Efficiency Enhancement of PV Solar Panels by Passive Cooling

A Final Year Project Report

Presented to

COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

Department of Mechanical Engineering

NUST

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Mechanical Engineering

By

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June 2022

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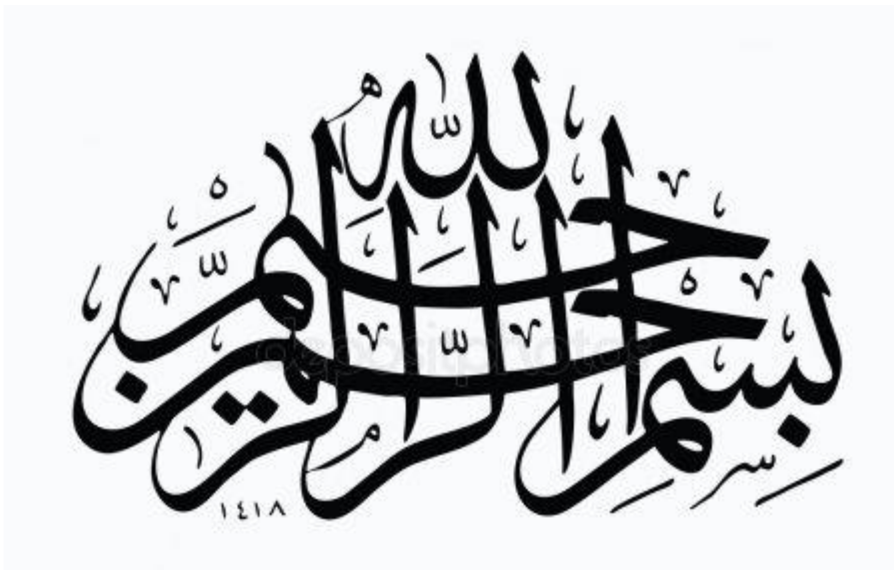
بسم الله الرحمن الرحيم
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CERTIFICATE OF APPROVAL

It is to certify that the project **"EFFICIENCY ENHANCEMENT OF PV SOLAR PANELS BY PASSIVE COOLING"** was done by **GC Izhar Sultan Nasir**, **GC Umair Babar**, and **PC M. Nazim** under the kind supervision of **Maj. Dr. Muhammad Ali Khan.**

In partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering, this project is submitted to the **Department of Mechanical Engineering**, CEME (College of Electrical and Mechanical Engineering), National University of Sciences and Technology, Pakistan.

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First and foremost, I want to express my gratitude to Allah Almighty. Who gives us the freedom, power, ability and courage to comprehend things, and by whose grace, every impediment and obstacle was removed in the completion of this difficult task.

Apart from the group's efforts, the success of any initiative is largely dependent on the support and guidance of many others. We would like to convey our gratitude to **Dr Muhammad Ali Khan**, our supervisor, who was extremely helpful and provided vital advice, support, and guidance.

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ABSTRACT

Due to the recent surge in global warming and improved energy security worldwide,there is an ever-increasing transitional need for shift towards more cleaner and renewable energy sources around the world in place of conservative power sources which include fossil fuels, natural gas etc. This is especially important as conservative power sources which include fossil fuels such as petroleum, oil and natural gas are exhausting. Among various renewable energy options, solar power is by far a capable solution interms of cleaner and greener energy production and utilization, owing to its cheap cost, reliability, and sustainability. Nevertheless, there are still challenges faced byresearchers and engineers around the world in the field of solar power. Particularly, their low efficiency due to limited absorption of solar spectrum curtails the production of electricity. Furthermore, environmental factors such as humidity, dust, panel temperature and uncertain solar intensity also contribute towards the power degradationand thus, in turn, a low conversion efficiency.

This project is aimed at utilizing the potential of various passive cooling approaches to develop a working prototype of energy efficient solar panel as compared to conventional solar panel. Development of working physical prototype of PV-PCM containment system which provides higher overall efficiency compared to the conventional PV Panel. Small scale 30 watts panels were obtained and phase change materials were utilized at the PV panel back to reduce their operating temperature and hence, to increase overall conversion efficiency. Effectiveness and efficiency of the solar panel can be improved by reducing the temperature by employing feasible and practical methods. One among the major capable solutions is the usage of PCM (Phase Change Materials). Such materials, when installed on a solar panel, can reduce their operating temperature and increase overall conversion efficiency. Phase change materials utilize their latent heat capacity to absorb/ release large amounts of heat on their phase conversion from waxy solid to melted liquid and vice versa resulting in reduced panel temperature due to increased heat transfer from panel back surface towards the ambient through PCM. Other options include use of fins as a heat sink.

The design that was tested for various electrical and thermal parameters was the one with rectangular PCM containment made with Aluminum sheet of thickness of 2.5mm. The containment was designed by Argon welding using TIG method. The systems showed significant reduction in panel temperature up to 5-6 degree Celsius. Container Design has an average relative efficiency increase of 1.55 % and 15 % improvement in power output, at average, is observed compared to the conventional PV Panel.

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ABBREVIATIONS

PV	Photovoltaics
TCE	Thermal Conductivity Enhancers
CdTe	Cadmium Telluride Solar Cell
FF	Fill Factor
PCM	Phase change material

NOMENCLATURE

Q	Heat transfer Rate
K	Thermal conductivity (W/(m.K))
A	Area(m^2)
T_s	System Temperature(°C)
T_a	Atmospheric temperature (°C)
I_{sc}	Short circuit current (A)
V_{oc}	Open circuit voltage (V)
Q_{gen}	Heat generated due to light (J)
Q_{res}	Residual heat (J)
P_{out}	Output Power
P_{in}	Input Power

CHAPTER 1
INTRODUCTION

In the current era, energy production by the means of conventional energy sources i.e. fossil remains such as coal, petroleum, oil and natural gas is declining, because of the reason that there is a rising demand for the implementation of green and clean technologies for Power production. Renewable energy technologies such as solar energy, wind energy and geothermal energy etc. are gaining attraction, in the recent years, due to their reduced environmental impactand carbon footprints. However, there are still technical and economic challenges that hinders their implementation on mass-consumer market. Particularly, in the field of solar power, Photovoltaic cell is one such invention that has to potential to change the global energy landscape. Nevertheless, technical improvements and research is still required to improve their efficiencies as conventional PV cells are only about 12-15% efficient.

Apart from that, there are other environmental factors that hinder the full-scale implementation of this technology including uncertain weather patterns, solar intensity variations, dust, humidity,and temperature. One of these parameters, temperature, has an adverse effect on the efficiency ofthe cells. On average, the efficiency of the solar cell drops by 0.3%-0.7% with every degree Celsius increase in temperature.

This project aims to explore the possibilities of implementation of different passive cooling methodologies to enhance the total conversion efficiency of solar cells. Cooling the Photovoltaic cells or panels will also help in reducing the degradation over time for the system, due to excessive heat absorption by the system. One of the primary aims is to experimentally test the available passive cooling methodologies including the application of Phase change Materials and fins to check for the performance enhancement of the panel. A comparative study has also been done on similar panels with above mentioned design for PCM Aluminum containment to indicate the performance improvement for the parameters like poweroutput, temperature and electrical conversion efficiencies.

CHAPTER 2
LITERATURE REVIEW

The need to look for a cheaper, economical, and efficient energy system has been an area of research interest due to the rise in demand of clean energy. One of the most widely used option for production of energy is the solar energy. It has various inherent benefits. In the context of the climate of Pakistan, one of the promising and best energy option among renewables in terms of various factors like setup and maintenance cost, life span and environmental conditions is solar energy production according to researchers [1]. Abdelrahman, H. E., et al. have used nanoparticles Al_2O_3 as TCE. The PV-PCM system having RT-35HC as PCM and cylindrical shaped fins achieved reduction of 20-46.3 % on the front surface of the panel which increases to 52.3 % along with Al_2O_3 nanoparticles at ambient conditions of around 20 ºC and heat flux range 279-820W/m2 [2]. Solar Photovoltaics built on silicon technology can transform 8-20% of the incoming solar energy into electricity while the largest percentage is ultimately manifested in the form of temperature which increases the Photovoltaic surface temperature and thus the electrical efficiency drops [3]. Furthermore, renewables are expected to take up 30% of the total share of electricity production globally in 2021. It is evident from the facts and figures quoted by IEA, that solar is the technologythat is going to change energy landscape globally; Solar PV expansion is going to reach 145 GW in 2021 and 162 GW in 2022, accounting for 55% expansion in renewables in these 2 years [4].

There is also ahuge concern regarding the sustainability and efficiency of this technology over the long period of time because of the rising demand and need for renewable technologies particularly Solar PV. According to world energy outlook report 2020 by International Energy Agency, Solar is by far the cheapest option available among the renewables surpassing oil and natural gas and is expected to grow by 13% each year in the next decade of 2020-2030 meeting one-third of electricity growth demand [5]. Thus, the effectiveness of solar PV having crystalline silicon reduces by 0.4-0.5% for every 1-degreeCelsius rise in temperature [6]. Thus, there is a need for efficiency improvement of the solar PV in order to increase its overall change in the efficiency as well as to increase the lifetime of the PV Module, which in turn further increases the power over PV Module life span and its performance towards the environment and response towards the circuitry and electrical loads connected to it.

Researchers have industrialized and verified different cooling systems and methods; namely classified as active and passive cooling approaches. Passive cooling approaches requires no additional energy input and thus, are inexpensive and simple to use while Active approaches requires some form of energy input such as fan, blower etc. A lot of researchers are trying PCM and fins for PV panel cooling as they can absorb large amounts of latent heat without changing the operating temperature of the panel, making them a suitable and effective technique for PV cooling. Kumar et al has done a comparative study of PV and Photovoltaic-PCM systems along with fins. It is determined that the Photovoltaic-PCM with outer Al fins greatly condensed the surface temperature of the module by 22.3 ºC which in turn translates to an efficiency increase of around 6.59 %. [7] Mahamudul, Rahman et al. did numerical investigation of attaching a PCM layer of RT35 on the PV module in terms of temperature loss of around 10 ºC for extended period of 4-6 hours. The study is also validated by experimental comparative study of developed prototypes [8].

Peter Atkin and Muhammad M. Farid tested and compared four systems: first simple PV, second with graphite infused PCM layer, the third with fins/heat sink and fourth with both PCM and fins. It is found that the last system is most effective for heat management of the Solar panel as efficiency improvement of 12.97% is recorded [9].

Qasim, M. A., et al. did experimental work for comparative study of PV-PCM system using hybrid PCM's. They achieved a maximum temperature drop of 26.5 ºC with the insertion of 11 fin with the parafin based PCM. Also, it was found out that the suitability of using two PCM's simultaneously is based on their melting point [10].

Hasan, McCormack et al. also conducted experiments on PV-PCM systems in two various weather conditions of Dublin, Ireland and Vehari, Pakistan. They have utilized two PCMs: CaCl2.6H20 and capric palmitic acid. It was found out that the CaCl2.6H20 performed better in reducing the panel operating temperature in both environmental conditions. In Vehari-Pakistan, it was noticed that both PCM's achieved higher and significant drop in temperature with 13% power conservation but compared to capric-palmitic acid, CaCl2.6H20 performed better with 3% more savings [11]. Wongwuttanasatian, T., et al. Utilized container containing fins in the heat sink with palm wax for thermal conservation and efficiency enhancement. Temperature drop was found out to be 6.1 ºC which enhanced efficiency by 5.3% [12]. Thus the surprisingly increasing demand for renewable energy never ends and is the cheapest way to overcome power outages.

As far as PCM containment at the panel back is concerned, there is a rising concern of low thermal conductivty of PCM which slows down the whole process of heat transfer. Thus, Researchers have tried to use nano-particles as heat conductivity enhancers to enhance the overall heat transfer characteristics. Mahamudul, Rahman et al. have used nanoparticles Mg2O3. The PV-PCM system having RT-25HC as PCM and spherical shaped fins achieved reduction of 25-46.3 % on the front surface of the panel incrementing to 42.8% along with Mg2O3 nanoparticles at ambient conditions of around 25 ºC [13].

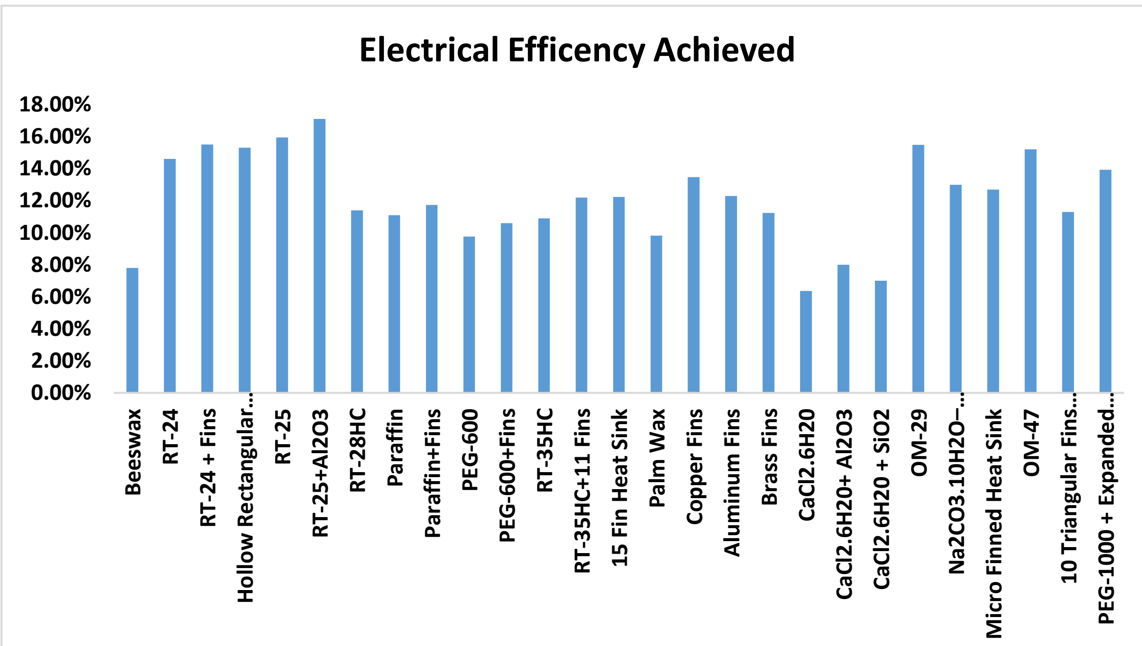


Figure 1: Efficiency Improvement Results achieved by different researchers published in literature. (“Experimental Study on Hybrid Organic Phase Change Materials Used for Solar Energy Storage - China National Solar Thermal Alliance”)

In the context of Pakistan, few governmental organizations are working in the field of solar cell manufacturing and panel assembling industry. One example is that of Pakistan Council of RET (Renewable Energy Technology) under the ministry of science and technology of government of Pakistan.

They are working on various solar energy/power applications including but not limited to: solar powered driven devices including geysers, greenhouse solar tunnel dryer, cooker, stove to be utilized in backward areas, solar driven rickshaw but it wasn't up to the standards to be commercialized due to its high cost and ineffectiveness on implementing the technology on a largescale. Also, facility houses the Pakistan's first solar cell manufacturing facility according to international standards. But there is still a lot of work and improvement required to improve the existing solar technology and to help us understand the underlying mechanism at the very basic level to enhance and discover the untapped potential present in the solar technology especially photovoltaics. Taking into account the solar energy possible in Pakistan, it is envisaged that the majority of the solar energy applications that are being utilized all over the planet are a lot of down to earth in the country. The Government of Pakistan (GoP) is extremely keen on creating solar energy projects in the country. At present a sum of six (06) solar PV power projects with combined limit of 430 MW are dispatched and are providing power to the public framework. Four (04) solar PV power projects with combined limit of 250 MW are under development and a lot more solar PV power projects are in pipeline. Late progression in the solar PV innovation and cost decrease has made solar PV as the most conservative choice for power age. Taking this into account, GOP is imagining to foster more than 7000MW solar PV projects in next 8 years (reference IGCEP 2021).

Following Table summarizes some of the efficiency and temperature reduction studies available in literature using differentpassive cooling techniques.

Table 1: Summary of significant work available in literature

Serial No.	Research Paper Title	Parameters	Conclusions
1	Performance improvement of photovoltaic cells by changing configuration and using PCM(RT35HC) with nanoparticles Al2O3 (Abdelrahman,	- Heat Sink Arrangement - Useful Heat Flux - PCM-Nano particles mixture with varying volume fractions	-Predicted Free Surface Temperature (74.5 degree Celsius at 850 W/m2) -Temp Reduction of 21.5 % (16 degrees) with fins application (21 fins in staggered configuration) -Temp drop by 34.5 degree Celsius by employing RT35HC + Fins (Heat Flux: 820 W/m2)

	Wahba et al. 2019)		-Using Al2O3 with above system, Temp drop of 1 to 4.5 degree Celsius using concentrations of 0.11 % and 0.77 % respectively -Finally, overall drop of **36.9-52.3 % (29.8 degree Celsius)** in the front panel surface temperature and efficiency improvement of 14.9 % for the above approach.
2	Refining the efficiency of photovoltaic cells using PCM filled graphite and aluminum fins (Atkin and Farid 2015)	-4 cases for thermal regulation -None -30 mm thick PCM Filled graphite -Aluminum Heat Tank or Sink 30 mm thick PCM -Filled graphite and aluminum heat sink -Fact Based Efficiency, Thermal Regulation and overall efficiency is measured and compared in all 4 cases	-Case D found out to be most effective with overall efficiency increase of **13 %** -Financial Analysis of the method shows that the whole thermal regulation setup is **10 %** of the total cost of commercial PV Panel. -Overall efficiency of case D is **14.38 %**, an improvement of 9.69 % compared to case A for 18 h operation.
3	Enhanced PV performance through temperature regulation by phase change materials: Materials comparison in different climates (Hasan, McCormack et al. 2015)	-Reference PV -PV-PCM 1 -PV-PCM 2 -Power Savings, Voc, Isc are compared in three system	Highest PV-temperature lessened from 49 °C to **43 °C & 40 °C** with **PCM1 & PCM2**, respectively in Dublin. While in Vehari, it dropped from **63 °C to 51 °C& 42 °C** with **two different PCMs**, respectively. Results discovered higher cost-effectiveness of PV-PCM systems in Vehari than Dublin
4	PV module temperature maintenance with the use of phase change materials (Klugmann-radziemska and wcisło-kucharek 2017)	- PCM-Nano particles mixture with varying volume fractions	The finest results were found for the PV/PCM configuration of a PV module with a steel tank filled with PCM1 (42–44 paraffin) with a thickness of 2 cm and water cooling, for simple PCM system, temperature drop of **7 K** was achieved.
5	Efficiency improvements of	Inspecting four different PV	Extreme drop (15 °C) in PV-temperature was observed in PV/PCM

	photovoltaic system using latent heat thermal energy storage (Tan, Date et al. 2017)	configurations i.e. finless, 3, 6 & 12 fins-PV/PCM under real outdoor conditions	with 12 fins, with **5.39%** improvement in PV-efficiency. Main reason was maximum PCM contact with metal surface leading to increased PCM melting rate.
6	Enhancing the performance of PV cells using pure and collective phase change materials – experiments and transient energy balance (hachem, abdulhay et al. 2017)	Pure (White petroleum jelly) and combined PCM (white petroleum jelly, copper, and graphite) on the thermal performance and electrical behavior of a PV panel	The electrical efficiency has been increased by an average of 5.8% when using combined PCM.
7	Thermal management of conventional PV panel using PCM with movable shutters–A numerical study (Waqas and Ji 2017)	Voc, Isc are compared in three system	Reduction in PV Temperature of 22 degree Celsius. Efficiency can be improved up to 9% during peak summer season for the PV panel.
8	Refining photovoltaics performance using yellow petroleum jelly as phase change material	2 10W monocrystalline panels with two configurations: one on stand and other on roof.	5.7-degree Celsius reduction in PV operating temperature

CHAPTER 3:
METHODOLOGY

The project under consideration is mostly distributed into three parts: first is the complete software analysis on Solidworks and ANSYS Workbench, second is the design and development of prototype of PV-PCM system and third is the experimental testing after preparing a model to test current, voltage and temperature in Arduino using different sensors and coding. Different thermal management approaches including use of fins and phase change materials were gauged in ANSYS for implementation, testing and choosing of the required more efficient PV fabricated model and a premeditated model, containing Aluminum containment and Paraffin Wax inside it was fabricated.

Upon considering the experimentations and research done previously for advancements in the field, there’s still room for improvement by implementing updated techniques and materials to achieve desired results. Our approach revolves around systematically evaluating the solar panel system, figuring out what possible modifications will lead to improve efficiency. The design setuphas involved achieving the outcome by varying multiple parameters, along with using sensor technology and chemicals (PCMs) for testing. There are certain factors which influence the results.This section covers the testing parameters, design selection and design of data acquisition system.The factors involve are as following:

3.1 SOFTWARE ANALYSIS

3.1.1 SOLID WORKS:

SolidWorks is a solid modelling programme that use a parametric feature-based method developed by PTC to create models and assemblies. The shape or geometry of the model or assembly is determined by the values of parameters. Numeric parameters, such as line lengths or circle diameters, and geometric parameters, such as orthogonal, parallel, concentric, horizontal, vertical, and so on, are examples of parameters.

The way the part's creator holds that it should respond to changes and updates is known as the design purpose. For example, regardless of the level or size of the can, the opening at the highest point of a refreshment can must stay at the top surface. SolidWorks allows the client to designate the opening as a top-surface element, and it will then appreciate their design requirements regardless of what other levels they later assign to the can. The term "features" refers to the part's structural elements. They are the processes and shapes that make up the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as holes, slots, and other similar shapes.

- **SolidWorks Design Models:**

At the first we made the Solar panel and PCM container model on the SolidWorks. In the figure below the solar panel side is shown in the dark greyish color on the bottom side and the PCM container with light grey on the upper side.

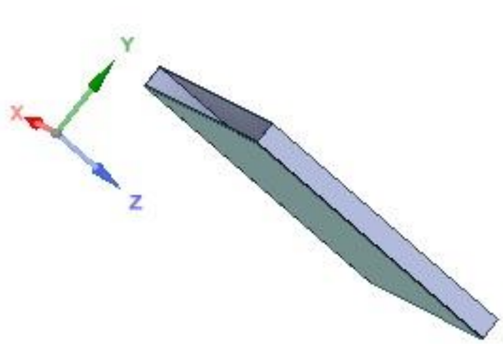


Figure 2: Solar Panel and the PCM Container Model

Then we made the model of the Solar panel with the fins at the back of it in SolidWorks. On the left side, there is a solar panel and on the right side, there are fins as shown in the figure:

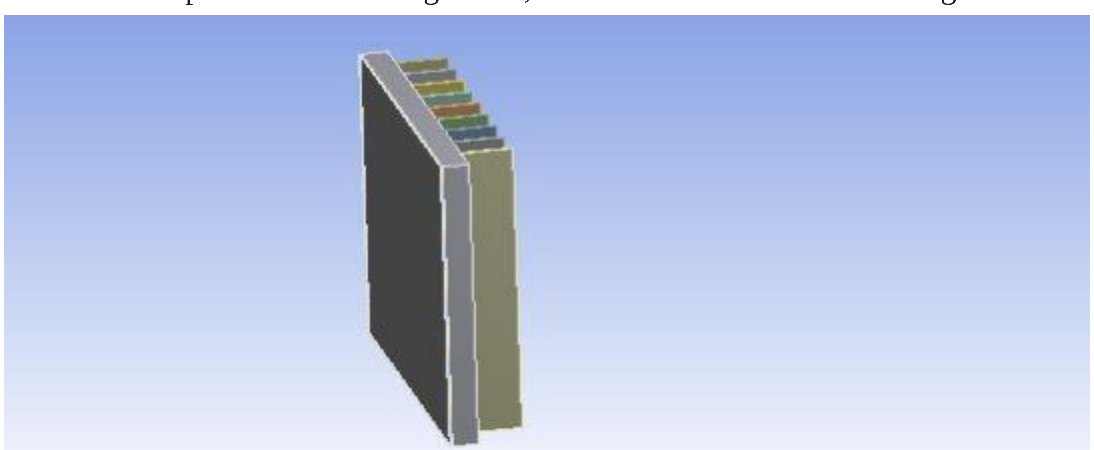


Figure 3: Solar Panel and the fins Design Model

3.1.2 ANSYS WORK BENCH:

The ANSYS Workbench stage allows you to incorporate information across engineering simulations to proficiently make more exact models more. ANSYS Workbench makes it simpler to pursue more educated design decisions by organizing all your reproduction information in one spot. Effectively oversee information across the entirety of your ANSYS items.

ANSYS helps in the different analysis on the different design models. It is very convenient way to analyze the different and complex results using ANSYS. It basically provides a path way to do the software based analysis of different real time models. For example, we can do the steady state analysis as well as the fluent state analysis of the different models just like we did it in our analysis.

1) **Steady State Solar Panel and Fins Model Analysis:**

The Solar panel and the Fins model is a solid 3D model with all the layers and the parts are solid. That's why we can do the Steady State Thermal analysis on it.

So, regarding the Solar Panel we know that we have the six different layers including in it. We added all the six layers to the model and add the thermal conductivities of every layer. These layers include ARC, EVA, Glass, PV Cells, Rear Contact, and Tedler.

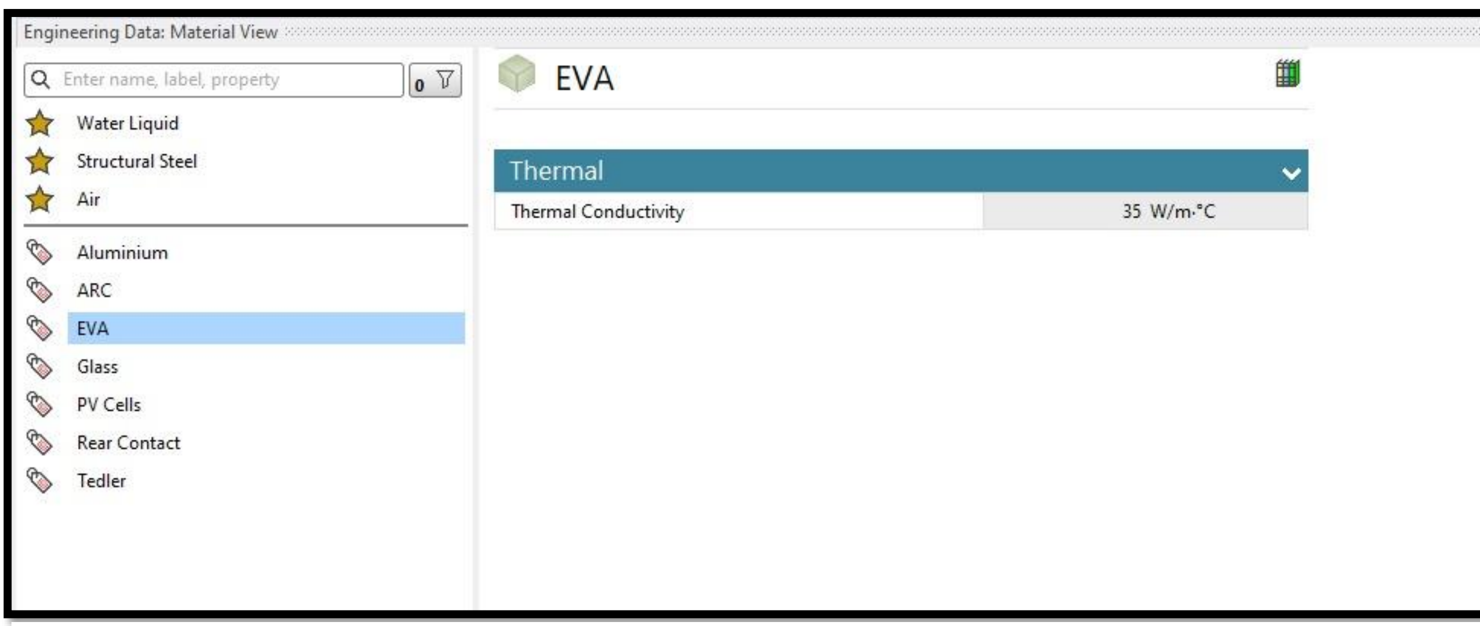


Figure 4: Thermal Conductivity of EVA

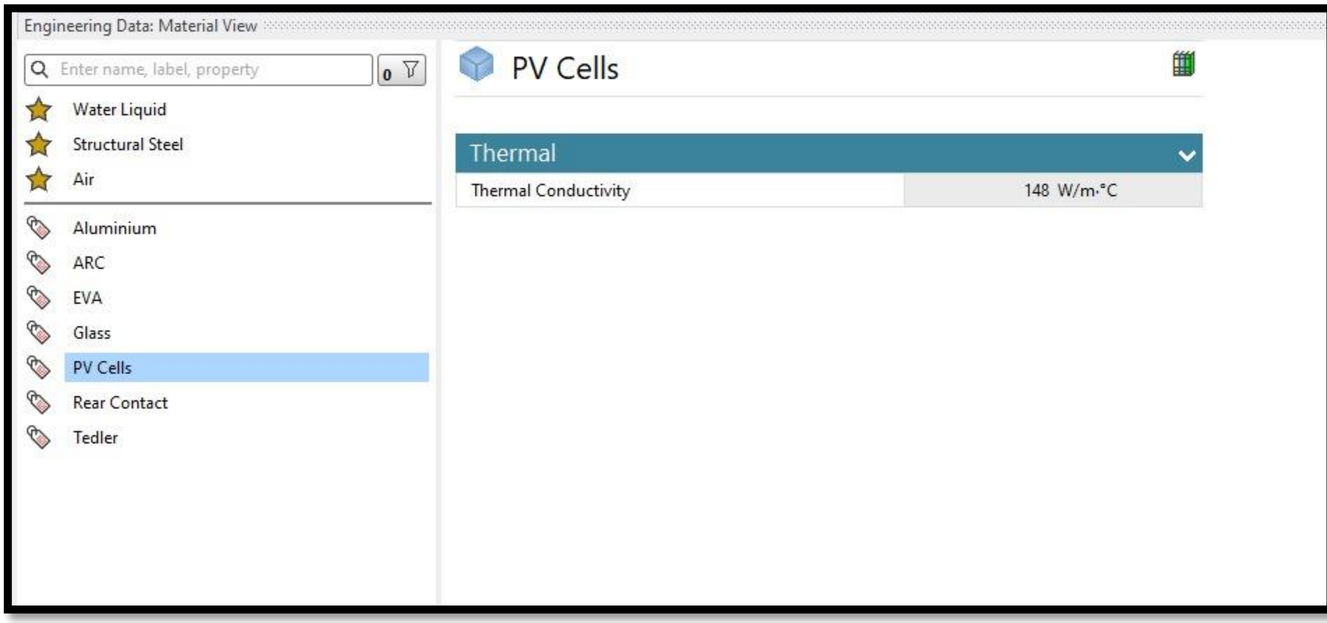


Figure 5: Thermal Conductivity of PV Cells

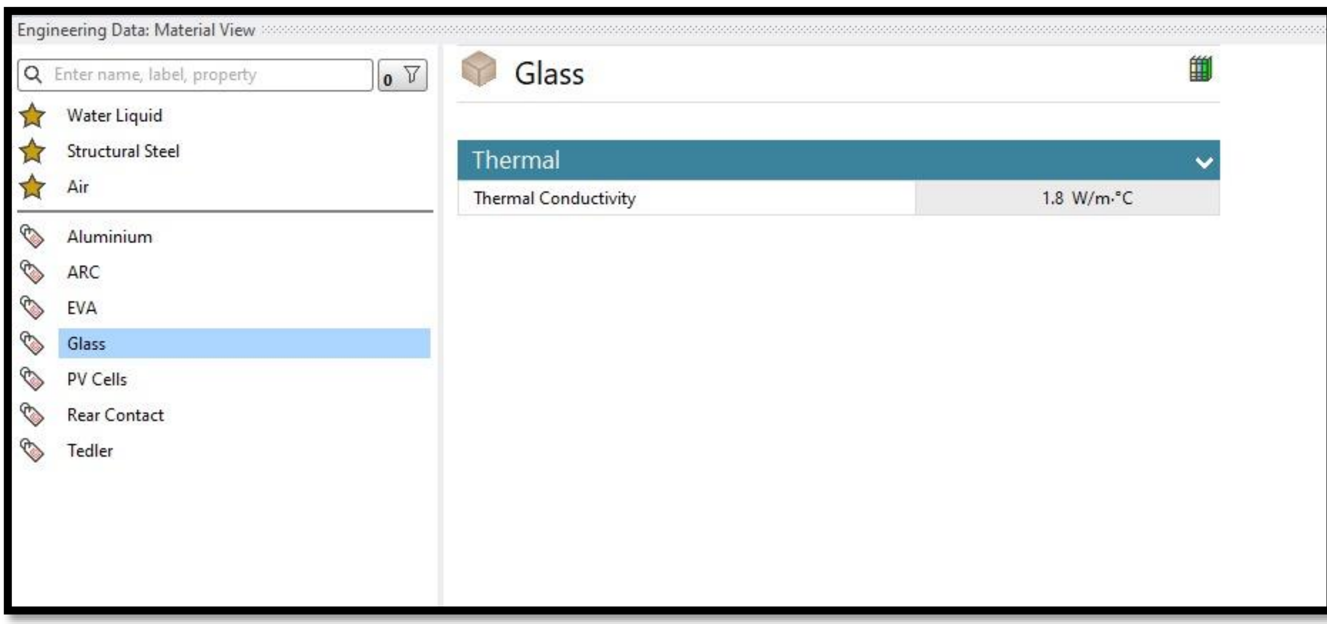


Figure 6: Thermal Conductivity of Glass

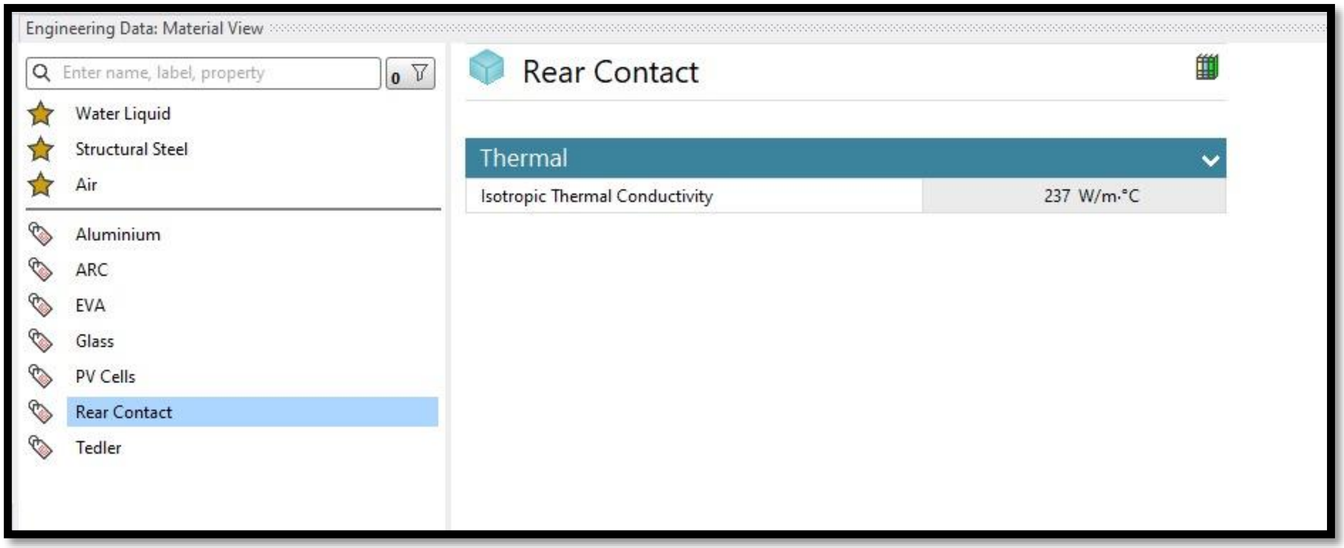


Figure 7: Thermal Conductivity of Rear Contact

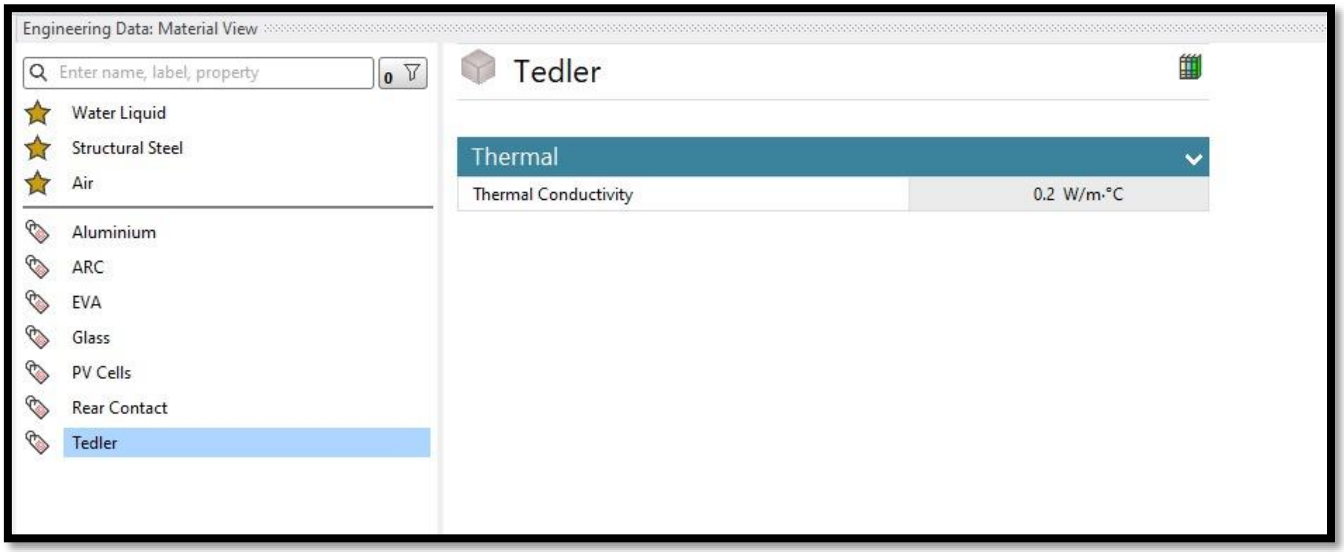


Figure 8: Thermal Conductivity of Tedler

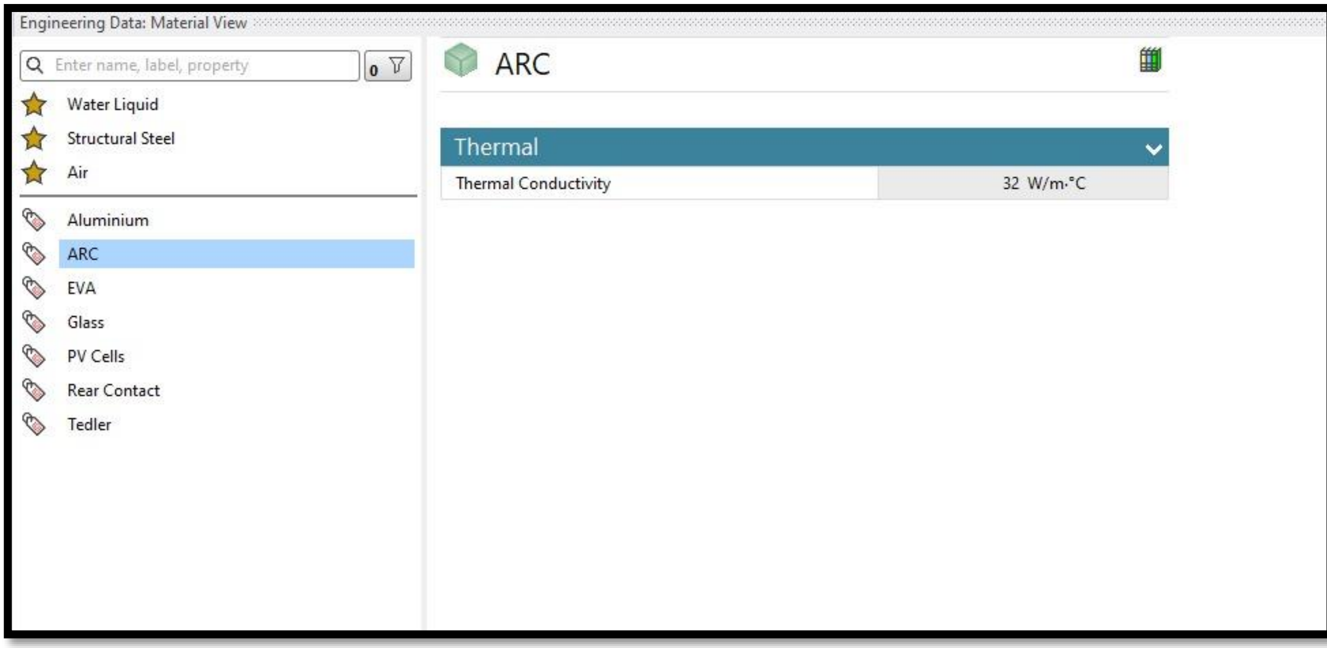


Figure 9: Thermal Conductivity of ARC

The fins are made up of the Aluminum and the heat conductivity of the fins is added as the thermal conductivity of aluminum for the simulation in ANSYS.

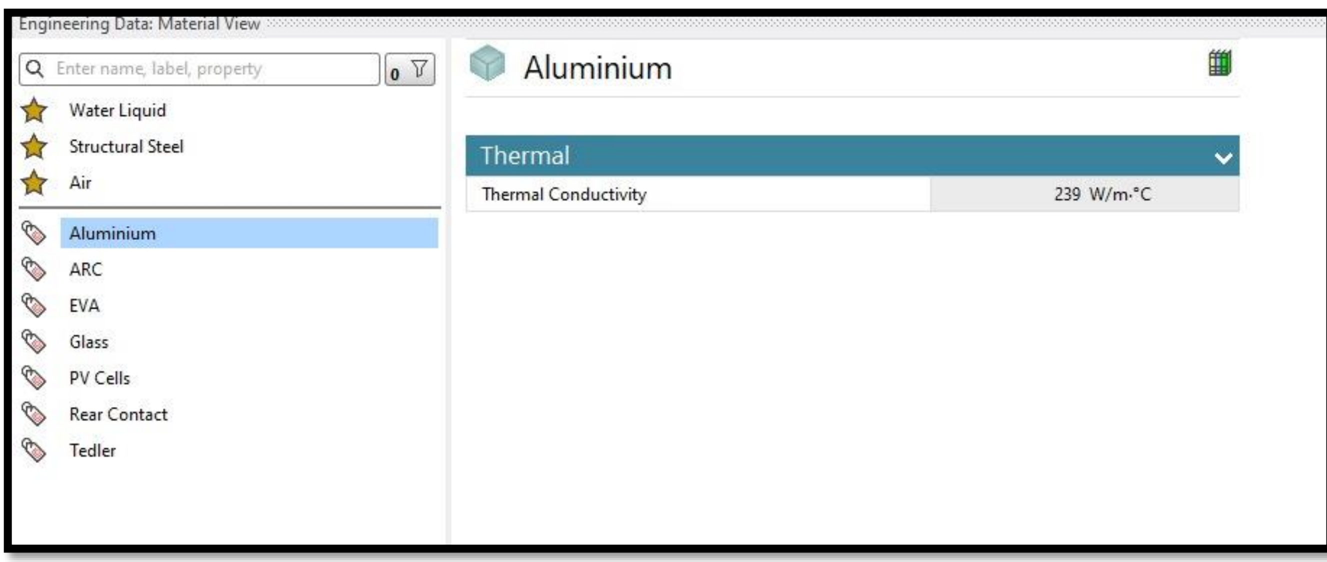


Figure 10: Thermal Conductivity of Aluminum

2) Fluent Flow Analysis on the Solar Panel and PCM Container Model:

As we know that the PCM is a liquid material after absorbing the heat so we cannot do the Steady-State analysis on it. That's why we are using the fluent flow analysis on it. We cannot show the solar panel so we used the boundary conditions for the analysis.

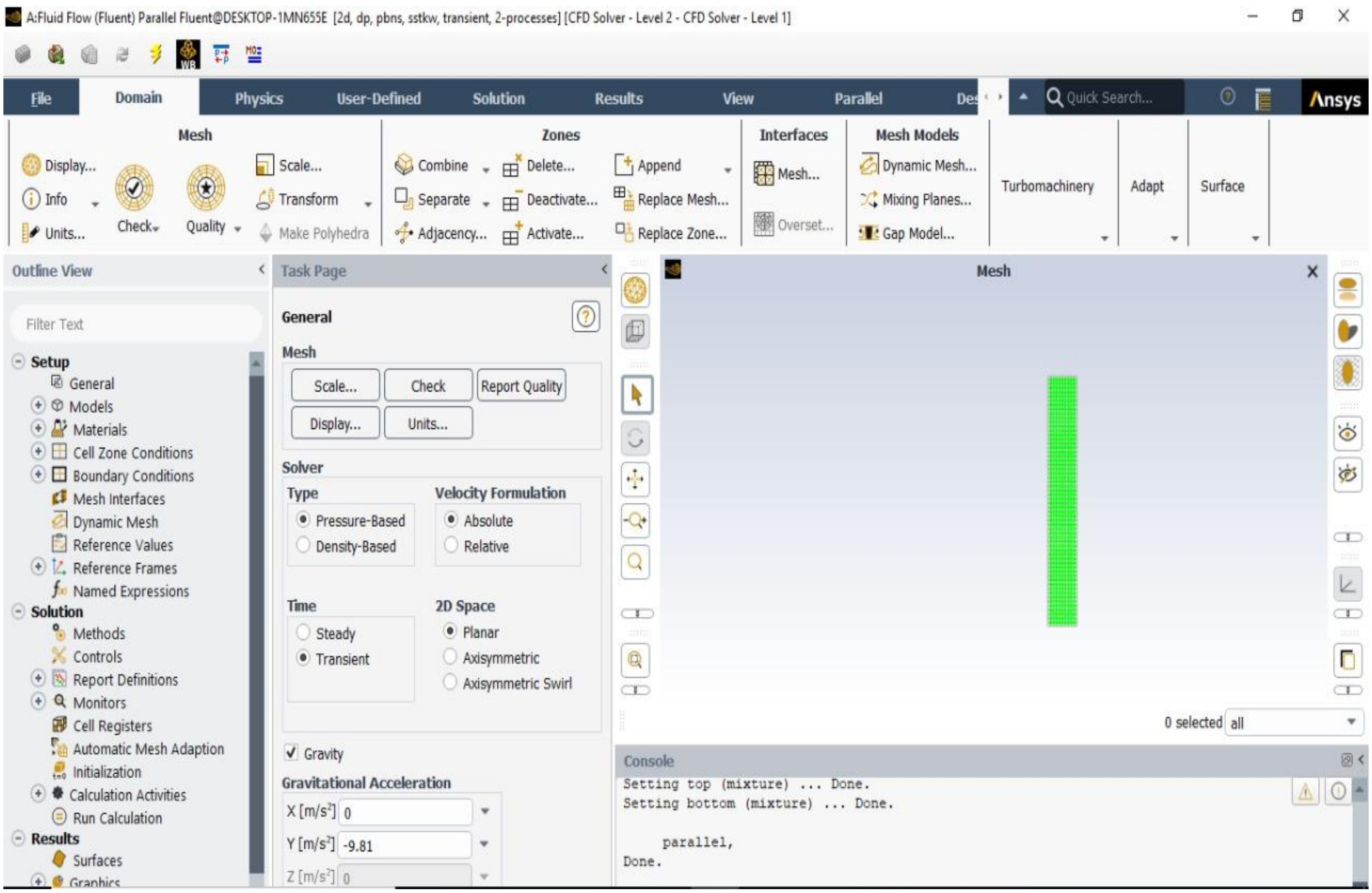
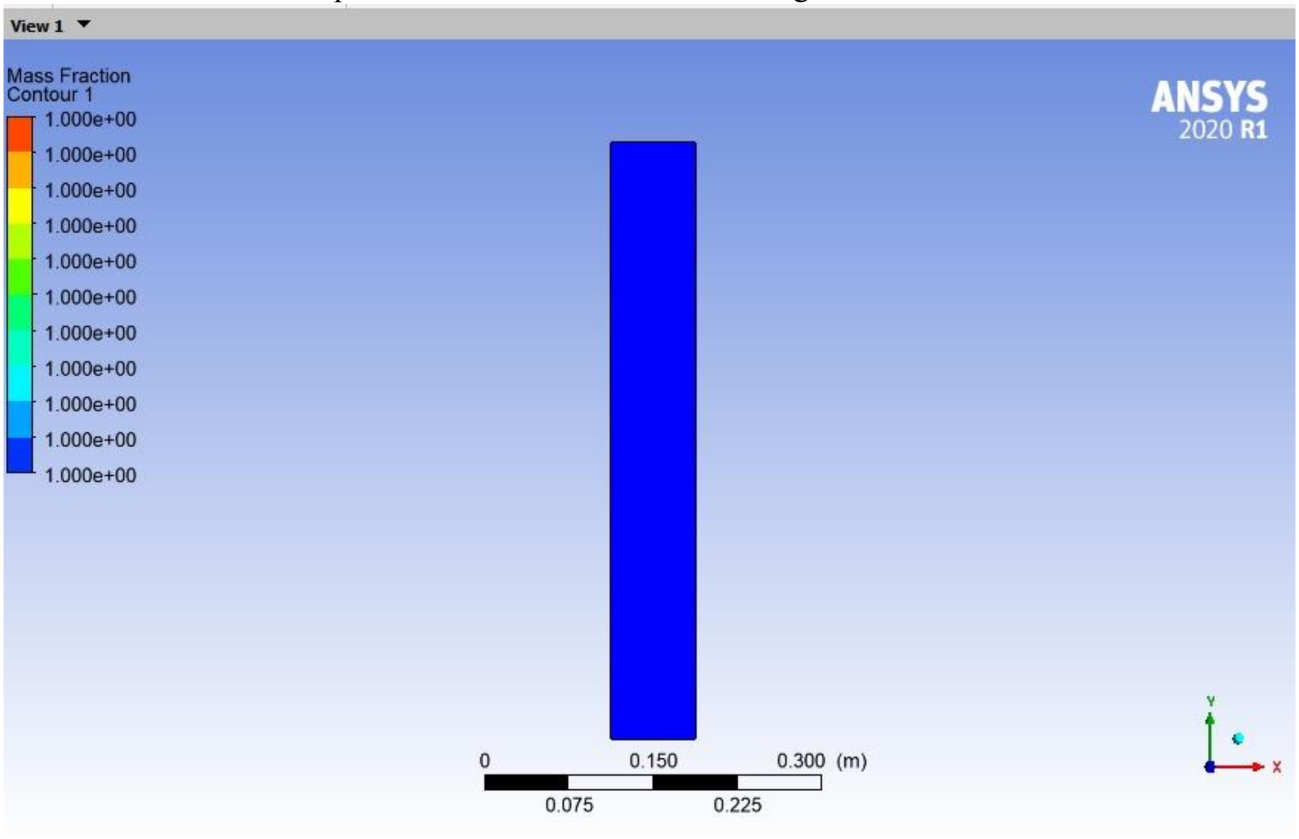


Figure 11: Fluent Flow Analysis of PCM Containment

The results for the PCM thermal analysis at the start when it is solid and at the end when it absorbs heat and melts are shown in the figures below:

Figure 12: Container when PCM is cool

After some time, the solar panel starts raising its temperature due to exposure in the sunlight and PCM behind the solar panel's containment starts absorbing heat which tends to the raise in the



temperature of phase change material and later, it starts to melt. Analysis of PCM's melting and heating phase is shown with different colors in ANSYS depicting the timely change in the temperature of the prototype.

Figure in the next page describes the condition of phase change material when heated for a long time and it later melts while absorbing heat and transferring it to the environment using heat transfer equation:

$$Q = kA(T_s - T_a)$$

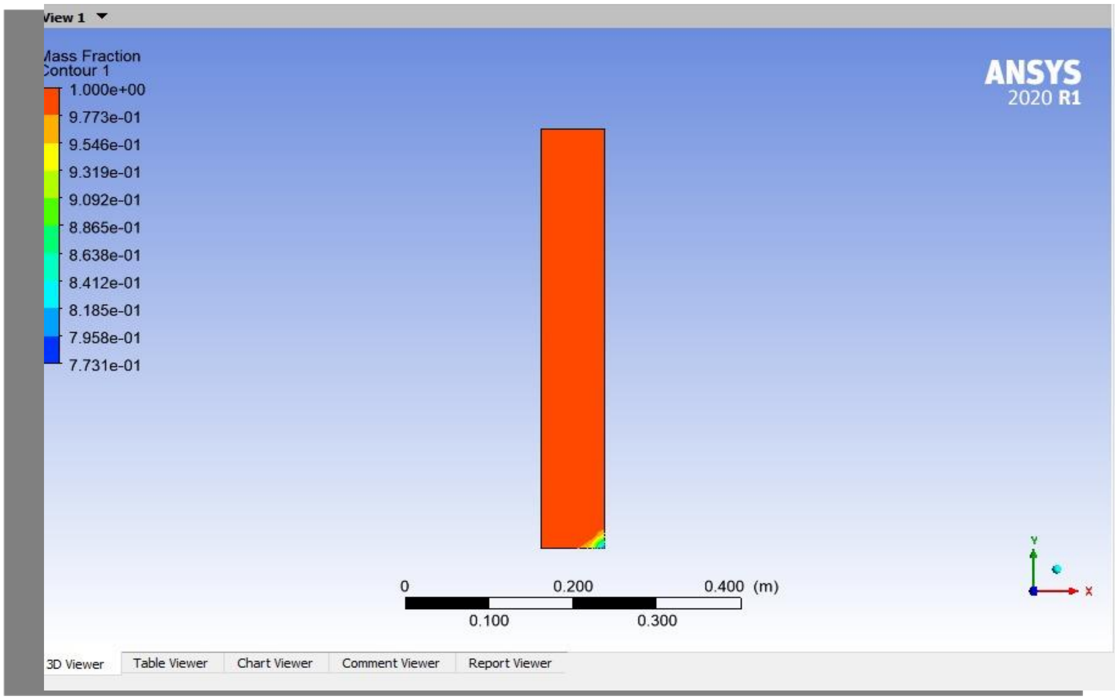


Figure 13: Melted PCM

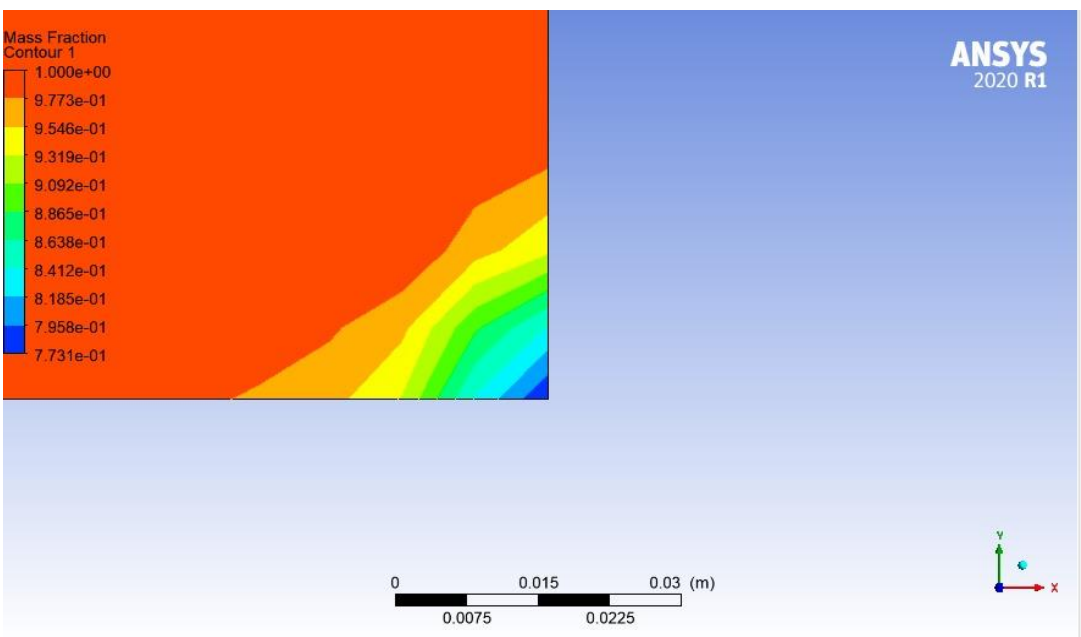


Figure 14: Zoom-in View of melted PCM

The above figure shows the zoomed-in view when the Phase Change Material is melted after absorbing the heat from the solar panel and there is some of the PCM that is left un-melted which is shown with different shades of colors.

PCM Properties:

The properties of the PCM are shown below in the following figures:

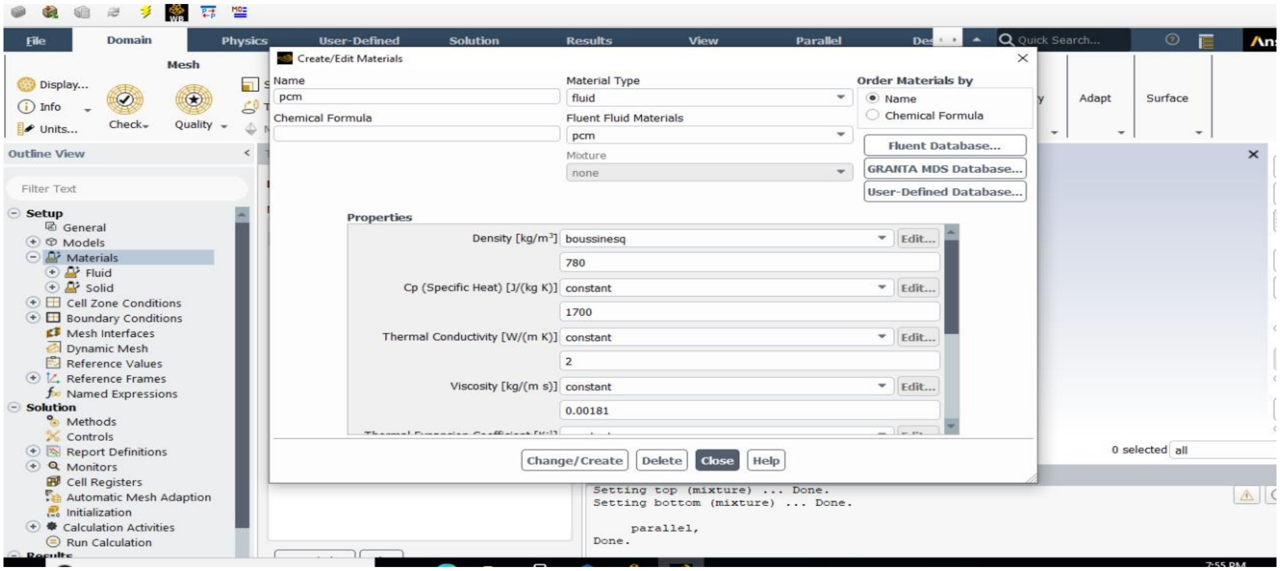


Figure 15: Properties of PCM (1)

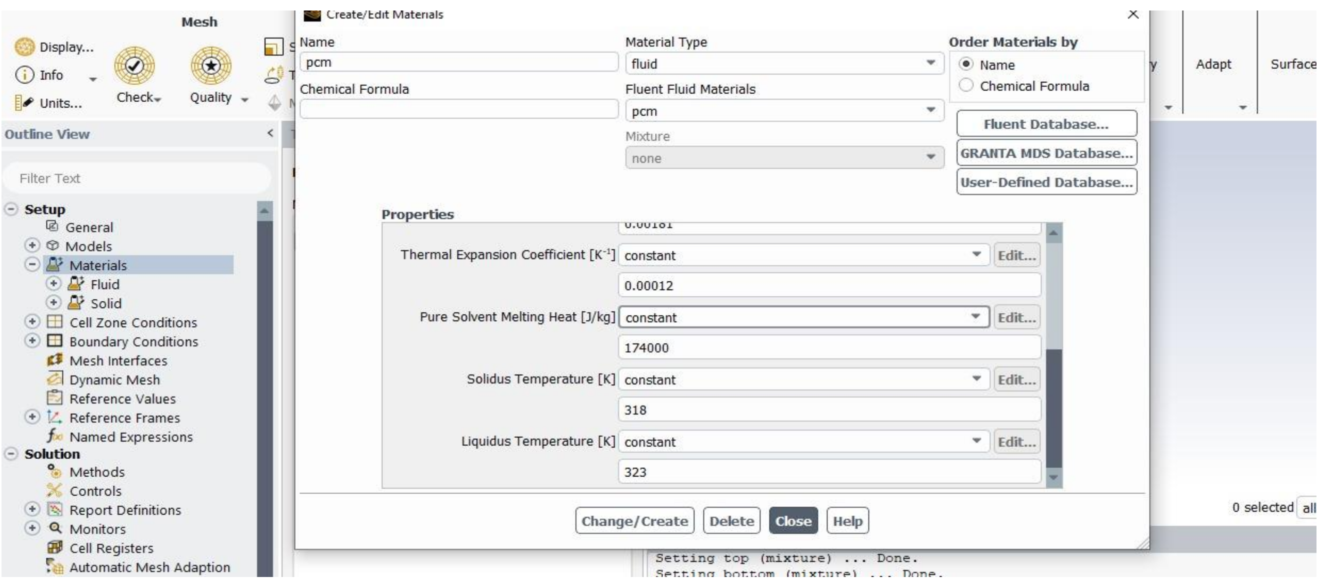


Figure 16: Properties of PCM (2)

Boundary Conditions:

The boundary conditions for the solar panel and the container side are the following:

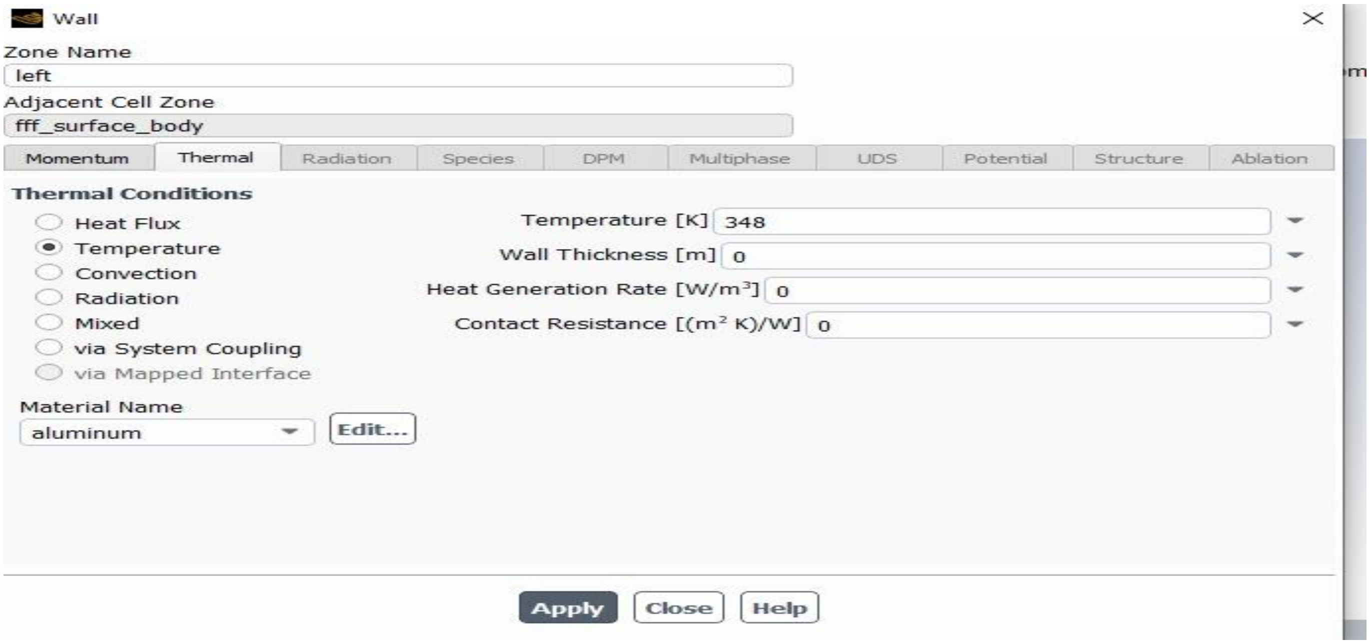


Figure 17: Boundary Conditions on Left of the Model

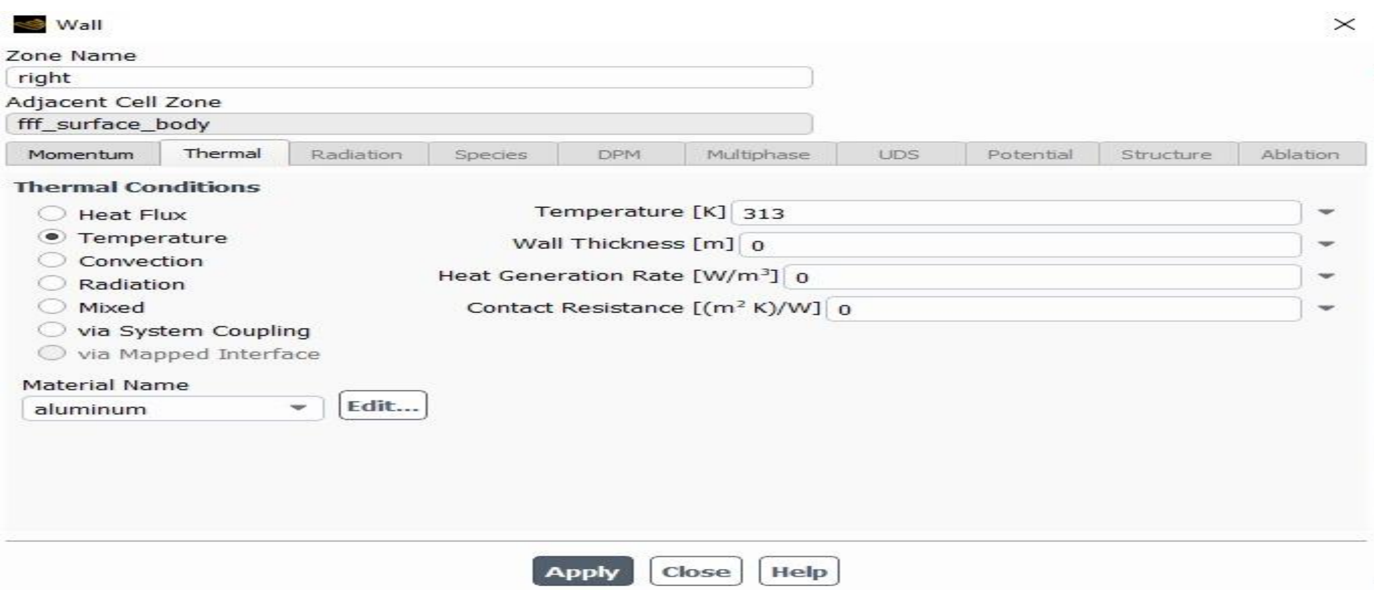


Figure 18: Boundary Conditions on Right of the Model

3.1.3 ARDUINO IDE:

The Arduino Integrated Development Environment (IDE), also known as the Arduino Software (IDE), includes a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and a series of menus. It connects to Arduino equipment to transfer and communicate with programming.

Sketches are programmes created with the Arduino Software (IDE). These sketches are saved with the ".ino" file extension and written with a text editor. Highlights for cutting/pasting and searching/replacing text are available in the editor. The message section provides input for storing and exporting, as well as displaying errors. The Arduino Software (IDE) produces text at the console, which includes complete error warnings and other data.

We designed a model to measure current, voltage and temperature of the conventional and fabricated panel in order to determine differences in the efficiencies, power and temperature of the panels and to calculate the differences in the efficiency within the time constraint.

<u>Apparatus used</u>

The apparatus used were:

- **Arduino Nano:**

Based on the ATmega328, the Arduino Nano is a compact, comprehensive, and breadboard-friendly board (Arduino Nano 3.x). It only has a DC power jack and uses a Mini-B USB cable rather than a standard one. It can be employed in sensor collection and portable electronics.

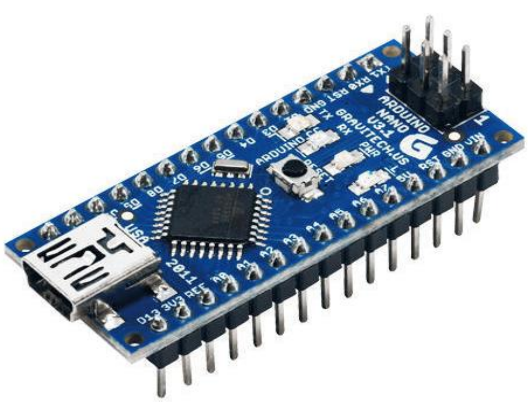


Figure 19: Arduino Nano

- **Thermistor 10K for temperature sensing:**

The term "thermistors" comes from the term "thermally sensitive resistors," and they are an extremely accurate and cost-effective temperature sensor. The NTC (negative temperature coefficient) thermistor is the most widely used to measure temperature. It comes in two types: NTC (negative temperature coefficient) and PTC (positive temperature coefficient).

Figure 20: Thermistor 10K for temp sensing

- **Voltage Divider Sensor for voltage measurement:**

A voltage divider is an ordinary circuitry system that converts **a high voltage to a lower voltage**. We can produce an output that is a portion of the input voltage with just two series resistors and an input voltage. One of the most fundamental circuits in electronics is the voltage divider.

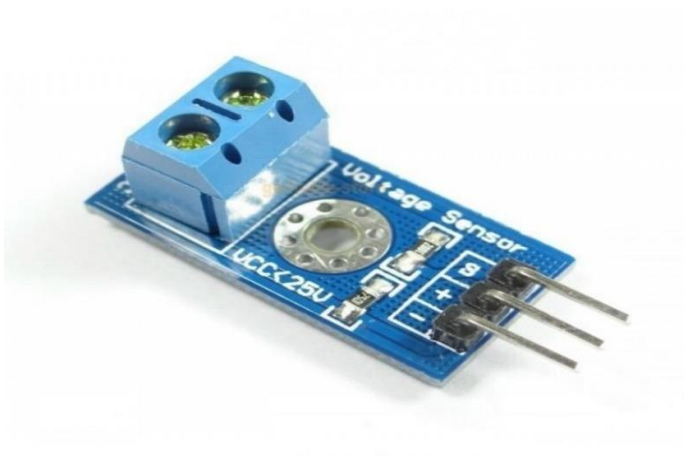


Figure 21: Voltage Divider for Voltage measurement

- **Vero board:**

The Vero board is a simple PCB with a lot of copper dots and little holes on it. Circuits can be built by soldering components to Vero boards. Data is routed in the layout's preferred direction using wires. This wiring board can be used for basic electronic control research, prototype design for bench testing, or small-scale electronic equipment fabrication.

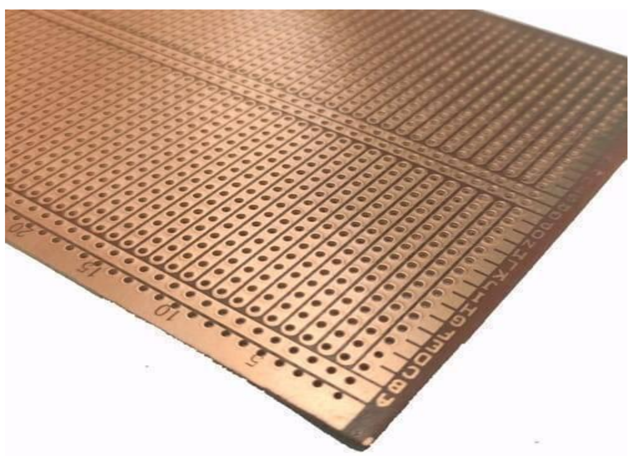


Figure 22: Veroboard for electronic setup fabrication

- **ACS 712 Current Sensor (5amp)**

The ACS712 is a current sensor that can be used in both AC and DC. This sensor is powered by 5 volts and produces an analogue voltage proportional to the current it detects. This device is made up of a group of precise Hall sensors with copper lines.

Figure 23: ACS 712 for Current measurement

- **LCD (16*2)**

On two lines, a 16x2 LCD can display 16 characters per line. Each character is displayed on this LCD using a 5x7 pixel matrix. The 16 x 2 intelligent alphanumeric dot matrix display can display 224 different characters and symbols. The two registers on this LCD are Command and Data.

Figure 24: LCD (16*2) for display of results

- **Jumper wires**

Jumper wires are used to connect two points in a circuit. All Electronics sells jumper wire in a variety of lengths and assortments. Frequently used with breadboards and other prototyping tools to make it easy to update a circuit as needed.

Figure 25: Jumper wires to connect circuitry

- **SD Card Module**

The SD Card Module is a breakout board for microcontrollers that allows them to read and write SD cards. The board is Arduino and other microcontroller systems compatible.

Figure 26: SD Card Module to store results

Coding was done in Arduino IDE to build a setup for temperature, current and voltage measurement in order to differentiate between the results of the panels and their efficiencies. Picture below portray the complete code that was run in the Arduino based hardware setup:

solar_temp_volt_curr | Arduino 1.8.19

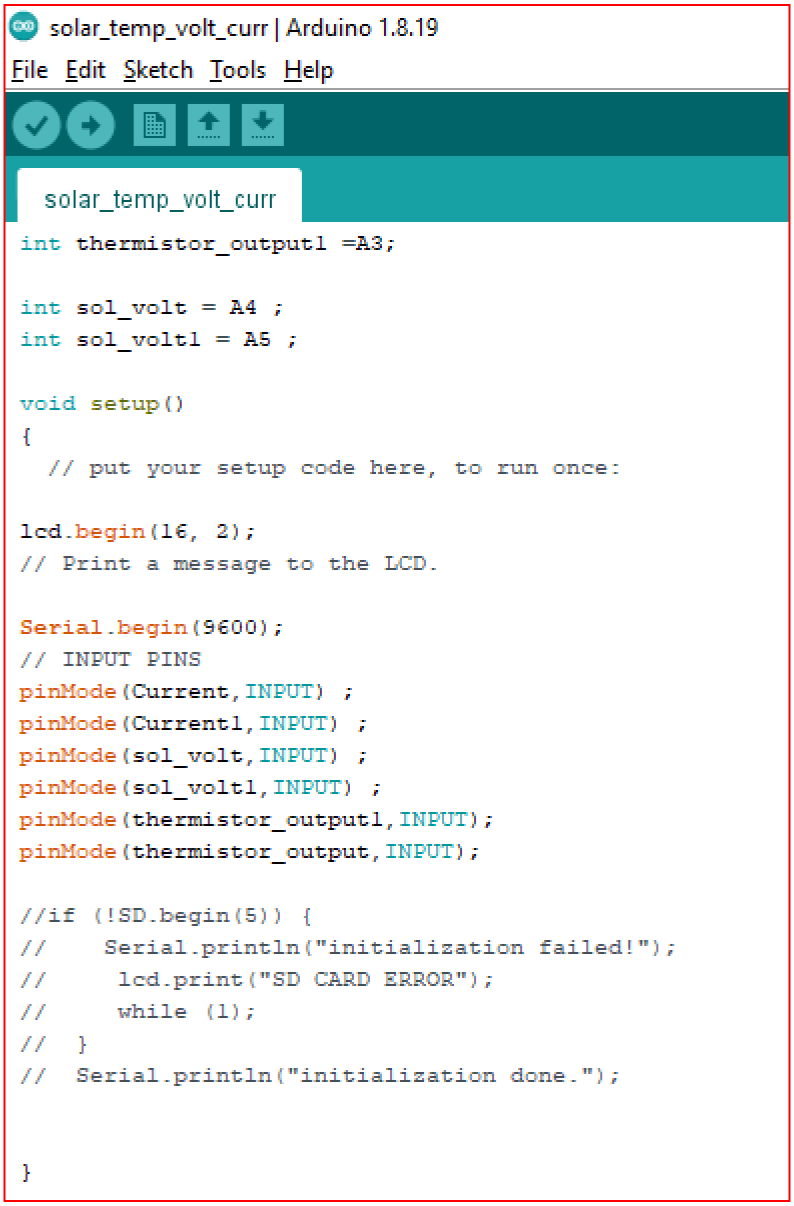
File Edit Sketch Tools Help

Verify

solar_temp_volt_curr

```
// include the library code:
#include <LiquidCrystal.h>

// initialize the library by associating any needed LCD interface pin
// with the arduino pin number it is connected to
const int rs = 2, en = 4, d4 = 9, d5 = 10, d6 = 7, d7 = 8;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

const int Current  =A0;
const int Current1 =A1;
#include <SPI.h>
#include <SD.h>

int counter = 0;

File myFile;

#include <math.h>
const int thermistor_output = A2;

float battery_volt,avgvolt,read_volt,volt,volt1,avg_volt,volt3,old_amps,read_bat = 0;
float volt11=0;
int mVperAmp = 185 ; // use 100 for 20A Module and 66 for 30A Module
int RawValue,RawValue1= 0 ;
int ACSoffset = 2500 ;
double MV,MV1 = 0 ;
double Amps,Amps1 = 0;
double amps,amps1 = 0;
```

Figure 27: Arduino Coding to measure Current, Temperature and Voltage of PV Panel (1)




```
int thermistor_output1 =A3;

int sol_volt = A4 ;
int sol_volt1 = A5 ;

void setup()
{
  // put your setup code here, to run once:

lcd.begin(16, 2);
// Print a message to the LCD.

Serial.begin(9600);
// INPUT PINS
pinMode(Current,INPUT) ;
pinMode(Current1,INPUT) ;
pinMode(sol_volt,INPUT) ;
pinMode(sol_volt1,INPUT) ;
pinMode(thermistor_output1,INPUT);
pinMode(thermistor_output,INPUT);

//if (!SD.begin(5)) {
//    Serial.println("initialization failed!");
//     lcd.print("SD CARD ERROR");
//     while (1);
//  }
//  Serial.println("initialization done.");


}
```

Figure 28: Arduino Coding to measure Current, Temperature and Voltage of PV Panel (2)

solar_temp_volt_curr §

```
    myFile.print("V1");myFile.println(avg_volt);
    myFile.print("V2");myFile.println(avg_volt1);

    myFile.print("I1");myFile.println(final_amps);
    myFile.print("I2");myFile.println(final_amps1);

    myFile.print("T1");myFile.println(temperature);
    myFile.print("T2");myFile.println(temperature1);

    myFile.println("-------------------------------------");

    // close the file:
    myFile.close();
    Serial.println("done.");
  }
  else
  {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
  }
  counter = 100; // timing setting for sd card saving
  }
  counter = counter-1;
  volt1 = 0;
  volt11 = 0;
  avg_volt = 0;volt =0;
  amps = 0 ;amps1 = 0;
  final_amps,final_amps1 = 0;
  delay(2000);lcd.clear();
}
```

Figure 29: Arduino Coding to measure Current, Temperature and Voltage of PV Panel (3)

Final Picture of the Arduino setup made

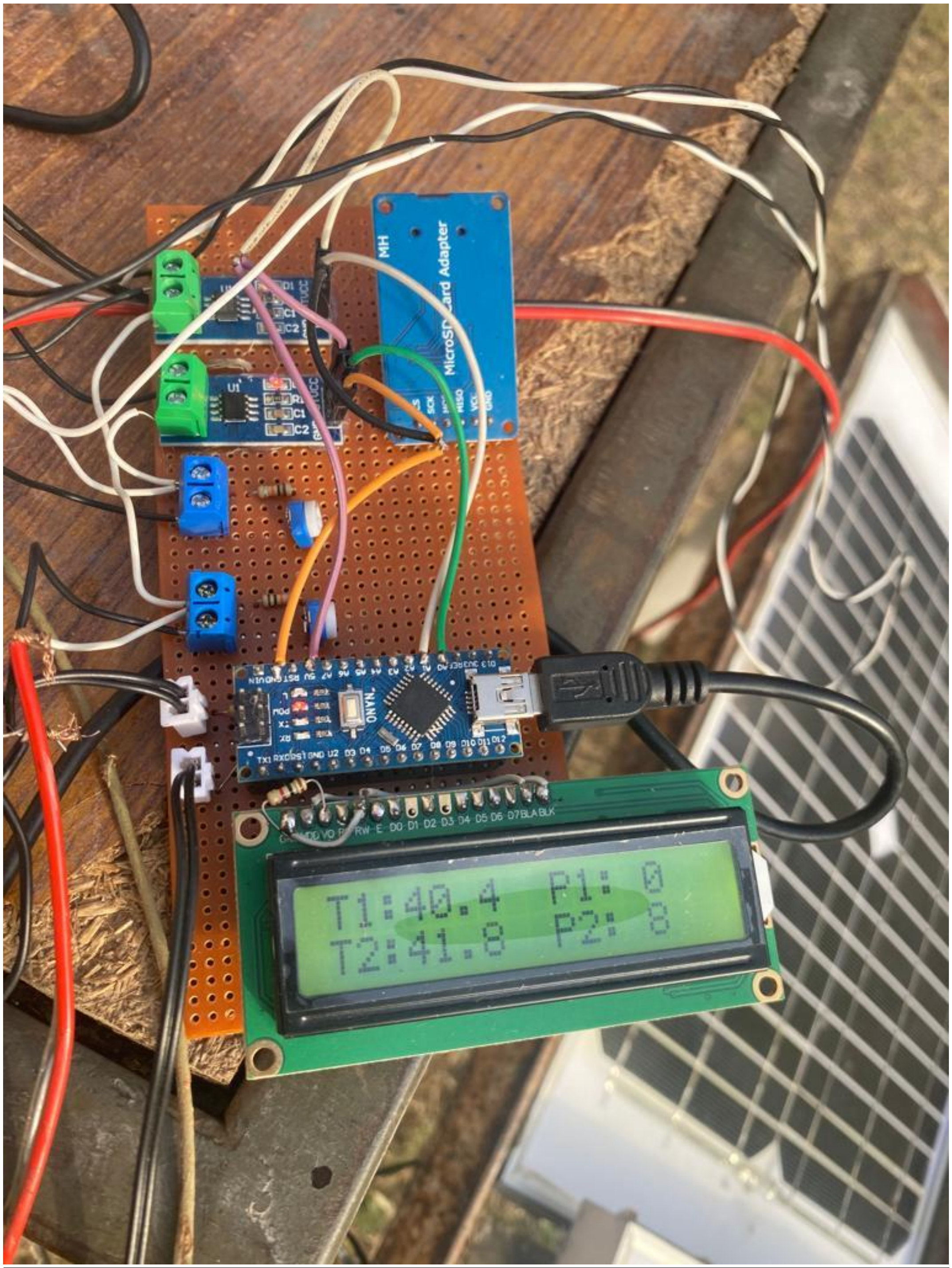


Figure 30: Final Image of Arduino Setup

3.2 DESIGN AND DEVELOPMENT OF FABRICATED MODEL

3.2.1 PV PANELS SELECTION:

The 30W solar panels was used for testing which can then be replicated on a bigger panel. Testing was conducted under the direct sunlight. However, due to changing weather conditions the results to be achieved were a bit inconsistent to some extent. Moreover, we set the panel at a proper varying angle stand to attain the precise results and vary the position as required. The angles can be set at 15, 20, 25, 30 and 45 degrees for convenient positioning of the panel such that it may work more efficiently by absorbing most of the light from the sun. However, complete testing has been done for an angle of inclination of 30 degrees with the horizontal during the fabrication phase.

3.2.2 EXPERIMENTAL SET UP:

A complete setup was installed to initiate the testing phase which consisted of mainly electrical equipment including Arduino, sensors, data logger (SD card Module), digital multimeter, angular stand to hold panel, jumper wires and 2amp fan to provide load to panels in order to measure current were used. The modified panel and general PV panel were tested simultaneously so the deviation can be evaluated as both were subjected to similar direct normal irradiance (DNI). The direct dependence of performance on DNI also impacts other parameters such as temperature, humidity and PCM heat absorption rate. The experimental collected data was further used to calculate the system's efficiency by comparing the performance of both panels.

The panel designs were based on multiple factors such as:

- Material availability
- Material characteristics
- Heat transfer rate
- Types of PCMs being used.

3.2.3 MATERIAL SELECTION:

Among a range of materials, the material selection involves several factors to be considered. Initially, the thermal conductivity co-efficient (k) plays a vital role as considerably high "k" is required such that additional temperature from the panel may escape to the surroundings.

The heat transfer rate is given by:

$$Q = kA(T_s - T_a)$$

Where T_s is system temperature and T_a is temperature of the atmosphere.

Few potential materials that can be considered are as follows:

Table 2: Potential Materials

SUBSTANCE	**THERMAL CONDUCTIVITY OF SUBSTANCE (W/m.k)**
Copper	401
Aluminum	250
Steel	50.2
Brass	109

Being easily accessible in the market, these materials we considered for use and we chose Aluminum for our fabricated containment. Copper was not used because of its very high thermal conductivity as it can damage the panel. Other major constraint that are needed to be taken under consideration are

- Material availability.
- Cost effectiveness.

Since we need to ensure the usage of end-product as a better version thus, low-cost manufacturing is required. For that purpose, we selected aluminum as it has high conductivity along with low cost as compared to others.

3.2.4 THERMAL MANAGEMENT:

Different methods of thermal management techniques are employed by researchers to improve power and efficiency of solar cell. These methods include phase change materials, water & air cooling, and usage of fins etc. Before applying any of the following techniques, a steady state thermal analysis will be performed which will show the temperature variation at different parts of the panel under variable solar irradiance as it varies day to day.

The most effective technique hence to be deployed is the usage of PCM for maintaining the temperature of solar panel through effective heat absorption. The phase change materials exhibit great latent heat of fusion per unit volume, more specific heat, density, and more thermal conductivity. Thus, being the perfect selection for achieving the desired results. There are certain potential PCMs selected based upon their melting temperature. However, the selection is restricted to paraffin wax due to unavailability of the other PCMs in the market.

3.2.5 DESIGN SELECTION:

The design consists of a container which is attached with the back of the solar panel and has a cavity for the containment of PCM. An aluminum sheet will be used since the thermal conductivity is higher ascompared to other materials. That is our prime purpose to release the heat in the atmosphere such that the panel temperature doesn't exceed a limit where it compromises its output. The heat transfer rate is given by:

$\boldsymbol{Qgen}$ is the total light energy available to solar cell which is converted into heat.

$Qgen = Irradiance * surface\ area\ of\ cell * efficieny\ of\ cell$

$\boldsymbol{Qres}$ is the rest of the heat which remains in solar cell after some of its heat energy has been removed by PCM.

$Q_{res} = h * A * \Delta T * (T_{cell} - T_{atm})$

The figure describes the proposed design of the modified solar panel with Aluminum containment where Phase change Material will be used.

Proposed Design of Modified Solar Panel with Aluminum containment:

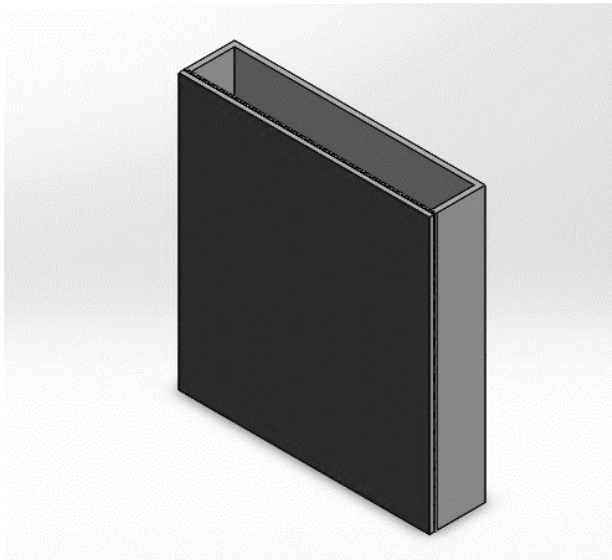


Figure 31: Front Isometric views of PCM container design showing Solar Panel

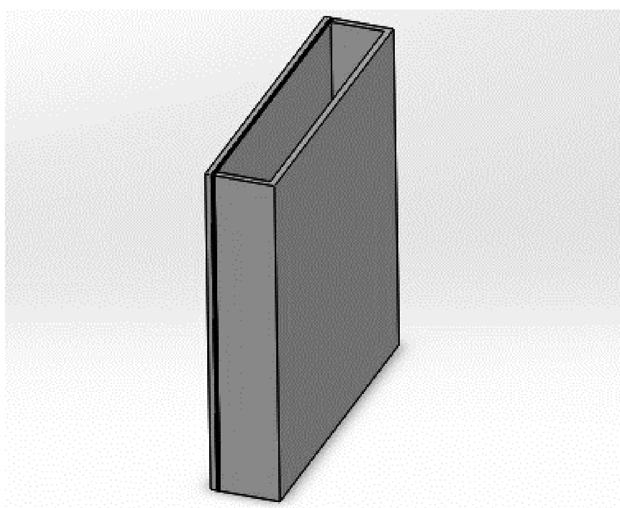


Figure 32: Rear Isometric views of PCM container design showing Aluminum Container

3.2.6 PERFORMANCE PARAMETERS:

Mentioned below are the measured parameters that were used to test the performance of the selected designs.

1. ***Temperature***

Panel's temperature at both the back and front sides were continuously monitored throughout the test to check for the temperature reduction that were achieved against the designs. Temperature was measured using the temperature sensor DS18B20 and thermistor 10k as well.

Similarly, ambient temperature was also be kept in check because different months have different peaks of temperature with higher peaks are expected to be observed at the end of May and start of June. The data for ambient temperature for the day of testing was taken at the moment of testing.

2. ***Short Circuit Current***

The amount of current that flows from the solar cell with zero potential across it which means that solar cell is short circuited, this is known as Short Circuit Current. Since there is no expected potential drop across the circuit, the value of current obtained will potentially the maximum value of current that is obtainable from the solar cell keeping the irradiance constant. The current will be measured using an ACS 712 Current Sensor.

3. ***Open Circuit Voltage***

The extreme value of voltage that is obtained from the PV cell in an open circuit (no current is flowing through the circuit) is called Open Circuit Voltage. It is potentially the extreme value that can be obtained from the solar panel keeping the irradiance constant. It will also be measured using an Arduino Voltage Divider Sensor (25V).

4. ***Maximum Power***

The maximum amount of power that can be obtained from a solar cell under specific set of conditions is the maximum power for that solar cell.

$$P_m = FF(I_{sc})(V_{oc})$$

5. ***Efficiency***

The ratio of extreme power generated by the solar cell at the output to the total irradiance power incident upon the solar cell is the efficiency for that solar panel.

$$\text{Efficiency} = \frac{\text{P}_{\text{out}}}{\text{P}_{\text{in}}} \qquad = \frac{\text{P}_{\text{max}}}{(\text{Solar intensity}) \times (\text{Panel Area})}$$

3.3 EXPERIMENTAL TESTING

The last process for the FYP was conducted on the start of June where the fabricated model was used for experimental testing and to check efficiency enhancement of the PV Panels with the help of Phase Change Material containment which includes Paraffin Wax within the aluminum containment.

Figure 33: Overall Experimental Setup

CHAPTER 4
RESULTS AND DISCUSSIONS

Two designs were analyzed during the software analysis in this project which includes fins model and the phase-change material containment arrangement. Based on temperature variations with time and the data provided above, PCM containment model resulted more efficient and supportive with the solar panels than the Fins with the solar panel model. Using container design and ANSYS simulations, we were able to achieve a maximum power increase of approx. 20-25% and a maximum efficiency increase of 2-5%. Another important development that can be pursued in this course is the use of composite PCMs that can be utilized in the container due to their increased thermal conductivity. As we use the composites of the PCMs with variation in the melting points and thermal conductivities so it will take time to melt because of the varying melting points and help to increase the power and enhance the thermal efficiency.

The PCMs being used should have two different melting point which will affect in the melting of the second PCM after the first has almost finished melting thus offering heat absorption at a much wider range of temperature. This process needs proper types of the phase-change materials for the work to be done. We have not used this method because it is very expensive and. Also, the addition of Nano particles in PCMs can greatly help enhance their conductivity. Further fabrication will be done on containment design and actual efficiencies and power increase based on differences in temperature as compared to conventional panel will be studied.

For the Fabrication purposes of the PCM containment and PV solar panel we have visited the market and keeping in mind the software analysis work. The PCM we chose for this purpose is the paraffin wax because of its good thermal conductivity and the cheap price and easy availability in the market. The paraffin wax is very good for this project considering the cost effectiveness and material stability as well. However, RT-25 is also very good but due to its unavailability in the market we are not using it for our project. It is just available in Germany and due to the high costs and shipment charges, we are not using it. Because we want to make a cheap and easily available project. This is also our focus in this regard.

The metal we are using for the PCM containment is the aluminum. The purpose why we are using the aluminum containment lies in the fact that it is a good thermal conductor and also it is very cheap as compared to the other metals in the market. However, copper is a very good conductor but we are not using it because of the many reasons it contains. Some of the reasons lies in that copper is that it is very expensive and due to its high thermal conductivity it may harm the solar cells. So, instead of getting benefit from the attachment we will get our solar panels damage because of the excessive heat we got from the copper containment. That is the reason why we are choosing aluminum for our project.

Another thing to discuss in the very end is the solar panel we are using for our project. As we visited market so there are two types of solar panels available in the market. One is the polyatomic and the other is the monoatomic. We are using the monoatomic PV panels because polyatomic solar panels do not work without the sunlight but the monoatomic solar panels can work in the shadow with lesser light as well. So we are using a 30 KW PV solar panel because it is suitable for our project and it is even a presentable panel. There are also very small and very large PV solar panels available in the market but we are using a standard size for fulfilling the project requirements. Relative results will be presented, showing comparison of improvement of a parameter relative to that of a normal PV panel.

We will discuss mainly the decrement of panel temperature using passive cooling techniques and its subsequent effect on the maximum power output and efficiency of the panel.

4.1 TEMPERATURE

During peak times, the passive cooling techniques used on the PV panels were successful in lowering the panel's temperature. The temperatures were recorded using a DS18B20 water-proof temperature sensor connected to the front and rear surfaces of the PV panel and an Arduino microcontroller that logged the data every six minutes during the testing period.

A comparison of the temperatures on the front of three panels is shown in figure below, for the testing period from 1000 to 1800 hrs. Lines for temperature of normal panel and one thermally managed panels along with the ambient temperature is shown by different colors. Further detailed data is given in Appendix I.

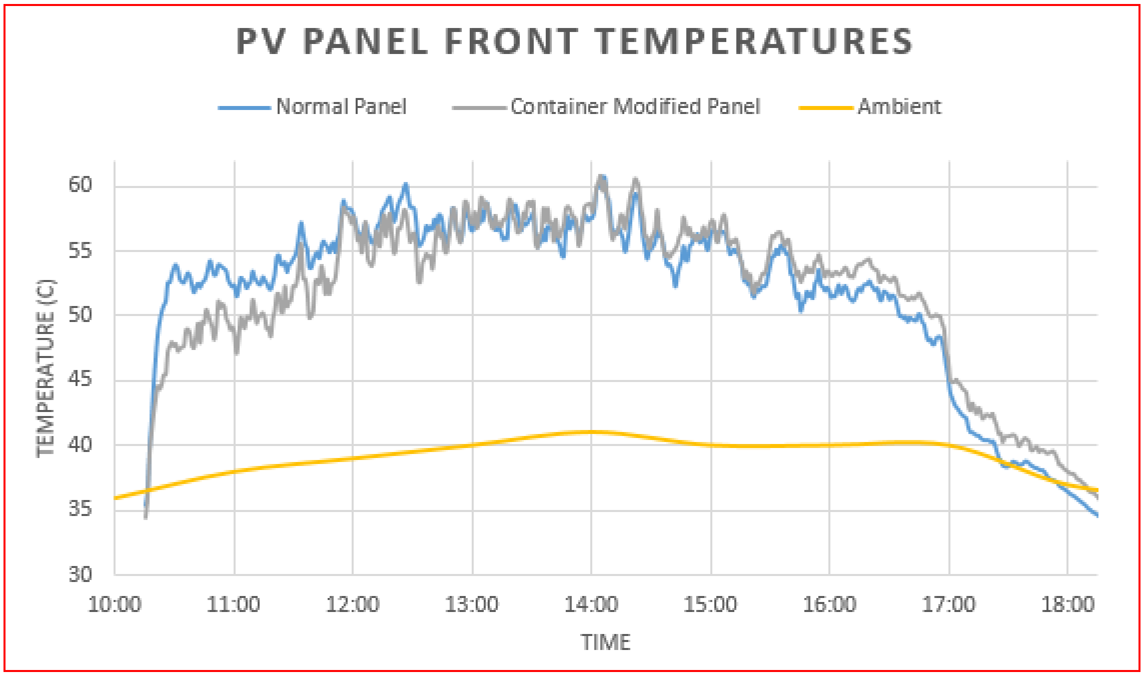


Figure 34: PV Panel Front Temperatures

When compared to a normal panel, the container modification to the PV panel achieved a maximum temperature drop of 6.5°C during the start and maintained an appreciable difference until 1300 hrs. The PCM has completely melted at this point. After that, its temperature equaled that of the normal panel, and later, around 1530 hrs, it became slightly hotter than the normal panel until the end, because the PCM will take longer to dissipate the heat it had absorbed. During peak periods of operation, the PCM container works as an excellent heat sink.

A comparison of the temperatures on the back of two panels is shown in figure below, for a similar testing period.

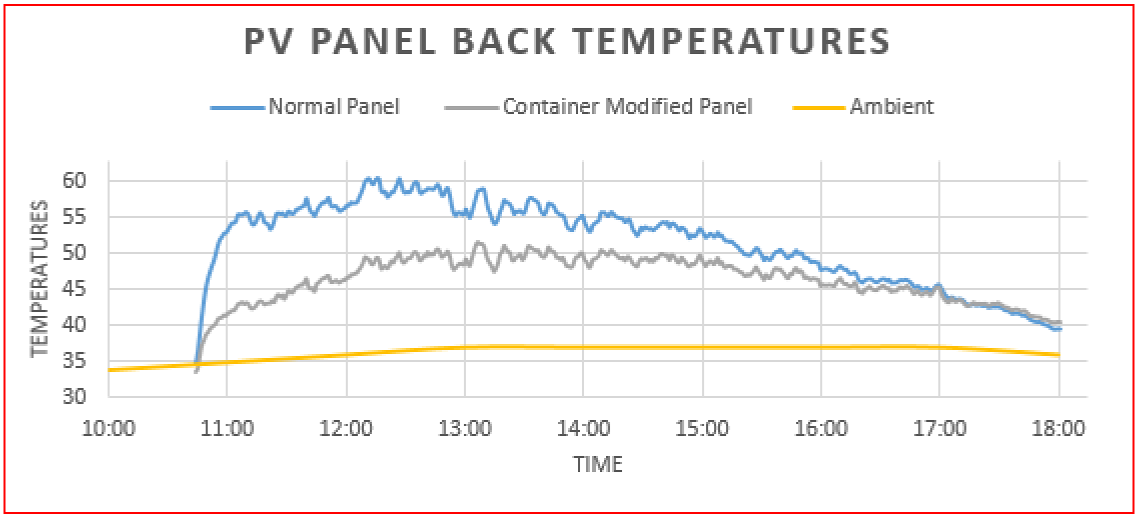


Figure 35. PV Panel Back Temperatures

The container modification to the PV panel achieved a maximum temperature drop of 6.45°C during the starting and kept an average difference of 2.51°C compared to a normal panel. The PCM container acts an effective heat sink absorbing the heat from the PV panel.

4.2 MAXIMUM POWER OUTPUT:

The impact of the cooling technology on the panels' maximum power output at a given time will be explored. These maximum power values are calculated using the IV-curve data to generate the PV-curve, which obtains the maximum power point at various intervals throughout the testing period.

Table 3 compares the maximum power output of PV panels after using cooling technique of aluminum containment containing PCM compared to normal panels.

Table 3 Maximum Power Output Comparison

Maximum Power Output (W)			
	Panels		**Improvement (%)**
Time	**Normal**	**Container**	**Container**
10:30	13.82	16.09	16.43 %
11:00	13.74	16.37	19.14 %
11:30	14.94	17.98	20.34 %
12:00	**15.73**	**19.42**	**23.46 %**
12:30	15.12	18.22	20.50 %
13:00	14.7	17.45	18.71 %
13:30	14.64	16.76	14.48 %
14:00	14.43	16.02	10.02 %
14:30	14.4	15.87	10.21 %
15:00	13.09	14.39	9.93 %
15:30	13.4	14.54	8.51 %
	Average		**15.612 %**

The maximum power obtained was **19.42 w** and this was for container modification. This shows that the container modification is an overall better enhancement. The improvement is because of the usage of passive cooling techniques.

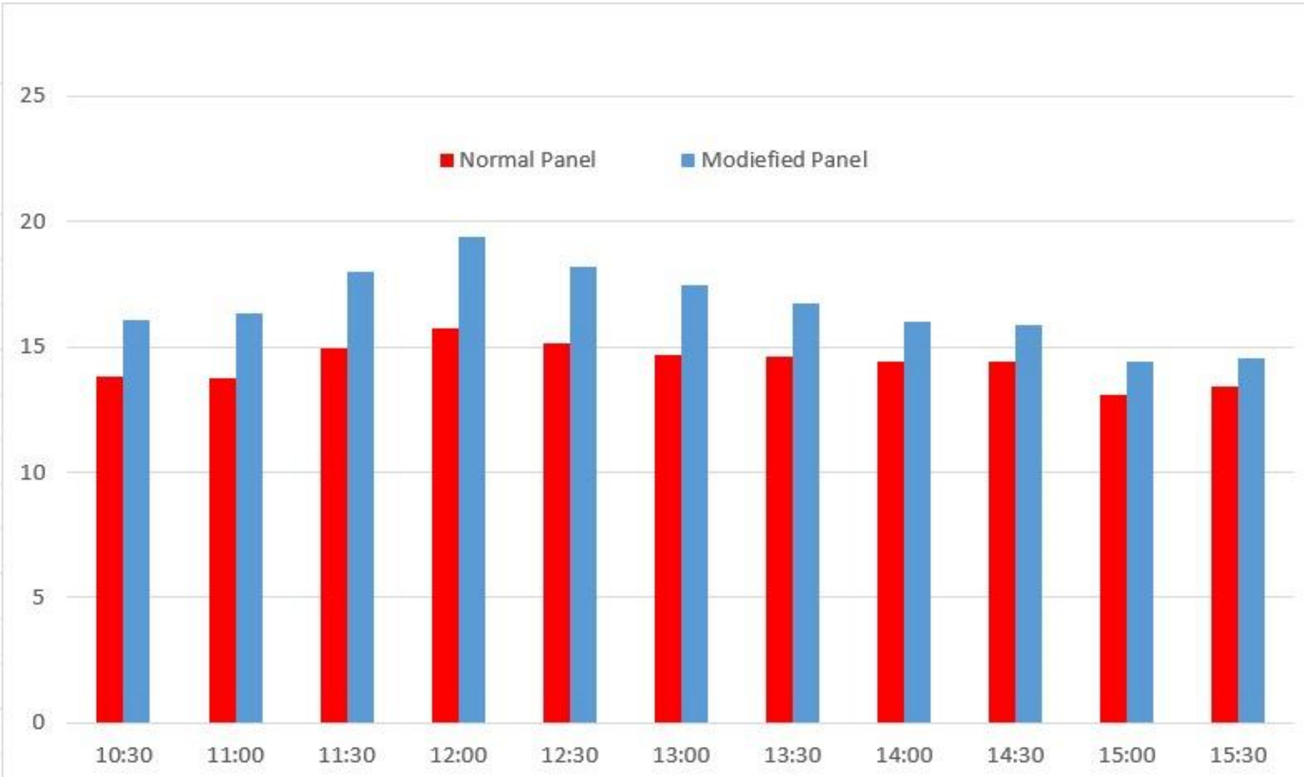


Figure 36: Power Output during hours in table

4.3 ELECTRICAL EFFICIENCY:

The impact of the passive cooling method on the electrical efficiency of the panels at a given time will be discussed. Using the formulae discussed in the methodology section, these electrical efficiency values are calculated using the maximum power point and solar intensity at various intervals and during the testing period.

Table below provides a detailed contrast of the Electrical efficiency of the PV panels after employing the cooling techniques and compared to normal panels.

Table 4. Efficiency Comparison

Efficiency (%)			
Panels			**Difference Achieved**
Time	**Normal**	**Container**	**Container**
10:30	8.37	9.75	1.38
11:00	8.32	9.92	1.6
11:30	9.05	10.90	1.85
12:00	**9.53**	**11.77**	**2.24**
12:30	9.16	11.04	1.88
13:00	8.90	10.58	1.68
13:30	8.87	10.15	1.28
14:00	9.20	10.22	1.02
14:30	9.70	10.68	0.98
15:00	9.33	10.26	0.93
15:30	10.15	11.02	0.87
	Average		**1.43**

The maximum efficiency obtained was 11.77% and this was for container modification indicating that it is a better enhancement to the PV panel.

A maximum difference of 2.24% from 9.53% to 11.77% for the container modification is observed. The increment in electrical efficiency is due to the lower temperature of the PV panel and cells because of the previously mentioned cooling strategies.

Figure 37: Electrical Efficiencies of the panels during hours in table

4.4 CFD VALIDATION:

We did the CFD analysis for one hour test from 11am to 12pm and the simulation results are attached below, and it shows that the temperature difference of almost 3^{o}C and in our practical results the temperature difference of 3.7^{o}C was achieved that are 23.33% more than the theoretical results. So, we can say that the on the base of temperature parameter our results satisfy the CFD results so, CFD validation occurs.

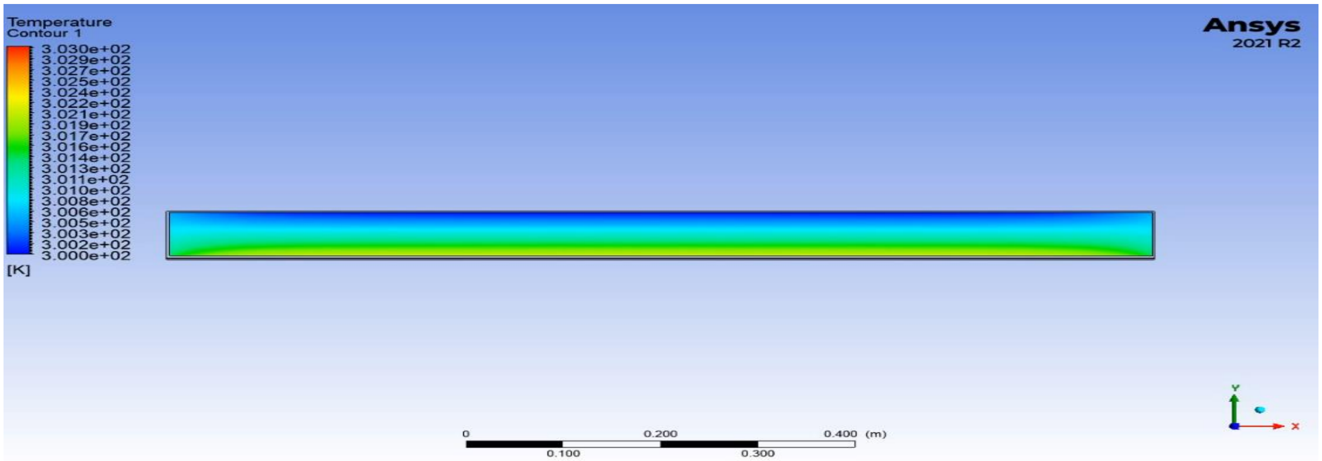


Figure 38: CFD Results

Time	Normal Panel	Modified Panel	Difference Achieved
11:03	52.94	47.69	5.25
11:09	53.44	51.21	2.23
11:15	52.75	49.64	3.11
11:21	54.56	51.44	3.12
11:27	53.94	50.04	3.9
11:33	56.19	52.74	3.45
11:39	53.69	48.76	4.93
11:45	55.75	51.19	4.56
11:51	54.88	51.49	3.39
11:57	58.25	54.49	3.76
12:03	56.19	53.21	2.98

Figure 39: Temperature from 11am to 12pm

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Thermal management of conventional 30-watt PV panels was accomplished through the use of a containment system that included phase change materials such as Paraffin wax. Various designs were developed and tested in real-time environmental conditions using various combinations of PCMs and data acquisition systems such as thermistor for temperature measurement, Voltmeter and Ammeter sensors for the acquisition of electrical performance parameters such as current and voltage, and so on.

We were able to get a maximum power increase of 25.3 percent using container design. Because it has more PCM for heat absorption and dissipation, the containment design was found to be more suited for situations with greater temperatures based on the data received. The impact of adding internal fins in conjunction with external fins should be investigated in future research. Fins optimization should also be done to determine the number of required fins and fin interspacing for the given panel area, in order to transfer heat from the panel structure (back) to the ambient environment efficiently and effectively.

Another key advancement that might be followed in this route is the usage of composite PCMs in the container due to their higher heat conductivity. The PCMs utilized should have two melting points that will affect the melting of the second PCM after the first has practically done melting, allowing for heat absorption over a much wider temperature range. In terms of system economic feasibility, low-cost PCMs with better thermal properties should be chosen following thorough real-time environmental testing on PV-PCM systems. The payback period for the early expenses involved during the installation of a PV-PCM system can be shortened by using a highly efficient design that allows for maximum heat transfer to the ambient environment, with the deciding factor being a PCM with better thermal characteristics such as latent heat capacity and thermal conductivity.

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APPENDIX I:
Panel front temperatures

The data given below is only for the temperatures recorded on 9th June 2022 after every six minutes as per the coding compiled in Arduino.

Time	Normal Panel	Container Modified Panel	Difference Container Modified Panel
10:15	35.44	34.44	1
10:21	48.5	44.56	3.94
10:27	52.56	47.19	5.37
10:33	52.81	47.44	5.37
10:39	52.31	47.63	4.68
10:45	52.69	49.38	3.31
10:51	53.25	49.13	4.12
10:57	52.75	49.44	3.31
11:03	52.94	49.81	3.13
11:09	53.44	51.19	2.25
11:15	52.75	49.81	2.94
11:21	54.56	51.63	2.93
11:27	53.94	51.06	2.88
11:33	56.19	53.94	2.25
11:39	53.69	49.94	3.75
11:45	55.75	53.19	2.56
11:51	54.88	52.94	1.94
11:57	58.25	57.81	0.44
12:03	56.19	56.06	0.13
12:09	55.63	53.81	1.82
12:15	58.31	57.75	0.56
12:21	57.81	55.25	2.56
12:27	59.19	56.69	2.5
12:33	55.44	52.56	2.88
12:39	56.88	54.56	2.32
12:45	57.13	56.25	0.88
12:51	58	58.19	-0.19
12:57	57.81	58.69	-0.88
13:03	57.06	57.56	-0.5
13:09	57.38	57	0.38
13:15	55.88	57.38	-1.5
13:21	58.56	57.19	1.37
13:27	57.13	58.56	-1.43
13:33	55.63	56.19	-0.56
13:39	56.69	57.13	-0.44
13:45	54.69	56.56	-1.87
13:51	57.38	57.56	-0.18
13:57	57.56	58.5	-0.94

14:03	59.88	60.31	-0.43
14:09	57.56	56.63	0.93
14:15	55.94	57.56	-1.62
14:21	59.38	60.5	-1.12
14:27	54.38	56.06	-1.68
14:33	56.13	56.69	-0.56
14:39	54	54.44	-0.44
14:45	54.25	56.31	-2.06
14:51	56	56.25	-0.25
14:57	55.5	56.06	-0.56
15:03	55.75	55.63	0.12
15:09	54.75	55.38	-0.63
15:15	53.75	54	-0.25
15:21	51.44	51.69	-0.25
15:27	52.44	53.63	-1.19
15:33	54.75	56.38	-1.63
15:39	53.25	54.81	-1.56
15:41	53.13	54.25	-1.12
15:47	51.13	53.25	-2.12
15:53	52.75	54.19	-1.44
15:59	52	53.38	-1.38
16:05	51.69	53.25	-1.56
16:11	51.13	52.94	-1.81
16:17	52.44	54.19	-1.75
16:23	52.13	53.44	-1.31
16:29	51.25	52.63	-1.38
16:35	50	51.5	-1.5
16:41	49.69	51.25	-1.56
16:47	49.38	51.06	-1.68
16:51	47.88	49.88	-2
16:57	47.25	48.94	-1.69
17:03	43	45.06	-2.06
17:09	41.44	43.06	-1.62
17:15	40.63	42.63	-2
17:21	40.38	42.44	-2.06
17:27	38.44	40.63	-2.19
17:33	38.69	40.44	-1.75
17:39	38.69	40.31	-1.62
17:45	38.13	39.63	-1.5
17:51	37.44	39.5	-2.06
17:57	36.75	38.25	-1.5

APPENDIX II:
Panel back temperatures

The data given below is only for the temperatures recorded on 9th June 2022 after every six minutes as per the coding compiled in Arduino.

Time	Normal Panel	Modified Panel	Difference Container Modified Panel
10:15	38.78	36.44	2.34
10:21	48.5	46.47	2.03
10:27	52.56	50.09	2.7
10:33	52.81	48.26	4.55
10:39	52.31	47.46	4.85
10:45	52.69	46.24	6.45
10:51	53.25	51.06	2.19
10:57	52.75	49.41	3.34
11:03	52.94	47.69	5.25
11:09	53.44	51.21	2.23
11:15	52.75	49.64	3.11
11:21	54.56	51.44	3.12
11:27	53.94	50.04	3.9
11:33	56.19	52.74	3.45
11:39	53.69	48.76	4.93
11:45	55.75	51.19	4.56
11:51	54.88	51.49	3.39
11:57	58.25	54.49	3.76
12:03	56.19	53.21	2.98
12:09	55.63	52.44	3.19
12:15	58.31	54.39	3.92
12:21	57.81	53.18	4.63
12:27	59.19	54.39	4.8
12:33	55.44	51.29	4.15
12:39	56.88	52.32	4.56
12:45	57.13	53.23	3.9
12:51	58	54.11	3.89
12:57	57.81	53.43	4.38
13:03	57.06	52.21	4.85
13:09	57.38	53.12	4.26
13:15	55.88	52.25	3.63
13:21	58.56	53.11	5.45
13:27	57.13	52.39	4.74
13:33	55.63	51.42	4.21
13:39	58.69	53.08	5.61
13:45	55.69	52.22	3.47
13:51	57.38	54.32	3.06
13:57	57.56	53.24	4.32

14:03	59.88	54.24	5.64
14:09	57.56	55.63	1.93
14:15	55.88	53.56	2.32
14:21	58.46	54.5	3.96
14:27	58.31	54.06	4.25
14:33	57.26	54.69	2.57
14:39	58.34	54.44	3.9
14:45	56.39	53.31	3.08
14:51	56.12	53.25	2.87
14:57	56.94	53.06	3.88
15:03	55.89	54.63	1.26
15:09	55.99	53.38	2.61
15:15	55.88	53	2.88
15:21	53.58	51.69	1.89
15:27	54.58	51.63	2.95
15:33	54.89	51.38	3.51
15:39	54.39	52.81	1.58
15:41	53.27	52.25	1.02
15:47	53.27	52.25	1.02
15:53	52.89	52.19	0.7
15:59	52.24	51.38	0.86
16:05	52.73	51.25	1.48
16:11	52.27	51.94	0.33
16:17	52.48	51.19	1.29
16:23	53.37	52.44	0.93
16:29	53.49	52.63	0.86
16:35	52.80	51.5	1.3
16:41	50.63	50.25	0.38
16:47	49.93	50.06	-0.13
16:51	50.02	50.88	-0.86
16:57	49.79	50.04	-0.25
17:03	47.60	50.06	-2.46
17:09	46.48	48.06	-1.58
17:15	46.67	46.63	0.04
17:21	46.32	46.44	-0.12
17:27	45.48	46.63	-1.15
17:33	45.63	46.44	-0.81
17:39	44.63	46.31	-1.68
17:45	44.17	45.63	-1.46
17:51	44.48	46.15	-1.67
17:57	44.79	45.25	-0.46

APPENDIX III:

Arduino Solar Temp, Vol and Current Measurement

Below is the complete Arduino code for the measurement of Temperature, Voltage and Current which shows Power as output for both the panels along with Temperatures as well. The code compiled is:

```
// include the library code:
#include <LiquidCrystal.h>

// initialize the library by associating any needed LCD interface pin
// with the arduino pin number it is connected to
const int rs = 2, en = 4, d4 = 9, d5 = 10, d6 = 7, d7 = 8;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

const int Current  =A0;
const int Current1 =A1;
#include <SPI.h>
#include <SD.h>

int counter = 0;

File myFile;

#include <math.h>
const int thermistor_output = A2;

float battery_volt,avgvolt,read_volt,volt,volt1,avg_volt,volt3,old_amps,read_bat = 0;
float volt11=0;
int mVperAmp = 185 ; // use 100 for 20A Module and 66 for 30A Module
int RawValue,RawValue1= 0 ;
int ACSoffset = 2500 ;
double MV,MV1 = 0 ;
double Amps,Amps1 = 0;
double amps,amps1 = 0;

int thermistor_output1 =A3;

int sol_volt = A4 ;
int sol_volt1 = A5 ;

void setup()
{
  // put your setup code here, to run once:
```

```
lcd.begin(16, 2);
// Print a message to the LCD.

Serial.begin(9600);
// INPUT PINS
pinMode(Current,INPUT) ;
pinMode(Current1,INPUT) ;
pinMode(sol_volt,INPUT) ;
pinMode(sol_volt1,INPUT) ;
pinMode(thermistor_output1,INPUT);
pinMode(thermistor_output,INPUT);

//if (!SD.begin(5)) {
//    Serial.println("initialization failed!");
//     lcd.print("SD CARD ERROR");
//     while (1);
//  }
// Serial.println("initialization done.");


}

void loop()
{
  // put your main code here, to run repeatedly:

 // READING SOLAR INPUT VOLTS 1
  for(int i = 0 ; i < 50 ; i++)
  {
  read_volt = analogRead(sol_volt);
  volt1 = (read_volt /1024) * 25 ;
  volt = volt + volt1;
  }
  avg_volt = volt/50 ;
  Serial.print("read_volt:");
  Serial.println(volt);

  lcd.setCursor(0,0);lcd.print("V1:");
  lcd.setCursor(3,0);lcd.print(avg_volt,1);

  //Serial.println();
  float read_volt1 =0;

 // READING SOLAR INPUT VOLTS 2
  for(int i = 0 ; i < 50 ; i++)
```

```
 {
 read_volt1 = analogRead(sol_volt1);
 volt11 = (read_volt1 /1024) * 25 ;
 volt1 = volt1 + volt11;
 }
 float avg_volt1 = volt1/50 ;

 lcd.setCursor(0,1);lcd.print("V2:");
 lcd.setCursor(3,1);lcd.print(avg_volt1,1);

//reading solar current 1
for (int i = 0 ; i < 300 ; i++)
{
RawValue = analogRead(Current);
//Serial.println(RawValue) ;

MV = (RawValue / 1024.0) * 5000; // Gets you mV
Amps = ((MV - ACSoffset) / mVperAmp);
amps = amps + Amps ;
}
float final_amps = abs(amps / 300) ;

Serial.print("AMPS=") ;
Serial.println(final_amps) ;

//reading solar current 2
for (int i = 0 ; i < 300 ; i++)
{
RawValue1 = analogRead(Current1);
//Serial.println(RawValue1) ;

MV1 = (RawValue1 / 1024.0) * 5000; // Gets you mV
Amps1 = ((MV1 - ACSoffset) / mVperAmp);
amps1 = amps1 + Amps1 ;
}

float final_amps1 = abs(amps1 / 300) ;

Serial.print("AMPS=") ;
Serial.println(final_amps1) ;

 lcd.setCursor(8,0);lcd.print("I1:");
 lcd.setCursor(12,0);lcd.print(final_amps,1);

 lcd.setCursor(8,1);lcd.print("I2:");
 lcd.setCursor(12,1);lcd.print(final_amps1,1);
```

```
  delay(2000); lcd.clear();


  //get panel 1 temperature
  int thermistor_adc_val;
  double output_voltage, thermistor_resistance, therm_res_ln, temperature;
  thermistor_adc_val = analogRead(thermistor_output);
  output_voltage = ( (thermistor_adc_val * 5.0) / 1023.0 );
  thermistor_resistance = ( ( 5 * ( 10.0 / output_voltage ) ) - 10 ); /* Resistance in kilo ohms */
  thermistor_resistance = thermistor_resistance * 1000 ; /* Resistance in ohms   */
  therm_res_ln = log(thermistor_resistance);
  /* Steinhart-Hart Thermistor Equation: */
  /* Temperature in Kelvin = 1 / (A + B[ln(R)] + C[ln(R)]^3)   */
  /* where A = 0.001129148, B = 0.000234125 and C = 8.76741*10^-8  */
  temperature = ( 1 / ( 0.001129148 + ( 0.000234125 * therm_res_ln ) + ( 0.0000000876741 *
therm_res_ln * therm_res_ln * therm_res_ln ) ) ); /* Temperature in Kelvin */
  temperature = temperature - 273.15; /* Temperature in degree Celsius */
  Serial.print("Temperature in degree Celsius = ");
  Serial.print(temperature);
  Serial.print("\t\t");

  //get panel 2 temperature
  int thermistor_adc_val1;
  double output_voltage1, thermistor_resistance1, therm_res_ln1, temperature1;
  thermistor_adc_val1 = analogRead(thermistor_output1);
  output_voltage1 = ( (thermistor_adc_val1 * 5.0) / 1023.0 );
  thermistor_resistance1 = ( ( 5 * ( 10.0 / output_voltage1 ) ) - 10 ); /* Resistance in kilo ohms */
  thermistor_resistance1 = thermistor_resistance1 * 1000 ; /* Resistance in ohms   */
  therm_res_ln1 = log(thermistor_resistance1);
  /*  Steinhart-Hart Thermistor Equation: */
  /*  Temperature in Kelvin = 1 / (A + B[ln(R)] + C[ln(R)]^3)   */
  /*  where A = 0.001129148, B = 0.000234125 and C = 8.76741*10^-8  */
  temperature1 = ( 1 / ( 0.001129148 + ( 0.000234125 * therm_res_ln1 ) + ( 0.0000000876741 *
therm_res_ln * therm_res_ln * therm_res_ln ) ) ); /* Temperature in Kelvin */
  temperature1 = temperature1 - 273.15; /* Temperature in degree Celsius */
  Serial.print("Temperature in degree Celsius = ");
  Serial.print(temperature1);
  Serial.print("\t\t");

  lcd.setCursor(0,0);lcd.print("T1:");
  lcd.setCursor(3,0);lcd.print(temperature,1);

  lcd.setCursor(0,1);lcd.print("T2:");
  lcd.setCursor(3,1);lcd.print(temperature1,1);

  float power1 = avg_volt*final_amps;
```

```
  float power2 = avg_volt1*final_amps1;

  lcd.setCursor(9,0);lcd.print("P1:");
  lcd.setCursor(13,0);lcd.print(int(power1));

  lcd.setCursor(9,1);lcd.print("P2:");
  lcd.setCursor(13,1);lcd.print(int(power2));

  if(counter <= 0)
  {
  myFile = SD.open("Data_base.txt", FILE_WRITE);

  // if the file opened okay, write to it:
  if (myFile)
  {
    Serial.print("Writing to test.txt...");

    myFile.print("V1");myFile.println(avg_volt);
    myFile.print("V2");myFile.println(avg_volt1);

    myFile.print("I1");myFile.println(final_amps);
    myFile.print("I2");myFile.println(final_amps1);

    myFile.print("T1");myFile.println(temperature);
    myFile.print("T2");myFile.println(temperature1);

    myFile.println("-----------------------------------");
    // close the file:
    myFile.close();
    Serial.println("done.");
  }
  else
  {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
  }
  counter = 100; // timing setting for sd card saving
  }
  counter = counter-1;
  volt1 = 0;
  volt11 = 0;
  avg_volt = 0;volt =0;
  amps = 0 ;amps1 = 0;
  final_amps,final_amps1 = 0;
 delay(2000);lcd.clear();
}
```