 0.74 for the Basal Metabolic Rate of humans on average.

## 2.2 Thermoelectric Module Studies:

The paper "A comparative analysis of thermoelectric modules for the purpose of ensuring thermal comfort in protective clothing"[1] presented the results of a series of laboratory tests conducted over a FTE1-01 flexible thermoelectric module, with 3 different types of heat sinks, i.e. polymer TEG way heat sink, a metal one, and a self-made one based on a superabsorbent. As a research and testing methodology, "skin test" was used. Whereby, a heating plate of constant temperature was attached to the cold side of thermoelectric module (in the middle). Overall, it was concluded that the dependence of heat flux over the almost linear, except for the TEG way heat sink case. The TEG way sink lagged due to the fact that stopped absorbing moisture after several dozen uses and, consequently, stopped fulfilling its intended function. Another observation was that with the increase in the ambient temperature, a decrease in the heat flux was noted.

The study "Analysis of Efficiency of Thermoelectric Personal Cooling System Based on Utility Tests" [2] used a flexible Peltier module TEGway FTE1-01 attached to a clothing made of Cool max openwork knitted fabric and had a form of a T-shirt. The heat sinks were made using the SAF (Super- Absorbent Fabric) Fabric 2644 super absorbent non-woven fabric by Technical Absorbents which was held in the shirt by pocket like components in various locations. The objective was to test the effectiveness of such a direct skin contacted cooling system. The limitation found out to be was of the supply power to having to be below 2 W, otherwise, heat dissipation in the module during its operation may become higher than what could be effectively removed by the heat sink, leading to the reversal of the thermal effect, leading to skin heating instead of cooling.

The paper "Thermal comfort study of a building equipped with thermoelectric air duct system for tropical climate" [3] aims at conducting a study on employing thermos-electric modules (TEMs) in air duct system. A thermos-electric air duct system (TE-AD) was designed and studied for this purpose. The testing region was Malaysia, which is more humid and hotter than the climatic conditions of Pakistan (i.e. the objective of the original project).

The experiments spanned over a period of 3 months, from 1st January, 2015 to 1st April, 2015. The sample space for test subjects was 20 (humans), out of which 10 were males and 10 females, each having an average surface of 1.62 $m^2$, and dressed up in regular summer clothes (0.5 clo). For each test subject, the TE-AD system was run/operated on 6 different currents (2A, 3A, 4A, 5A, 6A and 7A). The parameters of interest that were noted down as a result of each current input were indoor temperature, indoor relative humidity and average radiant temperature. The runtime of the tests for each current value was 12 hours. The tests resulted in concluding the optimum performance being achieved for the current value of 6A.

# CHAPTER 3: METHODOLOGY

### 3.1.1 Thermal Heat Load analysis

The students broadly adopted a methodology of 4 steps. First students looked at ASHRAE standardsto look for the human comfort conditions both during summers and winters. Owing to a lot of dataemanatingfromvariousgeographical regions and thebio-geneticmakeup of populations adapted tocertain climatic regions, it could deviate but across the board, ASHRAE settled on the values of 24-26 degrees Celsius and 40-70% humidity for human comfort.

Next, to keep the conditions as such (i.e. thermal comfort conditions) in a conserved space, the actual heating load dissipated by human body was determined, that needed to be handled by the cooling system to bring the bag to a reasonable thermally comfortable temperature. In his respect, both the literature was reviewed and simulations done, but the most substantial values came from HAP simulation, in which for the sake of being on the safe side, certain factors had been tweaked and certain variablesexaggerated andthefinalheatingloadgainedfor ahumanoccupant to remain at a consistent 24-26 degrees Celsius at all times was about 430 Watts, which was almost about thesame as gained from the literature, i.e. 250-350 Watts.

Next, that the heating load and target conditions had been determined, the students proceeded to determine the number of Peltier modules required and the specific models who data sheet indicatedsuitable variables for our operation range and timing window. As such, a heat exchanger consistingof 8 Peltier modules and 2 heat sinks had been designed. The heating load and the knowledge ofthermal comfort conditions were instrumental in determining the Peltier modules with the specifications for our operations.

The next steps will be to the start designing a robust control system for all the components that integrates all the parts on board to work in unison to the maximum efficiency of their mechanical/HVAC purposes. This control system will consist of feedback systems and deal mainlywith the operation of switching off and on the heat exchanger when conditions have been met, alsoconsidering the conditions outside of the bag.

### 3.1.2 Analytical Calculations

After students calculated thermal heat load, that with safety factor was 420W, it was necessary to design heat exchanger. Since heat exchanger components were Peltier modules, heat sinks, air blowers, duct system and control system it was important to do calculations using thermodynamics and heat and mass transfer concepts.

### 3.1.3 Heat sink design.

The Heat sinks were rectangular fins that allowed heat transfer from all sides. Initial conditions were 20C $T_b$, base temperature, 40C $T_\infty$, ambient air temperature. Analysis method was iterative, that is fin parameters were changed to achieve desired heat transfer rate, $q_f$, from single fin.

*Table 1-Fin Equations*

| Case | Tip Condition ($x = L$) | Temperature Distribution $\theta/\theta_b$ | Fin Heat Transfer Rate $q_f$ |
|---|---|---|---|
| A | Convection heat transfer: $h\theta(L) = -kd\theta/dx\|_{x=L}$ | $\frac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$ (3.75) | $M\frac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$ (3.77) |
| B | Adiabatic: $d\theta/dx\|_{x=L} = 0$ | $\frac{\cosh m(L-x)}{\cosh mL}$ (3.80) | $M \tanh mL$ (3.81) |
| C | Prescribed temperature: $\theta(L) = \theta_L$ | $\frac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$ (3.82) | $M\frac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$ (3.83) |
| D | Infinite fin ($L \to \infty$): $\theta(L) = 0$ | $e^{-mx}$ (3.84) | $M$ (3.85) |

$\theta \equiv T - T_\infty$ $\quad m^2 \equiv hP/kA_c$
$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\,\theta_b$

Fin type was Case A where m is the factor defined as.

$$m = \sqrt{\frac{hP}{kAc}}$$

$h = 10.45 - v + 10\sqrt{v}$, is defined as convective heat transfer coefficient.

$v = r\omega$, is velocity of air.

$P = 2 \times (l + w)$, is perimeter.

K, is thermal conductive constant.

$A_C = (l \times w)$, is cross sectional area.

Using table 3.4m case A

$$q_f = M\frac{\sinh mL + \frac{h}{mk}\cosh mL}{\cosh mL + \frac{h}{mk}\sinh mL}$$

Initial fin parameters.

Length = 7cm, Thickness = 5mm, Width = 160

Substituting in $q_f$;

$$q_f = 13.559W.$$

Fin effectiveness $\varepsilon f = \frac{qf}{hAc\theta b}$

$$\varepsilon_f = 13.104$$

Fin efficiency $\eta_f = \frac{\tanh mLc}{mLc}$

$$\eta_f = 0.915$$

Total heat transfer from heat sinks is given as

$$q_t = N\eta_f hA_f\theta_b + hA_b\theta_b$$

N is total number of fins, $\eta_f$ is fin efficiency, $A_f$ is surface area of fin and $\theta_b$ is temperature difference.

Hence

$$q_t = 210.919W$$

Using 2 heat sinks we can pump Q = 420W which is compatible with system.

Now we calculate how much time is required to achieve the temperature difference of 16K.

$$t = \frac{mc\Delta T}{Q}$$

Where Q= 421W, m is mass flowrate =1.225kg/m$^3$ and c is specific heat capacity=1.005KJ/Kg.K

That is t= 19.6minutes.

### 3.1.4 Peltier Modules

Now we select Peltier modules that can pump 400W of heat.

Referring to CUI devices,

The performance graph for model CP12715 is given as;

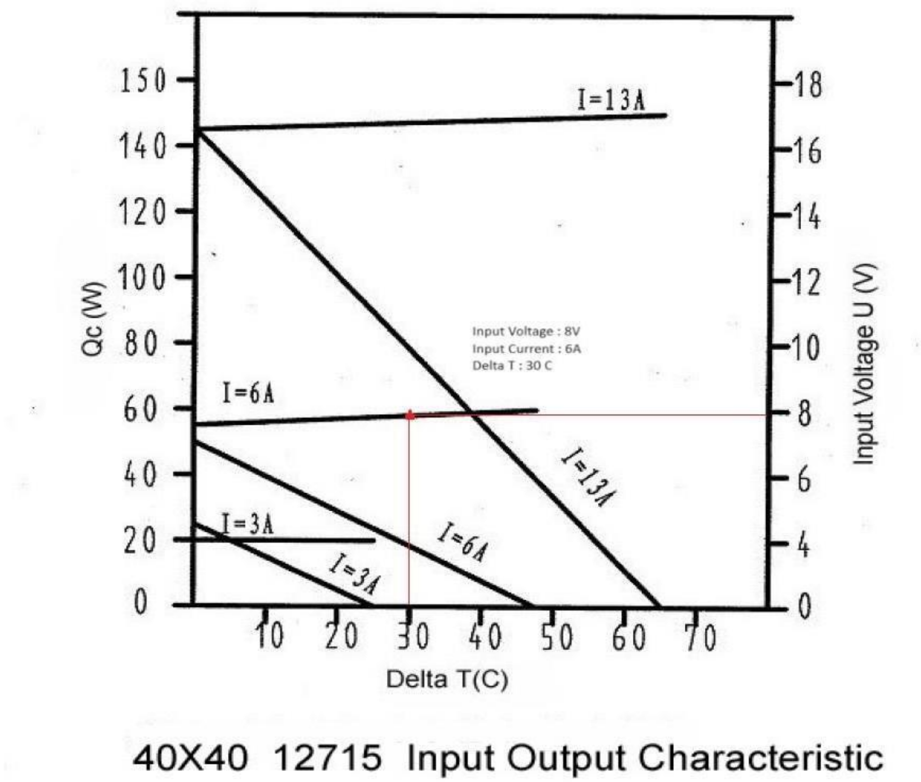



*Figure 1-Performance graph of Peltier Module 12715*

Peltier modules work on $\Delta T$ against supplied current and voltage. They are rated with maximum current and voltage. Efficiency is best achieved when it is operated at lesser currents and voltages than maximum values.

Parameters to read performance charts.

$\Delta T$, Q (W), I(A) and V.

So, Q(W) at $\Delta T = 30C$ is 56W and rated Current and Voltage is 8A and 11V respectively.

With 8 Peltier modules, the system can pump 448(W) that is compatible with requirements.

## 3.2 Prototype Design

### 3.2.1 Design Parameters

In developing the prototype for the battery-powered HVAC sleeping bag, careful consideration was given to various parameters to ensure optimal performance, user comfort, and practicality.

#### 3.2.2 Heat Exchanger Function

The primary objective of the heat exchanger in the battery-powered HVAC sleeping bag is to facilitate effective heat transfer between the ambient air within the sleeping bag and the Peltier modules. This process is fundamental for regulating the internal temperature of the sleeping bag, thereby ensuring optimal comfort for the user during operation. Heat Exchanger's dimensions are340mm, 250mm, and 250mm in length, width and thickness respectively. Mild Steel sheets of 0.98 mm thickness have been used for the casing of the heat exchanger.

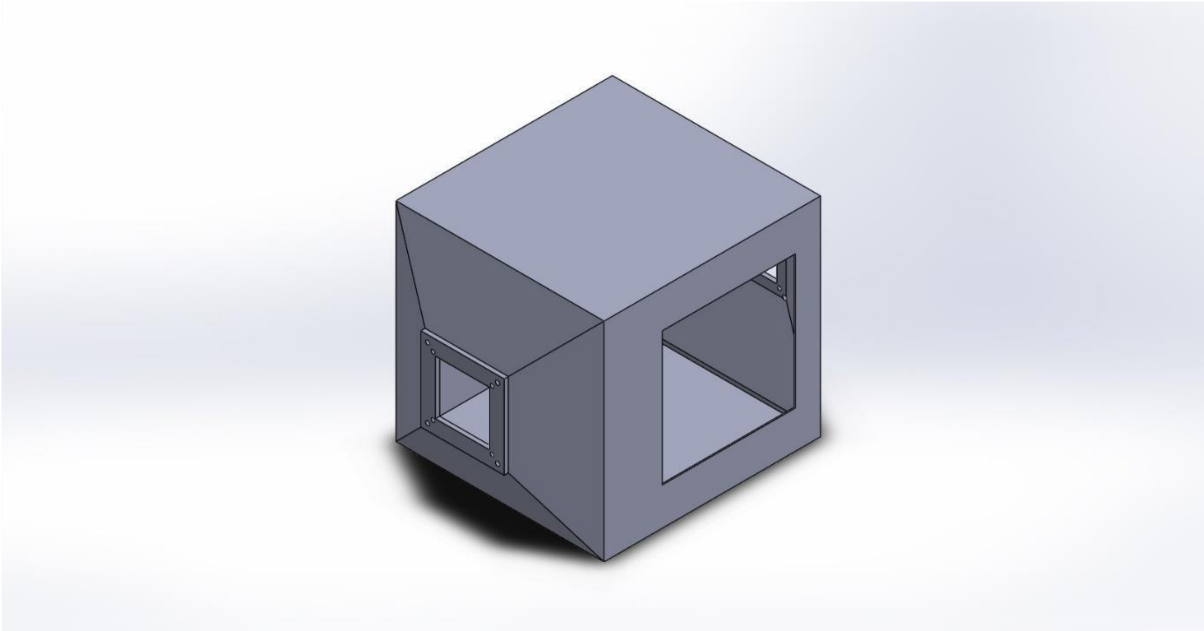


*Figure 2-Heat Exchanger*

### 3.2.3 Heat Exchanger Configuration

### 3.2.4 Fins Attachment

Fins have been attached to the hot side of the heat exchanger for effective heat dissipation. Initially, the dimensions of the fins was calculated to be 70mm, 160mm, and 5mm in length width and thickness respectively, having 16 fins on a base plate. 4 such heat sinks were required. But due to the cost constraints (Rs.20,000/- per heat sink), we opted to go with off the shelf CPU heat sinks, i.e. used for the cooling of processors. The new dimensions of the heat sinks are 50mm, 65mm and 1mm of length, width and thickness respectively with 43 fins, with Q capacity of 156 Watts.

### 3.2.4.1 Material Selection of Fins

Material for fins was selected to be Aluminum on account of its high thermal conductivity (237 W m-1 K-1) it also provides the added benefit of light weight.

### 3.2.4.2 Advantages of Using Fins

Fins have been integrated on the hot side of the Peltier module for temperature regulation of the HVAC sleeping bag. The large surface area of the fins helps increase the effective heat dissipation. In addition to that, fans have also been used to get forced convection for further enhancing the heat dissipation on the hot side. It is integral to have a constant and desirable temperature at the hot side in order to have the required temperature of the cold side. The purpose of the fins are to increase the effective heat transfer for the hot side of the Peltier module and also to increase the surface area for the interaction of the air within the heat exchanger that will blow inside the bag for the thermal comfort of the user.

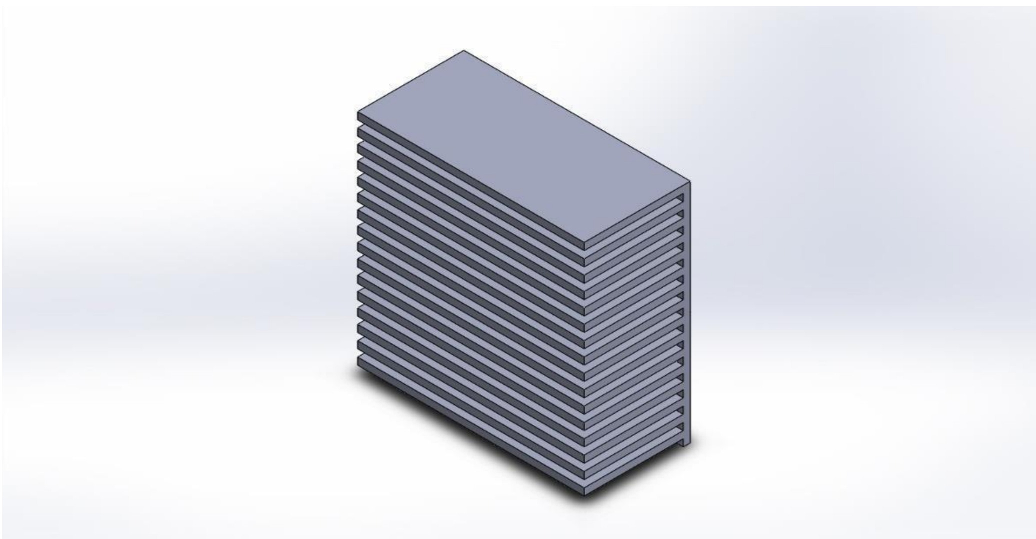


*Figure 3- Heat Sink for Hot Side of Peltier Module*

#### 3.2.4.3 Peltier Modules

Peltier module selection was based on the factors of power efficiency, durability and compatibility as per the delta T criterion. Eight Peltier modules have been selected, each with a 50W capacity. For the purpose of the project, such a Peltier Module had to be selected whose temperature gradient between the hot and cold sides should be 20°C. The size of the Peltier module is preferred as standard, i.e. 40mm by 40mm by 5mm by length, width and thickness respectively.

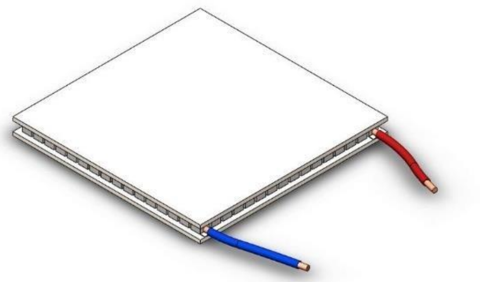


*Figure 4-Peltier Module*

#### 3.2.4.4 Air Circulation Using Fan

Since the sleeping bag's cooling mechanism is a closed cycle, therefore in order to circulate the air within the system, from the heat exchanger to the bag and back. The heat exchanger is placed at the inlet of the heat exchanger (casing) such that it takes incoming air from the bag and forwards it into the heat exchanger for the air to be cooled. With sufficient flow rate (calculated as per the convective heat transfer equations) the air is delivered back into the bag and thus the cycle continues.

*Figure 5-Air Circulation Fan*

#### 3.2.4.5 Flexible Duct Pipe

Two 1 meter duct pipes have been installed on both the inlet and outlet ends of the heat exchanger so as to transfer the air within the bag and the heat exchanger. This pipe serves 2 purposes, i.e. mass transfer and detachability. Since the pipe is directly attached to the inlet/outlet of the heat exchanger, the diameter was set to be 80mm . Initially, the team planned to go with PVC duct, but due to flexibility limitations, the final pipe material was chosen to be aluminum. Since the bag also has zippers which allow for limited openings (other than the main zipper), the two ducts can be inserted in these openings where the air enters and leaves the bag.

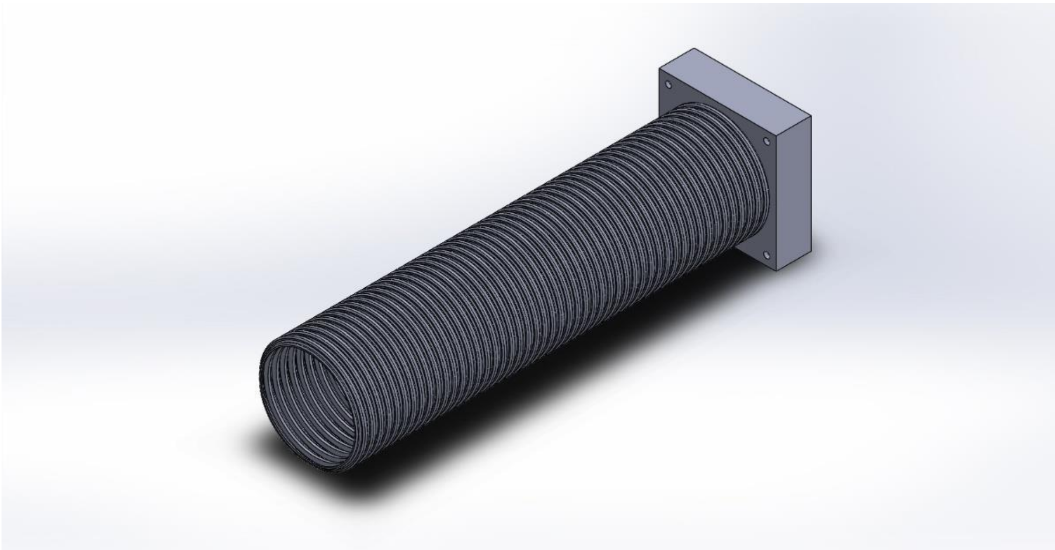


*Figure 6-Flexible Duct Pipe*

### *3.2.4.6* Heat Dissipation Fan for Peltier Module

Two 120 by 120mm fans have been placed directly in front of the heat sinks attached to the hot side of the Peltier module. These fans play an integral role in dissipating heat into the environment so as to have an optimum (consistent) temperature at the hot side. These fans help retain temperature at the hot side and avoid overheating issues and thus helps in the temperature regulation of the overall system.

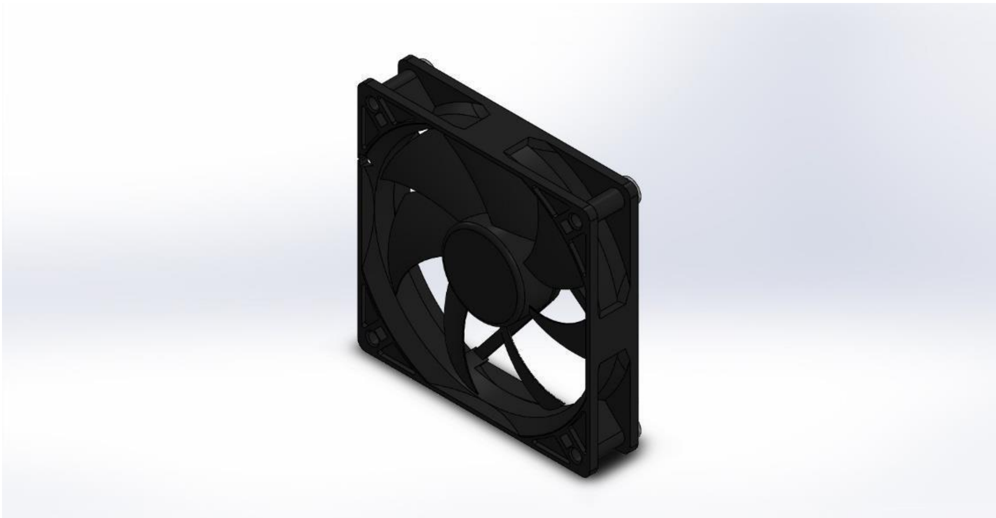


*Figure 7-Heat Dissipation Fan for Peltier Modules*

## 3.2.5 Overall Design

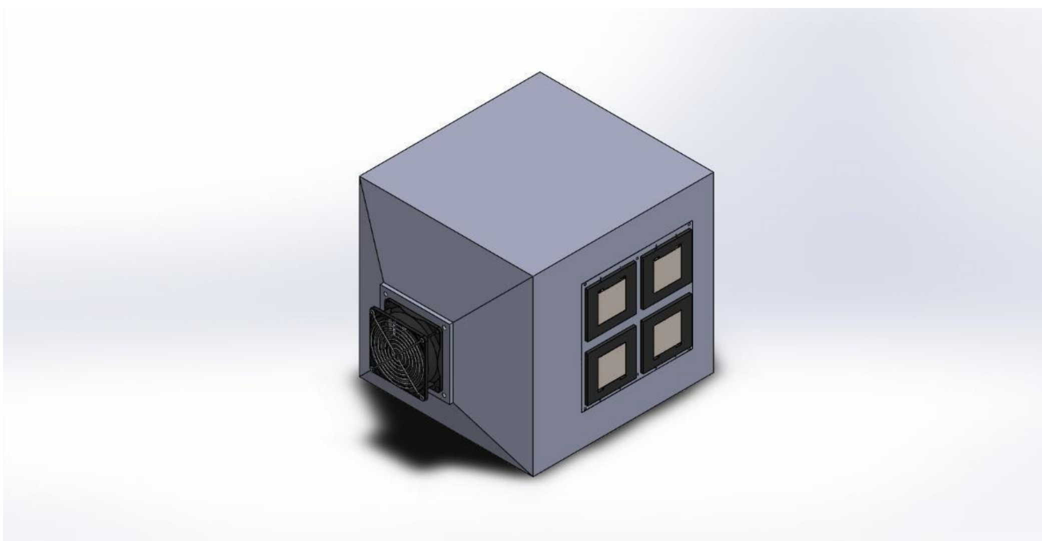


*Figure 8-Assembly of internal Fins, Peltier Modules, Air Circulation Fan and Heat Exchanger Duct*

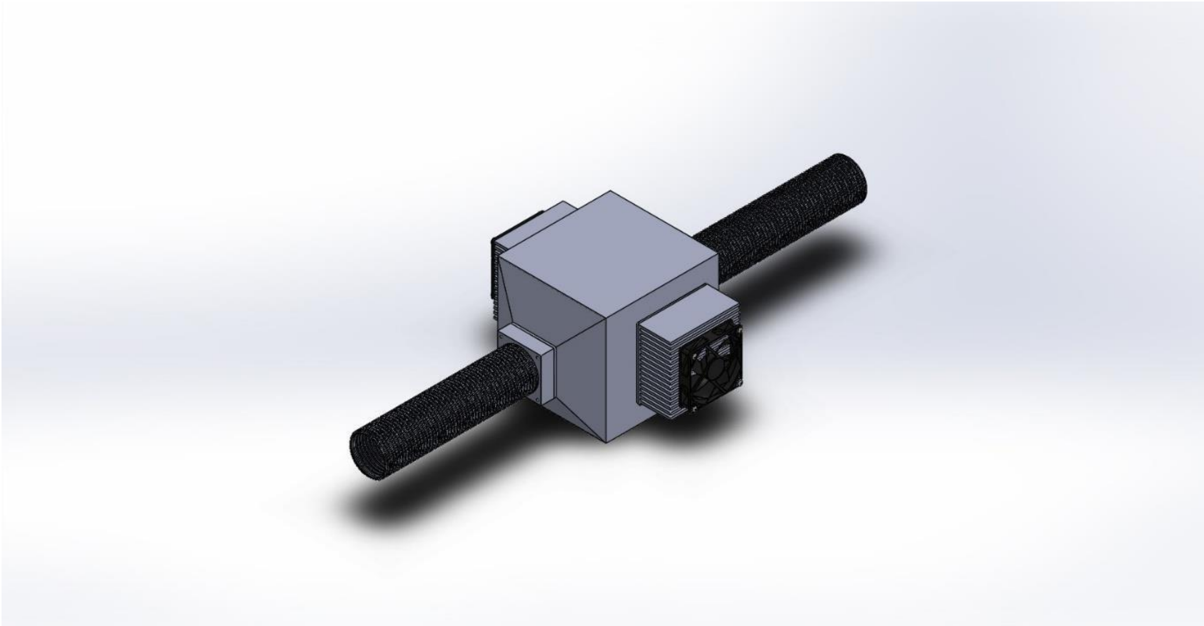


*Figure 9-Complete Design*

## 3.3 Control Module

### 3.3.1 Overview

The system is powered by a 12-volt DC power supply. For this purpose, a 12V AC-to-DC power supply has been chosen that is plugged directly into the 220V AC power outlet and converts itinto 12 volts DC. The power supply has 9 outlet points; 3 positive potential, 3 negative potential,1 ground and 2 inlet points for 220V AC power.

As the AC power is supplied to the power supply, 2 separate outlets are taken from it and channeled to separate paths.

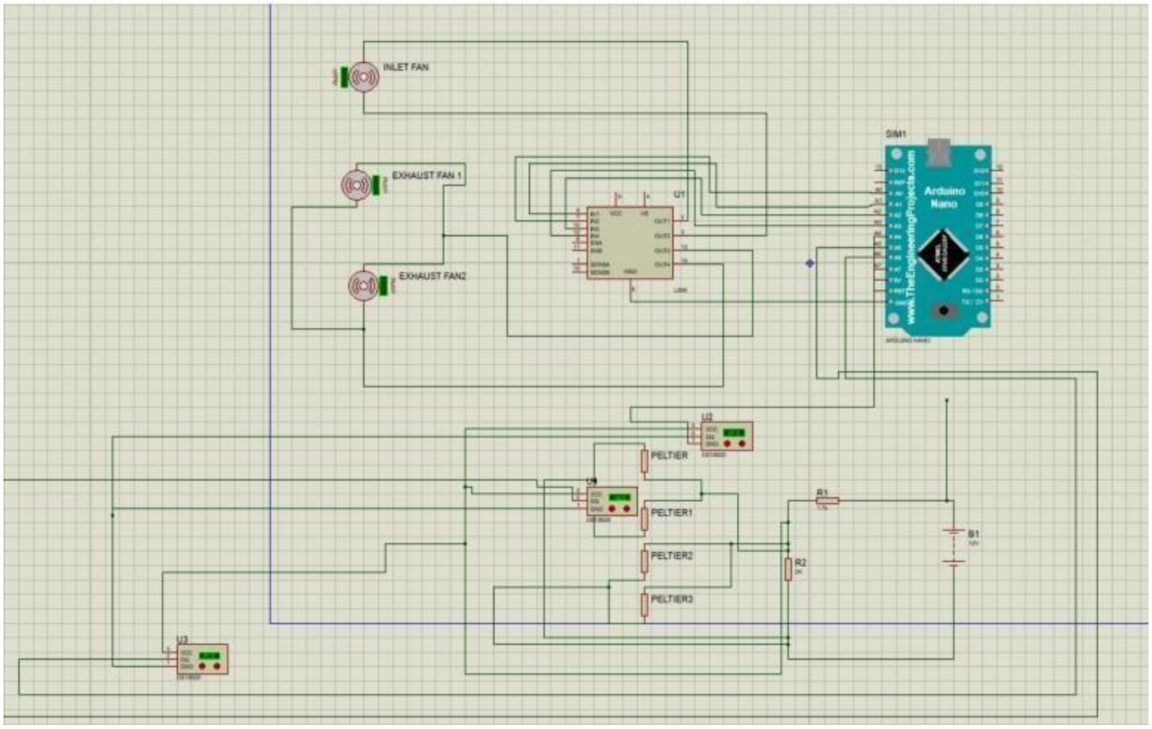



*Figure 10-Circuit Diagram on Proteus*

**Path # 1**

This path is the one where the 12V outlet is fed into a voltage regulator. The voltage regulator basically consists of a buck converter which is used to step down the voltage to the system requirement. To step down the voltage, the buck converter is also attached to MOSFETs. The purpose of the MOSFET, i.e. when used for voltage regulation with a buck converter, is to set the switching frequency at gate to calibrate the output voltage of the buck converter, i.e. the amountto which the buck converter reduces the voltage depends upon the switching frequency of the MOSFET. MOSFETs have 3 pins, namely gate, drain and source (as illustrated in the accompanying diagram). The connectivity of these pins have been listed down as:

- Drain - connected to the positive terminal (of the power source)
- Source - Connected to the negative terminal (of the power source)
- Gate - Output

## 3.3.2 Components

## 3.3.3 MOSFET

The MOSFET being used here is IRFP260. But since an individual IRFP260 has a drain current IDof 46 amperes and we want to increase the current carrying capability of the voltage regulator, we've connected 2 of those in parallel, i.e. connected gate, source and drain junctions of both the MOSFETs to further be connected.

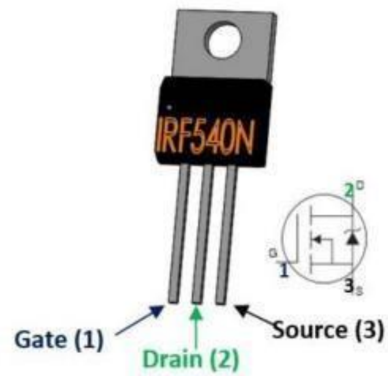



*Figure 11-Pinout of a generic MOSFET*

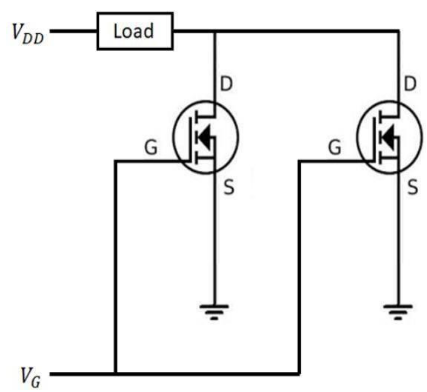



*Figure 12-Two MOSFETs connected in parallel configuration*

To summarize the connections, the positive terminal of the battery is connected to the drain ofthe parallel MOSFET setup (which also powers the buck converter). The negative terminal gives connections to both the buck converter and the source pin. The Output of the parallel MOSFETsetup is directed to the buck converter. In order to avoid surge of large current and failure of the component (buck converter)a 330-ohmresistance hasbeen connectedbetween thegate of theMOSFET and the buck converter. At the output of the voltage regulator, 6.5 volts are received. This 6.5-volt connection is further provided to the parallel assembly of 8 Peltier modules. Allthese 8 Peltier modules are connected in parallel and as such run on 6.5 volts.

## Peltier Module

A *Peltier* module is a thermoelectric module which works on the **Peltier effect**. It works by creating a temperature difference when current is passed through it. One side gets hot, whilethe other side gets cold. The amount of heat transferred from the cold side and the temperaturedifference between the hot and cold sides of the module depend upon the voltage provided and have been calibrated for each distinct model. It consists of numerous p-n junctions. These p-njunctions are connected **electrically in series, but thermally in parallel**. This provides theadded benefit of maximum performance/output from a design point-of-view. This p-n junctionassembly is covered on both sides by ceramic plates.

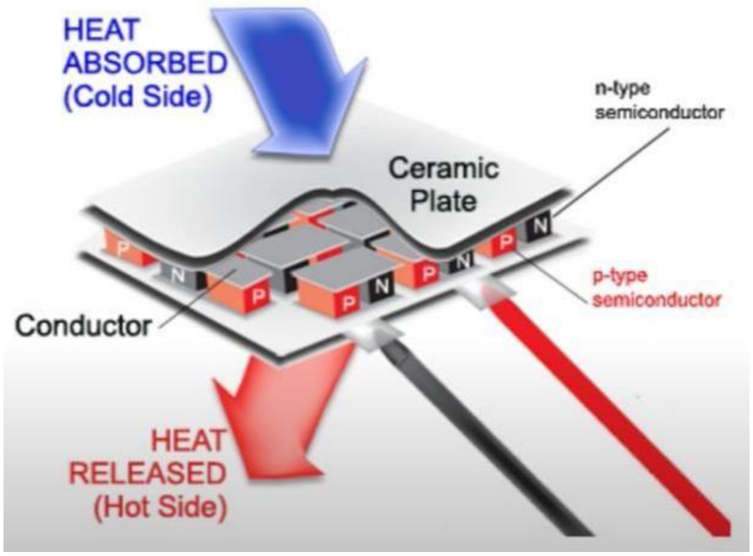



*Figure 13-Demonstration of the functionality of a Peltier module*

The Peltier module chosen for this application was TEC-1 12715. The nomenclature has been decrypted as below:

| TEC1-12715 Characteristic Parameters | |
|---|---|
| **Maximum Operating Voltage** | 15.4 V |
| **Maximum Operating Current** | 15 A |
| **Maximum Heat Pumping Capacity** | 136 W |
| **Maximum Temperature Difference** | 68°C |
| **Resistance** | 0.75 Ω |
| **Maximum Operating Temperature** | 90°C |
| Gross Weight | 40.3 g |

Above listed are the salient features of the mentioned Peltier module.

## Path # 2

The second path leads to a 7805CT regulator. The reason for using this regulator is that onwardsin the circuit, both 5 volts and 12 volts will be used, and as such this regulator is used to stepdown the voltage at one end and provide the 5 volts electronics, while also relaying 12 voltswhere required.

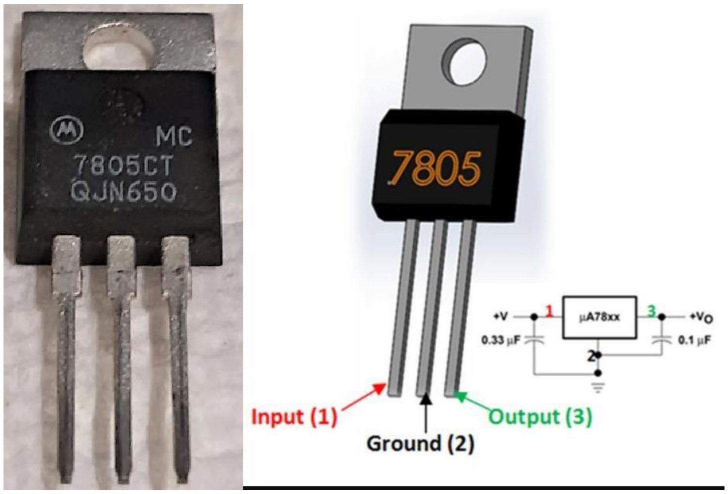



*Figure 14-7805CT regulator (right), Pinout of the 7805CT regulator (left)*

On the 5 volts side of the transistor, the power is supplied to the Arduino nano module. TheArduino nano controls the temperature sensors and the motor driver in the circuit. The Arduino is also connected to the LED to display the temperature results in the system. As for a standard16x2 LCD connection, in order to step down the 5 volts of Arduino, a 220 ohm resistance is connected between the Arduino board and the LCD. A potentiometer has also been placed soas to change the contrast of the LCD as per viewer convenience. The connection from the Arduino also goes to power up the motor driver L298N. The Arduino also provides RPM controlof the main inlet fan through potentiometer by the use of PWM. The temperature sensors arealso connected to the Arduino.

The 12V supply is further connected to a diode which also drops the potential by 0.7 volts. Itsmain purpose is to avoid any undesirable current flow towards the Arduino module since it isvery sensitive to voltages above 5V. This 12V connection is onward supplied to the L298N motorcontroller for running fans.

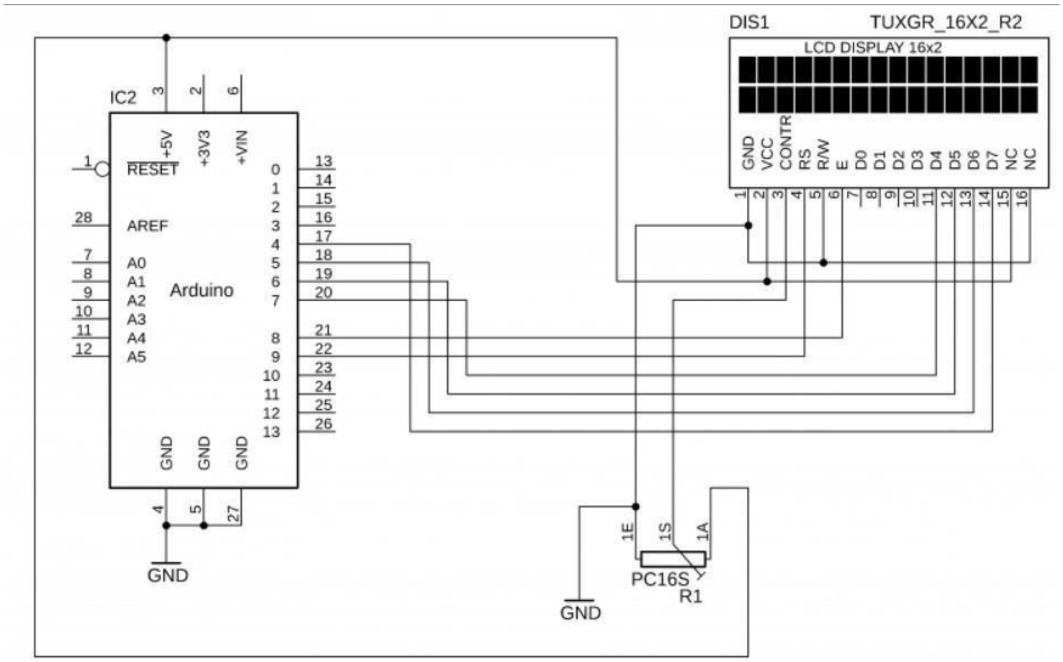



*Figure 15-Arduino nano connected to 16x2 LCD*

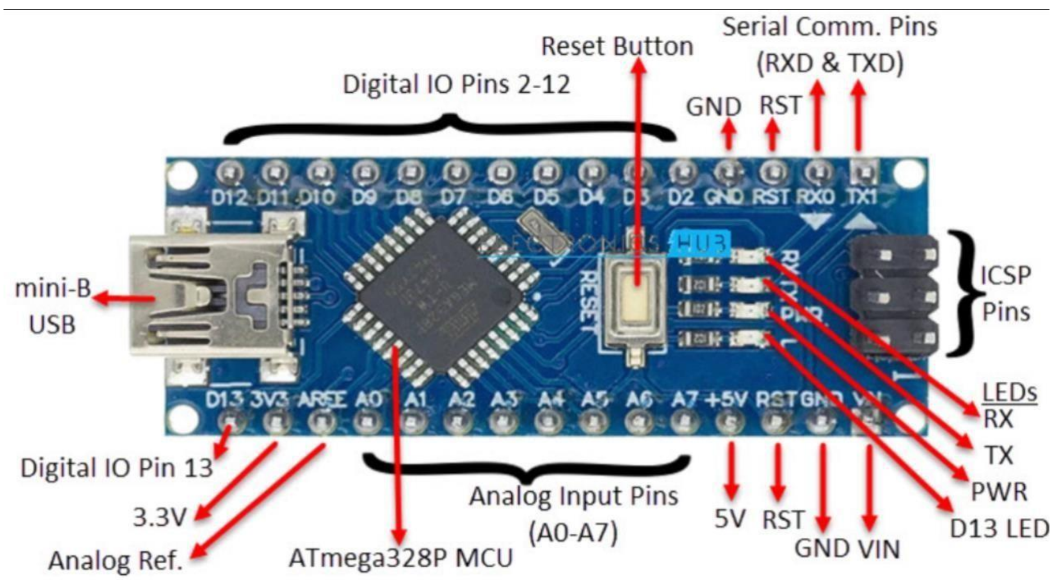



*Figure 16-Pinout of Arduino nano board*

## Motor Controller

The motor controller being used here is the L298N. Is can work on a range of voltages and thus is ample for working when running fans at the desired voltage(s). It draws power from the 12 voltsline of the 7805CT regulator. It needs to be controlled using Arduino. It is a dual H-bridge controller. Each H-bridge has capability of driving motors upto 35 volts and 2 Amps. Since weneeded at least 4 Amps to run all 3 of our fans in our application, both the H-bridges had beenconnected in parallel so as togiveanoutput of 4 Amps. Three fansarebeing controlledfromthecontroller: 2 of them in parallel, i.e. the exhaust side fans, while one (inlet) fan too.

This motor controller has the advantage of being bidirectional, and in addition to that, it can govern/change the RPMs of the fans. All the fans being used are DC motor powered fans, andthis motor controller also only works with DC motors.

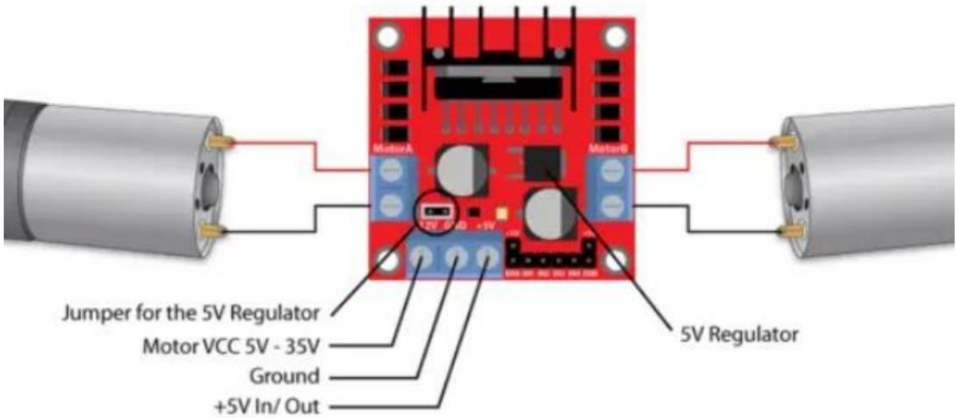



*Figure 17-Schematic of L298N motor controller*

## Temperature Sensors

The temperature sensors used in the system are DS18B20. It is an NTC type thermistor, meaning thereby its resistance decreases with increasing temperature, i.e. it has a negative thermal coefficient. It has many benefits over the other type of resistance-based temperature sensor, namely RTD. For starters, it is non-linear, and therefore highly accurate and sensitive. Its accuracy ranges up to ±0.5$^{o}$C within -10 $^{o}$C to 85 $^{o}$C, while the usable temperature range is between -55 to 125°C (-67°F to +257°F). It works between 3 to 5 volts and therefore uses the 5Vline from the 7805CT regulator. A 4.7k resistor is required as a pullup from the DATA to VCC linewhen using the sensor. Since this temperature sensor is a product of *Dallas Semiconductors*, ituses *onewire* protocol. It works on a single digital wire. Thus, for connection, it is connected tothe serial communication pin (pin # 2) of the Arduino nano board, in order for it's data (recordedtemperature) to be processed and displayed on other devices (i.e. LCD screen). Since it is onlycompatible with *onewire* protocol, the libraries <DallasTemperature.h> and <Onewire.h> had tobe used in coding for Arduino.

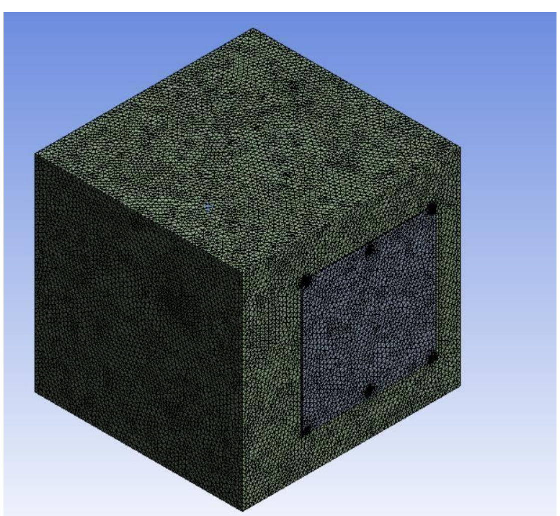
3 of these have been used in the circuit to measure the temperatures of the environment, the refrigerated space as well as the hot side of the Peltier module (i.e. in cooling conditions).

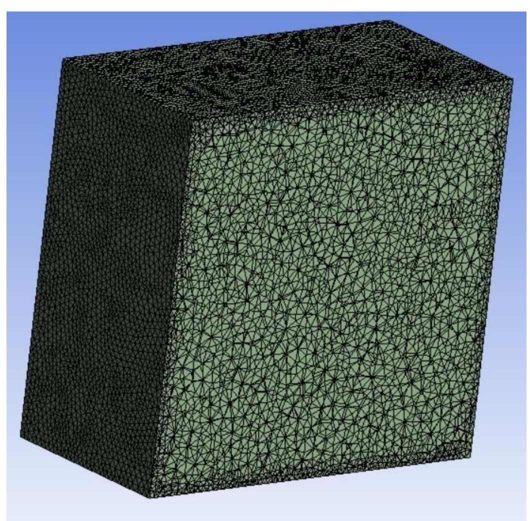
*Figure 18-L298N temperature sensor*

## 3.4 Flow Domain

Fluid domain is integral in determining the precision and accuracy of the results and that solely can be assured by having a well-defined and refined mesh. The mesh has been instrumental in converging to the desired results for validating and confirming with the already performed analytical calculations in prior. Thus, a really refined mesh is obtained with near 1 values of element quality and orthogonal qualitywhereas close to 0 value of skewness.

### 3.4.1 Mesh





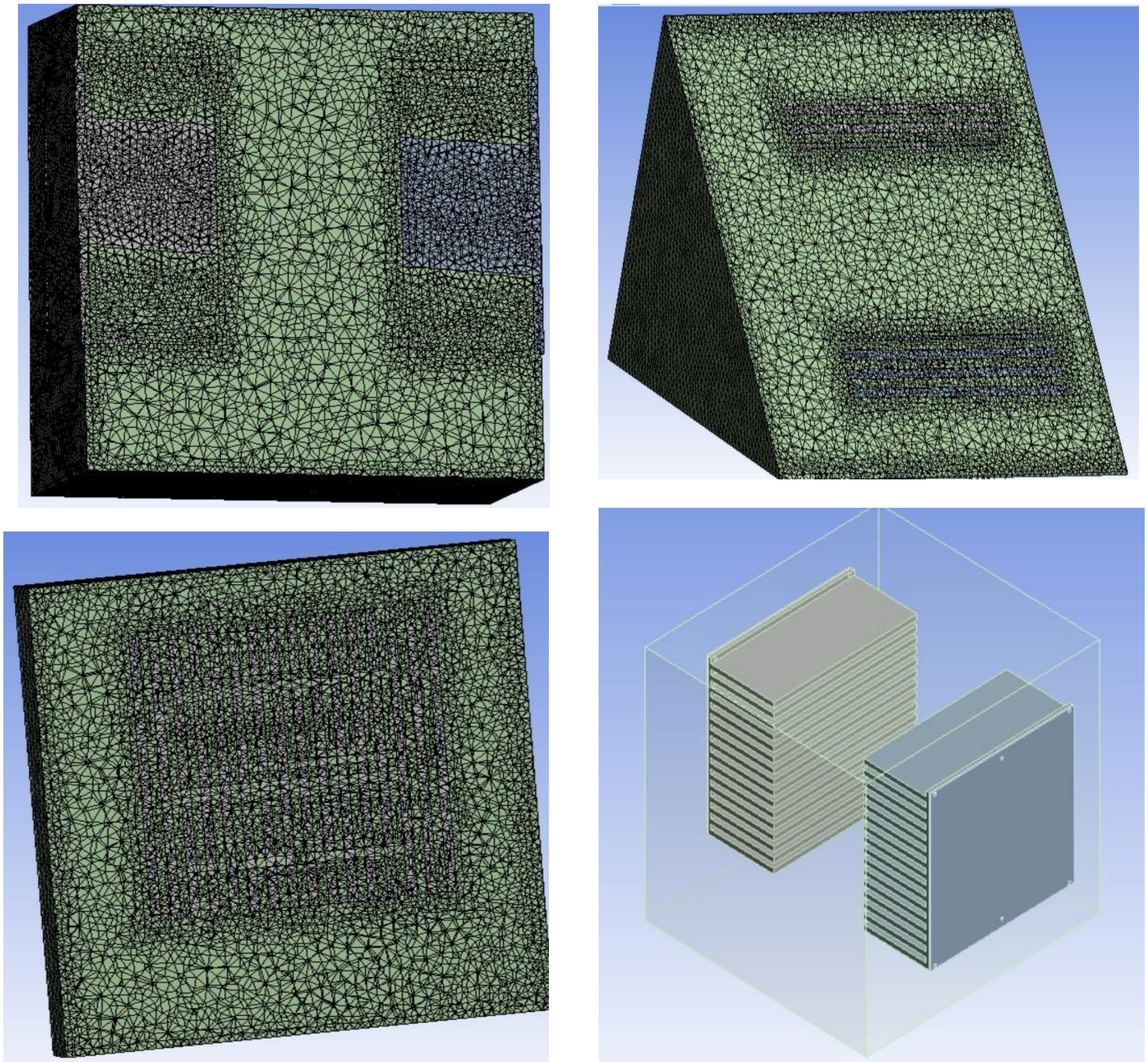


*Figure 19-Mesh*

| Quality | |
|---|---|
| Check Mesh Quality | Yes, Errors |
| Target Skewness | Default (0.900000) |
| Smoothing | High |
| Mesh Metric | Element Quality |
| Min | 0.20327 |
| Max | 0.9999 |
| Average | 0.79705 |
| Standard Deviation | 0.10872 |

*Figure 20-Mesh Element Quality*

| Quality | |
|---|---|
| Check Mesh Quality | Yes, Errors |
| Target Skewness | Default (0.900000) |
| Smoothing | High |
| Mesh Metric | Skewness |
| Min | 1.651e-004 |
| Max | 0.84195 |
| Average | 0.28604 |
| Standard Deviation | 0.1398 |

*Figure 21-Mesh Skewness*

| Quality | |
|---|---|
| Check Mesh Quality | Yes, Errors |
| Target Skewness | Default (0.900000) |
| Smoothing | High |
| Mesh Metric | Orthogonal Quality |
| Min | 0.15805 |
| Max | 0.99537 |
| Average | 0.71277 |
| Standard Deviation | 0.13814 |

*Figure 22-Mesh Orthogonal Quality*

### 3.4.2 Set up

ANSYS Fluent 2020 R2 solver has been used to set up and simulate the problem computationally/numerically. The solver has been kept as pressure based, while the transient solver was chosen. Since it is a conjugate heat transfer simulation, the model was chosen as K-omega SST, while energy equations were turned on. For materials, two domains were defined, i.e. fluid and solid, which were set as air and aluminum respectively. The inlet was set as velocity inlet with an inlet velocity of 8.13 m/s, while outlet was set as pressure outlet. The solution was hybrid initialized, and the calculation was aimed to be run till 1800 seconds.

### 3.4.3 Conjugate Heat Transfer Simulations

The simulations were aimed to run at least 1200 seconds as per the analytical calculations, however due to computational limitations of the computers/laptops, the maximum duration for which the case could be simulated was 80 seconds, i.e. barely till 6.7% of the intended time, yet the face averaged temperature 0.12 kelvin was obtained, i.e. 0.85% was obtained, which is a significant result.

## 3.5 Prototype Fabrication

## 3.6 Overview

Once we had completed the design, analysis, market research and cost analysis, we were all set to move towards fabrication of the prototype. Initially the idea was to manufacture the prototype considering preliminary design but with market research we introduced room for improvement.

### 3.6.1 Components

### 3.6.2 Overview

The prototype developed uses a versatile refrigeration system that is designed to control the circulated air temperature using external heat exchanger that in return maintains inside temperature of Sleeping Bag in ASHARE 55[6],[7] standards of 24-26C. The principle that makes it happen is Thermo-Electric Effect, an important phenomenon in thermoelectric science, this happens with use of thermoelectric coolers called Peltier modules. The Thermoelectric Effectoccurs when an electric current is passed through the junction of two different materials, that generates a temperature difference.

Using this principle, the prototype was designed to control the temperatures by alternately heating and cooling air, thus giving us a practical demonstration of this thermoelectric phenomenon. As a result, the prototype was to serve dual roles; it is equipped to function both as a heater and a cooler, hence offering flexibility of operation based on the desired outcome. The central element of the prototype is the thermoelectric Peltier module, a device widely usedin modern cooling systems and integral to this project.

#### *3.6.2.1* Major Components

**Peltier Modules:** These devices work on thermoelectric effect. If a current is supplied to its terminal, due to transfer of molecules from one semiconductor to another temperaturedifference is created. As a result, one side of it is at low temperature and other side is at high temperature. Our system uses 8 Peltier modules, with total operating capacity of 400W.

**Heat Exchanger Body:** The body of heat exchanger is made of Mild Steel 22 Guage sheetwith double insulation system that provides it delta T of 70 C protection.

**Heat Sinks:** In total 4 heat sinks are used that dump heat generated from hot side of Peltier modules into atmosphere allowing it to operate at optimum conditions and maintain its efficiency.

**Air circulation fans:** To facilitate forced convection mechanism and circulate air through sleeping bag, the system is using air circulation fans. These provide required h (convectiveheat transfer coefficient) for the system to perform well.

**Power Supply:** The system is using 12VDc power supply and using electronic system we are reducing it to 6.5V. This allows the system to operate at optimum ranges.

**Control module:** The control module is series of components connected to reduce the power supply and control the system using feedback mechanism. The mechanism allows to regulate voltage and fan speed depending on the temperature.

# CHAPTER 4: MATERIAL ACQUISITION

## 4.1 Overview

A comprehensive market survey was carried out with theobjective of determining the precise market prices of various materials and components associated with our project. Following thissurvey, a comprehensive list was compiled, and detailed price estimates were generated for each component. Upon completion of the cost estimation process, the procurement of materials and components commenced. Some components were not readily available in themarket and had to be ordered online. The entire process of procurement of materials for the fabrication and assembly of the project took around three weeks, which includes taking quotations from the vendors, closing the deal with the vendors having reasonable price brackets.

### 4.1.1 Market Survey

The market survey carried out in order to determine the availability of the components and elements used in the fabrication and integration of the project. The pricing of the components was also investigated for the sake of budget calculations. Market survey helps us to identify the potential vendors, comparison of prices and collecting the data of the components' availability or there alternatives in case the selected component was not available in the market.

The market survey also helped us to make timely decisions related to procure the components for the project locally or internationally. As one of the major sets back of the international procurement is that it takes a lot of time for the shipment of components from international market such as China and US, and also it cost a lot of budget.

### 4.1.2 Budget Planning

After completing the market analysis stage, the team moved on to planning the budget in which all the components were listed down and analysis of feasible components was carried out as well as the desirable vendors, so as to get the optimum price range for the best functioning prototype.

### 4.1.3 Procurement Process

After the finalization of the market survey and the budgeting, the next phase was to procure the finalized materials. The procurement also involved the process of manufacturing components like heat exchanger casing as per the specifications and the requirement of the project. The whole process of the placement of orders to the final delivery spanned the length of three weeks. Thus timely gathering of all the necessary materials and components so as to get the project executed swiftly.

## 4.2 Cost Estimation

The cost estimation was a significant component of the project's planning stage. It involved an extensive market survey, which served as a robust basis for determining the costs of all locally available materials and components required for the project. The survey findings were synthesized into a comprehensive cost estimation table, providing an overview of the total expenditure for the project. The table is presented below for reference:

| S.NO | COMPONENT | QUANTITY | RATE/UNIT | PRICE (PKR.EST) |
|---|---|---|---|---|
| 01 | Heat Exchanger Body-(MS 22 Guage Sheet) | 1 | 6000 | 6000 |
| 02 | Heat Sinks | 8 | 1000 | 8000 |
| 03 | Aluminum Sheet | 1 (1200x90x2) mm | 2200/kg | 3500 |
| 04 | Peltier Modules | 8 | 1050 | 8400 |
| 05 | Thermal Paste | 3 | 330 | 990 |
| 06 | Air Circulation Fans | 3 | 830 | 2490 |
| 07 | Sleeping Bag | 1 | 5000 | 5000 |
| 08 | Double Corrugated Sheet | 1 (65x75) cm | 500 | 500 |
| 09 | Polyurethane Sheet | 1 (4x2) ft | 35/sqr.ft | 280 |
| 10 | Adhesives | 2 | 725 | 1450 |
| 11 | Poly epoxy Glass fibre Sheet | 3 (120x90x1.5) mm | - | 7000 |
| 12 | Screws and Nuts | - | - | 1000 |
| 13 | Retractable Pipe | 8 ft | 150/ft | 1200 |
| 14 | Power Supply | 12VDC 50A | 25000 | 25000 |
| 15 | Control Module (Mosfet/Voltage regulator/Resistors/Capacitors/Potentiometers/ LCD/Thermal Sensors/Motor Controller) | - | - | 20000 |
| **Total** | | | | 90,310 |

# CHAPTER 5: RESULTS AND DISCUSSION

## 5.1 Conjugate Heat Transfer Simulation Results:

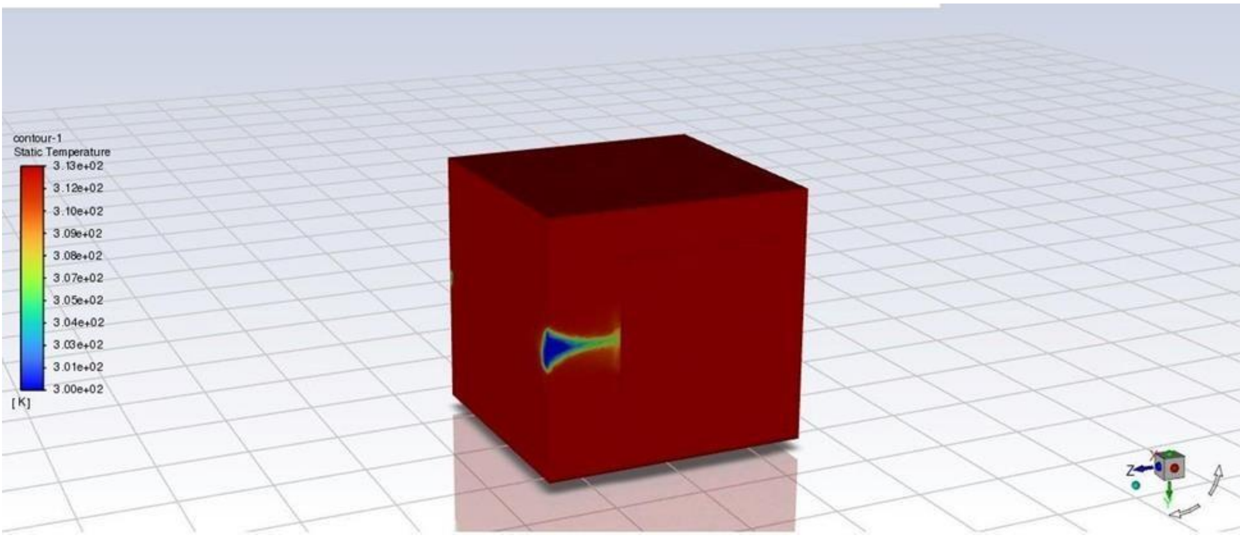



*Figure 23-Contours*

The above figure shows how at the exit region already temperatures of about 27 degrees Celsius have been achieved within in the first 80 seconds.

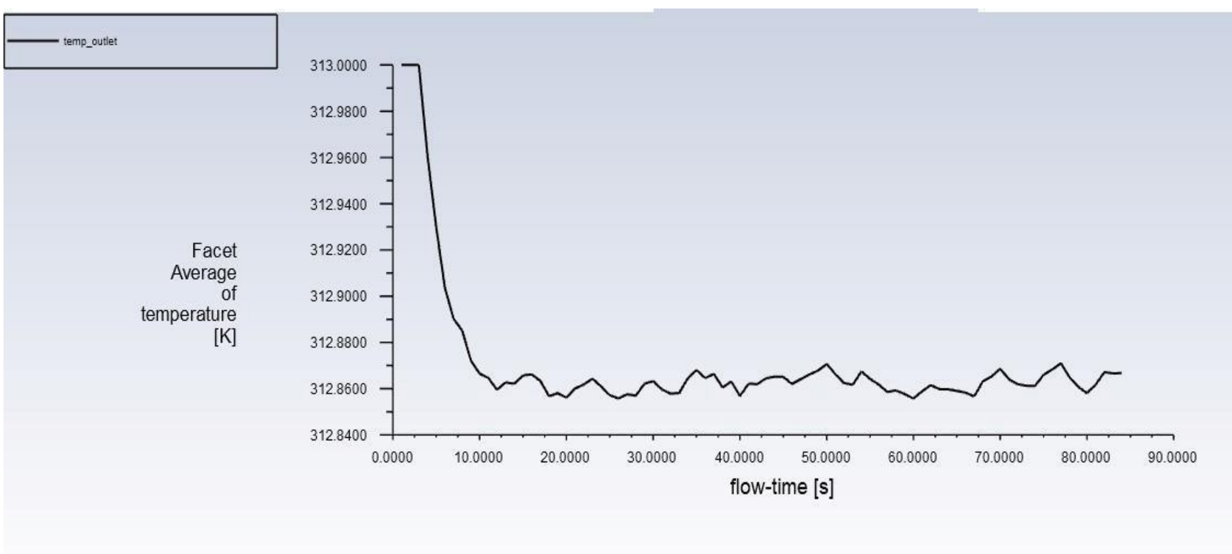



*Figure 24-Facet Average Value*

## 5.2 Testing Methodology:

After attaining the prototype, we proceeded towards the testing phase. The testing was conducted in 2 modes, vis a vis, the open loop and closed loop testing.

*Figure 25-Complete System*

### 5.2.1 Open Loop Testing:

In the open loop configuration, the aim was to test the temperature difference obtained between the hot and cold sides of the and the cold side and the environment. The intended purpose was to get the benchmark, i.e. without having any thermal losses, any thermal resistance and thermal load. This would be beneficial when gauging the effectiveness of the system integrated with the bag and having an occupant inside the bag.

### 5.2.2 Closed Loop Testing:

In the closed loop mode of testing, the peltier module assembly was integrated into the heat exchanger casing and the duct pipes were attached to the bag. The inlet fan was operated to allow the air circulation from the heat exchanger to the bag and back. The bag was occupied (human load). This test provides the real-world figures and data when the heat exchanger is fully functioning condition and attached to the bag.

### 5.2.3 Open Loop Testing Results:

A number of tests were conducted on the HVAC sleeping bag prototype in an open system configuration to assess its thermal regulation capabilities over varying time intervals. The intervalsof tests were 15, 30, 40, and 60 minutes to evaluate the system's performance across different durations.

During the test runs, the ambient environmental temperature remained relatively stable, in the range of 19.87 and 20.81 degrees Celsius, representing the typical outdoor conditions similar toovernight camping or outdoor activities.

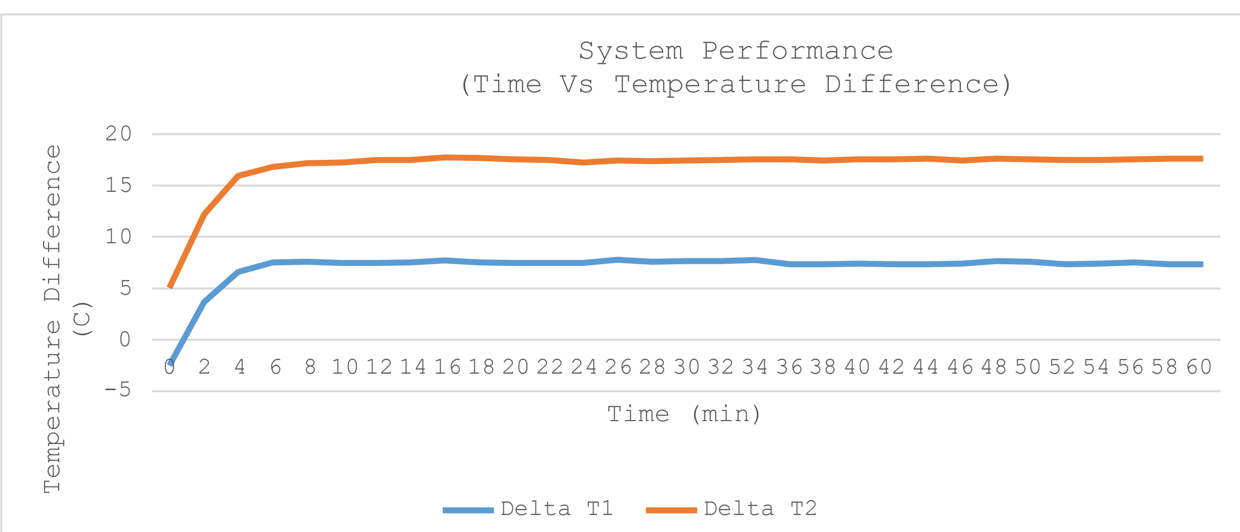
#### 5.2.3.1 Cold Side Thermal Performance:

Initially in ten-minute intervals, the temperature of the aluminum plate housing the cold side of the Peltier module registered at 13.25 degrees Celsius. After some intervals, a gradual decrease in temperature was observed, indicating the system's effective cooling capabilities. After 30 minutes, the temperature lowered to 12.88 degrees Celsius, further declining to 12.69 degrees Celsius after 45-minute. Notably, at the conclusion of the one-hour test period, the temperature stabilized at 12.56 degrees Celsius, showing cooling proficiency of the HVAC system.

#### 5.2.3.2 Hot Side Thermal Performance:

The heat sinks proved to exhibit consistent thermal behaviour in the tests. Initially, the hot side temperature was attained to be 30.5 degrees Celsius, which showed minor fluctuations at 45 minutes and 1 hour mark, i.e. 30.2 and 30.1 degrees Celsius respectively. This shows the selected components have enough/sufficient capability to maintain thermal equilibrium in the system, i.e. the bag.

In the figures below, ET corresponds to environmental temperature, BT corresponds to the temperature of the cold space (cold side in context of open loop testing) and HT corresponds to the hot side temperature (with fins).



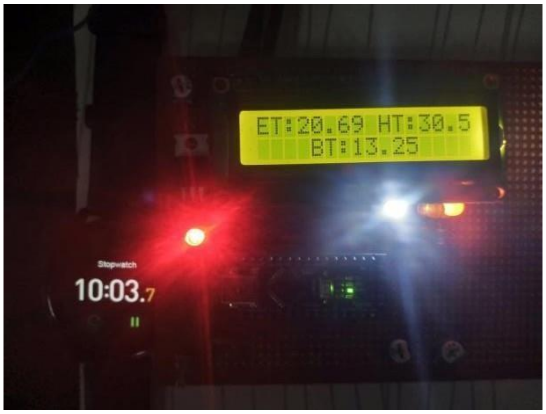



*Figure 28-System Temperature Conditions After 10 Minutes*


*Figure 29-System Temperature Conditions After 30 Minutes*


*Figure 30-System Temperature Conditions After 45 Minutes*

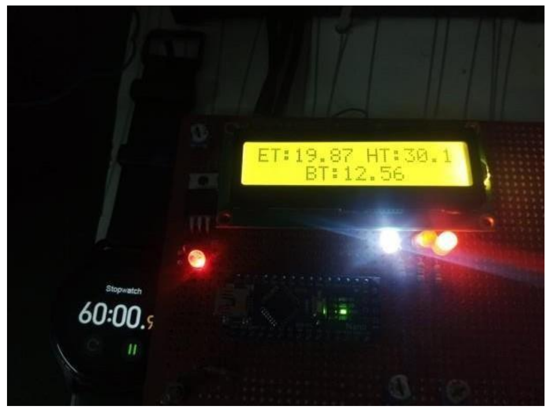



*Figure 31-System Temperature Conditions After 60 Minutes*

*Figure 1-System Performance*

### 5.2.4 Closed Loop Testing Results:

As described above, the closed loop testing mechanism was carried out to test real world conditions and capabilities of the system in real time. The test were conducted in intervals of 15, 30, 40 and 60 minutes. Over the course of testing duration, the ambient temperature (ET) remained consistent within the range of 17.50 to 22.31⁰C, thus giving a relatively reliable and consistent testing conditions to get values for analysing purposes.

#### 5.2.4.1 Cold Side Thermal Performance:

The test results were measured at various points in time. Initially, the cold side temperature (temperature of the cooled space in case of the closed loop testing) was attained to be 18.25 degrees Celsius. This dropped down to 17.44 degrees Celsius at 30 minutes mark and further fluctuated to 17.69 at 45 minutes mark. By an hour (completion of the test), the cold side temperature had stabilized to 17.00 degrees Celsius.

#### 5.2.4.2 Hot Side Thermal Performance:

The hot side temperature also indicated consistency during the duration of the testing. During initial 45 minutes of testing, the hot side at maintained the temperature of 23.3 degrees Celsius which only fluctuated to 23 degrees Celsius, and at final 1 hour mark this was noted to be 23.5 degrees Celsius.

In graph below, delta T1 is the temperature difference between environment and cold side of Peltier module. Whereas delta T2 is the temperature difference between hot side and cold side of Peltier module. The system is was tested to understand the performance of the system at minimum temperatures.


*Figure 33-System Temperature Conditions After 10 Minutes*


Figure 34-System Temperature Conditions After 30 Minutes


Figure 35-System Condition After 45 Minutes


Figure 36-System Temperature Conditions After 60 Minutes

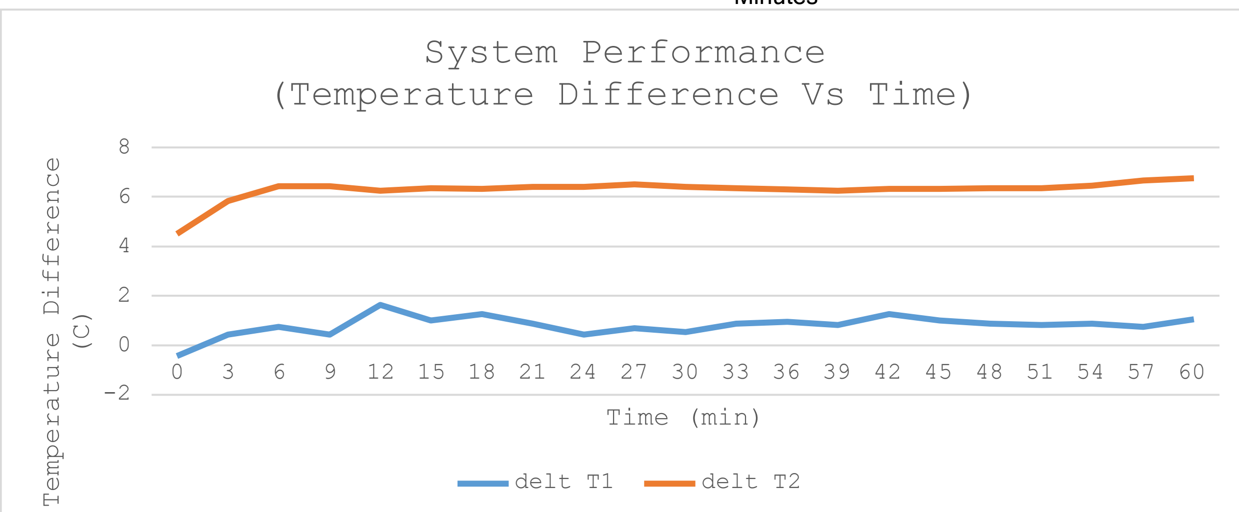



*Figure 2-System Performance*

## 5.2.5 Conclusion

The testing results both in open loop and closed loop configurations showed promoising results. Not only are the results coming out to be in the reasonable range (both hot and cold sides), the results showed how consistent values showed the durable and reliable nature of the design and its operation. The values obtained have been consistent, with little variations on both sides, for both the types of testing and this testifies to the workability of the model.

### 5.2.5.1 Thermal Regulation Efficacy

In both open and closed loop testing scenarios, the HVAC sleeping bag prototype demonstrated remarkable thermal regulation capabilities, maintaining optimal temperatures, e.g. the cold side temperatures for closed loop remained between 18 to 17 degrees Celsius throughout one hour testing whereas the hotside was noted to remain around 23 degrees Celsius. The gradual decrease in cold side temperatures (i.e. 17.44 to 17.00 degrees Celsius) over time intervals signifies the system's consistent cooling performance, ensuring sustained comfort for users. Likewise, the stable behavior of hot side heat sinks throughout the testing duration reflects the system's efficiency in dissipating heat generatedby the Peltier modules, thereby preserving thermal equilibrium within the sleeping bag environment.

### 5.2.5.2 Adaptability to Real-World Conditions

As discussed, the open loop testing was conducted to set a benchmark against which closed loop's performance can be marked. This robust testing methodology helped us demonstrate how durable and consistent the system is in a real world scenario where the external temperatures and conditions vary over long lengths of time and the heat exchanger would have to cater to an occupant.

### 5.2.5.3 Implications for Design Optimization

The design thus far has been successful in attaining design objectives, but since the window of optimization is always open, it is better to keep rectifying the base model. The major areas should be insulation and thermal/temperature regulation, i.e. making sure peltiers have to cool down effectively optimal area of the cold side such that the passing air has enough of a contact with it to get cool and provide comfort to the occupant. Similarly, the hot side should be having the best heat dissipation possible. Other than that, the sealings have to be introduced where any leakage of air has been detected. Further, in order to ease the load on the cold side of the Peltier module, the inside of the heat exchanger can be insulted too, save the area where the air is going to come into contact with the cold surface.

## 5.3 CONCLUSION AND RECOMMENDATION

The project aims to tap the potential market of sleeping bags which traditionally has not been the target of such commercial products. Traditionally, the sleeping bags come with heating only option (enabled by heating rod), which cannot work in an all-weather, mostly sub-Tropical climatic region like Pakistan. As such, in order to overcome this, thermoelectric modules have been opted to be incorporated in the prototype to provide the intended purpose, i.e. both heating and cooling.

The targeted temperature range of the sleeping is 24-26 degrees Celsius, as per ASHARE standard 55[6],[7], which sets the standards for human comfort levels.

Various tests were conducted to gather data on user experiences, and a control system was designed to automate thermal comfort adjustments, eliminating the need for manual intervention. The subsequent goal was to optimize the product by enhancing its portability and overall comfort levels. Through these iterative steps, the project aimed to create a versatile and user-friendly sleeping bag that addresses the specific climatic needs of the Pakistani market.

Two major Areas of the change are further optimization of design by introducing cold heat sinks atboth sides having effective length that allows system to cool and heat efficiently by allowing heat interaction between refrigerated space and air passing through it.

Second is the use of the lightweight body and thermal insulation which will reduce the weight of heat exchanger by 50%. It will also provide less cooling space than the heat rejection space. This allows for the system to maintain the temperature for longer hours and consume less work input.

## 5.4 Limitations

Despite these advancements, it is essential to acknowledge certain limitations. The sleeping bags are tailored for peak temperatures of 40 degrees Celsius in summers and 10 degrees Celsius in winters. Additionally, the inclusion of an external heat exchanger requires careful consideration and management during use.

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# APPENDIX:

## Code for Temperature Sensors and LED:

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include <LiquidCrystal.h>

// Data wire is connected to pin 2
#define ONE_WIRE_BUS 2

// Setup a oneWire instance to communicate with any OneWire devices
OneWire oneWire(ONE_WIRE_BUS);

// Pass our oneWire reference to Dallas Temperature sensor
DallasTemperature sensors(&oneWire);

// LCD module connections
#define LCD_RS 8
#define LCD_EN 9
#define LCD_D4 4
#define LCD_D5 5
#define LCD_D6 6
#define LCD_D7 7
#define LCD_COLUMNS 16
#define LCD_ROWS 2

// Initialize the library with the numbers of the interface pins
LiquidCrystal lcd(LCD_RS, LCD_EN, LCD_D4, LCD_D5, LCD_D6, LCD_D7);

void setup() {
 // Initialize DS18B20 temperature sensors

 sensors.begin();

 // Initialize LCD screen
 lcd.begin(LCD_COLUMNS, LCD_ROWS);
 lcd.clear();

 // Display initial message
 lcd.print("Air Sleeping Bag");

 // Set up serial communication
 Serial.begin(9600);
}

void loop() {
 // Request temperatures from DS18B20 sensors
 sensors.requestTemperatures();
```

```
// Read temperatures from sensors
float ET = sensors.getTempCByIndex(0);
float HT = sensors.getTempCByIndex(1);
float BT  = sensors.getTempCByIndex(2);

// Display temperatures on LCD screen with 2 decimal places
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("ET: ");
lcd.print(ET, 2);
lcd.print((char)223); // Degree symbol
lcd.print("C HT: ");
lcd.print(HT, 2);
lcd.print((char)223); // Degree symbol
lcd.print("C");

lcd.setCursor(0, 1);
lcd.print("BT: ");
lcd.print(BT, 2);
lcd.print((char)223); // Degree symbol
lcd.print("C");

// Delay for stability
delay(1000);
```

## Code for L298N Motor Controller:

```
// Define pins for L298N motor driver
const int ENA1 = 9; // Enable pin for first H-bridge (inlet fan)
const int ENA2 = 10; // Enable pin for second H-bridge (exhaust fans)
const int IN1 = 8; // Control pin 1 for first H-bridge
const int IN2 = 7; // Control pin 2 for first H-bridge

const int IN3 = 6; // Control pin 1 for second H-bridge
const int IN4 = 5; // Control pin 2 for second H-bridge

// Define analog pin for potentiometer
const int potPin = A0;

// Variables to store potentiometer value
int potValue = 0;

void setup() {
 // Set L298N control pins as outputs
 pinMode(ENA1, OUTPUT);
 pinMode(ENA2, OUTPUT);
 pinMode(IN1, OUTPUT);
 pinMode(IN2, OUTPUT);
 pinMode(IN3, OUTPUT);
 pinMode(IN4, OUTPUT);

 // Initialize serial communication
 Serial.begin(9600);
}

void loop() {
 // Read potentiometer value
 potValue = analogRead(potPin);

 // Map potentiometer value to PWM range (0-255)
 int pwmSpeed = map(potValue, 0, 1023, 0, 255);

 // Control first H-bridge (inlet fan) with PWM
 analogWrite(ENA1, pwmSpeed);
 digitalWrite(IN1, HIGH);
 digitalWrite(IN2, LOW);

 // Control second H-bridge (exhaust fans) without PWM
 analogWrite(ENA2, 255); // Full speed for exhaust fans
 digitalWrite(IN3, HIGH);
 digitalWrite(IN4, LOW);

 // Print potentiometer value for debugging
 Serial.print("Potentiometer Value: ");
 Serial.println(potValue);
```

```
// Add a delay to avoid reading the potentiometer too quickly
delay(100);
```