CAPSTONE TEAM PROJECT

MENG 411

NAME OF PROJECT:

DESIGN AND MANUFACTURING OF PV COOLING SYSTEM - HEAT PIPE VS PHASE CHANGE MATERIAL

GROUP NAME:

EASY COMPANY

GROUP MEMBERS:

147809	Othiman Saeed
147907	Qasi Albaytar
15700648	Sean Stevenson
15701962	Waddah Essamuldeen
16701003	Mpho Sothoane

SUPERVISOR: Assist. Prof. Dr. Murat Ozdenefe

SEMESTER: Spring 2018/2019

SUBMISSION DATE: 24th of June 2019

Eastern Mediterranean University

Department of Mechanical Engineering

ABSTRACT

Photovoltaic solar cell generates electricity by utilizing the solar irradiance. The electrical efficiency of photovoltaic (PV) cell is adversely affected by the significant increase of cell operating temperature during the absorption of solar radiation. The efficiency of the PV panels decreases by a certain percentage, varying between 0.4% - 0.5% per degree Celsius increase (Wu, 2014). Therefore, cooling techniques must be implemented to keep the PV Panel at an optimal operating temperature. Utilizing the Sun's energy is very important as it is a sustainable and clean source of energy that can be used to generate electricity or for many more applications. The Significance of PV Cooling techniques is that it helps to utilize as much energy from the Sun as possible thus maximizing the efficiency of the PV Panels. On top of that PV cooling techniques can help elongate the working life of the PV Panels, making these techniques very useful. The main objective of this project was to compare two PV cooling techniques, a **Phase Change Material (PCM) Cooling system vs a Heat Pipe Cooling System**. Comparing the two cooling systems for effectiveness and better efficiency deliverance. The constraints of this project were: Economic, Functionality, Maintenance, Manufacturability, Environmental, Social, Health & Safety and Inspect ability. The **PCM-PV** showed a maximum efficiency of **12.77%** and the **HP-PV** showed a maximum efficiency of **12.53%,** whereas the **Reference-PV** only had a maximum efficiency of **9.86%.** Furthermore, the **PCM-PV** provided a maximum power output of **122.54 W/m^2** followed by the **HP-PV** with **120 W/m^2** and the **Reference-PV** with **93.58 W/m^2.** The results indicated that both the cooling systems were able increase the overall PV Efficiency and Power Output by cooling down the panels and that the PCM Cooling system won the comparison. Even though the PCM-PV system delivered a higher efficiency, it also costed significantly more than the HP cooling system to complete by \$87 (300 \$/m^2). Therefore, it was concluded that the HP-PV cooling system was better suited for this project and the PCM-PV system would be better suited for a larger scale project.

ACKNOWLEDGEMENTS

First and foremost, the team would like to give a very big thank you to **Assist. Prof. Dr. Murat Ozdenefe** for inspiring us to take on this project and for the excellent guidance and support he showed us from the start to finish of this project. Without him we would not have been able to complete let alone attempt this project.

We would also like to thank **Assist. Prof. Dr. Devrim Aydın** for always providing us with additional information and equipment when asked in a truly kind and professional manner. We give thanks to **Sr. Instr. Cafer Kızılörs** and **Mr. Zafer Mulla** for offering their help and expert knowledge during the most critical manufacturing stages of this project.

Last, but definitely not least, we would like to thank **Res. Asst. Mr. Majid Karimnejhad** who was there and assisted us during the upmost important testing phase of this project. His help led to the completion of the experimental set-up and ensured everything ran smoothly which contributed tremendously to us being able to see which cooling system was the most effective.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

AISC	American Institute of Steel Construction.
ANSI	American national standards institute**.**
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials.
BIPV	Building-integrated photovoltaic
CPV	Concentrated Photovoltaic Panel
FF	Fill Factor
HP	Heat Pipe
HP-PV	Heat Pipe-Photovoltaic
I	Current
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NOCT	Nominal Operating Cell Temperature
OSHA	The Occupational Safety and Health Administration
P	Power
PCM	Phase Change Material
PCM-PV	Phase Change Material-Photovoltaic
PV	Photovoltaic
SELA	Solar Energy Industries Association
UAV	Unmanned Aerial Vehicle
V	Voltage

NOMENCLATURE

Proper Fin Length, L

Heat Transfer Coefficient, h

Contact Cross-sectional Area, A_c

Parameter of Contact Cross-sectional Area, p

Aluminum thermal Conductivity, k

Heat Pipe radius, r

Condenser Section length, $L_{condensor}$

Heat transfer with no fins, $\dot{Q}_{no\ fin}$

Heat Transfer Coefficient, h

Fin-Pipe Contact Area Temperature, T_b

Ambient Temperature, T_∞ or T_{air}

Fin Area, A_{fin}

Fin length, L

Fin width, w

Fin thickness, t

Fin number, n

Factor used to calculate fin efficiency, ξ

Heat transfer from the un-finned portion of the Pip, $\dot{Q}_{unfined}$

Heat to be removed from PV Panel, $\dot{Q}_{fin}$

Overall effectiveness of finned tube, $\varepsilon_{fin\ Overall}$

The amount to of Heat removed by fin system , $\dot{Q}_{total\ fin}$

Heat Pipe Cooling System Efficiently, $\eta_{Heat\ Pipe}$

Solar Panel Maximum Power Output, P_{max}

Insolation level, S

Surface area of the PV panel, $A_{Surface\ Area}$

Latent Heat of storage PCM, L_{PCM}

Specific Heat, c

PV Efficiency, $\eta_{PV\ Panel}$

Short-Circuit Current, I_{SC}

Open-Circuit Voltage, V_{OC}

Maximum Power, P_{MAX}

Current at Max Power, I_{MP}

Voltage at Maximum Power, V_{MP}

CHAPTER 1

1. INTRODUCTION

This section gives an introduction on photovoltaics and attributed problems. The project significance, objectives and constraints will be discussed as well. Lastly, this section will state the report organization.

1.1. DETAILED DEFINITION OF THE PROJECT

Renewable energy has had a large contribution to the worldwide sustainable development and environment conservation and has been growing more popular in the last decade (Ma, Yang, & Zhang, Using phase change materials in photovoltaic systems for thermal regulation and electrical efficiency improvement: A review and outlook, 2014). The use of renewable energy technologies including Solar Photovoltaics (PV) has been amplified due to the growing awareness of events such as Global Warming, O-zone depletion, energy shortages and the forever rising prices of fossil fuels. Building-integrated photovoltaic (BIPV) systems in particular, have received an extensive amount of scholarly attention due to this technology being considered as one of the most cost-effective means of clean energy & power generation technologies in cities as PV panels can be easily and aesthetically with homes and buildings in the architectural sense (Huang, 2010).

Currently, however, only 15–20% of the solar energy incident on a PV panel can be converted to electricity, with the rest of the energy being transformed into heat. This heat can well be absorbed by the PV device itself, causing its working temperature to reach up to 80°C. PV conversion efficiency is thereby decreased by 0.4–0.65% for every increased degree. For this reason, cooling off the cells or panels might be a necessity in order to keep efficiency optimum (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

Cooling techniques for heat applications were proposed early on in PV exploitation. The main advantage of cooling is evident: higher electrical output. However, cooling requires a separate system which will remove heat to some extent. Many prospective solutions for cooling systems have been arising, two of which are Heat Pipes (HP) and Phase Change Materials (PCM). This project focuses on cooling PV panels as well as on comparing these two mentioned cooling systems in order to find out which of the two is the better cooling system in removing heat. Cooling the PV panels will decrease the PV panel's working temperature and allowing the conversion efficiency of the PV module to maintain at its best.

Heat Pipes are specially designed equipment for transferring heat. HP do neither involve any moving parts, nor do they require power input for the heat transfer process (Anderson W, 2018). PCMs on the other hand are substances that absorb and release thermal energy during the process of melting and freezing (Pure Temp, 2018).

1.2. SIGNIFICANCE OF THE PROJECT

Solar PV energy is one of the most important forms of providing clean energy in today's world. Clean energy meaning that Solar PV energy does not emit any greenhouse gases. In a sense, PVs provides free electricity since they only depend on the sun for energy, and in return conserve other energy resources. For these mentioned reasons and many more, it must go without saying that obtaining as much energy from Solar Cells and PV panels as possible would be the goal. However, when these Solar Cells and PV panels surfaces' heat up too much, the goal becomes hindered.

There are two main effects regarding PV panels surfaces' heating up: Namely:

- The efficiency of the PV panels decreases immensely,
- There is also a decrease of the PV panel's working life.

The efficiency of PV panels decreases by a certain percentage, varying between 0.4% - 0.5% for every degree increase (Wu, 2014), meaning the PV panel will produces less electricity as the solar energy to electric conversion decreases, which is why cooling PV panels is important to keep the panels working as efficiently as possible. The decrease of power-output as temperature rises is shown in Figure 1 (Mohrram & Abd-Elhady, 2013).

Another significant role of cooling PV panels, is elongating the working life of the PV panels, as it has been perceived of the effects of high temperature on PV panels, as well as using a cooling system can increase the gaining of power by a minimum of up to five percent (Marco, 2016). The financial aspect on its own makes this project significant. Keeping the efficiency of the PV panels optimum means cleaner (and free) energy gains which leads to less spending on conventional electricity from power producers. Elongating the working life will be beneficial for end-users as well as it will result longer time periods between having to purchase new panels in order to replace inefficient ones.

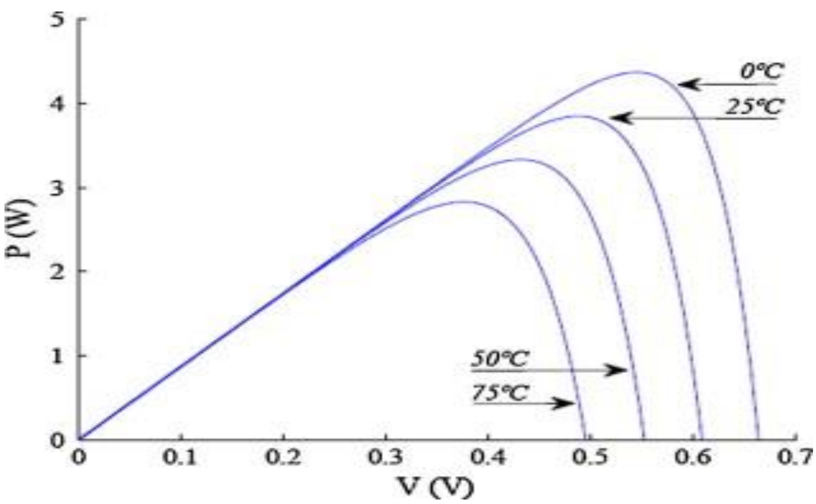


Figure 1 – PV Characteristics as Surfaces Temperature Rises (Marco, 2016)

1.3. DETAILED PROJECT OBJECTIVES

The objectives of this project are to:

I. Design and compare two PV Panel Cooling Systems and to find the most efficient system.
II. Efficiency is the target with regard to the Manufacturing cost and heat removal rate.
III. To perform a feasibility study of PV generator characteristics and models.
IV. To minimize the amount of solar energy and efficiency lost due to heating of solar and PV panels

The first cooling system is the HP cooling system that is used to maintain the temperature of the PV panels by extracting heat in a convective heat transfer manner. The second cooling system is Phase Change Material Cooling system; this system is used to prevent the PV panel's temperature from rising too much by utilizing the high latent heat capacity of the Phase Change Material. After the cooling systems have been designed, they will be manufactured, assembled and tested.

1.4. DETAILED PROJECT CONSTRAINTS

The main constraints of this project are Economic, Functionality, Maintenance, Manufacturability, Environmental, Social, Health & Safety and Inspectability.

Financial:

- Available budget of $500 US. The aim is to balance cost and quality.

Availability:

- Availability of materials limits the designs since Cyprus is an island and materials and components have to be imported into the country because of scarcity.

Function:

- Cooling the PV system by using heat pipe and using phase change material.

Serviceability:

- Product's maintenance must be simple and for long time.
- Design must include parts that are easily replaceable.
- Parts must be cheap to buy.

Manufacturability:

- Fabrication and installation will be in the university workshop.

- ❖ Two joining methods (welding and machine screws). Both can be done in the university workshop.
- ❖ Product's final finishing must be well done.

Environmental:

- ❖ The panels will be in a safe location. To avoid any damages to people.
- ❖ Manufacturing waste will be collected.

Social:

- ❖ Designs in favor of end users.

Health and Safety:

- ❖ Wearing safety shoes and glass and coverall during manufacturing processes.
- ❖ The product will be safe for the public.
- ❖ The product will not cause any noise.
- ❖ The materials used are not dangerous.

Inspectability:

- ❖ The system can be during maintenance service.

1.5. Report Organization

The report will give introductory information regarding Photovoltaics, Solar Energy and the project in Chapter 1. The significance of the project together with the project objectives and constraints will be discussed in the 1st chapter. The 2nd chapter focusses on literature reviews regarding PV Cooling; detailed info on existing solutions for PV cooling and specific attributes that come therewith. Chapter 3 looks at the proposed designs for this project by means of computer aided design analysis. Furthermore, Engineering Standards and the Design Methodology applicable to PV Cooling will be focused on together with Cost Analysis to conclude the 3rd chapter.

In the 4th chapter the processes of manufacture and assembly plans are laid out. Furthermore, the details on ordered and fabricated parts will be given.

The 5th chapter contains Testing plan of the manufactured and assembled prototype(s) against stated specifications and results recorded. This chapter will aim to verify the original project objectives.

The 6th chapter is an Evaluation; here it will be noted which are the specifications that were not met and how the prototype(s) design may be further developed. Along with further analysis of results. Finally, the conclusion and future works are discussed in the last chapter.

CHAPTER 2

2. LITERATURE REVIEW

This section aims to give some background information regarding important aspects of this project. Concurrent solutions of PV Cooling will be analyzed and compared and lastly this section will provide the engineering standards of the concurrent solutions.

2.1. BACKGROUND INFORMATION

2.1.1. PV Cooling

Cooling techniques for heat applications were proposed early on in PV exploitation. The main advantage of cooling is evident: higher electrical output. However, cooling requires a separate system which will remove heat to some extent. The construction and maintenance of that system can be expensive and there is a possibility that the cost of system maintenance could outweigh the benefits of the improved electrical yield. Two types of cooling can be distinguished: active cooling, which consumes energy (pump, fan, etc.,) and passive cooling, which uses natural convection/conduction to enable heat extraction (Grubišić-Čabo, Nižetić, & Marco, 2016).

Different cooling techniques have been examined and compared in multiple studies. It was mostly shown that active cooling techniques, as expected, have higher efficiency than passive ones. In several cases, however, passive cooling can replace active cooling, in order to save the installation costs. Such specific cases are mainly usage of PCM material and usage of small concentrated PV cells. Also, when pumping costs are considered, especially for back side cooling, passive techniques can sometimes yield more power gain than active ones (Hasan, McCormack, Huang, Sarwar, & Norton, 2014).

2.1.1.1. Active Cooling

Active cooling methods can be considered as those methods that continuously consume power in order to cool the PV module. Most of the methods used are based on air or water cooling. Hence, main consumption system is pump or fan needed for maintaining fluid circulation. In general, active cooling methods result in more produced power and more accessible thermal energy, but when power consumption is considered, questions arise if the cooling system can support itself (Grubišić-Čabo, Nižetić, & Marco, 2016).

2.1.1.2. Passive Cooling

When it comes to passive cooling techniques, they can be divided into three main groups: air passive cooling, water passive cooling, and conductive cooling. Conductive cooling mostly ends up with air passive cooling, but an important difference is that the prevailing mechanism of heat transfer from PV cells is conductive in nature. A special type of passive conductive cooling is phase change material cooling, PCM. Although this can't be viewed as cooling in the strict sense, it has the result of maintaining the same temperature. It can still be counted as a passive technique mainly because no additional work is needed to take away the heat - it is dissipated mostly conductively. Water passive cooling is somewhat more efficient, mainly because of the higher thermal capacity of water (Huang, 2010).

2.1.2. Heat Pipe

The concept of the heat pipe dates to 1831 where Angier Perkins, an American Engineer, took out a patent on a "hermetic boiler tube". His invention used a working fluid but only in a single-phase sense at high pressure. Years later, a descendent of Angier Perkins, Jacob Perkins, an American Inventor, invented the Perkins tube. The Perkins Tube was a system consisting of an evaporator and condenser with water operating in two-phases (liquid and Steam) being passed within the system. The two-Phase heat transfer tube was used in the recovery of wasted heat. These Inventions were the early models of what is now known in the present day as the Heat Pipe (AMS Energy, 2018).

It wasn't until 1963, where the modern concept of the Heat Pipe was invented in the Los Alamos National Laboratory by the nuclear physicist, George M. Grover. Working under the U.S. space program, Dr. Grover was trying to find a way to extract heat efficiently from nuclear reactors in space. With help of his co-workers, Dr. Grover managed to invent the modern Heat Pipe which now used in many applications such as Electronics-Cooling and as air heaters on boilers (The New York Times, 1996).

Heat pipe cooling is combination of phase change cooling together with convection of cooling medium. On one side cooling medium evaporates and expands (or rises, depending of the variant) taking up heat. On the other side medium condensates and releases the heat into the surrounding. The medium travels back as liquid via capillary tubes and evaporates, thus completing the cycle (Grubišić-Čabo, Nižetić, & Marco, 2016).

2.1.3. Phase Change Material

Phase Change Materials or PCM are substances with high heat of fusion, capable of storing and releasing large amounts of heat. These materials are used in many areas such construction, clothing, thermal energy storage and cooling. PCM can classified into three categories: Organic, Inorganic and Eutectics, illustrated in Figure 2 on the following page (Textilelearner, 2018). These types have different and varying properties and can only be selected depending on the application (Farid, 2015).

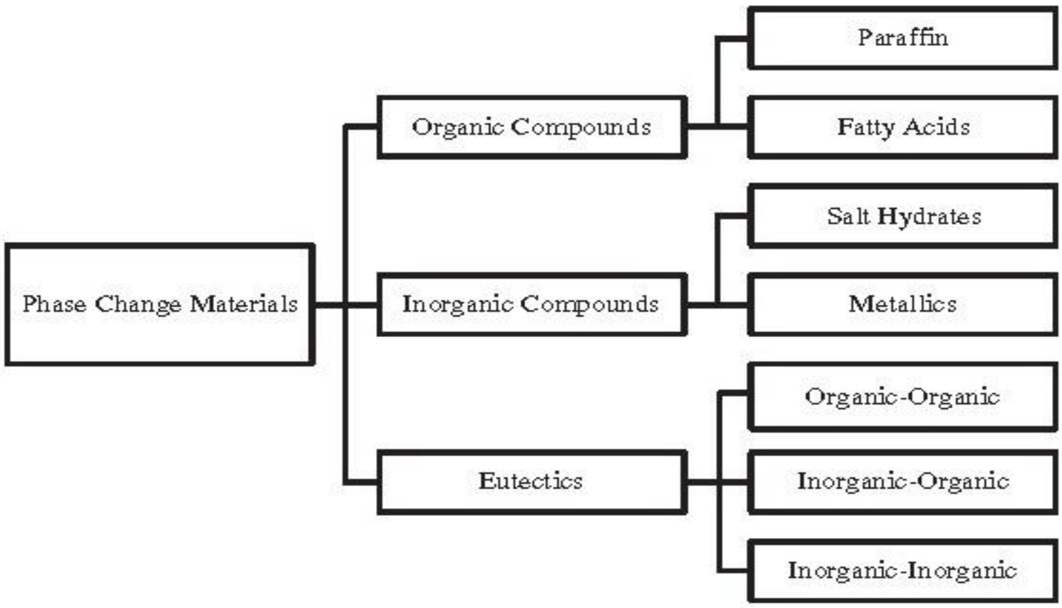


Figure 2 – PCM Categories (Textilelearner, 2018)

The first documented use of PCM was in 1948, by the American scientist, Dr. Maria Telkes who had an interest in the possibilities of Solar heating. Unable to find a research institution to support her experiment, a client funded her project. With help of an architect Dr. Telkes construct PCM residential house in Dover, Massachusetts, USA.

Dr. Maria Telkes placed steel drums containing $4m^3$ Glauber's salts located under sunny spaces inside the house in between rooms. In Winter, the spaces where ventilated with fans to move heat to the living areas inside the house. In summer, the Glauber's salts acting as an PCM stored the heat to cool the surrounding rooms (Hardland, Mackay, & Vale, 2015). This experiment was successful for two and half seasons, Afterwards, the phase transition capability of the salt vanished.

Since 1948, more research and experimentation has been done in the development of the PCM. Despite the extensive research of the PCM especially in 1980s and 1990s to prove the material's high performance and durability it was still hard to see market acceptance. In 2014, a conclusion has been drawn that simply the cost-to-benefit ratio is too high in PCM applications to be the first choice in design problems (Farid, 2015).

As a summary and for visual demonstration purposes, a summary has been made and is shown in Table 1 on the following page. From this table, the important dates for both Heat Pipes and Phase Change Materials as well as for Photovoltaics may be followed better. This table just aims to highlight the important dates in the timelines of both these subjects.

Table 1 – HP, PCM & PV Timeline

Heat Pipes	
F.W. Gay 1942	F.W Gay invented what is now known as the Gas-to-Gas heat pipe heat exchanges. It included the use of external fins to improve the heat transfer (AMS Energy, 2018).
R. S. Gaugler 1944	R. S. Gaugler introduced the modern heat pipe model while working for General Motors company. He created a heat pipe heat exchanger for use in a refrigeration process. (AMS Energy, 2018).
William Haskin 1966	Haskin invented a cryogenic heat pipe for use in jet engine applications. He was working for the Wright-Patterson Air Force Base Laboratory. (AMS Energy, 2018)
Phase Change Materials	
In 1970s	The University of Delaware were researching PCM for thermal storage application. They used PCMs with solar collectors to store heat (Whiffen & Riffat, 2013).
In 1980s	During the 1980, Paraffinic PCM were being manufactured for building application. The PCMs were used to control the indoor temperate (Hardland, Mackay, & Vale, 2015).
Photovoltaics	
Edmund Becquerel 1839	A nineteen-year-old French experimental physicist, discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes (ThoughtCo., 2018).
Charles Fritts 1883	Fritts, an American inventor, described the first solar cells made from selenium wafers.
Albert Einstein 1923	Einstein received the Nobel Prize for his theories explaining the photoelectric effect.
1996	The U.S. Department of Energy announces the National Center for Photovoltaics, headquartered in Golden, Colorado.

2.2. CONCURRENT SOLUTIONS

Cooling systems for PV panels fall into two main categories. The first category is passive cooling and the second is active cooling. Passive cooling aims to dissipate heat by natural means, whereas active cooling aims to dissipate heat using a mechanical system. Examples of each are shown as follows.

2.2.1. Heat Sink

A heat sink is a passive heat transfer device made from highly conductive metals. The metal is extruded or machined to form a shape that consists of many long and thin surfaces called fins. The heat sink is attached to the rear of the PV panel out of the direct sunlight and the heat from the PV panel is transferred to the heat sink via conduction. Due to the finned surfaces the heat sink has a large surface area, which increases the rate of both convection and radiation heat transfer, cooling the PV panels surface (Y & A, 2015). Figure 3 below shows a Heat Sink.

Figure 3 – Extruded Aluminum Heat Sink (Verdict Elec. Ltd., 2018)

2.2.2. Phase Change Material

PCM is a passive cooling method. The PCM is attached to the rear of the solar panel. Originally the PCM is in a solid state but absorbs heat from the PV panel. Once the temperature of PCM reaches a certain point it begins to melt. During this phase change it continues to absorb heat from the PV panel. Once the PCM completely melts it begins to re-solidify and reject its stored heat and then the cycle starts again (Microtek Laboratories Inc., 2017). Variety of PCMs exists and include organic, inorganic, and eutectics, all available in a wide range of melting/freezing points. Melting and solidification processes of PCM occur in different transformation stages due to heat transfer between the PCM and the heat source. Figure 4 below shows some phase change material.

Figure 4 - Phase Change Material Example (Crypopak, 2016)

2.2.3. Spray Water Cooling

Spray water cooling is an active cooling method. A water pipe is fitted along the top edge of the PV panel. The pipe has holes along its length to allow a constant flow of water to pass over the PV surface to keep it cool. There are two types of spray systems used. The first uses a constant water supply and the wastewater is drained away. In the second type the wastewater is collected and passed through a heat exchanger to cool it (S, O, & K, 2015). Figure 5 below shows Spray Water Cooling on a PV.

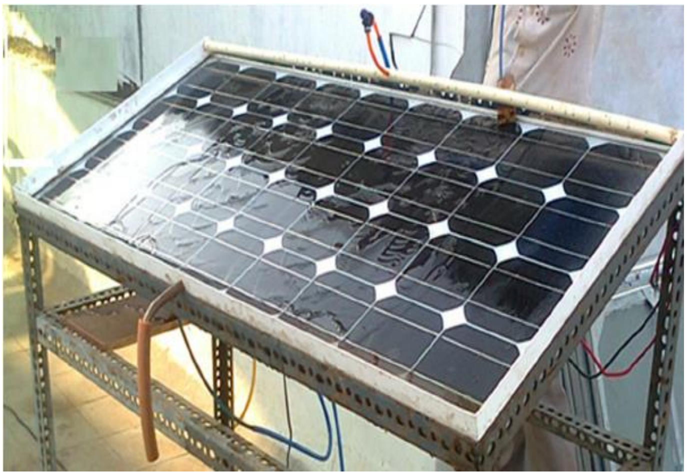


Figure 5 - PV Panel with Spray Water Cooling (S, O, & K, 2015)

2.2.4. Heat Pipe

A heat pipe is a passive cooling method. It uses the principles of phase change to remove heat from the PV Panel. It is made up of two sections an evaporator (PV panel) and a condenser. It is filled with a working fluid that absorbs heat in the evaporator section causing the fluid to vaporize, which then travels to the condenser where the heat dissipates and the fluid is condensed back to liquid (Anderson W, 2018). Figure 6 below shows a heat pipe cooling system.

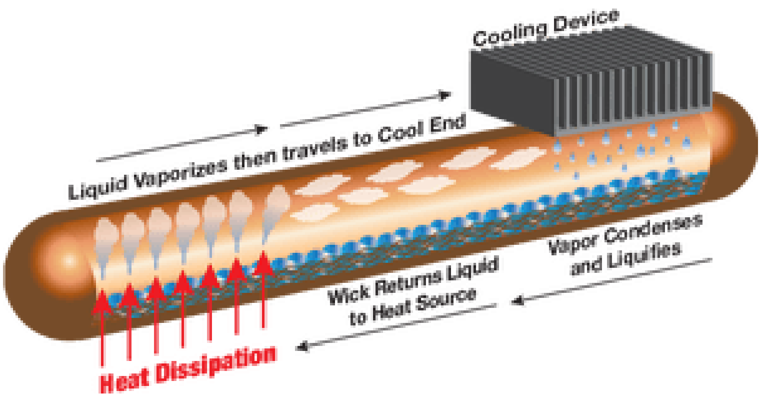


Figure 6 - Working Principles of Heat Pipe (Anderson W, 2018)

2.2.5. Immersion

Immersion is a passive cooling technique where the PV panel is submerged at an optimum depth in a liquid bath. Silicone oil or deionized water are two common cooling liquids used. Instead of a standard PV panel, a concentrated photovoltaic panel (CPV) must be used in its place. The surface of the CPV panel is kept cool by the surrounding fluid (S, P, M, & S, 2014). Figure 7 below shows a CPV submerged.

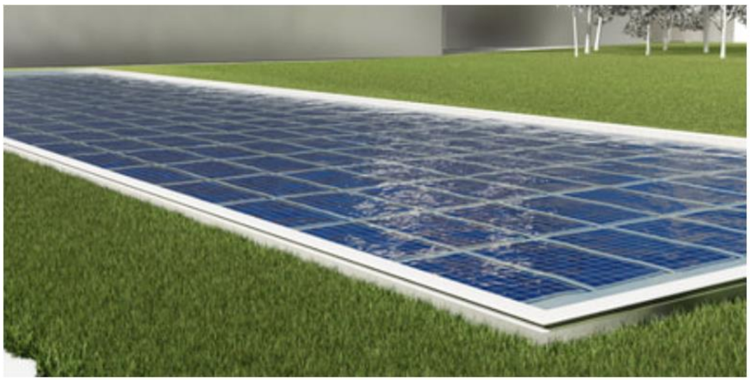


Figure 7 - Submerged PV Panels (S, P, M, & S, 2014)

2.2.6. Forced Convection

Forced convection is an active cooling method. A duct or series of ducts is constructed on the rear side of the PV panel to concentrate the air flow. An electric fan is fitted to the manifold and forces air over the panel. The increased air flow increases the rate of heat transfer due to convection (F, S, & T, 2015). Figure 8 below shows a PV panel being cooled via Forced Air Convection.

Figure 8 - PV Panel with Forced Air Convection (F, S, & T, 2015)

2.3. Comparisons of the Concurrent Solutions

Table 2 below compares the currently used solutions for cooling PV panels.

Table 2 - Tabular Comparison of Concurrent Solutions

Type	Pros	Cons
Heat Sink [a]	• Simple Design • High Thermal conductivity • Pre-made Heat Sinks Readily Available	• Difficult to Manufacture • Not as Effective When Ambient Temperature Is High • Expensive on a Large Scale
Phase Change Material [b]	• Simple Design • Relatively Cheap • High Heat of Fusion	• Availability • Can React with Other Materials • How the PCM is Packaged
Heat Pipe [c]	• High Thermal Conductivity • No Maintenance • Can be Used Over Wide Temperature Range	• More Complex Design • Materials Can be Expensive
Immersion [d]	• Simple Design • Increases Efficiency • No Degradation of PV Cells Due to Immersion	• Requires More Expensive CPV Panel • Loss of Cooling Liquid Due to Evaporation • Decreases Power Output
Forced Convection [e]	• Good Cooling Rate • Can be Combined with Heat Sink for Increased Convection Rate	• Requires Power to Run Fan • More Complex Design • Not as Effective When Ambient Temperature is High
Spray Water Cooling [f]	• Very Good Cooling Rate • Keeps PV Panel Clean • Can be Combined with Thermal Solar Panel to Produce Hot Water	• Requires Power to Run Pump • Wasteful of Water • More Complex Design

[a] (Y & A, 2015) [b](Microtek Laboratories Inc., 2017) [c] (S, O, & K, 2015). [d] (Anderson W, 2018)

[e] (S, P, M, & S, 2014) [f](F, S, & T, 2015).

In Table 2, the pros and cons of six different cooling methods are giving. Heat sink, phase change, heat pipe and immersion are passive cooling techniques whereas forced convection and spray water are active cooling. The passive cooling techniques are simpler and cheaper than the active cooling but are not always as effective. Spray water cooling increases the efficiency by the largest amount; however, the increased complexity of the system increases cost and some of the increased power output is needed to run the pump.

2.4. ENGINEERING STANDARDS OF THE CONCURRENT SOLUTIONS

Standards are an important part of engineering, serving as rules to measure or judge capacity, quantity, content, extent, value and quality. As solar energy is still an area in development, legislation and regulation of standards is also under development. Also, standards vary according to specific application and country. In this project the international standards will be used.

Main Standards are:

- **PV Panel**

  IEC, TC82: International Electrotechnical Commission

  The main tasks of TC82 are to prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy.

  ANSI: The American national standards institute**.**

- **Heat Pipe, Heat Sink and PCM Material**

  ASTM: The American Society for Testing Materials.

  AISC: The American Institute of Steel Construction.

  ASME: The American Society of Mechanical Engineers

- **Design and engineering drawing**

  ISO: International Organization for Standardization.

- **Safety**

  SELA: solar energy industries association.

  OSHA: The Occupational Safety and Health Administration.

CHAPTER 3

3. DESIGN AND ANALYSIS

This section will discuss the proposed designs of the HP-PV and PCM-PV systems. Engineering Standards regarding these designs will be investigated followed by design calculations for the best orientations of the solar panels throughout the year; HP-PV specific calculations and PCM-PV calculations. Lastly, this section will give a cost analysis for each of these systems.

3.1. Proposed Designs

3.1.1. PV Panels

The following three solar panels have been chosen to compare between them and choose the most suitable solar panel for the objectives and constraints of this project

A. Newpowa 30 Watts PV panel
B. TommaTech 40 Watts PV panel
C. HQST 30 Watts PV panel

Table 3 below are the characteristics that are being compared through for decision making:

Table 3 - Characteristics Comparison Between Solar Panels

	NEWPOWA	TOMMATECH	HQST
POWER OUTPUT	30W (good)	40W (better)	30W (good)
VOLTAGE	18.79V (good)	21.61V (good)	12V (bad)
SHORT CIRCUIT CURRENT	1.6 A (good)	2.38 A (better)	1.1 A (bad)
PRICE	50 USD (decent)	45 USD (better)	50 USD (decent)
WEIGHT	2.9Kg (good)	3.0Kg (decent)	3.2Kg (bad)
DIMENSIONS	(0.675x0.028x0.357) m (good)	(0.674x0.424x0.025) m (decent)	(0.66x0.05x0.38) m (good)

Given all the characteristics, the TommaTech 40 Watts PV panel was chosen due to it being the most suitable considering the price (one of the main constraints) and for it having a power output, weight and dimension better than the other two solar panels. Detailed electrical and mechanical characteristics of the PV panel are shown in G-1: PV Panel Specifications.

3.1.2. Proposed HP-PV System

The following figures (Figure 9 & Figure 10) show the proposed design of the HP-PV system.

<u>Finned HP-Saddle Cooling System</u>

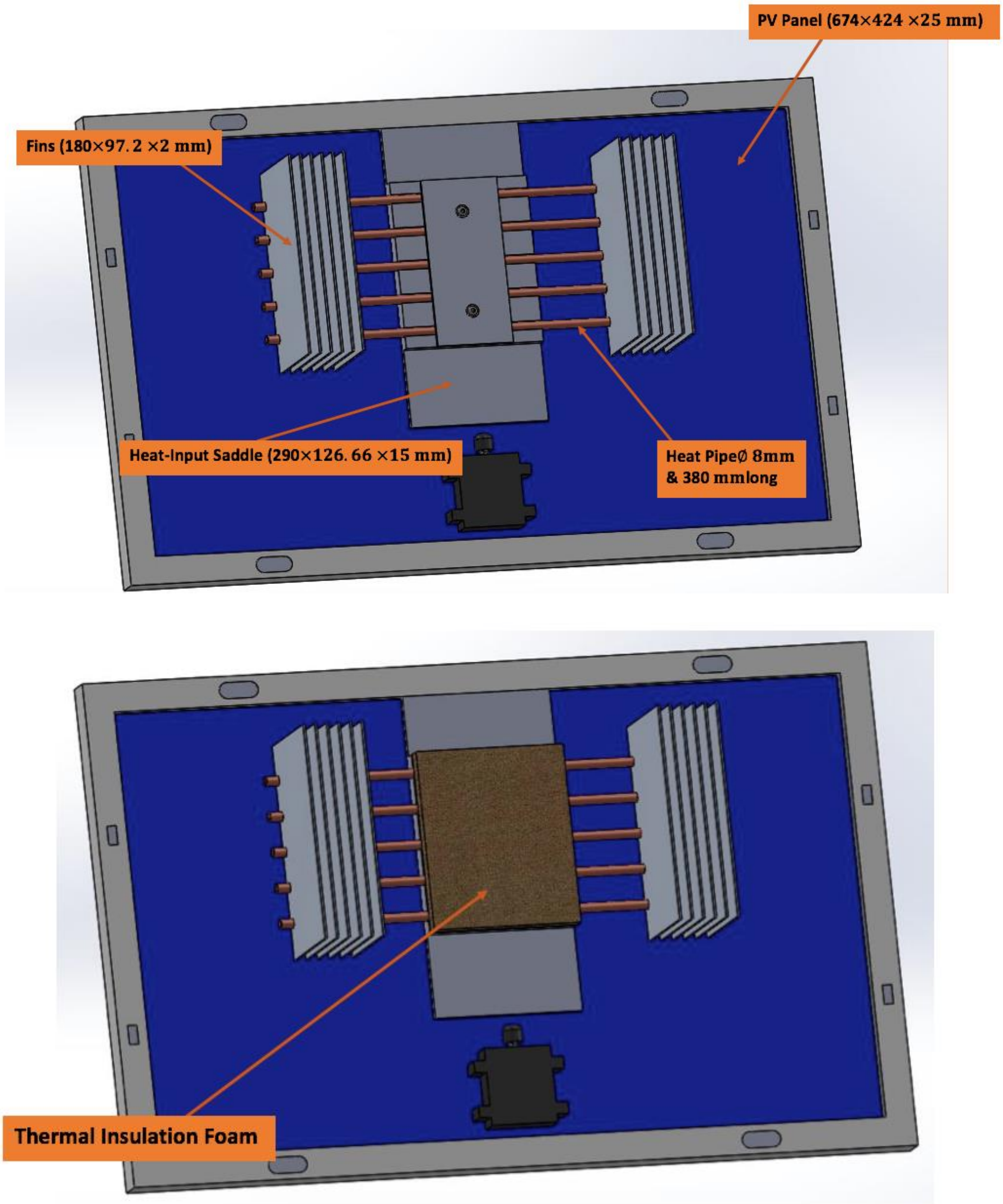


Figure 9 - Heat Pipe Cooling System Components

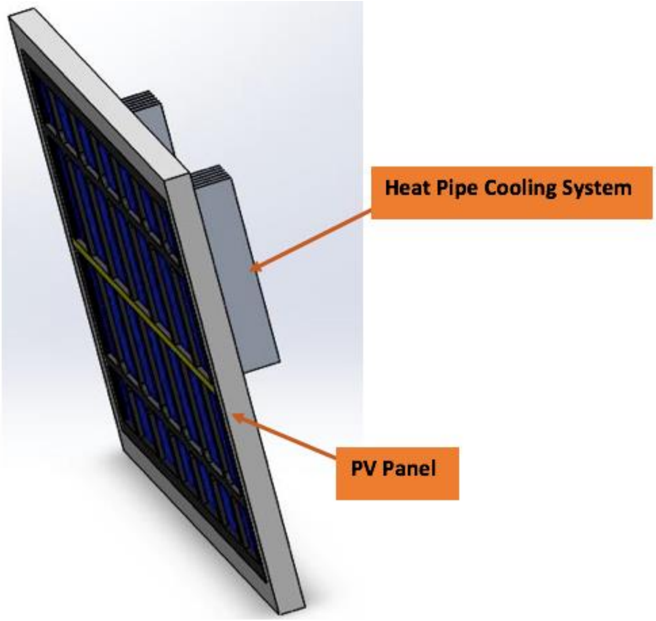


Figure 10 - Side view Of Heat Pipe Cooling System

3.1.2.1. Finned HP-Saddle Cooling System

This design consisting of Heat pipes, Fins and a Saddle was adapted from a previous scientific report by Hughes et al. (Hughes, Cherisa, & Bég, 2012). The design was tested out through ANSYS thermal simulation and was proven to be both feasible and efficient. Therefore, the following proposed design was created relatively similar to the previously tested design shown in Figure 11 & Figure 12 below.

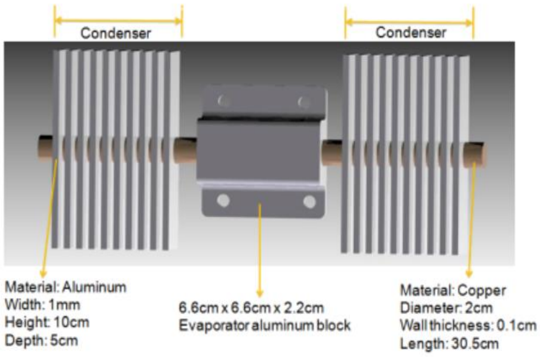


Figure 11 - Shows Previously tested Design (Hughes, Cherisa, & Bég, 2012)

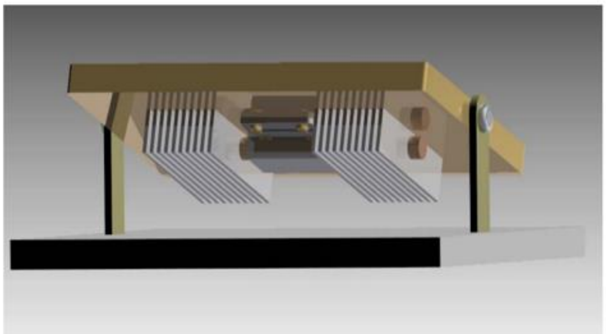


Figure 12 - Shows Previously test design attached to a Solar Panel (Hughes, Cherisa, & Bég, 2012)

3.1.2.2. Selection of Heat Pipe material, Diameter and Length

Based on the temperature range of interest, the two commonly used Heat pipes, namely

A. Aluminum Heat Pipe
B. Copper Heat Pipe

Table 4 - Heat Pipe Decision Matrix

Pipe Material	**Thermal Conductivity**	**Availability**	**Cost**	**Manufacturability**
Copper	Higher	High	Higher	off-the-shelf
Aluminum	Lower	High	Lower	off-the-shelf

Observing the decision matrix (Table 4), it can be seen that the copper and aluminum pipe are both suitable of the design but given that main criteria is the conduction of heat from the saddle and then the cost, **copper** is more suitable.

Depending on how much Heat is to be removed, the choice of diameter and length of the Heat Pipe can be very important. The diameter and length of the pipe can affect the heat transfer process drastically. The larger the diameter, the larger the amount of heat energy that can be transported through the Heat pipe. As the length of pipe increase, the amount of transferred heat decreases (Enertron, 2015). Figure 13 below shows relationship between the Heat pipe length and Heat transported for standard Heat Pipe diameters:

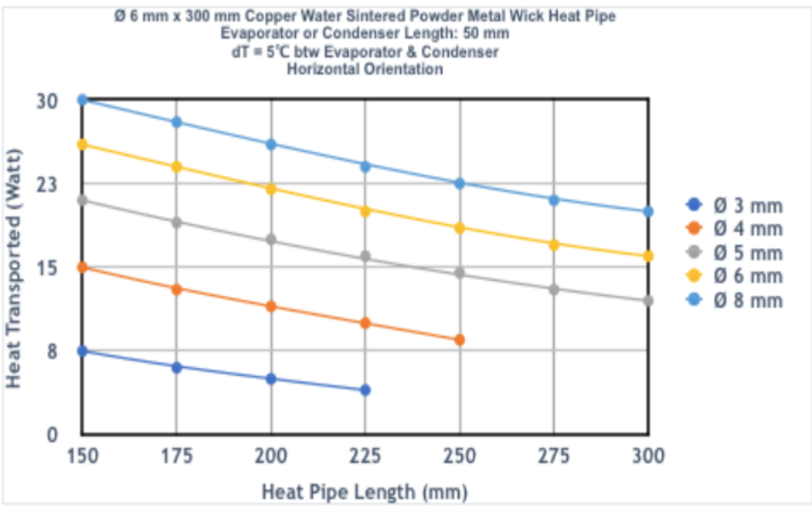


Figure 13 - Performance affect by Heat Pipe length and Diameter (Enertron, 2015)

Since the amount of heat to be removed from the PV panels is **246W** (evaluated in the Design Calculations section) choosing a large diameter Pipe will the more suitable and more economical instead of having many smaller diameter heat pipes to achieve the same task. Table 5 shows the selected heat pipe specification:

Table 5 – Selected Heat Pipe Specification (Conrad, 2019)

Category	Heat pipe
Type	QY-SHP-D8-380SA
Type	Sintered
Material	Copper , Water
Material properties	Anti-corrosive coating
Q_{max} at T_e (70 °C)	61 W
R_{th} (min.)	0.1 C/W
R_{th} (max.)	0.2 C/W
Fastener length (front end)	12 mm
Fastener length (tail end)	6 mm
Length	380 mm
(Ø)	8 mm
RoHS-compliant	Yes
R_{th}	0.10 - 0.20 C/W

Based on the above data and the required heat removal of **246W**, the desired configuration is a **5** Heat Pipe.

3.1.2.3. Selection of Saddle material

Table 6 – Saddle Decision Matrix

Pipe Material	**Thermal Conductivity**	**Density**	**Availability**	**Cost**	**Manufacturability**
Copper	Higher	High	Low	Higher	Difficult
Aluminum	Lower	Low	High	Lower	Easy

Although the thermal conductivity of copper is higher than Aluminum and would be more suitable for this application, given the large size of the saddle, the copper saddle will be heavier than Aluminum one. Raw aluminum is less expensive, more available and highly manufactural. Therefore, **Aluminum** will be chosen for the saddle. This can be seen in Table 6 above.

Moreover, Aluminum has many alloys and each alloy has varying properties. Choosing the Aluminum with the highest thermal conductivity is an important criterion. Table 7 compares the common types of Aluminum alloys and their thermal conductivities:

Table 7 – Saddle Decision Matrix: Material

	Aluminum 1100	Aluminum 6061	Aluminum 6063
Thermal Conductivity W/m-K	220	170	190

Comparing these alloys, it can be seen that **Aluminum 1100** has the highest thermal conductivity and would be the most suitable for the design purpose of extracting heat for the PV panels.

3.1.2.4. Selection of Wick structure and Material Fluid

There are mainly four types of wick structure:

1- Groove Wick

2- Sintered Wick

3- Screen Wick

4- Fiber Wick

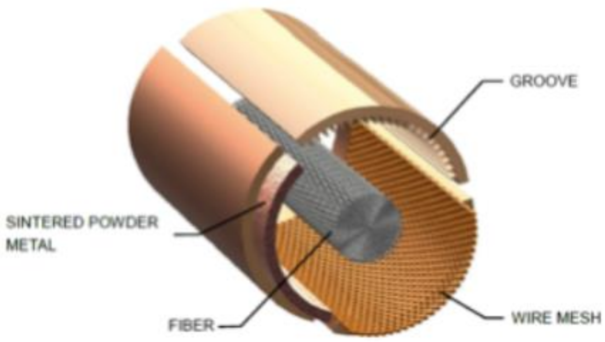


Figure 14 - The Four Types of Wick Structures (AMS Energy, 2018)

Table 8 - Advantages and Disadvantages of each wick structure adapted from (CELSIA, 2017) (Enertron, 2015)

WICK TYPE	ADVANTAGES	DISADVANTAGES
SINTERED WICK	- Commonly Used - Highest Capillary Force - Highly Available	- Most Expensive
SCREEN WICK	- Cheaper than Sintered Wick	- Lower Capillary Force than Sintered Wick
GROOVE WICK	- Cheapest Wick Structure	- Lowest Capillary Force
FIBER WICK	- Best for tight radius bends	- Only effective for Heat pipes with tight bends

Looking at the advantages and disadvantages of each wick structure in Table 8 above, the **Sintered Wick** structure is the best choice due to its highest capillary force and common use.

Figure 15 below shows the performance of Heat Pipes with different wick structures when in a Horizontal position which is the same orientation as the proposed Heat Pipe design. It can be seen that thermal resistance increases as the length of Heat Pipe increases for each wick structure. It can also be seen that the sintered Heat pipe has the best performance than other wick pipes, thus further proving that the sintered Heat pipe is the most suitable for the given Heat Pipe Design. The wick material will be copper due to its high availability with the purchase copper heat pipes.

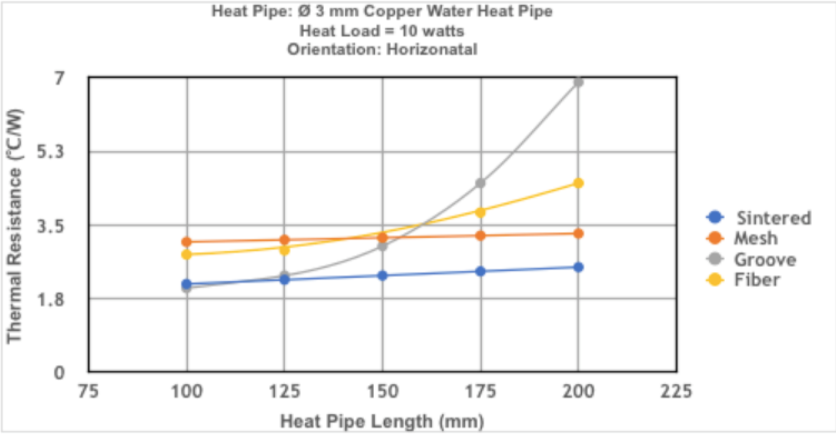


Figure 15 - Thermal Resistance Vs Heat Pipe length with different wick structure (Enertron, 2015)

3.1.2.5. Selection of Heat Pipe Working Fluid

The selection of the working fluid is very important as it will determine the system's efficiency and operation lifecycle. The selection depends on the two factors:

A. Operating conditions:

The operation conditions are temperature range which the fluid work within and for the design its between (**3**℃ to **45** ℃)**.** Figure 16 shows the Heat Pipe working fluids and at what temperature ranges they are useful.

Medium	Melting point (°C)	Boiling point at atmos. press. (°C)	Useful range (°C)
Helium	−271	−261	−271 to −269
Nitrogen	−210	−196	−203 to −160
Ammonia	−78	−33	−60 to 100
Pentane	−130	28	−20 to 120
Acetone	−95	57	0 to 120
Methanol	−98	64	10 to 130
Flutec PP2[1]	−50	76	10 to 160
Ethanol	−112	78	0 to 130
Heptane	−90	98	0 to 150
Water	0	100	30 to 200
Toluene	−95	110	50 to 200
Flutec PP9[1]	−70	160	0 to 225
Thermex[2]	12	257	150 to 350
Mercury	−39	361	250 to 650
Caesium	29	670	450 to 900
Potassium	62	774	500 to 1000
Sodium	98	892	600 to 1200
Lithium	179	1340	1000 to 1800
Silver	960	2212	1800 to 2300

Figure 16 - (Lee, 2010) *Heat Pipe Working Fluids*

Looking at the common working fluids used in Heat pipes, it can be seen that under the design operating conditions, the following fluids can be used:

a) Water
b) Ammonia
c) Methanol
d) Ethanol
e) Acetone

Although the useful range for water is (30℃ to 200℃) and the operation temperature 3℃, the system could warmup until the water heat pipe begins to operate (Anderson, Dussinger, Sarraf, & Tamanna, 2008).

B. Fluid compatibility with the copper pipe:

Based on previous surveys done by: Dunn and Reay (P.D & D.A, 1994), Brennan and Kroliczek (P.J & E.J, 1979), Anderson W.G (W.G, 2007) & (Anderson, Dussinger, Sarraf, & Tamanna, 2008) is that Copper Heat Pipes are compatible with the following fluids:

a) **Compatible with**: Water, Methanol and Ethanol
b) **Incompatible with**: Ammonia
c) **Unsuitable with**: Acetone

Previous research (Masaki, Masao, Ken-ichiro, Kenji, & Makoto, 2005) also showed that water has the highest capillary force compared with other compatible fluids. Figure 17 on the next page shows the wicking power (capillary force) of copper heat pipe with different working fluid combinations under different temperatures.

As mentioned before water is best working fluid in combination with the copper heat pipe under the system operating condition. Figure 17 below shows the wicking limit against the temperature.

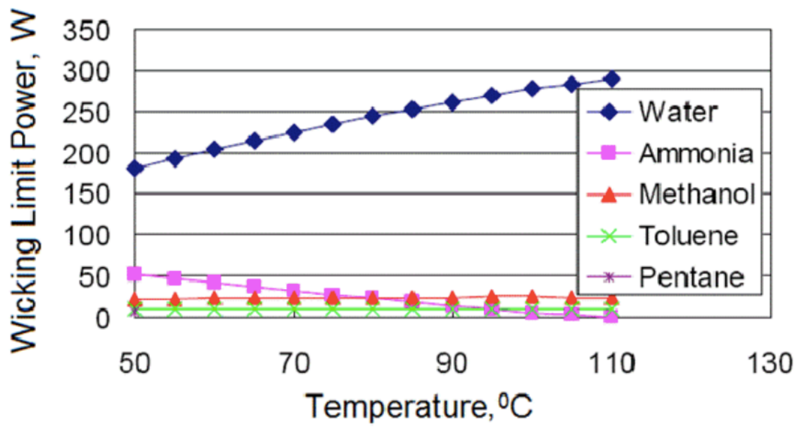


Figure 17 - Wicking Limit vs Temperature (Masaki, Masao, Ken-ichiro, Kenji, & Makoto, 2005)

3.1.2.6. Selection of Fins material

When it comes to fin material selection, the most important criteria the heat dissipation rate to the environment. The two common materials are Aluminum and Copper. Table 9 below compares them.

Table 9 - Fins Material Decision Matrix

Pipe Material	**Heat Dissipation**	**Availability**	**Cost**	**Manufacturability**
Copper	Higher	High	Higher	Easy
Aluminum	Lower	High	Lower	Easy

It can be seen that Heat Dissipation rate of aluminum is higher and more cost efficient. **Aluminum 1100** will be used for this design as it has been used before in similar experimentations as a fin material.

Table 10 below summaries the HP-PV System as disused until here.

Table 10 – HP-PV System Summary

Parameter	Value	Quantity
Heat Pipe		**5**
1. Heat Pipe Length	380 mm	-
2. Condenser or Evaporator	126.66 mm	-
3. Copper Heat Pipe Diameter	8 mm	-
Heat Input Saddle		**1**
4. Material	1100 Aluminum	-
5. Dimensions	$290mm \times 126.66mm \times 15mm$	-
Fins		**12**
6. Material	1100 Aluminum	-
7. Dimensions	$180mm \times 97.2mm \times 2mm$	-

3.1.3. Proposed PCM-PV System

The following figures (Figure 18-Figure 20) show the proposed design of the PCM-PV System.

FINNED PCM COOLING SYSTEM

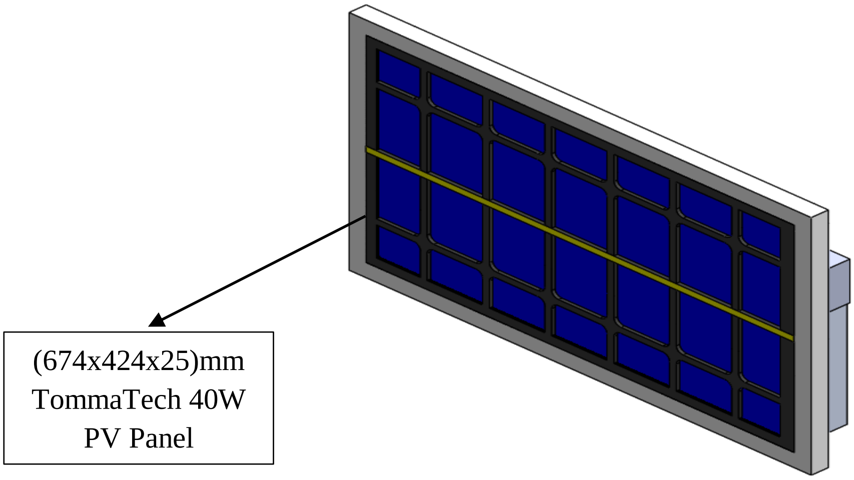


Figure 18 – PCM-PV System

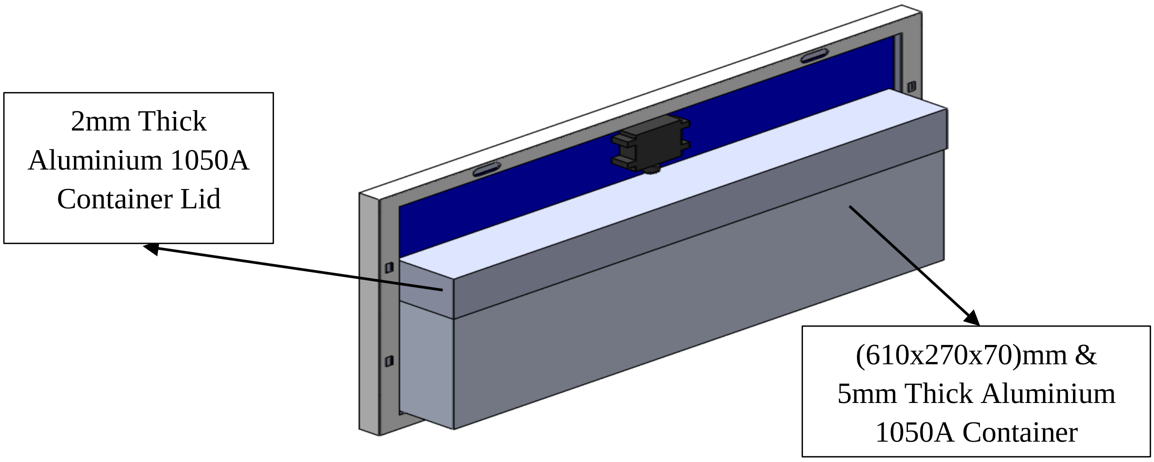


Figure 19 – PCM-PV System Container

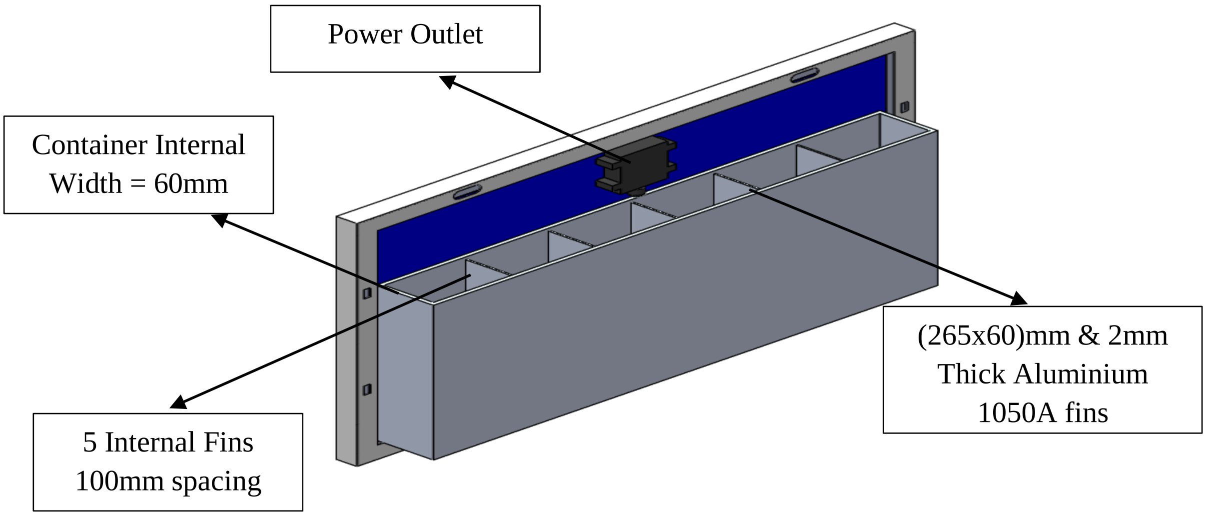


Figure 20 – PCM-PV System Internal Fins

3.1.3.1. PCM Selection

When selecting a PCM, the following is what governs the selection process. The PCM should:

A. Possess a melting point for the temperature range of application.

B. Possess high latent heat of fusion per unit mass, so that a smaller amount of material stores a larger amount of energy to be as effective as can be.

C. High specific heat to provide more heat storage pre and post melting.

D. High thermal conductivity, so that the temperature gradients for charging and discharging stored material are small.

E. Small volume changes during phase transition. This avoids usage of an excessively large container.

F. Possess chemical stability, no chemical decomposition and corrosion resistance to materials of containers or construction materials.

G. Contain non-poisonous, non-flammable and non-explosive elements/compounds.

H. Available in large quantities at low cost (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

25°C is the temperature that the STC power is measured (i.e. 30W for this panel), beyond this temperature, the panels begin to lose efficiency (Peacock, 2012). The rate at which efficiency is lost is given in the specifications of the panel. The Newpowa panel used in this project will lose 0.5±0.05% of its max power for every degree above 25 (see Appendix G-1: PV Panel Specifications). Therefore, it is obvious that a PCM lowering the panel's temperature close to 25ºC will mean better efficiency. Besides this, high latent heat is in a PCM is also desired for it can store more energy and for a longer time period. Table 11 shows the comparisons of different PCMs and selection of a PCM for this project.

Table 11 – PCM Selection

PCM	*Melting Temp*	*Latent Heat*	*Specific Heat*	*Density*	*Availability*
Ca chloride hexahydrate[a]	30ºC	$190\frac{kJ}{kg}$	$1.4\frac{kJ}{kg*K}$	$1710\frac{kg}{m^3}$	Ship from US
RT28HC[b]	28ºC	$250\frac{kJ}{kg}$	$2.0\frac{kJ}{kg*K}$	$770\frac{kg}{m^3}$	Min. 1 kg, Ship from Ger
RT25HC[b]	25ºC	$210\frac{kJ}{kg}$	$2.0\frac{kJ}{kg*K}$	$770\frac{kg}{m^3}$	Min. 1 kg, Ship from Ger
Paraffin PCM32[c]	32ºC	$185\frac{kJ}{kg}$	$1.8\frac{kJ}{kg*K}$	$780\frac{kg}{m^3}$	Min. 6 lb, Ship from US
Paraffin PCM28[c]	28ºC	$200\frac{kJ}{kg}$	$1.8\frac{kJ}{kg*K}$	$780\frac{kg}{m^3}$	Min. 6 lb, Ship from US

[a] (Hasan, McCormack, Huang, Sarwar, & Norton, 2014) [b] (Rubitherm, 2019) [c] (Microtek Labs, 2018).

The chosen PCM from the table is RT28HC. Details in Appendix G-2: Phase Change Material

3.1.3.2. PCM Container Design

Now that the PCM has been chosen based primarily on the temperature range of application, the next most important factors to consider are:

A. The geometry of the PCM container and
B. the thermal and geometric parameters of the container required for a given amount of PCM.

These factors are important to consider because they all have a direct influence on how heat is transferred in the PCM and ultimately also have an effect on the effectiveness of the PCM and the melt time thereof (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

Since the PV panel has a rectangular shape, it would be best for the container to have a rectangular shape as well. The size of the container should be one of closely the same cross-sectional area of the panel. The larger the area of the container in contact with the panel, the greater and faster the heat transfer will be from the PV panel to the PCM. The PV panel has back dimensions of 624mm x 376mm, the container's dimensions should as close to this as possible. The thickness of the container should be a modest thickness that will just be enough for the PCM required for this application (Zivkovic & Fujii, 2000). Figure 21 on the right shows the designed geometry of the PCM container.

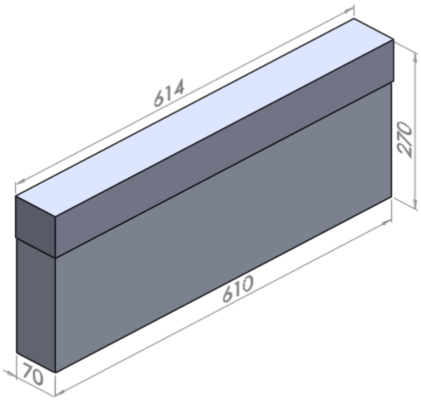


Figure 21 - Container Geometry

3.1.3.3. PCM Container Material

The material of the container is very important. This can either increase or decrease the latent heat storage (LHS) and/or increase or decrease the heat transfer rate of the PCM. An optimum container would be one of light weight, high thermal conductivity, non-corrosive, strong and will not react with the PCM. Some materials that meet these criteria are shown and compared in below adapted from (Ibrahima, Al-Sulaimana, Rahmana, Yilbasb, & Sahinb, 2017) for objectives of this project.

Table 12 - Container Material Selection

Material	*Thermal Conductivity* $(W/m*K)$	*Density* (kg/m^3)	*Estimated Cost* $(\$/m^3)$
Graphite Foil	150	1000	10,000.00
Aluminium	200	2700	7,000.00
Stainless Steel	20	7800	20,000.00
Carbon Steel	30	7800	15,000.00
Copper	350	8800	40,000.00

The selected material from this table is Aluminium. Aluminium Alloy 1050A with shown properties in Appendix G-3: Aluminium 1050A

3.1.3.4. Heat Transfer Enhancement

Organic and non-metallic based PCMs have low thermal conductivities requiring heat transfer enhancement techniques to improve their rates of charging and discharging of energy. Prior studies of investigating the use of PCM have reported poor thermal conductivity therefore requiring heat transfer enhancement. As a result, current studies implore methods such as fins, insertion/dispersion of high thermal conductivity materials, heat pipes and usage of multiple PCMs (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

Consequently, the low thermal conductivity leads to poor heat exchange between the PCM and the heat source and hence, the need for enhancement. As the geometry of the container is rectangular and it is made of aluminium, from the studies conducted by N.I. Ibrahim et al. (Ibrahima, Al-Sulaimana, Rahmana, Yilbasb, & Sahinb, 2017), the best heat transfer enhancement technique would be introducing fins. A summary of their study and their recommendations are attached in G–4: PCM Heat Transfer Enhancement.

3.1.3.5. Enhancement with Fins

Fins are generally used to increase the heat transfer area between PCM and heat source and consequently improve the thermal performance of heat storage or removal system. Selection of the fin material depends on its thermal conductivity, density, cost and corrosion potential. Since the container also depends on this, the same material will be used for the fins. The objective of the fins will be to increase the heat being transferred from the PV to the PCM, this will be done by increasing the heat removal from the PCM to the environment by increasing the area the PCM is in contact with. Therefore, the fins will be internally imbedded in the container. Fan et al. also reported that the presence of internal fins in PCM-based heat sink system provides better performance regardless of the type of PCM (Fan, Xiao, Zeng, & Fang, 2013). This leads to the final PCM container design with five internal fins, 2mm thick and 100mm equally spaced as shown in Figure 22 and Figure 23 below.

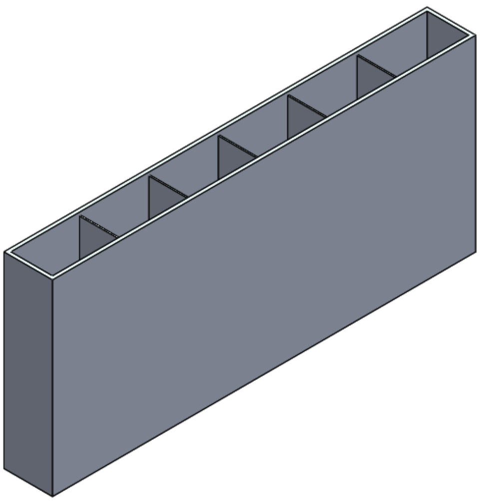


Figure 23 - PCM Container with Fins

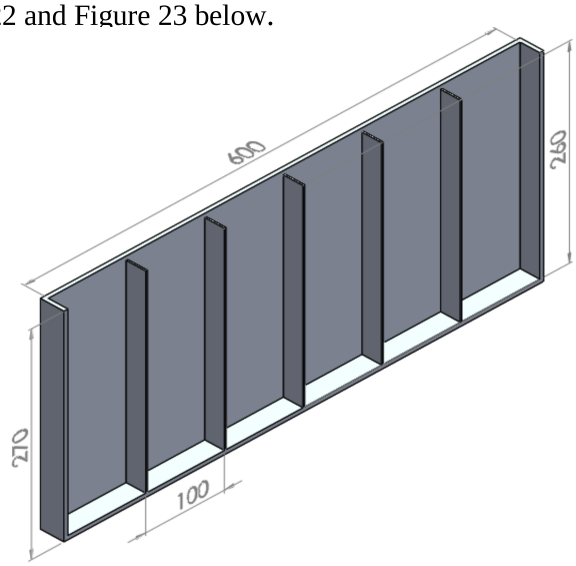


Figure 22 - PCM Container with Fins Section View

3.2. ENGINEERING STANDARDS

Throughout this project, General Workshop Safety rules were followed when carrying out mechanical related work which is explained in the Detailed Manufacturing Process Chapter.

3.2.1. PV Panels

IEC 62548:2016 sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions (IEC, 2018). See appendix for C-1: Solar Panel Standards for details

3.2.2. HP-PV System

The heat pipe is classed as an electric or electronic component and as such must not contain hazardous substances. The heat pipe to be used is RoHS compliant (EU Directive 2002/95/EC) (RoHS Guide Compiance, 2018), see Appendix C-2: HP-PV Standards, for data sheet of safe levels.

The material used in the saddle and fins is Aluminum 1100 must be capable of dissipating 211W of heat. Aluminum mechanical properties are covered by ASTM B209 - 14 (ASTM, 2014) see appendix C-2: HP-PV Standards for material data sheet.

Manufacturing of the heat pipe cooling system will take place in the mechanical engineering workshop. General safety and health in the workshop is covered by OSH Act 1970. (United States Department of Labor, 2018)

The mechanical engineering drawings used in the Heat Pipe Cooling System are to standard set according to (ISO 01.100.20) (International Orginization for Standardization, 2018)

3.2.3. PCM-PV System

The specific heat of Aluminium 1050A is 900 J $kg^{-1}.k^{-1}$, the thermal conductivity is 229 W $cm^{-1}.K^{-1}$, emissivity is 0.02 – 0.10 and the melting range is 645 -658 C (ASTM, 2014).

Alloy 1050 is excellent corrosion resistance, high ductility and highly reflective finish (ASTM, 2014).

The mechanical engineering drawings used in the Phase Change Material Cooling System are to standard set according to (ISO 01.100.20) (International Orginization for Standardization, 2018)

For welding of the PCM container, Arc-welded joints in Aluminium and its alloys: Quality levels for imperfections (ISO 10042:2005), Standard will be referred to.

There are no national and international standards for testing PCMs (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

3.3. Design Calculations

3.3.1. PV Panel Surface Temperature

The calculations carried out henceforth will be based on the following average temperatures displayed in Figure 24 below which were obtained from Cyprus Network (CyprusNet, 2018). The temperatures are based on an eight-year historical averages measured at Larnaca International airport which is 40 km away from Famagusta.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature	**12**	**12**	**14**	**17**	**22**	**26**	**27**	**28**	**26**	**22**	**17**	**14**
Avg. Max Temperature	17	17	19	22	27	31	32	32	31	28	23	18
Avg. Min Temperature	7	7	8	12	16	20	22	22	20	17	12	9
Avg. Rain Days	8	6	6	5	2	0	0	0	0	4	5	6

Figure 24 - Historical Average Temperatures (CyprusNet, 2018)

The Operating cell temperature of a PV Panel, $\boldsymbol{T_{cell}}$, is given by the following equation (Migan, 2013):

$$T_{cell} = T_{Air} + \frac{NOCT-20}{800} S \qquad (1)$$

- ❖ $\boldsymbol{T_{Air}}$, Ambient Air temperature.
- ❖ $\boldsymbol{NOCT}$, the nominal operating cell temperature that the PV surface reaches if it is exposed to 0.8 kW/m^2 of solar radiation, an ambient temperature of 20°C, and a wind speed of 1 m/s = 47°C
- ❖ $\boldsymbol{S}$, insolation level based on STC, Standard Testing Conditions (Niclas, 2014)= 1000 W/m^2.

Evaluating eq. 1, and using the temperatures in Figure 24 as $\boldsymbol{T_{Air}}$, the monthly average operating cell temperatures of the PV Panel were calculated and are shown in Figure 25 below:

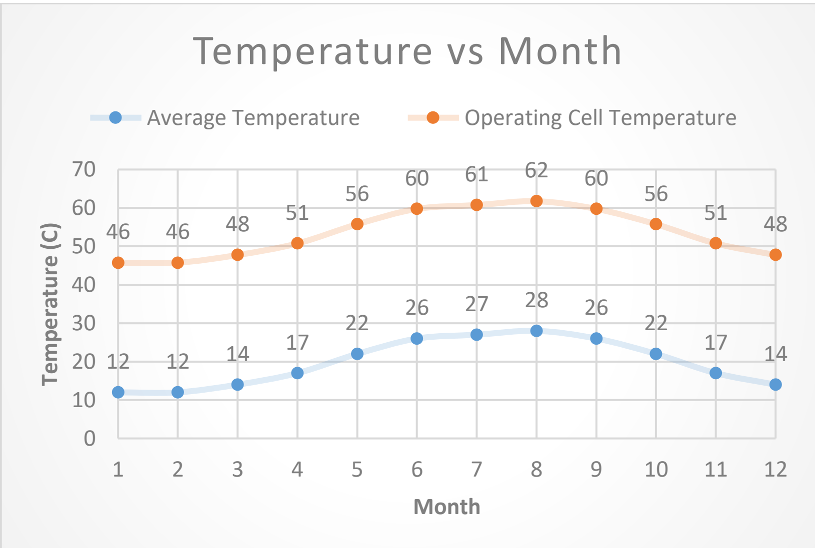


Figure 25 - Monthly Operating Cell Temperatures

3.3.2. PV Panel Specific Calculations

3.3.2.1. Optimum tilt for solar panels

The tilt of the solar panel has high significance, because the tilt allows the solar panel to capture more energy due to the increase of surface area of the solar panel being hit by the sun rays, rather that if the panel was vertical or horizontal to the surface, which in turn allow for more power generation, which means more electricity. The amount of tilt varies depending on the season due to the 23.5 degrees' tilt of the earth relative to the sun, so it is better to be able to change the tilt of the panel depending on the season, but if that is not possible, the optimum tilt angle for all year best performance is found by:

90° – location latitude = optimum fixed year-round setting (Boxwell, 2017).

Famagusta Coordinates = 35.2857° N, 33.8411° E

Therefore: 90 - 35.2857 = 54.7143 ≈ **55 degrees** referenced vertically.

3.3.2.2. Solar Panel Stand Design

Table 13 – Stand Dimensions

	Length (mm)	Quantity	Profile (mm)
Hypotenuse Legs	1200	2	30x30
Support Cross Bar	600	2	30x30
Joining Cross Bar	540	1	30x30
Hind Leg	664	2	30x30

Table 13 above shows the dimensions of the PV panel stand.

3.3.2.3. PV Panel Stand Analysis

After assembling the solar panel frame, analysis was done for the frame under the load of the PV Panels and the HP and PCM cooling system loads added respectively for the deformation of the frame. The total mass of the HP-PV system is about 6Kg and for the PCM-PV system is about 15Kg. The material of the stand is 30x30 mm Mild Steel bars. An important objective of the stand is to be able to support the heavy PCM and Aluminium container in the event that the glue fails to hold the system together.

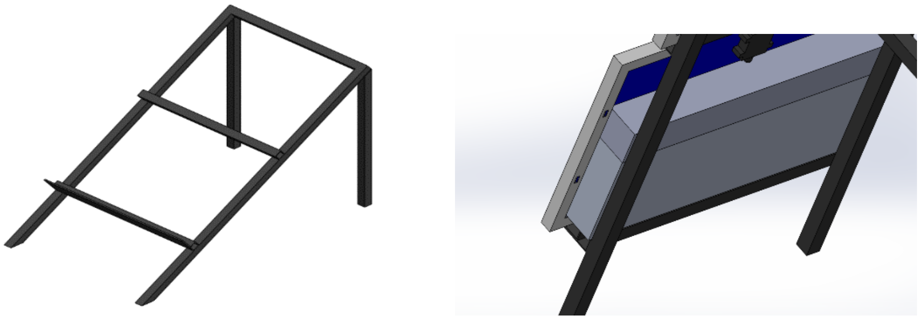


Figure 26 – PCM Container Support

3.3.2.4. PV Panel Efficiency

The following formula is utilized for the efficiency of the PV panel (RF Wireless World, 2017).

$$\eta_{PV\ Panel} = \frac{P_{max}}{S \times A_{Surface\ Area}} \times 100 \qquad (2)$$

Using the Insolation Level as $S = 1000\ W/m^2$ which is the standard testing value used at STC (Niclas, 2014).

$$\eta_{PV\ Panel} = \frac{40W}{1000\frac{W}{m^2} \times 0.286m^2} \times 100$$

$$\boldsymbol{\eta_{PV\ Panel} = 13.986\% \approx 14\%}$$

Therefore, the Maximum Efficiency of the TommaTech 40W PV Panel is 14%.

From the Catalogue, the Open-Circuit Voltage (V_{OC}) and the Short-Circuit Current (I_{SC}) are given as 21.61V and 2.38A respectively. Furthermore, the Voltage at Maximum Power (V_{MP}) and Current at Maximum Power (I_{MP}) are also given as 18V and 2.22A respectively. These values are then used in obtaining the Fill Factor (FF) which is the ratio of Maximum Obtainable Power to the product of the Open-Circuit Voltage and Short-Circuit Current (PV Education, 2019).

The graph below, Figure 27, shows where the where the FF is found, which is basically just the ratio of the Theoretical Power to the Maximum Power or how well the small rectangle fits in the big rectangle.

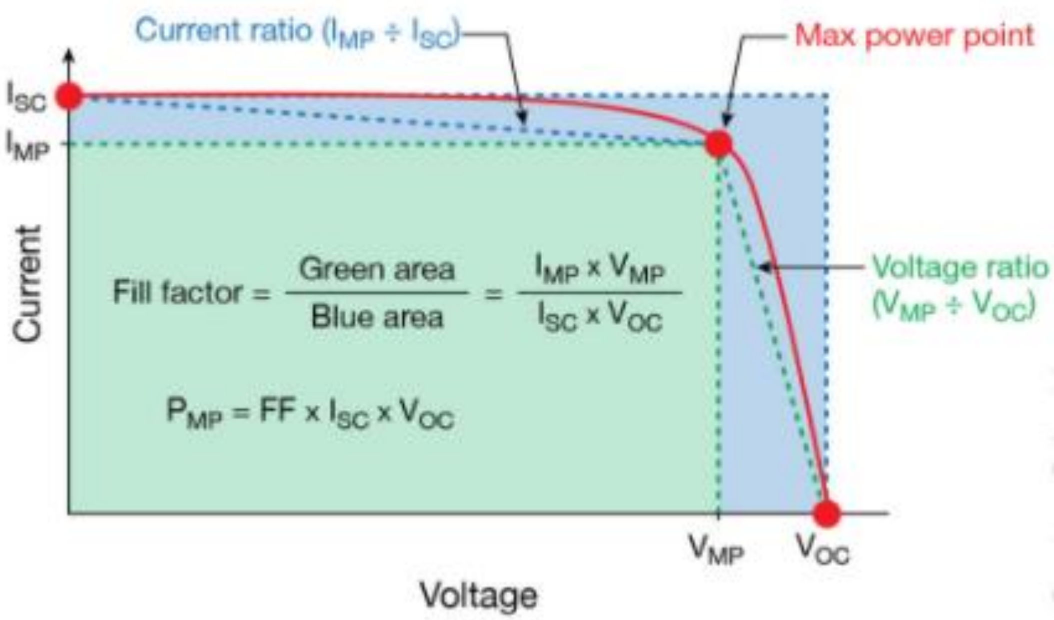


Figure 27 - Fill Factor (PV Education, 2019)

The formula for finding the Fill Factor is given by (PV Education, 2019):

$$FF = \frac{P_{MAX}}{V_{OC}I_{SC}} = \frac{V_{MP}I_{MP}}{V_{OC}I_{SC}} \tag{3}$$

$$\boldsymbol{FF} = \frac{18V * 2.22A}{21.61V * 2.38A} = 0.77695 = \mathbf{77.70}\%$$

With the Fill Factor known, it can be used to determine the efficiency of the PV Panel when only V_{OC} and the I_{SC} are known using equation 4 below (PV Education, 2019):

$$\eta = \frac{V_{OC}I_{SC}}{P_{IN}}FF \tag{4}$$

3.3.3. HP Specific Calculations

Only a portion of the absorbed energy by the PV Panels is converted to electricity and the rest of the energy must be extracted otherwise it will increase temperature of PV panels. The concentrated solar energy is delivered to the solar cell at up to 20 to $100\frac{\mathrm{W}}{\mathrm{cm}^2}$ (Anderson, Dussinger, Sarraf, & Tamanna, 2008).

For defining the performance of a PV cell, the concept of Standard Test Conditions (STC) is needed. The reference electrical power produced by a photovoltaic panel is defined for an intensity of solar radiation of 1000 W/m². A heat pipe cooling system was developed to remove the excess heat flux from the panels given the following parameters:

The amount Heat removed during cooling operation (Pollard, 2017):

$$Q_{Heat\ to\ be\ removed} = Q_{disspated\ from\ PV\ panel} = \left(S \times A_{Surface\ Area}\right) - Q_{Electric\ Power\ output} \tag{5}$$

- ❖ $\boldsymbol{S}$, insolation level $= 1000\ \frac{W}{m^2}$
- ❖ $\boldsymbol{A_{Surface\ Area}}$, is the surface area of the PV panel = Length × Width = 0.674 × 0.424=**0.286**$\boldsymbol{m^2}$
- ❖ $\boldsymbol{Q_{Electric\ Power\ output}} = 40W$

$$Q_{Heat\ to\ be\ removed} = 1000\frac{W}{m^2} * 0.286m^2 - 40W = 246\ W$$

Table 14 – HP-PV Cooling Requirements

Solar Panel Size	**0.674m × 0.424m**
$\boldsymbol{S}$ **, Insolation level**	$\mathbf{1000}\ \boldsymbol{W/m^2}$
Q Heat Removal During Operation	$\mathbf{246}\ \boldsymbol{W}$
Temperature range of Interest	3℃- 45 ℃

Estimation of Air Heat Transfer Coefficient using date from (Engineering ToolBox, 2003). Figure 28 on the right shows that at a wind speed of **3 m/s**, the Heat Transfer Coefficient is ≈ **23 *W/(m²K)***

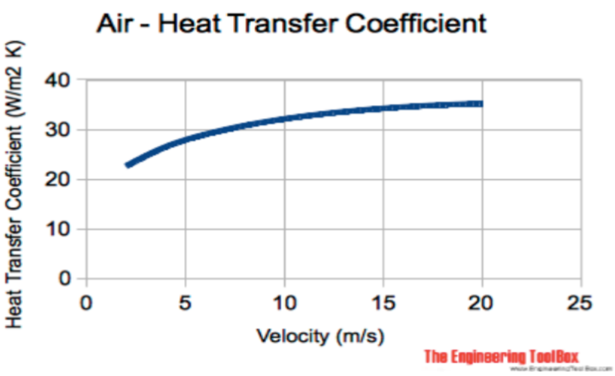


Figure 28 - Air Heat Transfer Coefficient and Air velocity relation (Engineering ToolBox, 2003)

3.3.3.1. Proper Fin Length Calculation:

Heat transfer drops exponentially as the length of the fin increases and beyond a certain length, the heat transfer goes to zero. Therefore, a proper fin length is to be calculated to avoid waste of material and excessive weight (CENGEL, 2002).

To Calculate the proper length of a fin, we compare heat transfer from a fin of finite length to heat transfer from an infinitely long fin under the same conditions. (CENGEL, 2002)

In practice, a fin length that corresponds to about $a\text{L} = 1$ will transfer **76.2 percent** of the heat that can be transferred by an infinitely long fin, and thus it should offer a good compromise between heat transfer performance and the fin size (CENGEL, 2002).

$$aL = 1$$

$$where,\ a = \sqrt{\frac{hp}{kA_c}}$$

$$L = \frac{1}{\sqrt{\frac{hp}{kA_c}}} = \frac{1}{\sqrt{\frac{23 \ \times 0.362}{220 \times 1.8 \times 10^{-4}}}} = 0.097263m = 97.263mm$$

Assumptions: Width $(\boldsymbol{w})$ & Thickness $(\boldsymbol{t})$ are 180mm and 2mm respectively

- $h = 23\ W/(m^2K)$
- $\text{A}_\text{c} = wt = 180 \times 2 \times 10^{-6} = 3.6 \times 10^{-4}\ m^2$
- $p = 2(w + t) = 2(0.180 + 0.002)\ 0.364\text{m}$
- $k = 220\text{W/m} - \text{K}$

Proper Fin Length, L = $\mathbf{0.097263m = 97.263mm}$

3.3.3.2. Fin Density Calculation:

By intuition, it would be better to have more fins per unit area, but in reality, this is not true. If the space between fins is too small it will decrease the heat dissipation rate, as the air won’t be able to flow within confined spaces and their won’t be enough area for each fin to radiate heat (Elliott, 2013).

Table 15 below provides a system to determine the optimum spacing between fins based on the fin’s length and wind speed.

Table 15 - Fins spacing vs Airflow and Fin length (Elliott, 2013)

Fin length (millimetres)	**75**	**150**	**225**	**300**
Airflow (metres / sec)	**Fin Spacing (mm)**			
Natural convection	6.5	7.5	10	13
1.0	4.0	5.0	6.0	7.0
2.5	2.5	3.3	4.0	5.0
5.0	2.0	2.5	3.0	3.5

Using the above data, it can be estimated that the optimum **Fin spacing ≥ 2.646mm** given an Airflow of 3m/s and **fin length of 97.2 mm.**

Heat transfer rate with no Fins attached to Heat Pipe

$A_{\text{no fin}}$, Area with No Fins attached shaded in yellow

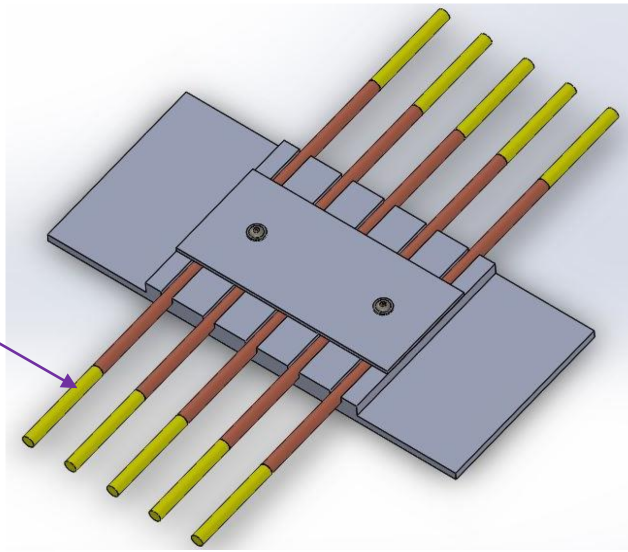


Figure 29 - Shows Shaded No fin Area

$$A_{\text{no fin}} = 4 \times 2\pi r L_{\text{condensor}} = 5 \times 2\pi \times 0.004 \times 0.12666 = 0.01591\ \text{m}^2$$

- $r = 0.004m$
- $L_{\text{condensor}} = 0.12666m$

$$\mathbf{A_{\text{no fin}} = 0.01591}$$

$\dot{Q}_{\text{no fin}} = hA_{\text{no fin}}(T_b - T_\infty) = 23 \times 70.01591 \times (65 - 30) = 12.812W$

- $h = 23\ W/(m^2K)$
- $T_b = 65°C$
- $T_\infty = 30°C$

$$\dot{Q}_{\text{no fin}} = 12.812W$$

Heat transfer rate with Fins attached to Heat Pipe

$A_{fin} = n2w\left(L + \frac{t}{2}\right) = 2 \times 0.18\left(0.097263 + \frac{2\times10^{-3}}{2}\right) = 0.03537m^2$

A_{fin}, Area of the Fin

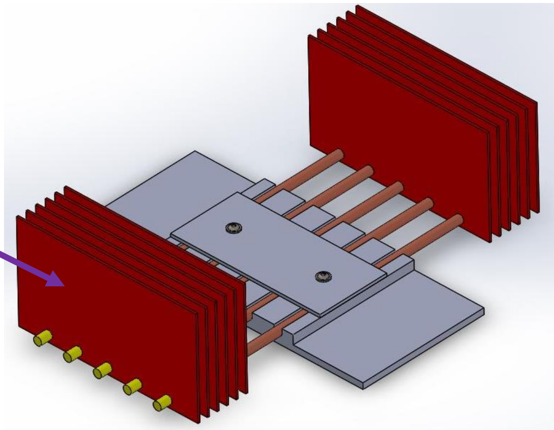


Figure 30 - Shows A_{fin} to be Calculated

- $L \approx 0.097263m$
- $w = 0.18m$
- $t = 2 \times 10^{-3}m$
- $n = 1$

$$A_{fin} = 0.03537m^2$$

Factor used to calculate fin effciency,ξ

$\xi = \left(L + \frac{t}{2}\right)\sqrt{\frac{h}{kt}} = \left(0.097263 + \frac{2\times10^{-3}}{2}\right)\sqrt{\frac{23}{220 \times 2\times10^{-3}}} = 0.710$

$$\xi = 0.710$$

Evaluated from Figure 31 on the next page.

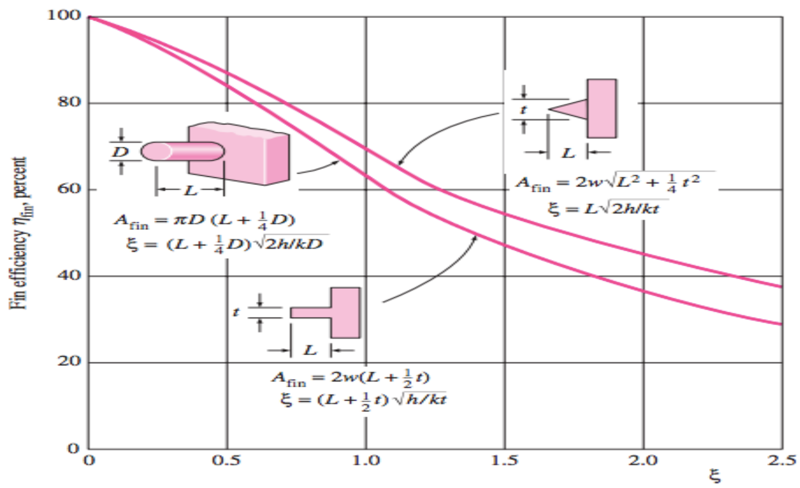
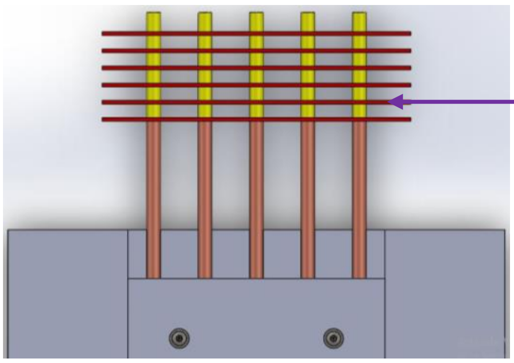


Figure 31 - Efficiency of circular, rectangular, and triangular fins (CENGEL, 2002)

Using the above data, $\boldsymbol{\eta_{fin} \approx 73\% = 0.73}$

$$n = \frac{\dot{Q}_{fin}}{\eta_{fin} h A_{fin} (T_b - T_\infty)} = \frac{246}{0.73 \times 23 \times 0.03537 \times (65-30)} = 11.835 \approx \mathbf{12}\ \boldsymbol{fins}$$

$$\mathbf{12}\ \boldsymbol{fins\ will\ be\ used}$$



$A_{unfinned}$, Area with No fin attached

Figure 32 - Shows Unfinned Area

$$\dot{Q}_{unfined} = hA_{Total\ unfinned}\,(T_b - T_\infty)$$

$$\dot{Q}_{unfined} = 23 \times (0.0129) \times (65 - 30) = \mathbf{10.385}\boldsymbol{W}$$

$$\dot{Q}_{unfined} = 10.385\mathrm{W}$$

$$\varepsilon_{fin\ overall} = \frac{\dot{Q}_{total\ fin}}{\dot{Q}_{no\ fin}} = \frac{\dot{Q}_{total\ fin}}{\dot{Q}_{no\ fin}} = \frac{\dot{Q}_{fin} + \dot{Q}_{unfined}}{\dot{Q}_{no\ fin}} = \frac{246 + 10.385}{12.812\mathrm{W}} = 20.01$$

$$\boldsymbol{\varepsilon_{fin\ overall} = 20.01}$$

3.3.4. PCM Specific Calculations

The mass of the Aluminium alloy container is found to be:

Aluminium Alloy 1050A has a density of $2700 \frac{kg}{m^3}$. The entire container will be a system that consist of an open top container, 5 internal fins and a lid to close the container. The complete closed system is shown in Figure 33 below with the fins already inside. Other than the container that was made from a 5mm thick sheet, the lid and the fins utilize a 2mm thick sheet.

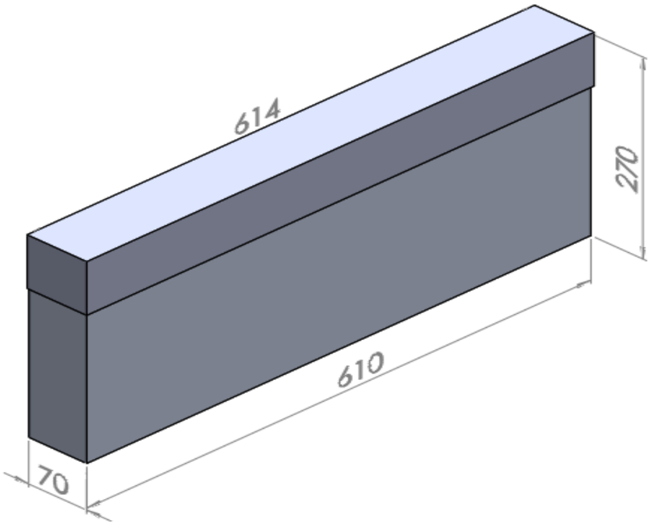


Figure 33 – Complete Container with Dimensions

By use of SolidWorks, the mass of the whole container was found to be:

$m = 5985.5\ grams \approx 6.00\ Kg$

The internal volume of the PCM container is found to be:

$V_{internal} = lbh = 0.600m * 0.060m * 0.265m = \ 0.00954m^3$

A gap of about 70mm will be dedicated at the top of the container for expansion as similarly done in other studies. Also, the container will have five fins, each 2mm thick, internally placed which makes the actual volume to be considered for the PCM to take up to be:

$V_{actual} = V_{internal} - V_{fins} - \ V_{gap}$

$V_{actual} = 0.00954m^3 - (5 * 0.002m * 0.060m * 0.260m) - (0.60m * 0.06m * 0.07)m$

$V_{actual} = 0.006864m^3$

This is the volume PCM the Container should hold. When phase change occurs and the solid changes and melts to a liquid, it expands by 12.5% because the density changes from $880 \frac{kg}{m^3}$ to $770 \frac{kg}{m^3}$.

$$V_{liquid} = 0.006864m^3 * \frac{112.5}{100} = 0.007722m^3$$

This proves to be less than $V_{internal}$. Therefore, the 70mm gap left at the top of the container is sufficient for this expansion. Using this volume and the density of the selected PCM in liquid form, the mass that the container will hold is found to be:

$$m = \rho V_{actual} = 770 \frac{kg}{m^3} * 0.007722m^3 = 5.945kg \approx 6kg\ PCM$$

The energy stored by the PCM is calculated as follows (Ibrahima, Al-Sulaimana, Rahmana, Yilbasb, & Sahinb, 2017):

$$Q_s = mc(T_{PV} - T_{amb}) \quad (6) \quad T_{amb} < T_{PV} < T_m$$

$$Q_s = mc(T_m - T_{amb}) + H \quad (7) \quad T_m \leqslant T_{PV} < T_m + \Delta T$$

$$Q_s = mc(T_m - T_{amb}) + H + mc(T_{PV} - T_m) \quad (8) \quad T_{PV} \geqslant T_m$$

Using equation 8 with $H = mL_{PCM}$, representing the Enthalpy of fusion, Table 16 below was formed

Where: $L_{PCM} = 250\, kJ/kg$ & $C = 2\, kJ/kgK$ from catalogue

Table 16 – PCM Heat Storage Capabilities

Month	Average Temperature (ºC)	Operating Cell Temperature (ºC)	PCM Heat Storage (kJ)
January	12	46	**2118**
February	12	46	**2118**
March	14	48	**2142**
April	17	51	**2178**
May	22	56	**2238**
June	26	60	**2286**
July	27	61	**2298**
August	28	62	**2310**
September	26	60	**2286**
October	22	56	**2238**
November	17	51	**2178**
December	14	48	**2142**

3.4. Cost Analysis

3.4.1. Bill of Materials

3.4.1.1. HP-PV System BOM

Table 17 Below shows how much was spent on the components and materials for the HP-PV System:

Table 17 – HP-PV System BOM

Bill of Material

Product: Heat Pipe-PV System	Date: 12th of May, 2019
Assembly: Sean Stevenson	

Item No	Drawing No	Part Name	Description	Quantity	Source	Cost (USD)
1	A-1-1	PV Panel	TommaTech 40W PV Panel	1	Gunes (TRNC)	45
2	C-1-1	Heat Pipe	8mm Round Copper Heat Pipe	3	Conrad (GER)	87
3	C-1-2	Fins	2mm Aluminum 1050A Material	0.36m x 0.60m	Halil Tozaki (TRNC)	-
Minimum Available Size of 2mm Aluminum 1050A Sheet				0.50m x 1.00m	Halil Tozaki (TRNC)	20
4	C-1-3	Saddle	15mm Aluminum 1050A Evaporator	0.127m x 0.29m	Halil Tozaki (TRNC)	-
Minimum Available Size of 15mm Aluminum 1050A Sheet				0.15m x 0.48m	Halil Tozaki (TRNC)	37
5	E-1-1	Thermal Paste	Thermal Conductive Paste	100ml	DigiTech (TRNC)	11

Total cost: 200 USD

	Prepared by: Sean Stevenson
	Checked by: Mpho Sothoane
	Approved by: Waddah Essamuldeen
	Page 1 /3

The Mechanical Design Process (Ullman, 2008) Designed by Professor David G. Ullman

Copyright 2008, McGraw Hill Form # 23.0

3.4.1.2. PCM-PV System BOM

Table 18 Below shows how much was spent on the components and materials for the PCM-PV System:

Table 18 – PCM-PV System BOM

Bill of Material

Product: Phase Change Material-PV System	Date: 12th of May, 2019
Assembly: Mpho Sothoane	

Item No	Drawing No	Part Name	Description	Quantity	Source	Cost (USD)
1	A-1-1	PV Panel	TommaTech 40W PV Panel	1	Gunes (TRNC)	45
2	D-1-1	Phase Change Material	RT 28 HC Wax PCM	6 kg	Rubitherm (GER)	72
3	D-1-2	PCM Container	5mm Aluminum 1050A Sheet	0.74m x 0.87m	Halil Tozaki (TRNC)	-
Minimum Available Size of 5mm Aluminum 1050A Sheet				1.00m x 1.00m	Halil Tozaki (TRNC)	125
4	D-1-3	Fins	2mm Aluminum 1050A Material	0.26m x 0.30m	Halil Tozaki (TRNC)	-
5	D-1-4	Container Lid	2mm Aluminum 1050A Material	0.10m x 0.66m	Halil Tozaki (TRNC)	-
Minimum Available Size of 2mm Aluminum 1050A Sheet				0.50m x 1.00m	Halil Tozaki (TRNC)	20

Total cost: 262 USD

	Prepared by: Mpho Sothoane
	Checked by: Sean Stevenson
	Approved by: Othiman Saeed
	Page 2/3

The Mechanical Design Process (Ullman, 2008) Designed by Professor David G. Ullman

Copyright 2008, McGraw Hill Form # 23.0

3.4.1.3. HP-PV & PCM-PV System Shared BOM

Table 19: Below shows how much was spent on the components and materials used for both the HP-PV & PCM-PV System

Table 19 - Shared BOM

Bill of Material

Product: HP-PV & PCM-PV System Shared Material	Date: 12th of May, 2019
Assembly: Mpho Sothoane	

Item No	Drawing No	Part Name	Description	Quantity	Source	Cost (USD)
1	B-1-1	PV Panel Stand Hypotenuse Legs	30mm x 30mm Mild Steel Profile	2.40m	İlkay M. Genç Ltd. (TRNC)	-
2	B-1-2	PV Panel Stand Hind Legs	30mm x 30mm Mild Steel Profile	1.328m	İlkay M. Genç Ltd. (TRNC)	-
3	B-1-3	PV Panel Stand Support Cross Bars	30mm x 30mm Mild Steel Profile	1.20m	İlkay M. Genç Ltd. (TRNC)	-
4	B-1-4	PV Panel Stand Joining Cross Bars	30mm x 30mm Mild Steel Profile	0.54m	İlkay M. Genç Ltd. (TRNC)	-
Minimum Available Size Mild Steel Profile				6.00m	İlkay M. Genç Ltd. (TRNC)	14
5	E-1-2	Epoxy Resin Glue	Adhesive Aluminium Glue	300ml	Arkadaş Ticaret (TRNC)	7
6	E-1-3	Alcohol	Clear Spirits	500ml	Arkadaş Ticaret (TRNC)	3
7	E-1-4	Spray Paint	Matt Black Canister	300ml	Arkadaş Ticaret (TRNC)	3

Total cost: 27 USD

	Prepared by: Mpho Sothoane	
	Checked by: Sean Stevenson	
	Approved by: Othiman Saeed	
		Page 3/3

The Mechanical Design Process (Ullman, 2008) Designed by Professor David G. Ullman

 Form # 23.0

3.4.2. Manufacturing and Handling Costs

3.4.2.1. PV Panel & Stand Costs

The PV Panels were bought from a local supply which eliminated shipping and any other handling costs. The PV Panel Stand could not be manufactured at the department's workshop because it was at capacity, therefore an independent manufacturer with cutting and welding equipment had to be sourced. Fabrication of the PV Stand costed 20 USD, thus bringing the total shared costs of the project to:

$$Cost_{Total\ Shared} = Cost_{Materials} + Cost_{\ Manu\&Handling} = 27 + 20 = 47\ USD$$

3.4.2.2. HP-PV System Costs

The PCM is was bought and shipped from Conrad, the German branch. Shipping from Conrad to Eastern Mediterranean University, North Cyprus, was via DHL postal service at a cost of 12 USD. All the manufacturing regarding the HP-PV system was done in the University's workshop and the Aluminium was sourced locally, thus eliminating any extra manufacturing Costs. This brings the total cost of the HP-PV system to:

$$Cost_{Total\ HP-PV} = Cost_{Materials} + Cost_{\ Manu\&Handling} = 200 + 12 = 212\ USD$$

The Pie-chart below (Figure 34) illustrates in detail the cost breakdown of the HP-PV system.

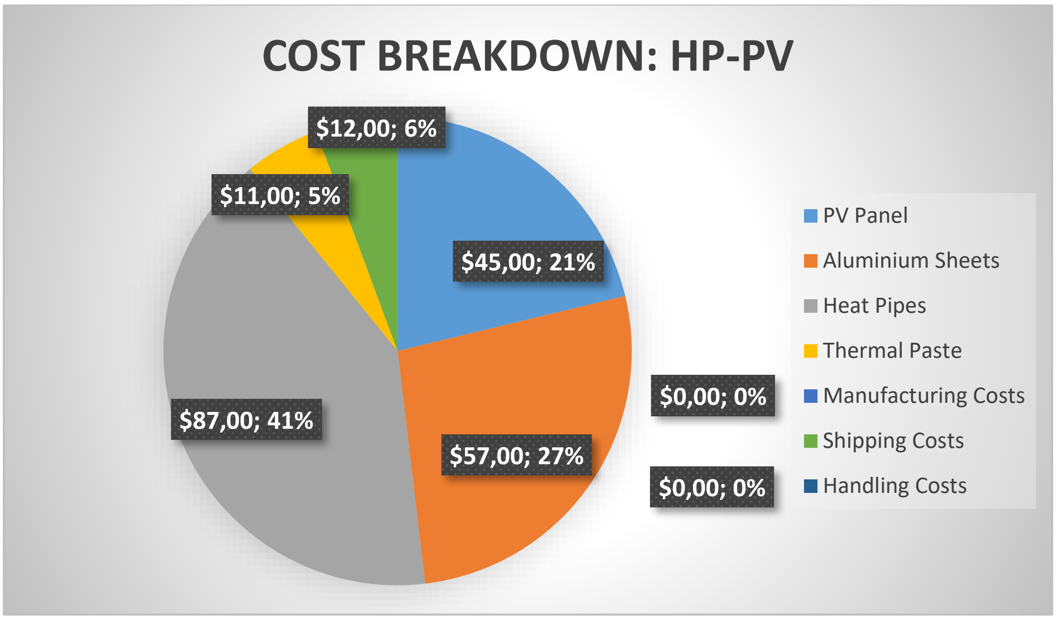


Figure 34 – Cost Breakdown: HP-PV System

The Heat Pipes Covered most of the costs as expected.

3.4.2.3. PCM-PV System Costs

The PCM is was bought and shipped from Rubitherm, a German company. Shipping from Germany to Eastern Mediterranean University, North Cyprus, was via DHL postal service at a cost of 40 USD. 6Kg of PCM was considered a small quantity for the company to manufacture, therefore, a surcharge of 47 USD was charged. Furthermore, a packaging charge of 5 USD was added to the PCM. This yielded to an expenditure of 175 USD for the PCM.

The PCM Container required TIG welding, equipment for this was not available at any of the University's workshops. Therefore, the welding was done at a private workshop with TIG welding equipment which costed 25 USD. Table 20 below shows the encountered costs:

Table 20 - PCM-PV System Manufacturing & Handling Costs

Part	Description	Cost (USD)
PCM	Shipping	40
	Surcharge	47
	Packaging	5
PCM Container	TIG Welding	25
Total PCM-PV System Manufacturing & Handling Costs		**117 USD**

Adding the Total Manufacturing and Handling Costs to the PCM-PV System BOM Costs determined in Table 18, the Total Cost of the PCM-PV system was found to be:

$$Cost_{Total\ PCM-PV} = Cost_{Materials} + Cost_{\ Manu\&Handling} \ = 262 + 117 = 379\ USD$$

The following Pie-Chart (Figure 35) shows the impact of several costs on the entire PCM-PV System where we see that the PCM only costed a fifth of the total system

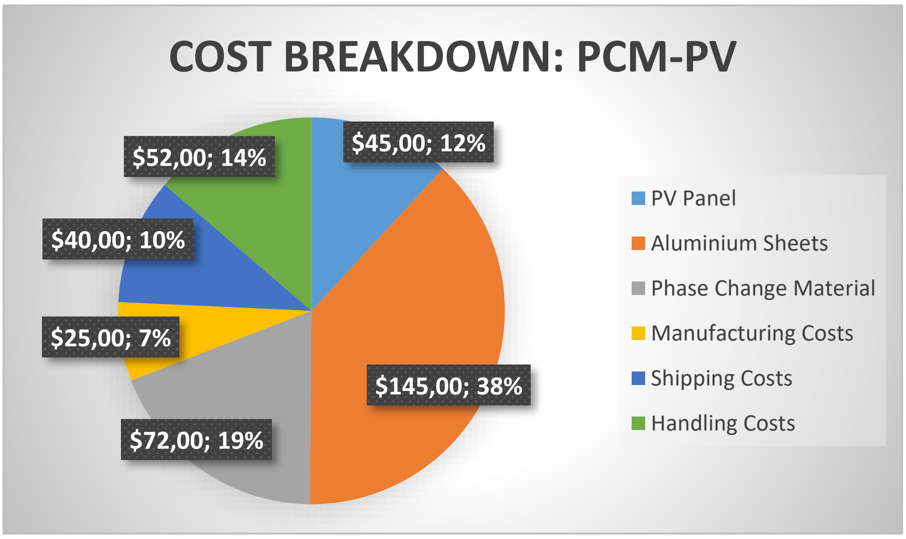


Figure 35 - Cost Breakdown: PCM-PV System

3.4.2.4. Total Project Cost

The total cost for the project was found to be:

$$Cost_{Total} = Cost_{HP-PV} + Cost_{PCM-PV} + Cost_{Shared} = 212 + 379 + 47 = 638\ USD$$

The following Pie-Chart (Figure 36) shows the weight and the total costs of each Cooling System as well as the costs shared amongst them respectively.

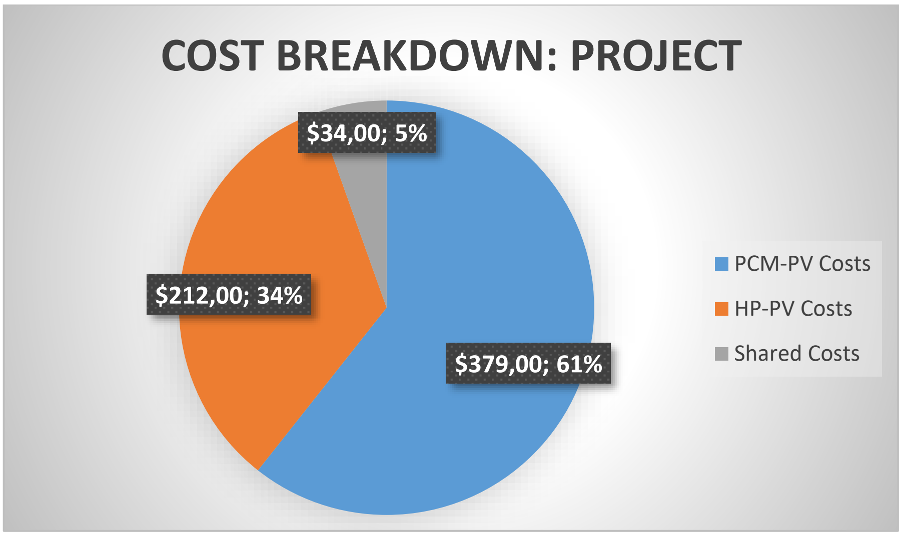


Figure 36 – Cost Breakdown: Project

It is seen that the PCM-PV system was where most of the project costs fell. Figure 37 below shows exactly where the costs fell in the following chart. This is used for later discussions.

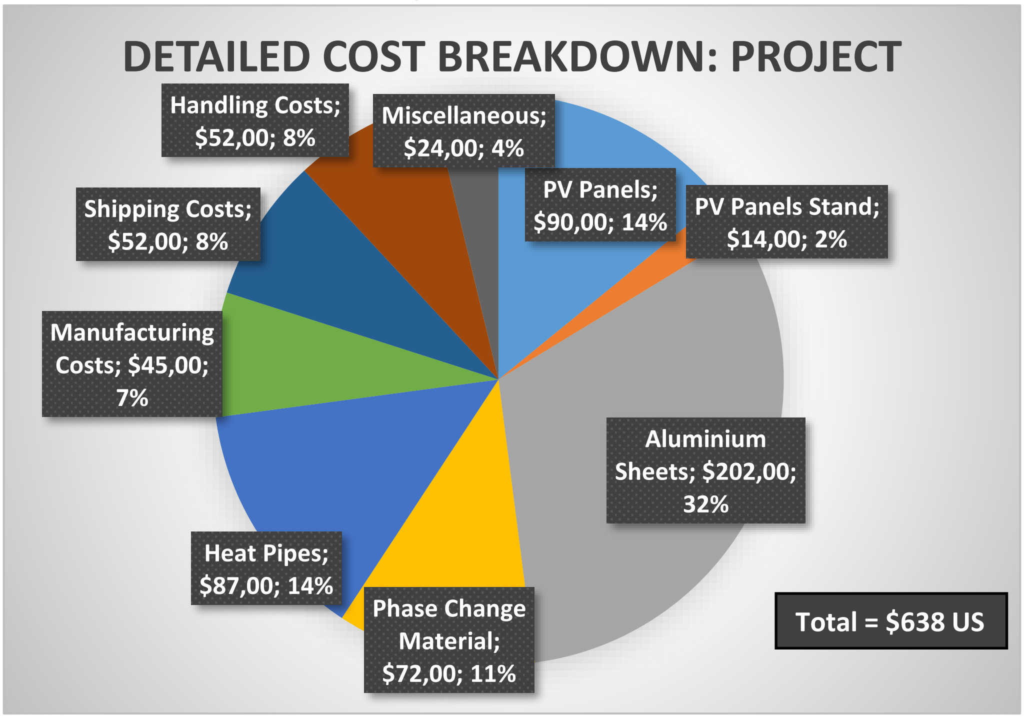


Figure 37 - Detail Cost Breakdown: Project

CHAPTER 4

4. MANUFACTURING

This chapter will discuss the manufacturing plans of the PV Panel stands; HP-PV system and PCM-PV systems. A Manufacturing process will be chosen for the stands and systems followed by detailed explanation of the selected processes. Lastly, this section will give an Assembly process for each system.

4.1. MANUFACTURING PROCESS SELECTION

According to Groover, a manufacturing process is a procedure designed to make physical changes to a starting work material with the intention of increasing the value of that material (Groover, 2010). For the purposes of this project, the value of the materials will be increased (Shaped) in a manner that will contribute to the project objectives be met. Manufacturing operations are divided into two basic types:

A. Processing operations
B. Assembly operations.

4.1.1. Solar Panel Stand Processing Operations

The material used for the PV panel stand is steel hollow 30x30 mm mild steel profiles. The stand was designed to have a 35^{o} angle referenced from the ground. A very simple design was opted for in order to ease manufacturing and have a low cost. Furthermore, a crucial objective for the stand was to provide support to the PCM-PV system that has a combined weight of 15Kg.

4.1.1.1. Manufacturing Process Selection:

There are two processes needed for manufacturing the stand as shown in Figure 38.

A. Cutting
B. Welding

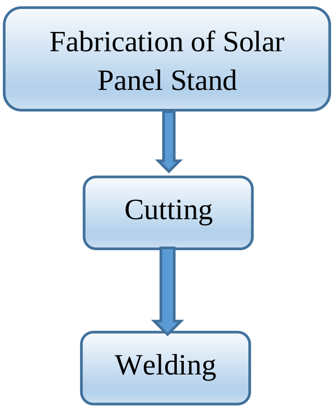


Figure 38 – PV Panel Stand Processing Flow Chart

4.1.2. HP-PV System Processing Operations

To manufacture the Aluminum Fins to the desired shape, a Cutting and Drilling process will be used. A raw Aluminum Block will go a through a Milling process to produce the wanted Saddle shape and then three holes will be drilled horizontally for the three Heat Pipes. The organogram below (Figure 39) summarizes the manufacturing processes used to produce the Heat Pipe Cooling System components:

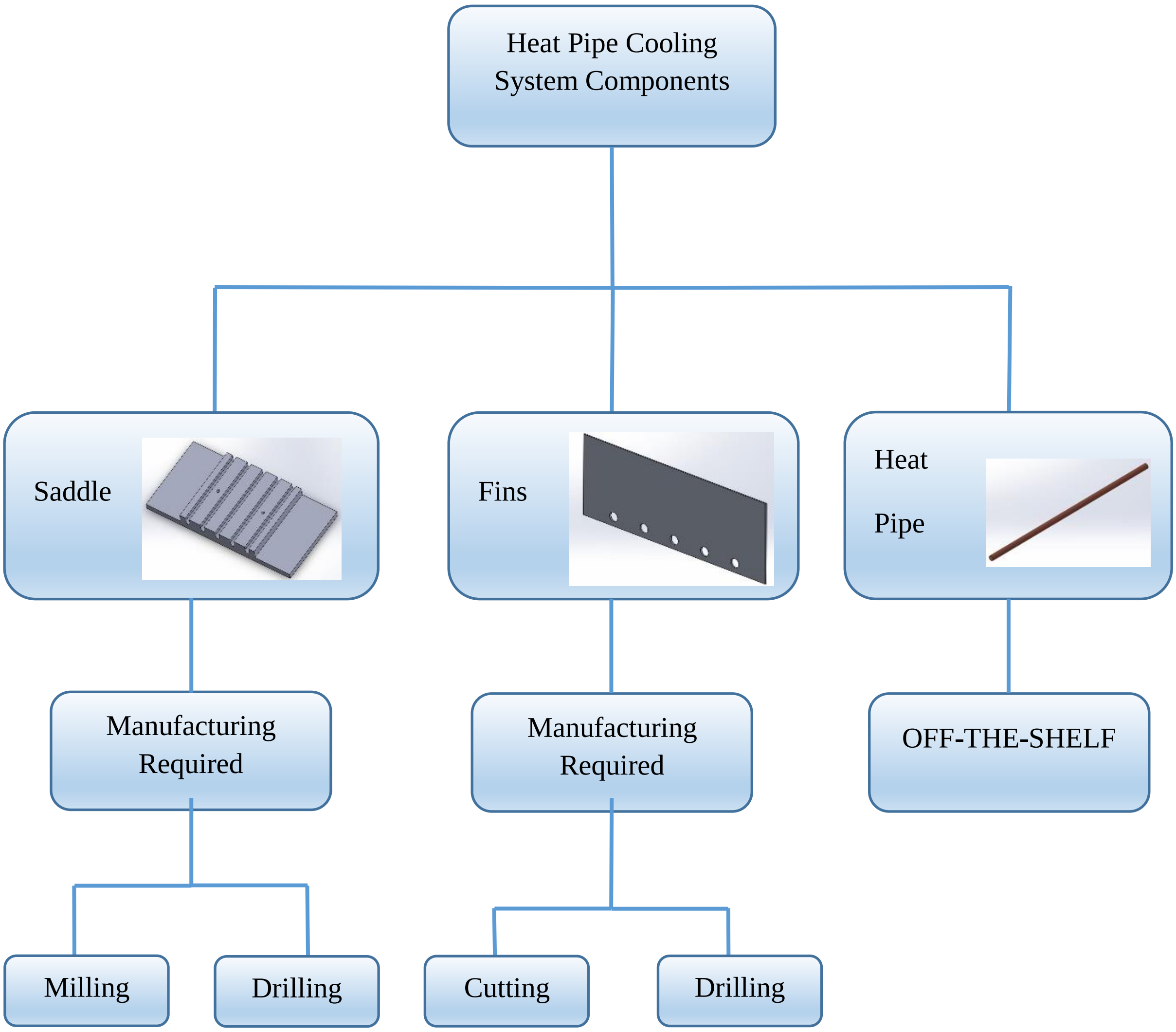


Figure 39 - HP-PV System Processing Organogram

4.1.3. PCM-PV System Processing Operations

To manufacture the Aluminum Container to desired shape, a cutting process followed by a bending and welding processes were used. To manufacture the Aluminum Fins to the desired shape, a Cutting process was used followed by a welding process. The organogram below (Figure 40) layouts the processing operation.

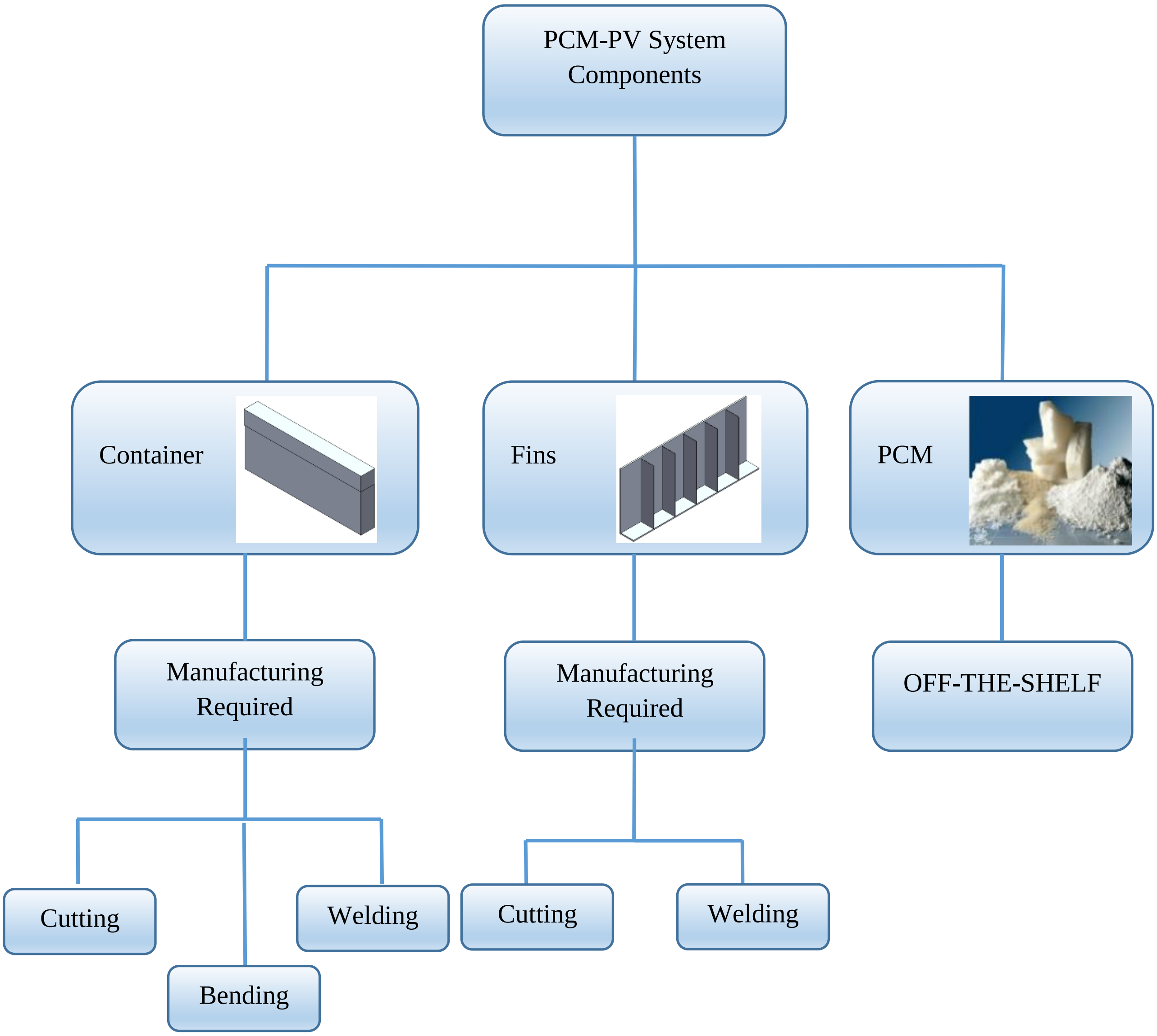


Figure 40 - PCM-PV System Processing Organogram

4.2. DETAILED MANUFACTURING PROCESS

4.2.1. PV Panel Stand Detailed Manufacturing Operations

Before beginning the manufacturing of the Stand, the overall lengths of the metal bars had to be summed up in order to know how much will be needed to complete the stand. Taking the lengths from Table 13 in section 3.3.2.2., the overall length of the metal profile needed is found to be:

$$Overall\ profile\ length = 2(1200) + 2(600) + 2(664) + 540 = 5468mm = 5.46m$$

A 6m profile was brought (standard available sizes) for manufacturing the stand. Since the Universities workshop was at capacity, the stand had to be manufactured at a privately-owned workshop. Below is detailed description of how the PV Panel stand was manufactured:

4.2.1.1. Metal Bars Cutting

Before cutting the 6m profile down to required sizes, they had to be marked down using a measuring tape and a pencil to make the markings as shown in the images below (Figure 41). Accuracy is important here in order to obtain a perfect 35º angle.

Figure 41 - Marking of Steel Profiles

After at the necessary markings were made of on the steel profile, the profile was cut down to size using a Chop saw as shown in the Figure 42 below:

Figure 42 - Chop Sawing

The last step before welding is to cut a 55º angle at the bottom of the hypotenuse legs so that they may make a 35º angle with the ground and to make a 35º angle at the top of the Hind legs where the Hypotenuse legs will join. This is shown in Figure 43 on the right:

Figure 43 - Legs Cut at an Angle

4.2.1.2. Arc Welding for PV Panel Stand

Once the profile has been cut down to appropriate sizes, welding commenced. For welding Mild Steel bars, Arc Welding was used. After marking off where each piece needed to be welded, the Cross Bars were welded onto the Hypotenuse Legs first and then all together welded onto the Hind Legs. Burs were removed using an angle grinder. The following images (Figure 44) show the welding sequence:

Figure 44 - Welding Sequence

4.2.1.3. Spray Painting

In order to protect the metal from corrosion and for aesthetic purposes, the stand was spray painted Matt Black. The spray-painting of the stand is shown in the figures below (Figure 45):

Figure 45 - Spray-Painting

4.2.2. HP-PV System Detailed Manufacturing Operations

4.2.2.1. Aluminum Fins

A. A **cutting** process was used to obtain the desired Aluminum Fin size. The process was to cut the raw Aluminum Sheets to the desired fin dimension of $180mm \times 97.2mm$. The dimensions were marked and drawn using a Scriber and Ruler on the raw Sheets. Afterwards, the marked lines were cut on the guillotine, then the desired fin size was achieved.

   The tools that were used during this process are:

   a) Scriber

   b) Steel Ruler

   c) Guillotine

B. The Second process was **drilling**, where the Heat pipe diameter size was drilled through the sheets. The first step was to locate the center of all the holes needed using the Scriber and Ruler. To make the center of the hole location more visible and to aid drilling the hole center was marked using a hammer and center punch. The fins were then secure in the machine vice on the pillar drill. The speed of the drill was set to the correct speed for an 8mm drill bit and the holes drilled. To finish the operation all burs and sharp edges were removed.

4.2.2.2. Heat Input Saddle

To manufacture the Saddle to the desired shape, a **milling** process was used. First the raw aluminum block was to its rough dimensions on a reciprocating saw. The milling process was started by securing the raw Aluminum block in the machine vice, that was secured to the milling table. Using an end mill the external dimensions of the saddle were cut. Next an 8mm slot mill was used to partially cut the slots where the heat pipe is located. A modified drill bit was used to cut the remaining metal from the slots. This created a rounded hole in the slots ensuring that the heat pipe was in good contact with the saddle to better ensure heat conduction. The final stage of manufacturing was to drill and tap 2 holes on the top of the saddle. Figure 46 below show some of the milling of the Heat Pipe slots operation.

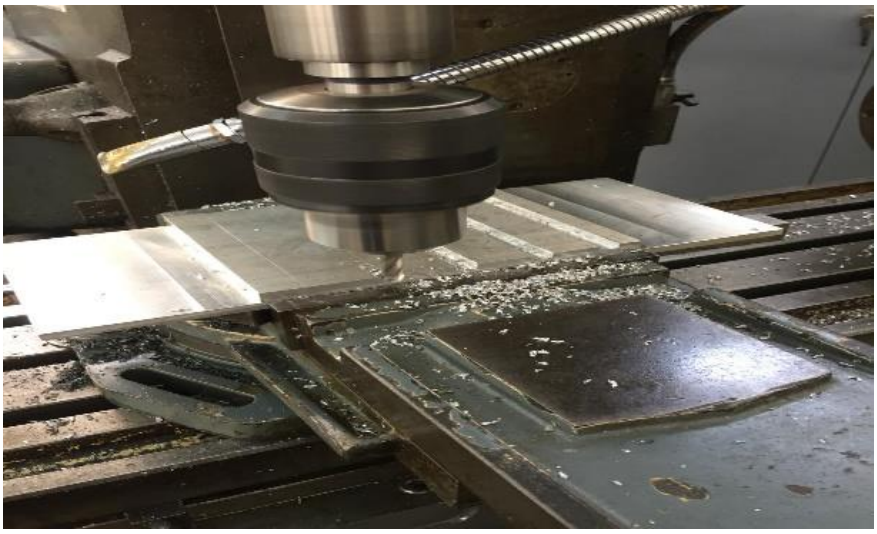


Figure 46 – Heat Pipe Slots

4.2.2.3. Inserting Heat Pipes

After the parts for the heat pipe had been manufactured it was then assembled. All of the parts were thoroughly cleaned with alcohol to remove any grease. A thermal paste compound was applied to the slots, this helped to ensure that all the air gap was filled that could affect thermal conduction as shown in Figure 47 below.

The heat pipes were then fitted into the slots, making sure that the evaporator and condenser sections were equal length. Next the heat pipes were secured in place by screwing an aluminum plate over the top of them. Then a section of insulation foam was glued over the condenser section of the heat pipe, this was to ensure that ambient heat was not transferred to the heat pipe. Next the aluminum fins were fitted on to the two evaporator sections of the heat pipe. The drilled holes on the fin were coated in thermal pastes and then slid on to the heat pipe.

Figure 47 - Thermal Paste in HP Slots

When the fins were accurately positioned, they were secured in place with epoxy glue. The final stage in assembly was to secure the assembled heat pipe to the PV-panel. The surface of the saddle was made rough using emery paper to make the glue stick better. The surface of the saddle and the PV-panel were cleaned using alcohol. Glue was applied to the entire surface of the saddled and then the pressed against the PV-panel as shown in Figure 48 below. The saddle was held under pressure from a Friday to Monday to ensure the glue set.

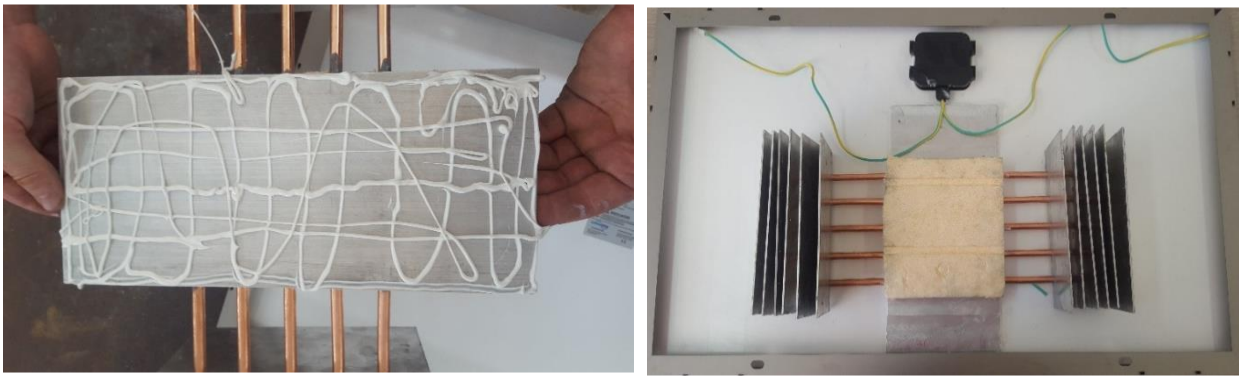


Figure 48 - Final Assembly Sequence

4.2.3. PCM-PV System Detailed Manufacturing Operations

4.2.3.1. PCM Container Cutting

The PCM container was fabricated from a 5mm Aluminum 1050A sheet. Ideally a 4mm sheet would be used for less weight however, only 4mm sheets were not available. Standard sizes of 5mm thick Aluminium 1050A sheets that were found was 1x1m sheets. One sheet was enough for the rectangular shaped container of dimensions 610mm x 270mm x 70mm. these dimensions of the container were finalized after measuring the back of the PV panel (meaning fabrication did not start until PV panels were delivered) as shown in the figures below (Figure 49).

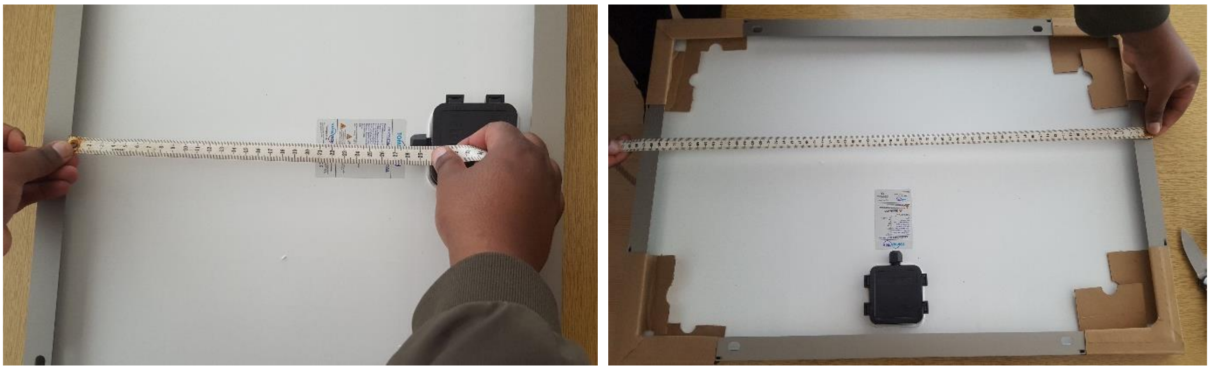


Figure 49 - Measurements of PV Panel's Back

The 1m x 1m Aluminium sheet was first cut down into two smaller sized sheets that would later be bent and welded together. The dimensions of the two smaller sized sheets are 610mm x 340mm and 740mm x 270mm respectively. This plate was cut using a Guillotine in one of the Universities larger workshops.

4.2.3.2. PCM Container Bending

After the smaller sized sheets were cut, they were then bent using a bending machine to form two counter parts (L and U shaped) to be welded together later as shown in the figures below (Figure 50)

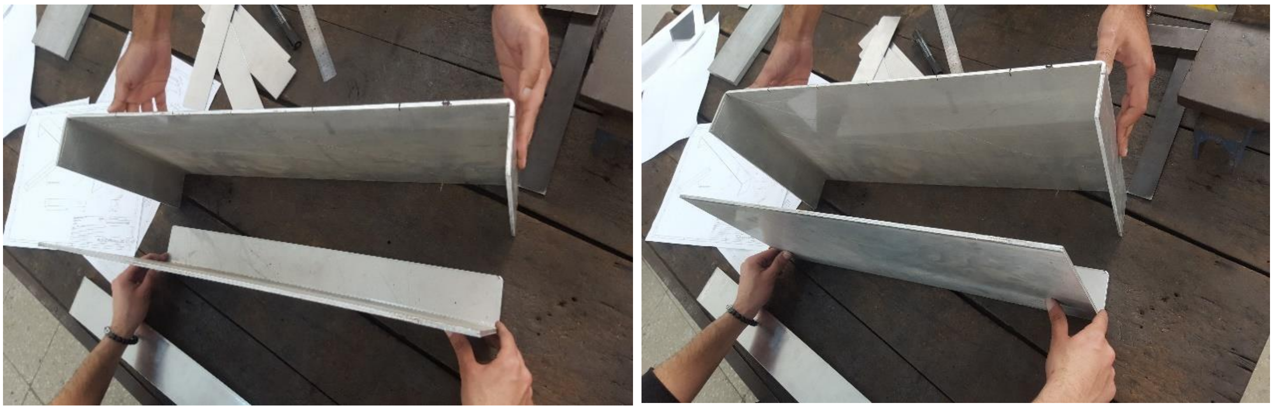


Figure 50 - Aluminium Sheets Post Bending

4.2.3.3. PCM Container Fins and Lid Cutting

The PCM-PV system Fins and PCM container lid were all manufactured from a 2mm thick sheet Aluminium 1050A sheet. Sheets were only sold in standard sizes of 1m x 1m, this was more than enough for five PCM fins of dimensions 265mm x 60mm as well as the lid which was fabricated from a 660mm x 70mm sheet bent at the edges to form a U-shape to fit on top of the container. The rest of the sheet was utilized in the HP-PV system. The fins and lid where cut simultaneously with the 5mm Aluminium sheet for the container in the larger university workshop. The figures below (Figure 52, Figure 53 and Figure 51) show the fins and lid:

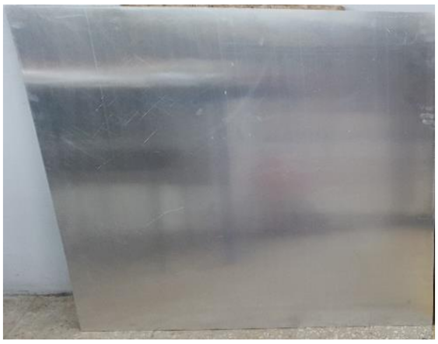


Figure 52 - 2mm Thick Al Sheet

Figure 53 - Container Lid

Figure 51 - PCM Fins

4.2.3.4. PCM Container TIG Welding

Once all sheets for the container and fins had been cut down to their respective sizes and bent into counterparts were necessary, welding was ready to commence. Before welding, it is crucial to double check all dimensions and mark of where certain parts need to be placed. 100mm spacing was marked inside the container to indicate where the fins need to be placed as shown in Figure 54 below:

Figure 54 - Fins Marking

TIG welding equipment was not available at any of the university’s workshops, therefore the welding had to be outsourced to a private company. The fins only required a spot weld to hold them in place (one at the top and another at the bottom), however the container had to be leak proof therefore, it had to be welded all around. The following figures (Figure 55) show the container post welding:

Figure 55 - PCM Container Post Welding

4.2.3.5. PCM Preparations

Once the container was ready, the PCM could be inserted. The PCM however was already in a solid state and needed to be melted in order to be able to extract it fully from its packaging. The PCM was melted by keeping it submerged in a bath of hot water. A large Plastic bath was used to hold the water and the water was heated using a 3 kW element. Once the water reached temperatures of around 50^{o}C to 60^{o}C (temperature of PCM not to be exceeded monitored with a thermometer), the PCM was held placed in the water until enough of it melted and poured out into the Aluminium container. This procedure was repeated several times until the 6 kg PCM had completely melted and took roughly 4-5 hours. After all the PCM had been melted and inserted into the Aluminum container, the system was left in a cool area to allow for PCM solidification overnight. The following figures (Figure 56 - Figure 59) show the processes which were all carried out in the Thermal Sciences Laboratory. Figure 56 below shows the PCM in raw material whilst solid, before the melting procedure commenced.

Figure 56 - RT 28 HC PCM

The melting procedure consisted of heating the water with an electrical element, using a thermometer to measure the water temp and lastly submerging the PCM in the water as shown in Figure 57 below.

Figure 57 - Melting PCM Procedure

Once the PCM was already melted, it was poured into the container as shown in Figure 58 below.

Figure 58 - Pouring PCM into Container

Figure 59 below shows the PCM in the container already solidified a day after being left in a cool spot.

Figure 59 - Solidified PCM a Day Later

4.2.3.6. Attaching Container to PV

Once the PCM was inside the container and had solidified, the lid was permanently fixed onto the container by means of using Sealant Silicon and left for a few hours for the Silicon to dry. The PCM system was now ready to be attached to the back of the PV panel. In order to get a good and adhesive bond, the container side to stick to the PV panel was sanded to roughen the surface. Before applying the Aluminium glue, the container and the back of the PV panel needed to be thoroughly cleaned using Alcohol. Glue was applied all over the container surface and attached to the back of the PV Panel. This assembly was left to at constant pressure from a Friday to a Monday to alloy for enough settling time. These procedures were also followed by Hassan et al (Hasan, McCormaack, Huang, Sawar, & Norton, 2015). The following figures (Figure 61 and Figure 60) show the last procedures of the PCM-PV system:

Figure 61 - Sanding of Container Surface

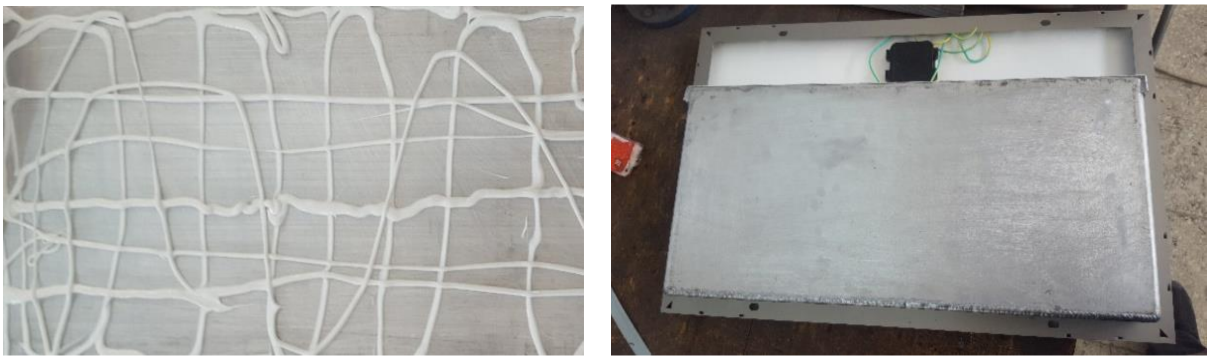


Figure 60 – Final Assembly Sequence

4.3. Assembly Processes

4.3.1. HP-PV System Assembly Operations

After all the parts had been purchased and manufactured, they were assembled as illustrated in the following figures (Figure 62).

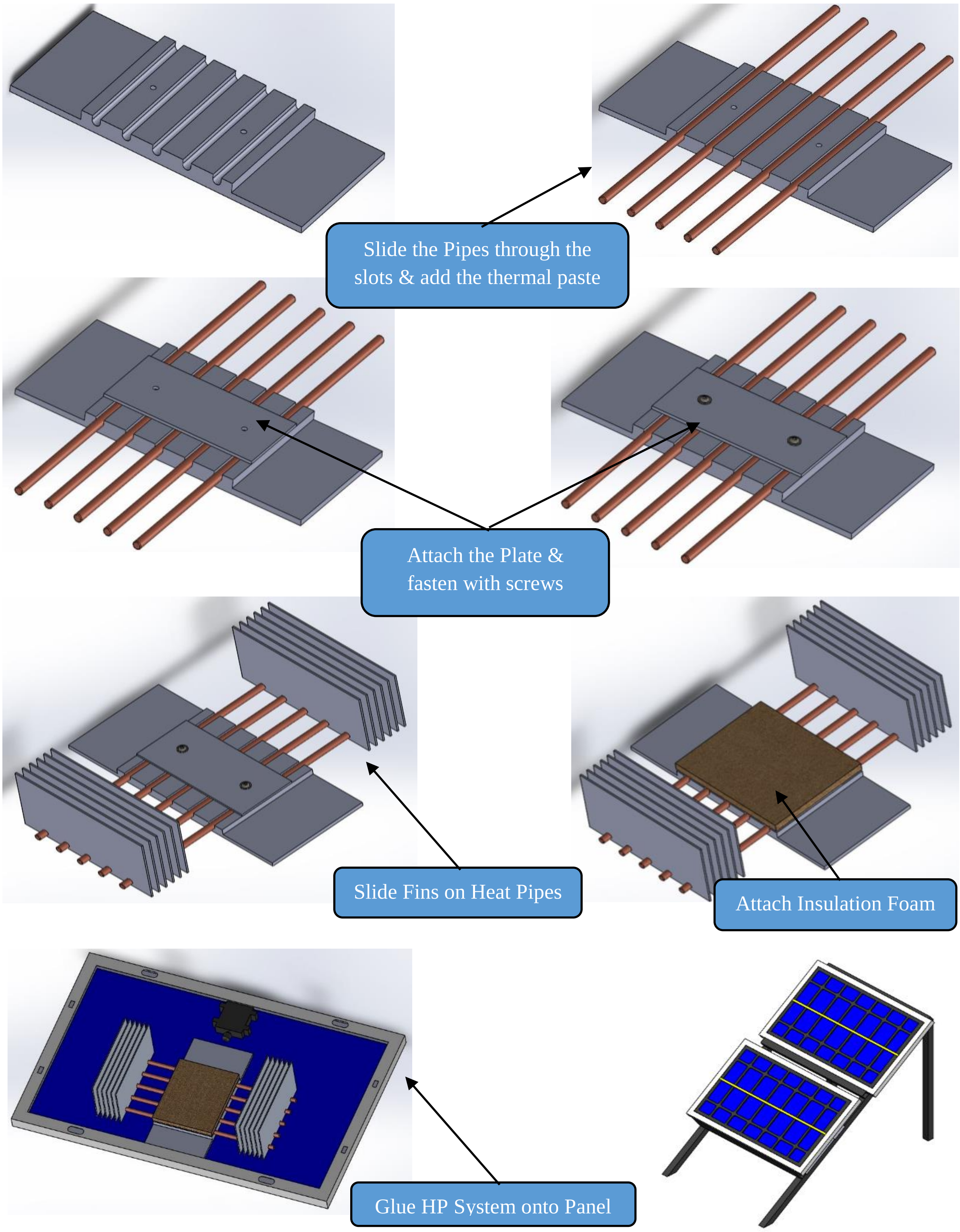


Figure 62 – HP-PV System Assembly Sequence

4.3.2. PCM-PV System Assembly Sequence

The following figures (Figure 63) give a visual representation of the assembly sequence underwent for the PCM-PV part of this project:

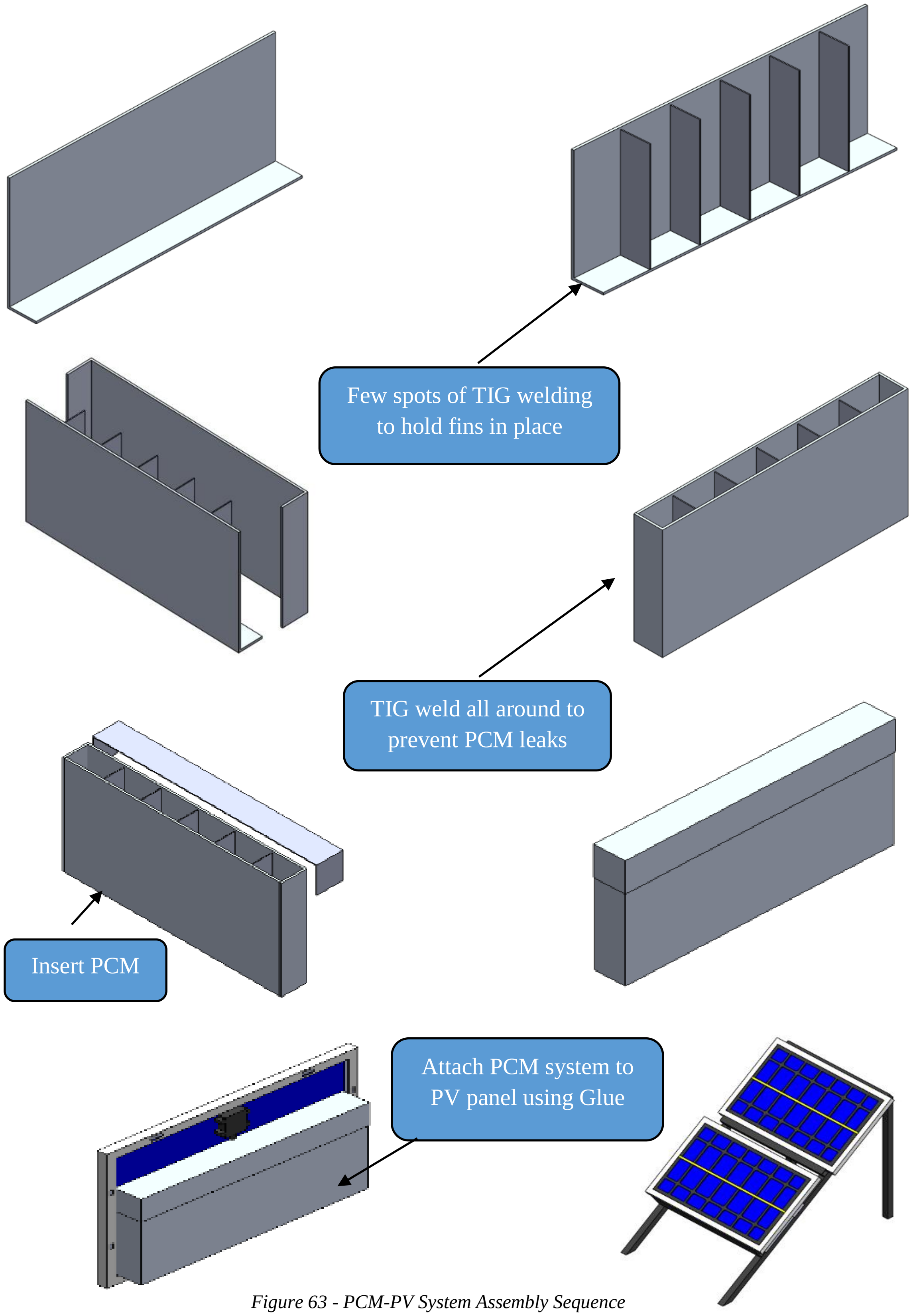


Figure 63 - PCM-PV System Assembly Sequence

CHAPTER 5

5. PRODUCT TESTING

This chapter aims to discuss whether the objectives of this project were met or not. Furthermore, the testing methods used will be laid out together with a testing setup. Lastly, this chapter aims to verify whether applied standards were met throughout this project.

5.1. Verification of the Objectives of the Project

The objectives of the project were to design and build two cooling systems for a PV panel in order to see which system is more effective. For the project to be a success, the cooling system must effectively and efficiently remove heat form the PV panel. By removing heat from the PV panel, the efficiency and power output of the PV panel should improve. As stated in Section 1.3 on page 3, the objectives of this project were as follows:

5.1.1. Objectives Verifications

I. Design and compare two PV Panel Cooling Systems and to find the most efficient system.
   i. A Finned HP-Saddle Cooling System and a Finned PCM Cooling system were fully designed and fully manufactured.
   ii. The two cooling systems have been attached on separate PV panels for comparison and the better cooling system will be known post testing.

II. Efficiency is the target with regard to the Manufacturing cost and heat removal rate.
   i. The two cooling systems were both designed with regards to cost. Affordable and highly available parts were sourced.
   ii. The cooler PV system will produce more power and in return this will have a higher efficiency.

III. To perform a feasibility study of PV generator characteristics and models.
   i. Post testing, the feasibility of the designed systems will be discussed.

IV. To minimize the amount of solar energy and efficiency lost due to heating of solar and PV panels.
   i. The PCM cooling system is designed to remove from the PV panel, store it and dissipate the heat to the surroundings, this cools the panel and in turn minimizes solar energy and efficiency losses.
   ii. The HP cooling system is designed to remove from the PV panel and dissipate the heat to the surroundings, this cools the panel and in turn minimizes solar energy and efficiency losses.

5.1.2. Experimental Setup

To test the systems, the following were used:

A. Temperature Sensor

A temperature sensor was attached to the back side of the PV panel to obtain the back-surface temperature of the and afterwards attached to the front side of the PV panel to obtain the front-surface temperature.

B. Pyranometer

A pyranometer was set up in order to measure the solar irradiance.

C. Multi-Meter

A Multi-Meter was used to record the Open-Circuit Voltage (V_{OC}) and Short-Circuit Current (I_{SC}) described as follows. Set to the volts setting, touch the positive multi-meter lead to the positive solar panel wire and the negative to the negative solar panel wire and record the open circuit voltage. Set the multi-meter to the amps setting and repeat the above steps to record the short circuit current. These values are for determining Power Output as follows (PV Education, 2019):

$$P_{MAX} = V_{OC} I_{SC} FF \tag{9}$$

D. Reference PV Panel

A pre-existing PV panel was used for to get a better understanding of the recordings and for more comparisons. However, the reference PV panel was for a different model, meaning the composition of the Panel was not the same and temperature readings differed significantly. Regardless, the efficiency is not dependent on that.

E. Weather Data

The ambient air temperature along with the windspeeds were also recorded using a reliable weather service provider such as Accuweather (AccuWeather, 2019).

F. Repetition

Recordings were taken every half-hour between 10am and 5pm as it is the part of the day with most sunlight and would give the best results. Testing was carried out for two consecutive days staring on the 13th of May 2019. The recordings were tabulated and graphed for comparison purposes of the efficiency's and temperatures of each PV panel with the cooling systems respectively.

5.1.3. Testing Schematic

The following schematic (Figure 64) shows the how the experiment layout:

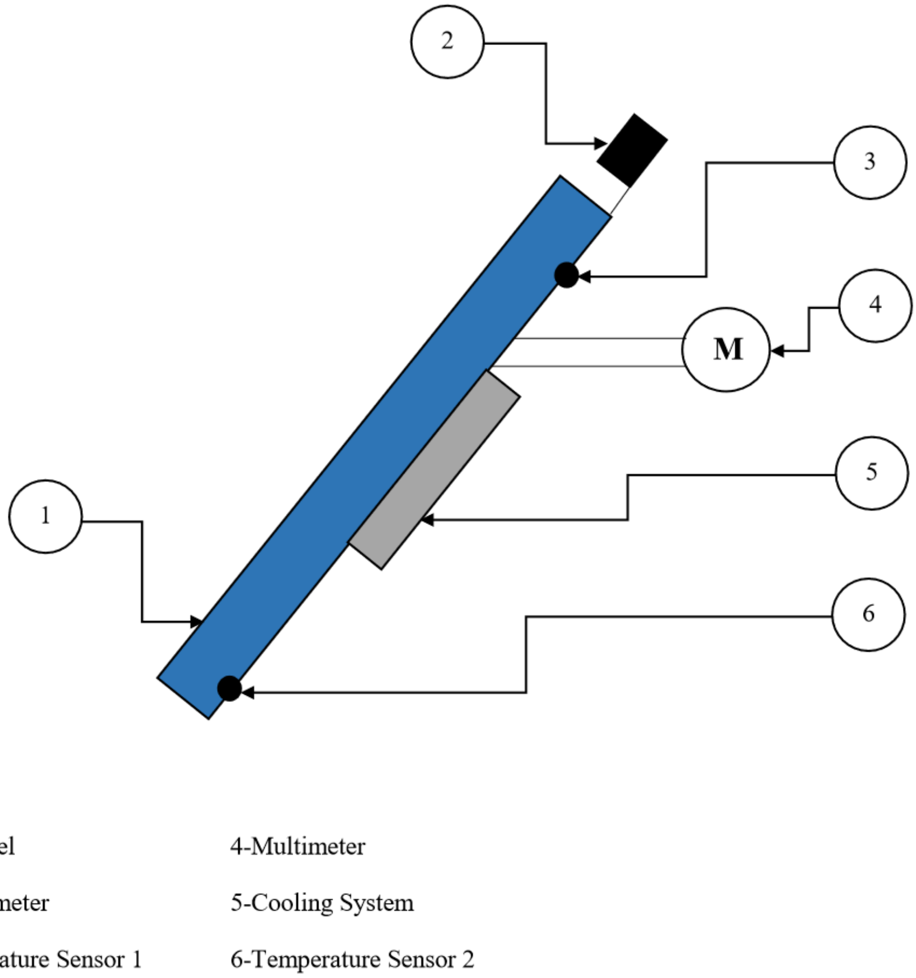


Figure 64 - Experiment Layout Schematic

The experimental layout schematic above (Figure 64) shows that:

A. The two temperature sensors are connected on the back surface of the PV panel on two different places, this is done in order to achieve an average temperature across the surface.

B. The multimeter connects to the electrical cable coming from the PV panel. The Voltage and the Current are the measured accordingly.

C. The pyranometer is to measure the solar radiation falling on the PV panels in order to calculate the available amount of energy.

D. As shown in Section 4, the cooling system is glued on the back of the PV panel.

5.1.4. Testing Layout

The following schematic (Figure 65) shows the Testing layout where the equipment used can be seen:

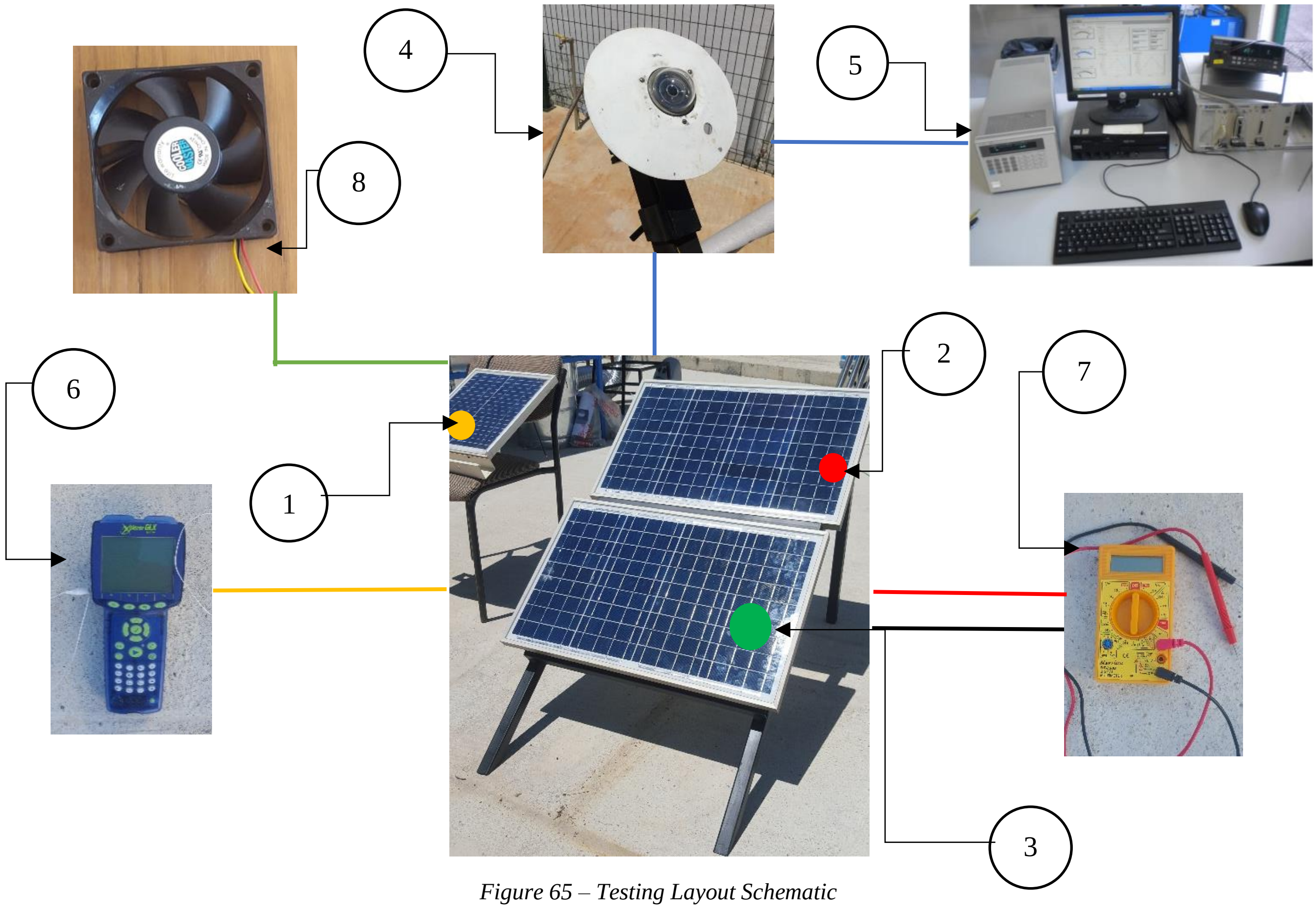


Figure 65 – Testing Layout Schematic

Legend:

1- Reference PV Panel	2-HP-PV Panel System	3-PCM-PV Panel System
4-Pyranometer	5-Data Logging PC	
6-Xplorer GLX	7-Multimeter	8-DC Load

5.2. VERIFICATION OF APPLIED ENGINEERING STANDARDS

The constraints the project is to be evaluated on are Economic, Functionality, Maintenance, Manufacturability, Environmental, Social, Health & Safety and Inspectability.

Financial:

- Initial budget was 500 USD. The aim was to balance cost and quality.
  - The calculated total cost of the project is 638 USD which is over budget. A large part of this is due to the shipping and handling cost of the PCM and another factor was the high price of Aluminium sheets due to low availability.

Function:

- Cooling the PV system by using heat pipe and using phase change material.
  - The test plan in section 5.1 will verify if this constraint has been met.

Serviceability:

- Product's maintenance must be simple and for long time.
  - Once the heat pipe and PCM cooling system are installed they will require no maintenance.
- Design must include parts that are easily replaceable.
  - All the parts are readily available and easy to replace
- Parts must be cheap to buy.
  - All parts except from the Aluminium sheets were at a reasonable price.

Manufacturability:

- Fabrication and installation were done in the university workshop.
  - The design for the heat pipe and PCM cooling systems allows for fabrication and installation in the university workshop. Except for the welding of Aluminium and the PV panel stand
- Two joining methods (welding and machine screws). Both can be done in the university workshop.
  - Both designs only require the mentioned joining methods.
- Product's final finishing must be well done.
  - The products final finish will be assessed after fabrication.
- Local availability of chosen equipment and if unavailable they must be outsourced and within cost constraints.

- Shipping cost for some equipment was not within the cost constraints. An effort to source the equipment locally or more cost effectively was made.

Environmental:

- The panels were put in a safe location. To avoid any damages to people.
  - The panels are located safely next to the Thermal lab (a dedicated space) to avoid dangers to people.
- Manufacturing waste will be collected.
  - Waste from the manufacturing process was cleared and disposed of properly.

Social:

- Designs in favor of all people.
  - The designs do not create any limitations on who can use them.

Health and Safety:

- Wearing safety shoes and glass and coverall during manufacturing processes.
  - All relevant workshop practices were followed during manufacturing process.
- The product is safe for the public.
  - All relevant engineering standards were adhered to ensure the safety of the public.
- The product does not cause any noise.
  - The deigns does not generate any noise.
- The materials used are not dangerous.
  - The materials used are provided with data sheets and certification to show that they do not contain any dangerous substances. Except for the PCM which is sealed

Inspectability:

- The system can be inspected during maintenance service.
  - The designed cooling systems are easily accessible for inspection during maintenance.

5.3. Failure Modes and Effects Analysis

This section will analyse the Project Failure Modes and Effects Analysis (FMEA) the HP-PV and PCM-PV systems could undergo. Table 21 below shows the various forms by which the systems could fail through the parts they each comprises of.

Table 21 – Project FMEA

FMEA (Failure Modes and Effects Analysis)

Product: PV Cooling | Organization Name: Eastern Mediterranean University (Easy Company)

#	Function	Potential Failure Modes	Potential Failure Effects	Potential Causes of Failure	Recommend Actions	Responsible Person	Taken Actions
1	PV Panel	Weak/No Power Output	Cooling systems unable to perform their function	Unreliable PV panel & manufacturer	Ensure manufacturer is certified by a recognized body	All Members	Well known manufacturer sourced + warranty sourced
2	PV Panel Stand	Fail to support PV panel & cooling system	Damage PV panel & cooling system	Weak support	CAD analysis	All Members	ANSYS Static Structural Analysis
3	Heat Pipes	Not cooling PV panel	PV Panel overheating, lower efficiency	Wrong working fluid	Investigate proper working fluids for desired temp range	HP Team	Reliable literature sources used for determining working fluid.
4	HP Saddle	Not absorbing heat from PV Panel	PV Panel overheating, lower efficiency	Poor contact with PV panel	Ensure contact surface is machined flat	HP Team	Inspect surface post machining and calibrate accordingly
5	HP Fins	N/A				HP Team	
6	Phase Change Material	Not cooling PV panel	PV Panel overheating, lower efficiency	Melting temp above NOCT	Investigate and calculate NOCT	PCM Team	NOCT calculations sourced from reliable literature sources
7	PCM Container	Leaking	PCM leaving container	Improper sealing	Test sealing prior to inserting PCM	PCM Team	Check if container can hold another liquid (water) without leaking successfully
8	PCM Fins	N/A				PCM Team	

HP Team: Sean, Waddah	Prepared by: Mpho	
PCM Team: Mpho, Othiman	Checked by: Sean	Approved by: Mpho Sothoane

The Mechanical Design Process (Ullman, 2008) Designed by Professor David G. Ullman

 Form # 22.0

CHAPTER 6

6. RESULTS

This chapter aims gives the results that were obtained during the testing phase of this project. A comparison between the thee PV panels is made in this chapter through graphical representation of the results. Furthermore, the Engineering Standards that were applied and followed are presented. Lastly, this chapter will identify the constraints met throughout this project.

6.1. The Results

6.1.1. PV Panels Specifications Review

Figure 66 and Figure 67 show the specifications of the PV panels. It seen that both the panels have the same Open-Circuit Voltage and therefore it can be used for comparison unlike the Short-Circuit Current

Area = 0.29 m^2

Figure 66 - PVs With Cooling Specifications

Area = 0.14 m^2

Figure 67 - PV Without Cooling Specification

6.1.2. Testing Day 1

Testing was done on 2 consecutive days and 1 more day a week later at Eastern Mediterranean University in Famagusta, TRNC with coordinates: 35.2857° N, 33.8411° E. The first day of Testing was on Monday the 13th of May 2019 starting from 13h00 until 17h00 (GMT+3). The Weather data for this day was taken to be as shown in the Table 22 below from AccuWeather (AccuWeather, 2019). The temperature was double checked by use of a thermometer. Sunset started occurring at around 16h40.

Table 22 – 13 May 2019 Weather Conditions

TIME	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
AIR TEMP(^{O}C)	30	31	31	31	30	30	29	29	27
WIND SPEED(M/S)	4	4	4	5	5	6	5	6	7

The following graph (Figure 68) shows the Open-Circuit Voltage of each panel as was measured:

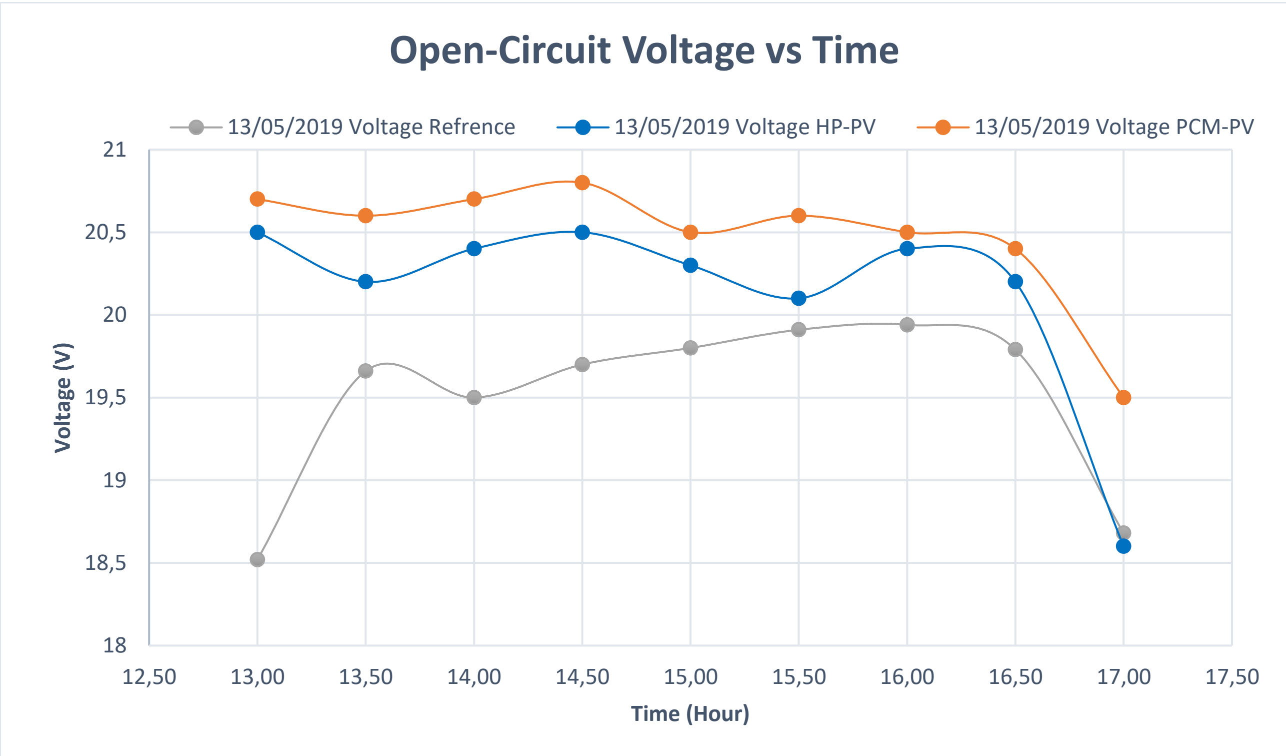


Figure 68 - Voltage vs Time 13/05/2019

From this graph it seen that the PCM-PV system had a higher voltage output whilst the Reference PV panel was trailing both cooled PVs with about 2 Volts on average.

The following graph (Figure 69) shows the Short-Circuit Current of each panel as was measured:

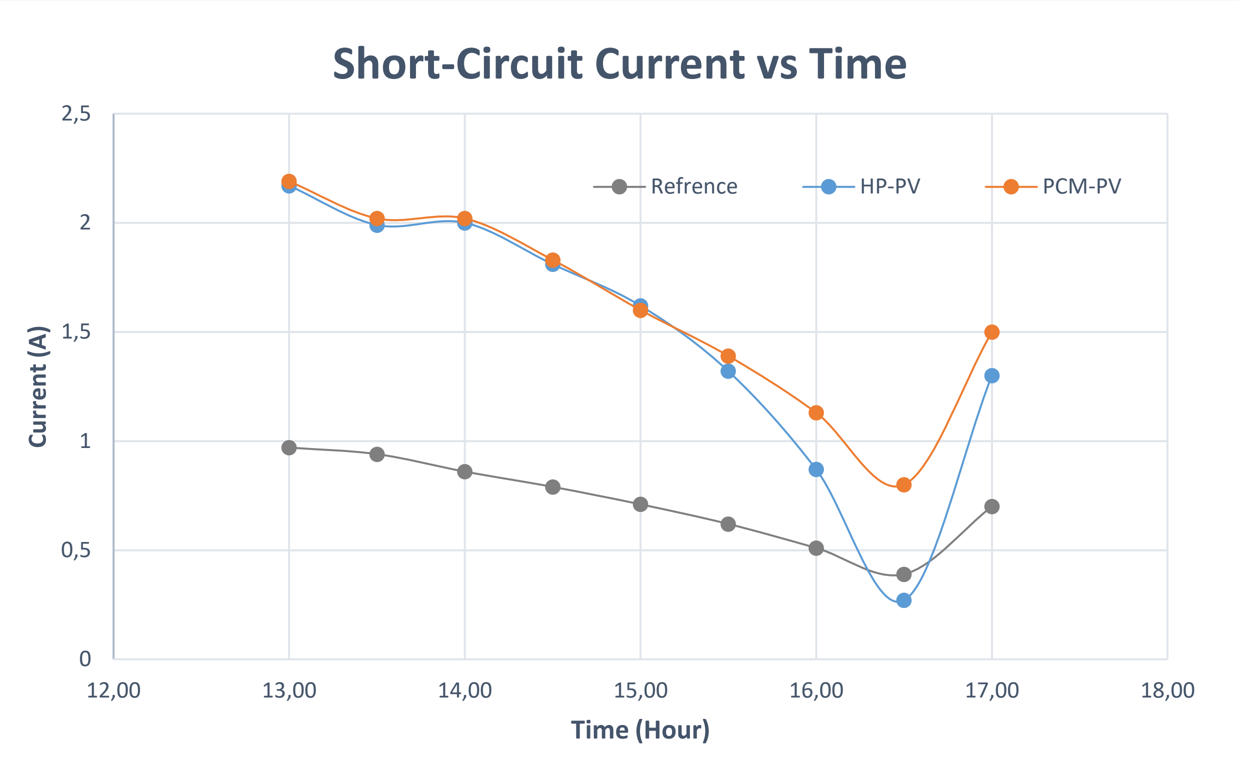


Figure 69 - Current vs Time 13/05/2019

From the above graph, it is seen that the PCM-PV system had a slower drop in Current output compared to the HP-PCM. This was likely due to the Phase Change Process.

6.1.3. Testing Day 2

The Second day of Testing was on Tuesday the 14th of May 2019 starting from 10h00 until 17h00 (GMT+3). The Weather data for this day was taken to be as shown in the table below from AccuWeather (AccuWeather, 2019). Sunset started occurring at around 16h30.

Table 23 - 14 May 2019 Weather Conditions

TIME	10:00	10:30	11:00	11:30	12:00	12:30	13:00
AIR TEMP (^{O}C)	28	28	30	32	32	33	34
WIND SPEED (M/S)	5	5	3	2	5	4	4

TIME	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
AIR TEMP (^{O}C)	34	34	34	33	32	31	31	28
WIND SPEED (M/S)	8	6	7	6	6	6	5	4

The following graph (Figure 70) shows the Open-Circuit Voltage of each panel as was measured:

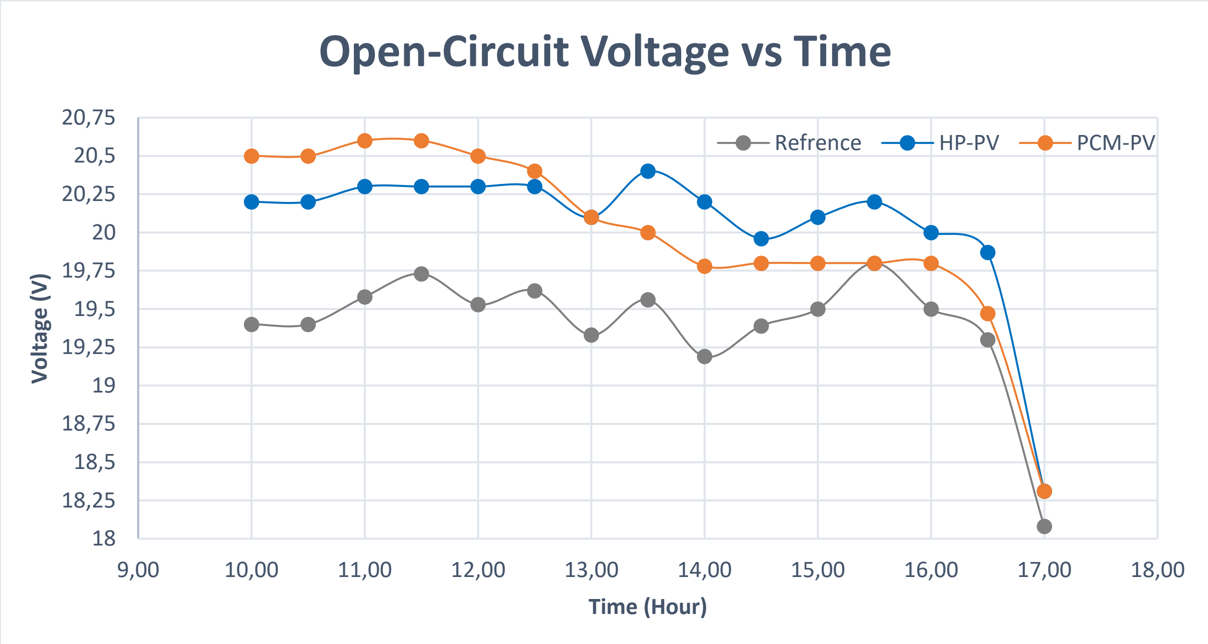


Figure 70 - Voltage vs Time 14/05/2019

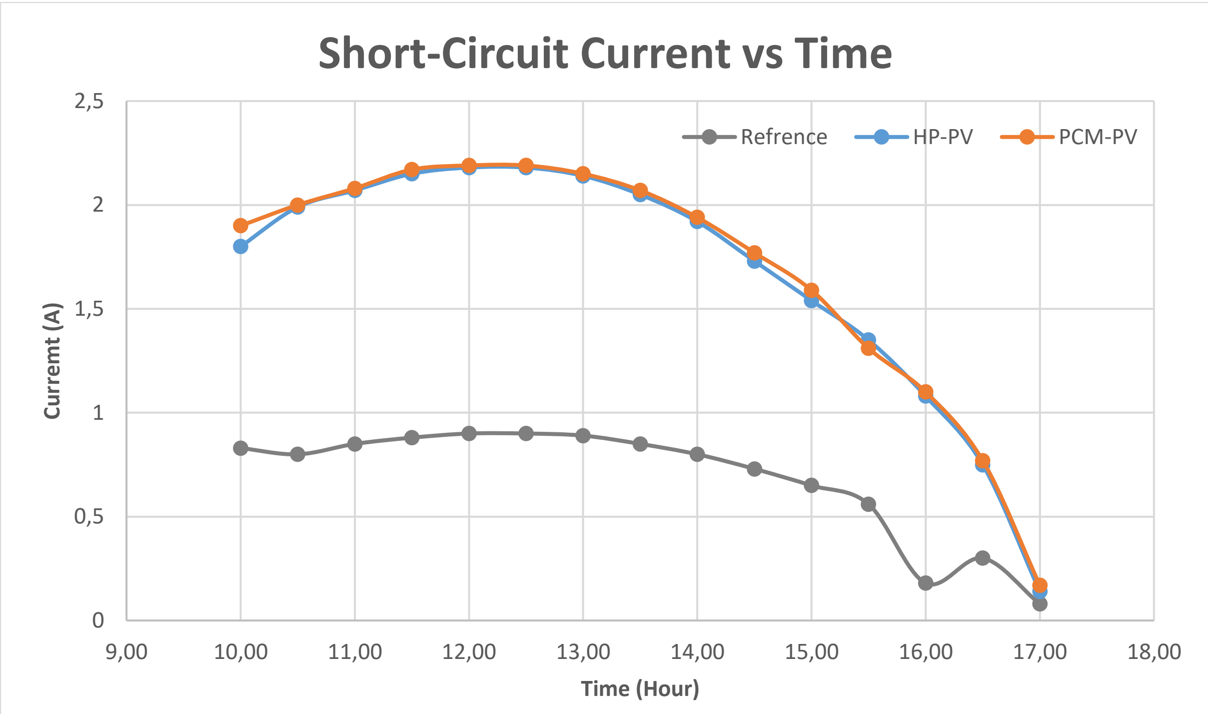


Figure 71 – Current vs Time 14/05/2019

From the voltage graph (Figure 70) it seen that the PCM-PV system started with a higher voltage output, however the HP-PV system remained at a steadier output and surpassed the PCM-PV system halfway through testing. The Reference PV panel remained trailing both cooled PV with about 2 Volts on average. The current output of the two cooled PV panels remained nearly identical throughout the day as seen in Figure 71.

6.1.4. Surface Temperatures

Part of the objectives of this project was to decrease the surface temperature of the PV Panel, to verify this, the temperature of the back of the PV Panels were recorded and found to be as shown in the following graphs (Figure 72 and Figure 73):

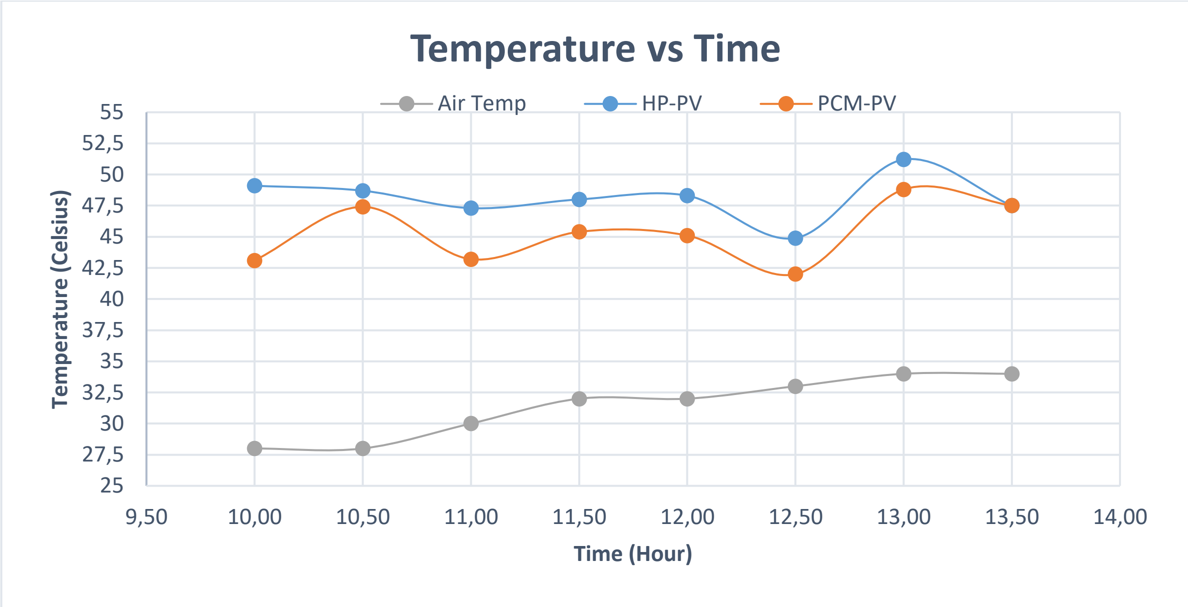


Figure 72 - Temperature vs Time 14/05/2019

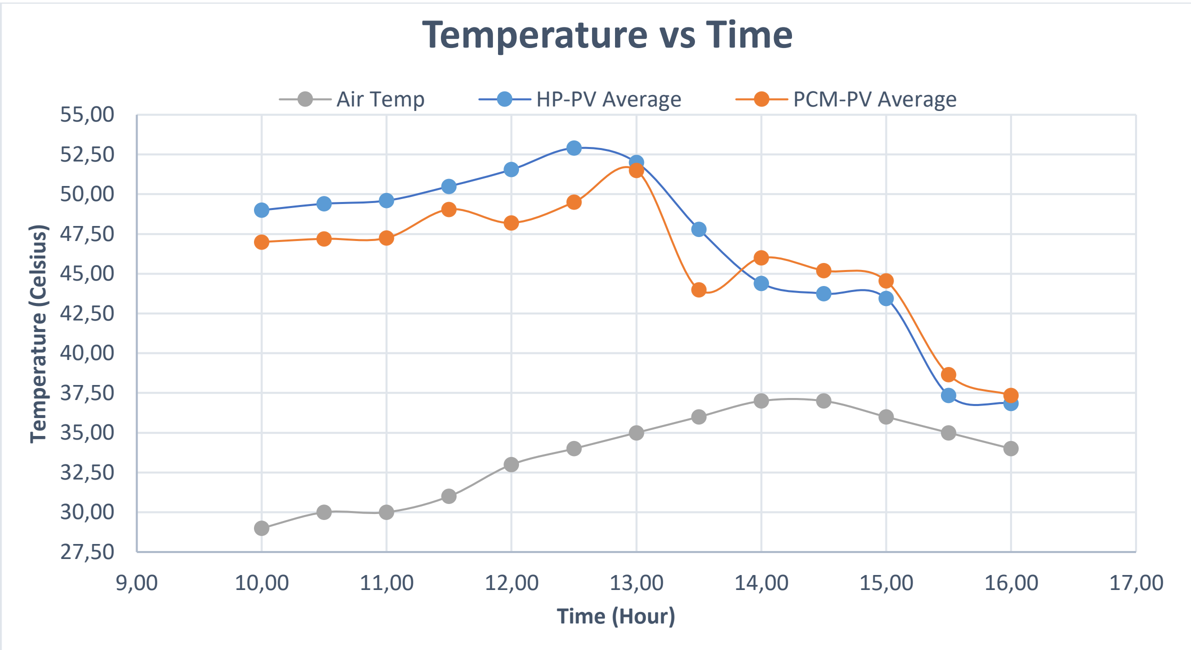


Figure 73 - Temperature vs Time 23/05/2019

From both the graphs above it is seen that the PCM-PV system starts out the day stronger brings the Panel to about 4ºC less than the HP-PV system. The HP-PV began leading later in the day from around 14h00 on both days. This was likely due to the PCM lasting until that time (finished melting).

6.1.5. PV Efficiency & Power

Unlike on the 1st day, the Solar Radiation was recorded successfully for the 2nd day. Table 24 shows the recorded Solar Radiation values:

Table 24 - Solar Radiation

Time	10:00	10:30	11:00	11:30	12:00	12:30	13:00
Solar Radiation (W/m^2)	886,48	901,01	915,54	959,16	1002,76	988,24	973,71

Time	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00
Solar Radiation (W/m^2)	930,08	886,48	770,22	683,02	595,82	508,64	377,84	188,92

With enough data on this day, the Solar Irradiance made it possible for the PV efficiencies to be calculated over the span of the day. The following Bar-Chart (Figure 74) shows the Calculated PV efficiency of each systems respectively:

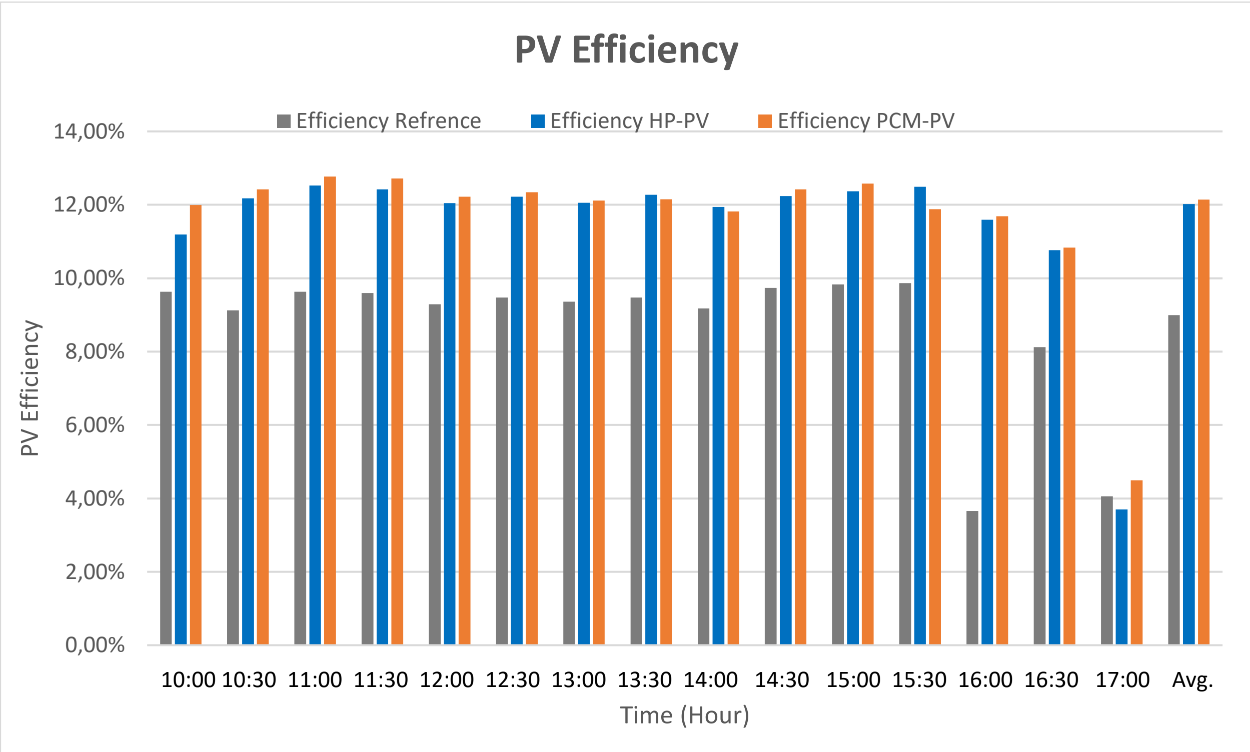


Figure 74 - Overall PV Efficiency

The PCM-PV and HP-PV each showed Maximum Efficiencies of **12,77%** and **12,53%** respectively while the Reference PV showed a Maximum Efficiency of **9.86%.**

The following Bar-Chart (Figure 75) shows the Calculated PV Power output per unit area of each systems respectively to compare the three PVs' the Power outputs:

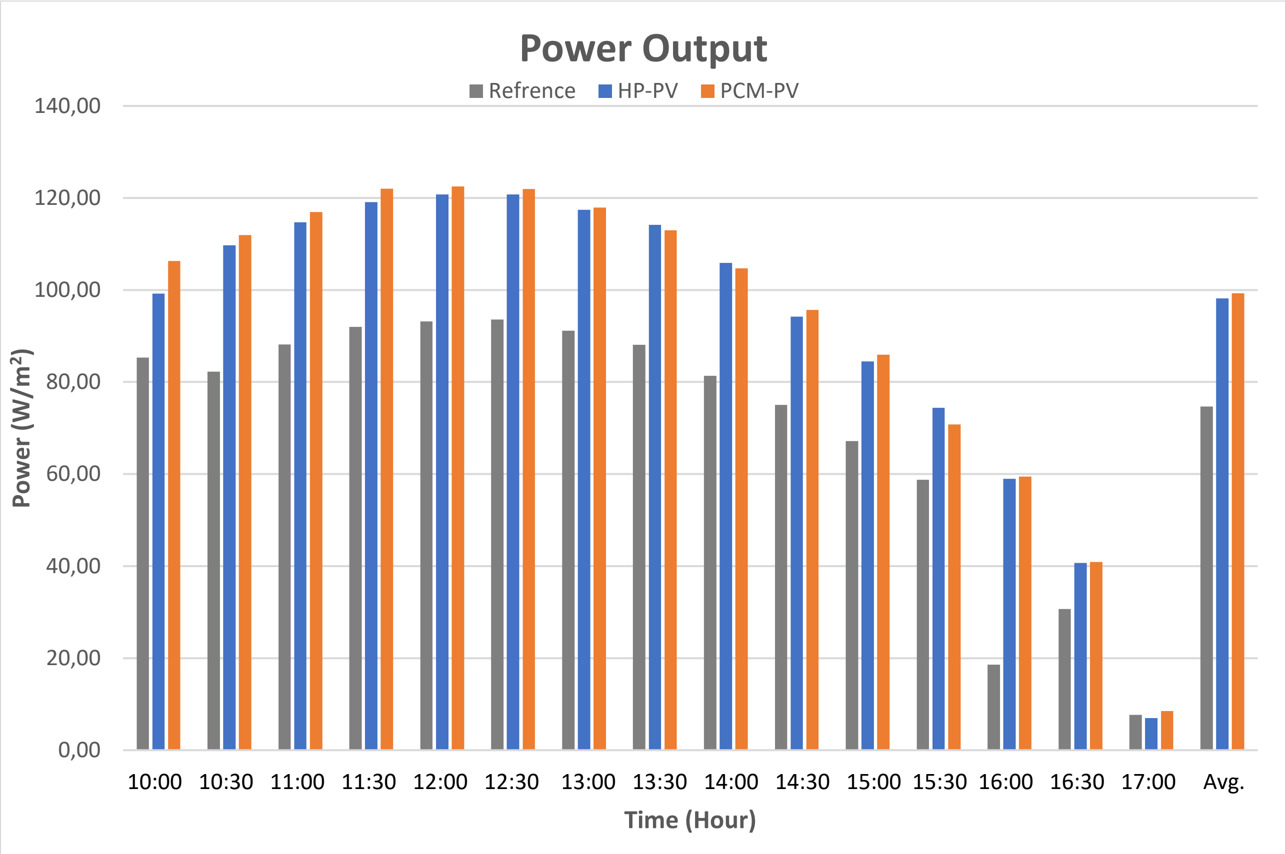


Figure 75 - PV Power Output

The power outputs of each system were calculated per unit area for comparison purposes where the surface-area of the Reference-PV was 0.14 m^2 and the surface-areas of both the HP-PV and PCM-PV were 0.29 m^2 each. As seen in Figure 75 above, the PCM-PV showed a maximum power output of **122.54 W/m²** and the HP-PV showed a maximum power output of **120.79 W/m²**. Both the cooled systems surpassed the Reference-PV which only reached a maximum power output of **93.58 W/m²**. Even in terms of average power output, the PCM-PV **(99.29 W/m²)** still delivered a more average power output than the HP-PV **(98.18 W/m²)** and the Reference-PV **(74.67 W/m²)**.

6.2. The Engineering Standards

Throughout this project, General Workshop Safety rules were followed when carrying out mechanical related work which is explained in the Detailed Manufacturing Process Chapter.

6.2.1. PV Panels

IEC 62548:2016 sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions (IEC, 2018). See appendix for C-1: Solar Panel Standards for details

6.2.2. HP-PV System

The heat pipe is classed as an electric or electronic component and as such must not contain hazardous substances. The heat pipe to be used is RoHS compliant (EU Directive 2002/95/EC) (RoHS Guide Compiance, 2018), see Appendix C-2: HP-PV Standards, for data sheet of safe levels.

The material used in the saddle and fins is Aluminum 1050A must be capable of dissipating 246W of heat. Aluminum mechanical properties are covered by ASTM B209 - 14 (ASTM, 2014) see appendix C-2: HP-PV Standards for material data sheet.

Manufacturing of the heat pipe cooling system took place in the mechanical engineering workshop. General safety and health in the workshop are covered by OSH Act 1970. (United States Department of Labor, 2018)

The mechanical engineering drawings used in the Heat Pipe Cooling System are to standard set according to (ISO 01.100.20) (International Orginization for Standardization, 2018)

6.2.3. PCM-PV System

The specific heat of Aluminium 1050A is 900 J $kg^{-1}.k^{-1}$, the thermal conductivity is 229 W $cm^{-1}.K^{-1}$, emissivity is 0.02 – 0.10 and the melting range is 645 -658 C (ASTM, 2014).

Alloy 1050 is excellent corrosion resistance, high ductility and highly reflective finish (ASTM, 2014).

The mechanical engineering drawings used in the Phase Change Material Cooling System are to standard set according to (ISO 01.100.20) (International Orginization for Standardization, 2018)

For welding of the PCM container, Arc-welded joints in Aluminium and its alloys: Quality levels for imperfections (ISO 10042:2005), Standard will be referred to.

There are no national and international standards for testing PCMs (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

PCM Safety and Handling Standards were followed as laid out by Rubitherm (Rubitherm, 2019). See C-4: PCM Safety Standards.

6.3. THE CONSTRAINTS

The main constraints faced throughout this project are Financial, Availability, Functionality, Manufacturability, Health & Safety and Inspectability.

Financial:

- ❖ The design was limited by the funding, since the project was carried out by students who had a very low initial budget and this in turn limited the design to cheap and available materials.
- ❖ Initial budget was 500 USD. The aim was to balance cost and quality equally. Due to this, only 2 PV panels were bought instead of 3 for better comparison.

Availability:

- ❖ Availability of materials also limited this design since Cyprus is an island and all materials and components had to be imported into the country because they are usually not found on the island.
- ❖ The price of Aluminium sheets in Cyprus are very expensive. More than 40% of the entire expenditures were just on Aluminium.
- ❖ Ordering to Cyprus from other countries takes a long time as everything must got through Turkey first.

Function:

- ❖ Cooling the PV system by using heat pipe and using phase change material.
- ❖ The results between these systems had to at least show different results for successful comparison.

Serviceability:

- ❖ Product's maintenance must be simple and for long time.
- ❖ Design must include parts that are easily replaceable.
- ❖ Parts must be affordable to buy.

Manufacturability:

- ❖ Fabrication and installation were planned to be done in the university workshops. However, as previously discussed in Chapter 3, TIG welding and Manufacturing the stand could not be done in the university workshop.
- ❖ Two joining methods (welding and machine screws). Both can be done in the university workshop.

- ❖ Product's final finishing had to be well done and safe to use.
- ❖ Local availability of chosen equipment and if unavailable they must be outsourced and within cost constraints.
- ❖ Lack of testing equipment hindered further results like obtaining PV panel surface temperatures.

Environmental:

- ❖ The panels will be in a safe location. To avoid any damages to people.
- ❖ Manufacturing waste will be collected.

Social:

- ❖ Designs in favor of end users.

Health and Safety:

- ❖ Safety of the user also limits the configuration of the design as we must make the design very safe for people to use.
- ❖ Wearing safety shoes and glass and coverall during manufacturing processes.
- ❖ The product will be safe for the public and animals.
- ❖ The product will not cause any noise.
- ❖ The materials used are not dangerous.

Inspectability:

- ❖ The system can be easily inspected during maintenance service.
- ❖ Burs were removed in order to prevent harm during handling.

CHAPTER 7

7. CONCLUSIONS AND FUTURE WORKS

This chapter aims to conclude the project. The results will be discussed and hence attest to the success of the project and its viability. Lastly, this chapter will discuss some future works that can be done.

7.1. Results Discussion

Before a successful conclusion can be made, the results need to be discussed more in depth.

7.1.1. Efficiency in Terms of Open-Circuit Voltage

Table 25 below shows the specified Open-Circuit Voltages of the respective PV panels on their catalogues as well as the measured Open-Circuit Voltages. The Open-Circuit Voltages efficiencies of each are also determined in Table 25 below using Equation 10 below:

$$\text{Open Circuit Voltages Efficiencies} = \frac{V_{OC_{Measured}}}{V_{OC_{Max}}} * 100\% \tag{10}$$

Table 25 - Open Circuit Voltages

PV Panel	Specified Max. V_{OC}	Measured Max. V_{OC}	Measured Avg. V_{OC}	Max. V_{OC} Efficiency	Avg. V_{OC} Efficiency
Reference	21.61V	19.80V	19.49V	91.62%	90.18%
HP-PV	21.61V	20.40V	20.17V	94.40%	93.35%
PCM-PV	21.61V	20.60V	20.12V	95.32%	93.10%

The average Open-Circuit Voltage Efficiencies of the Reference PV **(90.18%),** HP-PV (**93.35%)** and PCM-PV **(93.10%)** showed that the HP-PV system had the higher efficiency followed by the PCM-PV system by just **0.25%**, while the Reference PV was trailing by about **3%.** This shows that cooling systems met the objective through increasing the V_{OC} efficiency with **3%** on average.

7.1.2. Efficiency in Terms of Short-Circuit Current

Table 25 on the following page shows the specified Short-Circuit Currents of the respective PV panels on their catalogues as well as the measured Short-Circuit Currents. The Short-Circuit Currents efficiencies of each are also determined in Table 25 on the following page using Equation 11 below:

$$\text{Short Circuit Current Efficiency} = \frac{I_{SC_{Measured}}}{I_{SC_{Max}}} * 100\% \tag{11}$$

Table 26 - Short Circuit Currents

PV Panel	Specified Max. I_{SC}	Measured Max. I_{SC}	Measured Avg. I_{SC}	Max. I_{SC} Efficiency	Avg. I_{SC} Efficiency
Reference	0.96A	0.90A	0.72A	93.75%	75.00%
HP-PV	2.38A	2.18A	1.78A	91.60%	74.79%
PCM-PV	2.38A	2.19A	1.80A	92.02%	75.63%

Comparing the average Short-Circuit Current Efficiencies of the Reference PV **(75.00%),** HP-PV (**74.79%)** and PCM-PV **(75.63%)** it can be seen that PCM-PV system had the higher efficiency followed by the Reference PV system by **0.63%**, while the HP-PV was trailing by about **0.2%.** unlike with the voltage, the current was less effected by the operating temperature, however the PCM-PV still proved to be the better one.

7.1.3. PV Efficiency

Comparing the highest obtained PV Efficiencies of the Reference PV **(9.86%),** HP-PV (**12.53%)** and PCM-PV **(12.77%),** it is seen that PCM-PV system had the highest efficiency followed by the HP-PV system by **0.24%**, then lastly the Reference PV which was trailing by just under **3%.** Also Comparing the daily average obtained PV Efficiencies, the Reference PV **(9.00%),** HP-PV (**12.02%)** and PCM-PV **(12.14%),** it is seen that the PCM-PV system still delivered the highest average efficiency which was more than **3%** efficient compared to the Reference PV**.**

7.1.4. PV Operating Cell Temperature

In section 3.3.13.3.1 (PV Panel Surface Temperature), it was shown that the Operating Cell Temperature of a PV Panel is reaches around 30°C above the Ambient Air Temperature as also stated in other studies (Migan, 2013). Throughout testing, it was found that both Cooling systems kept the PV Operating temperature to no more than 20°C above the Ambient Air Temp as shown in Figures 75 & 76. i.e. When the Air temperature reached a high of 35°C at 13h00, the PV Panel only reached 52°C. This indicated that Cooling Systems most definitely did provide cooling.

7.1.5. Results Justification

Since no cooling system is attached to the reference panel, a smaller portion of the solar irradiance energy is converted to electricity while the other portion heated the panel unless it was removed, thus decreasing the efficiency. The cooling systems in the other two panels removed some of the heat, therefore increasing the overall efficiencies of the panels. The obtained efficiencies were just over 1% less than the expected maximum theoretical values and shows that the cooling system achieved their design purpose of increase the efficiency.

This shows that cooling systems meet the objective of increasing the efficiency by removing heat. Even though the percent increase was slightly more than **3%** on average. However, given the following implications the results can be accepted as a successful result:

A. The reference PV and the cooled PVs are of different brands which can affect the experimental results due to different type of materials may be used in the manufacturing process.

B. The reference panel had a different Power output than the cooling systems panel.

An improvement to the experimental setup to increase the reliability of the experiment can be:

A. To perform the experiment in an open area to minimize shadow interferences that can affect the current readings.

B. Perform more recording over different days with longer hours.

C. Using the same size and brand for the all the PV panels to be tested and compared.

D. Using well calibrated high-quality measuring devices.

7.1.6. Cooling Systems Comparisons

After identifying the cooling systems have achieved their design purpose and the set-out objectives, now comparing PCM-PV and HP-PV systems, the **PCM-PV** Cooling system won the comparison in terms of overall efficiency and power output. Excluding the cost of the PV panels and leaving out shipping and surcharges as they are more relative factors, the PCM cooling system costed \$242 (834 $\$/m^2$) and HP cooling system costed \$155 (534 $\$/m^2$). The difference in outcome was less than **1%** higher efficiency but given the fact the PCM-PV system costed \$87 (300 $\$/m^2$) more to complete, the HP-PV system was more feasible and the <**1%** difference in efficiency did not justify the higher cost. Lastly, the PCM-PV system would better be suited for a larger scale project as this would make it more economically feasible by avoiding a Sur-charge which for this project was **47 USD.**

7.2. The Conclusion

In conclusion, the main objectives of this project were to compare two PV panel cooling system in terms of efficiency and cost. This study thus confirms the advantages of using the PCM-PV and HP-PV cooling systems to increase the overall efficiency of the solar panels. Both Cooling systems were able to remove the heat from the solar panels as theoretically expected and the PCM-PV system was the better cooling system

Every percentage count when it comes to efficiency and the results of cooling the PV panels do make a difference in Power output and will in turn lead to less electricity dependence from the grid. The surface temperatures of the PV Panel did not decrease until the desired operating temperature of around 25°C as what was set out to achieve, thus the increase in efficiency did not reach the PV Panel's maximum efficiency, this was expected since the cooling systems are both passive.

Lastly, the manufacturing cost for the PCM-PV were about 25% more than that of the HP-PV cooling system, thus encouraging the utilization the HP-PV cooling system. The PCM itself was cheaper than the Heat Pipes, however unexpected charges like the Surcharge led the PCM-PV system to be more than the HP-PV system. Therefore, in conclusion: Yes, the Phase Change Material cooling system was more efficient than the Heat Pipe cooling system, however it is better suited for a larger scale application and the Heat Pipe cooling system was better suited for this project.

7.3. The Future Works

The results from the PCM-PV and HP-PV cooling systems show that both systems can successfully be used to increase the efficiency of PV Panels. As the heat conducting capabilities of the PCM and the heat pipe used in the project are already known, it can be assumed that other factors in the design such as how they are assembled and mounted are preventing them from removing as much heat from the PV Panels as theorized. Redesigning the saddle for the Heat Pipe cooling system and the container of the Phase Change Material cooling system so that they cover larger surface areas and therefore remove heat from the entire panel should be considered together with the optimal PCM container wall thickness.

More research should be carried out on what glue to use for attaching the PCM container and the Heat Pipe saddle to the PV-panel, to ensure that one that is both strong enough and has good heat conductive properties are used. Making use of computer modeling programs to experiment with various configurations, materials and designs should be utilized before manufacturing another prototype. Due to testing being carried out in May Operating Cell Temperature did not reach their maximum calculated temperatures where the efficiency drops the most, testing should be repeated in July or August to give a clearer picture of how effective the designs are.

REFERENCES

AccuWeather. (2019, May 12). *Cyprus Weather, Famagusta*. Retrieved from Accuweather: https://www.accuweather.com/en/cy/cyprus-weather

Agyenima, F., Hewitta, N., Eamesb, P., & Smytha, M. (2009). A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS). *Elsevier*, 616-625.

AMS Energy. (2018, October 19). *Heat Pipe Technology History*. Retrieved from AMS Energy: http://www.amsenergy.com/heat-pipe-technology-history/

Anderson W, D. P. (2018). *Heat Pipe Cooling Of Concentrating Photovolaic Cells*. Retrieved from Advanced Cooling Technologies: https://www.1-act.com/heat-pipe-cooling-of-concentrating-photovoltaic-cells/

Anderson, W. G., Dussinger, P. M., Sarraf, D., & Tamanna, S. (2008). *Heat pipe cooling of concentrating photovoltaic cells* . Conference Record of the IEEE Photovoltaic Specialists Conference .

ASTM. (2014). ASTM B209-14, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate. ASTM International, West Conshohocken, PA, United States of America.

CCI. (2018). *00C93480101 - Heat Pipe, Heat Pipe, Copper, Round, 65 W, Copper, 300 mm*. (CCI) Retrieved from Farnell Element 14: https://uk.farnell.com/cci/00c93480101/heat-pipe-300mm-8mm-dia/dp/1373311

CELSIA. (2017). *Heat Pipe & Vapor Chamber Technology Overview*. (C. Inc, Producer) Retrieved from Celsiainc: https://celsiainc.com/heat-pipe-and-vapor-chamber-technology-overview/

CENGEL, Y. A. (2002). HEAT TRANSFER: A Practical Approach . In Y. A. CENGEL, *HEAT TRANSFER* (p. 570). Boston, USA: Mcgraw-Hill .

Conrad. (2019, April 05). *Heat Pipes*. Retrieved from Conrad: https://www.conrad.com/p/heat-pipe-02-cw-x-l-8-mm-x-380-mm-quickcool-qy-shp-d8-380sa-180992

CyprusNet. (2018, November 01). *Weather averages*. Retrieved from CyprusNet Weather: https://www.cyprus-weather.com/article/cyprus-average-temperatures.html

Elliott, R. (2013, March 10). *The Design of Heatsinks*. (Elliott Sound Products) Retrieved from Whsites: http://sound.whsites.net/heatsinks.htm#s15.1

Enertron. (2015). *Things to Consider When Designing With Heat Pipes*. Retrieved October 30, 2018, from Enertron Total Thermal Mangement Solution: https://www.enertron-inc.com/products/designing-with-heat-pipe/

Engineering ToolBox. (2003). *Convective Heat Transfer*. Retrieved from Engineering Tool Box: https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html

F, G., S, N., & T, M. (2015). *Photovoltaic Panels: A Review of Cooling Techniques.* Transactions of Famena Xl.

Fan, L.-W., Xiao, Y.-Q., Zeng, Y., & Fang, X. (2013). Effects of melting temperature and the presence of internal fins on the performance of a phase change material (PCM)-based heat sink. *Elsevier*, 114-126.

Farid, M. (2015). Phase Change Materials in Architecture. *Victoria University of Wellington*, 1-10.

Groover, M. P. (2010). *Fundamentals of modern manufacturing: materials, processes and systems, 4th ed.* Lehigh University: JOHN WILEY & SONS, INC.

Hardland, A., Mackay, C., & Vale, B. (2015). PHASE CHANGE MATERIALS IN ARCHITECTURE. *University of Wellington*, 4.

Hasan, A., McCormaack, S., Huang, M., Sawar, J., & Norton, B. (2015). Increased photovoltaic performance through temperature regulation by phase change materials: Materials comparison in different climates. *Elsevier: Solar Energy*, 264-276.

Hasan, A., McCormack, S., Huang, M., Sarwar, J., & Norton, B. (2014). Increased PV performance through temp regulation by PCM . *Elsevier*, 264-276.

Huang, M. J. (2010). Solar Energy Materials & Solar Cells. *Elsevier*, 2.

Hughes, B., Cherisa, N., & Bég, O. (2012). *Computational Study of Improving the Efficiency of Photovoltaic Panels in the UAE.*

Ibrahima, N. I., Al-Sulaimana, F. A., Rahmana, S., Yilbasb, B. S., & Sahinb, A. Z. (2017). Heat transfer enhancement of phase change materials for thermal energy storage applications: A critical review. *Elsevier: Renewable and Sustainable Energy Reviews*, 26-50.

IEC. (2018, December 02). *Photovoltaic (PV) arrays - Design requirements.* Retrieved from Webstore International Electrotechnical Commission: https://webstore.iec.ch/publication/25949

ILO. (2014, June). *INTRODUCTION TO OCCUPATIONAL HEALTH AND SAFETY: Your health and safety at work.* International Labour Organization. Retrieved from International Labour Organization: http://training.itcilo.it/actrav_cdrom2/en/osh/intro/inmain.htm

International Orginization for Standardization. (2018, December 6). *Mechanical Engineering Drawings*. Retrieved from Orginisation Internationale de Normalisation: https://www.iso.org/ics/01.100.20/x/

ISO. (2018, November 15). *International Organization for Standardization*. Retrieved from International Organization for Standardization: https://www.iso.org/home.html

Lee, H. (2010). *Thermal Design.* Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Ma, T., Yang, H., & Zhang, Y. (2014). Using phase change materials in photovoltaic systems for thermal regulation and electrical efficiency improvement: A review and outlook. *Renewable & Sustainable Energy Reviews*, 2.

MAGNABEND. (2018, December 06). *Sheet metal forming*. Retrieved from http://www.magnabend.com/

Marco, T. G. (2016, 06). *Photovoltaic panels: A review of the cooling techniques.* Retrieved from research gate: https://www.researchgate.net/publication/304785444_Photovoltaic_panels_A_review_of_the_cooling_techniques

Masaki, S., Masao, I., Ken-ichiro, W., Kenji, M., & Makoto, T. (2005). *The influence of operation temperature on the output properties of amorphous silicon-related solar cells* . Science Direct, Japan.

Meyer, G. (2016, August 26). *Design Considerations When Using Heat Pipes*. (Celsia Inc.) Retrieved from Electronics Cooling: https://www.electronics-cooling.com/2016/08/design-considerations-when-using-heat-pipes/#

Microtek Laboratories Inc. (2017). *How do PCM's Work?* Retrieved from Mirotek: http://microteklabs.com/how-do-pcms-work.html

Microtek Labs. (2018, November 08). *PCM Blend*. Retrieved from Micrrotek Laboratories: https://www.microteklabs.com/pcmblend

Migan, G.-A. (2013). *Study of the operating temperature of a PV module.* Faculty of Engineering, Lund University, Energy Sciences. Lund University.

Mohrram, K., & Abd-Elhady, M. (2013). Enhancing the performance of pholovoltaic panels by water cooling. *Ain Shams Engineering Journal*, 2.

Niclas. (2014, Februray 3). *Comparing major solar panel testing conditions*. Retrieved from Sino Voltaics: https://sinovoltaics.com/solar-basics/comparing-major-solar-panel-testing-conditions/

P.D, D., & D.A, R. (1994). *Heat Pipe* (Vol. 4). New York: New York : Elsevier Science.

P.J, B., & E.J, K. (1979). *Heat Pipe Design Handbook* (Vol. 1). USA: NASA.

Peacock, F. (2012, February 03). *How To Read A Solar Panel Specification: Part #1 Power & Temperature Specs.* Retrieved from Solarquaots: https://www.solarquotes.com.au/blog/how-to-read-a-solar-panel-specification-part-1-power-temperature-specs/

Pollard, C. (2017, September 9). *How do I calculate the amount of heat dissipated from a solar cell?* Retrieved from Quora : https://www.quora.com/How-do-I-calculate-the-amount-of-heat-dissipated-from-a-solar-cell

Pure Temp. (2018, October 20). *Phase Change Materials*. Retrieved from Pure Temp: http://www.puretemp.com/stories/understanding-pcms

PV Education. (2019, May 17). *Fill Factor*. Retrieved from PV Education: https://www.pveducation.org/pvcdrom/solar-cell-operation/fill-factor

PV Education. (2019, May 17). *Solar Cell Efficiency*. Retrieved from PV Education: https://www.pveducation.org/pvcdrom/solar-cell-operation/solar-cell-efficiency

RF Wireless World. (2017). *Solar Cell Efficiency calculator*. Retrieved from Solar Cell Efficiency calculator: http://www.rfwireless-world.com/calculators/Solar-Cell-Efficiency-Calculator.html

RoHS Guide Compiance. (2018, 12 6). *Welcome to RoHS Guide*. Retrieved from RoHS Guide: http://www.rohsguide.com/

Rubitherm. (2019, February 28). *PCM RT-line*. Retrieved from Rubitherm Phase Change Material: https://www.rubitherm.eu/en/index.php/productcategory/organische-pcm-rt

S, M., P, R., M, D., & S, S. (2014). *Performance of Solar Panel With Water Immersion Technique.* Bhopal.

S, S., O, A., & K, A. (2015). *Performance Enhancement of PV Array Based On Water Spraying Technique.* international Journal of Sustainable and Green Energy.

SEIA. (2018, October 20). *Photvoltaic (Solar Electric)*. Retrieved from SEIA: https://www.seia.org/initiatives/photovoltaic-solar-electric

Textilelearner. (2018, October 20). *Phase Change Materials*. Retrieved from Phase Change Materials (PCM): http://textilelearner.blogspot.com/2012/10/phase-change-material-pcm.html

The New York Times. (1996, November 3). George M. Grover, 81, Inventor Of Popular Heat Transfer Device. *Archives*, p. 1.

ThoughtCo. (2018, October 23). *History: Photovoltaics Timeline* . Retrieved from ThoughtCo.: https://www.thoughtco.com/photovoltaics-timeline-1992481

Ullman, D. G. (2008). *The Mechanical Design Process 4th Edition.* New York: The McGraw-Hill Companies, Inc.

United States Department of Labor. (2018, December 6). *OSH Act of 1970*. Retrieved from Occupational Saftey and Health Administration: https://www.osha.gov/laws-regs/oshact/toc

Verdict Elec. Ltd. (2018, October 18). *Heat Sink*. Retrieved from Verdict electronics Private Limited: http://www.verdictelectronics.net/heat-sink.html

W.G, A. (2007). *Intermediate Temperature Fluids for Heat Pipes and LHPs.* St. Louis: Science Direct.

Whiffen, T., & Riffat, S. (2013, Septemper 1). A review of PCM technology for thermal energy storage in the built environment: Part I . *Low Carbon Technologies, 8*(3), 147-158.

Wu, S. (2014, 03 26). *Passive cooling technology for photovoltaic panels for domestic houses*. Retrieved from Oxford Academic: https://academic.oup.com/ijlct/article/9/2/118/633328

Y, C., & A, G. (2015). *Heat and Mass Transfer Fundamentals & Applications* . New York: McGraw Hill.

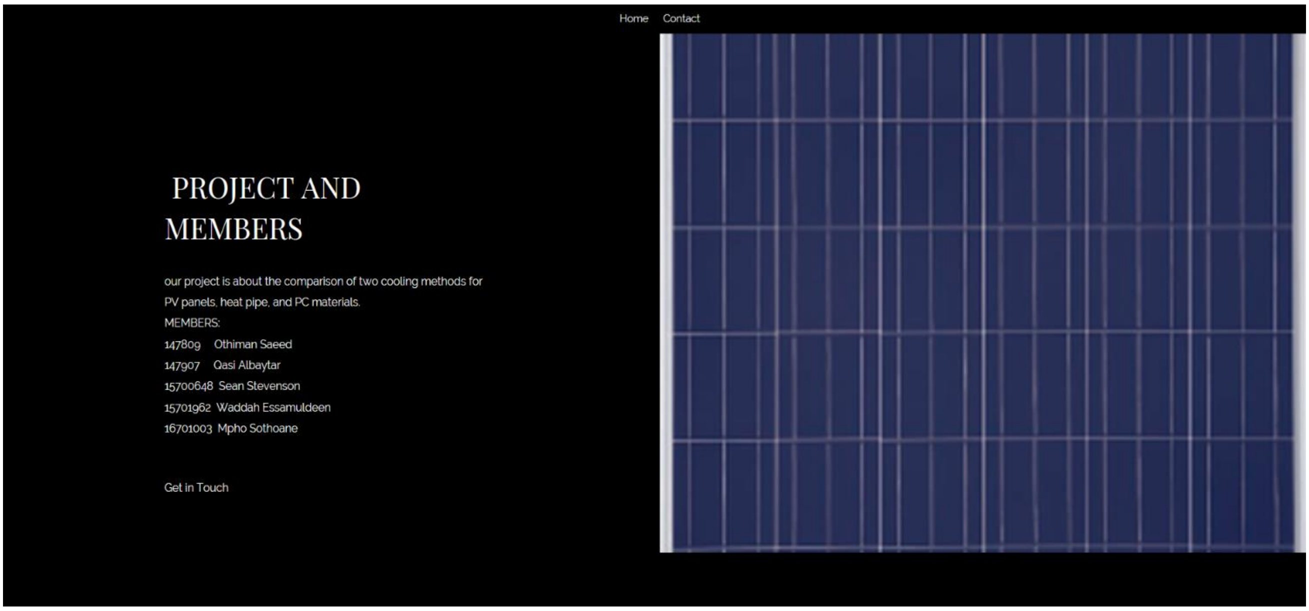
Zivkovic, B., & Fujii, I. (2000). AN ANALYSIS OF ISOTHERMAL PHASE CHANGE OF PHASE CHANGE MATERIAL WITHIN RECTANGULAR AND CYLINDRICAL CONTAINERS. *Solar Energy Vol 70 No 1*, 51-61.

APPENDICES

APPENDIX A: ELECTRONIC MEDIA

A – 1: WEBSITE

This Project is may be followed from the following website:
https://capstoneteam2019.wixsite.com/pvpanel



A – 2: EMAIL ADDRESS

The Team may be contacted at capstoneteam2019@gmail.com

APPENDIX B - CONSTRAINTS

The main constraints of this project are Financial, Functionality, Maintenance, Manufacturability, Environmental, Social, Health & Safety and Inspectability.

Financial:

- The design was limited by the funding, since the project is carried out by students' available funds are very low and this in turn limited the design to cheap and available materials.
- Available budget of $ 500 USD. The aim was to balance cost and quality equally.

Availability:

- Availability of materials also limited this design since Cyprus is an island and all materials and components had to be imported into the country because they are usually not found on the island.

Function:

- Cooling the PV system by using heat pipe and using phase change material.
- The results between these systems had to at least show different results for successful comparison.

Serviceability:

- Product's maintenance must be simple and for long time.
- Design must include parts that are easily replaceable.
- Parts must be afordable to buy.

Manufacturability:

- Fabrication and installation will be in the university workshop.
- Two joining methods (welding and machine screws). Both can be done in the university workshop.
- Product's final finishing must be well done.
- Local availability of chosen equipment and if unavailable they must be outsourced and within cost constraints.

Environmental:

- The panels will be in a safe location. To avoid any damages to people.
- Manufacturing waste will be collected.

Social:

- Designs in favor of end users.

Health and Safety:

- Safety of the user also limits the configuration of the design as we have to make the design very safe for people to use.
- Wearing safety shoes and glass and coverall during manufacturing processes.
- The product will be safe for the public.
- The product will not cause any noise.
- The materials used are not dangerous.

Inspectability:

- The system can be during maintenance service.

APPENDIX C – STANDARDS

C-1: SOLAR PANEL STANDARDS

IEC 62548:2016. This International Standard sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions. The standard includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads. An exception is that provisions relating to power conversion equipment are covered only where DC safety issues are involved. The interconnection of small DC conditioning units intended for connection to PV modules are also included.

The object of this standard is to address the design safety requirements arising from the particular characteristics of photovoltaic systems. Direct current systems, and PV arrays in particular, pose some hazards in addition to those derived from conventional AC power systems, including the ability to produce and sustain electrical arcs with currents that are not greater than normal operating currents.

In grid connected systems, the safety requirements of this standard are however critically dependent on the inverters associated with PV arrays complying with the requirements of IEC 62109-1 and IEC 62109-2.

C-2: HP-PV STANDARDS

RoHS Restricted Substances and Limits		
Lead	(Pb):	<1000 ppm
Mercury	(Hg):	<1000 ppm
Cadmium	(Cd):	<100 ppm
Hexavalent Chromium:	(Cr VI)	<1000 ppm
Polybrominated Biphenyls	(PBB):	<1000 ppm
Polybrominated Diphenyl Ethers	(PBDE):	<1000 ppm

Figure 76 - RoHS Restricted Substances Data Sheet (RoHS Guide Compiance, 2018)

PRODUCT DATA SHEET Aluminium 1100 UNS A91100

Aluminium alloy 1100 contains a minimum of 99.00% aluminium, and is sometimes known as 'Commercially Pure Aluminium'. It has excellent electrical conductivity, good formability and highresistance to corrosion, and is used where high strength is not needed. It has the low density andexcellent thermal conductivity common to all aluminium alloys

Typical Applications General sheet metal work where moderate strength is adequate: lightlystressed panels, architectural flashings, name plates, heat exchangers, food and chemical handling and storage equipment, drawn or spun hollowware, light reflectors, welded assemblies.

Chemical Composition

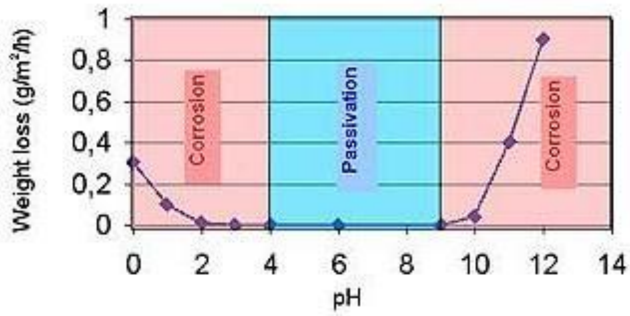
AS/NZS 1734 Aluminium and aluminium alloys- Flat sheet, coiled sheet and plate

Element	%	Element	%
Aluminium	99.00% min	**Manganese**	0.05 max
Copper	0.05 – 0.20	**Zinc**	0.10 max
Silicon + Iron	0.95 max	**Others, each**	0.05 max

Equivalent specifications:
USA: AA1100; Japan: JIS A1100P: France: NF 1100; ISO Al 99.0 Cu.
The properties in this data sheet meet Australian/New Zealand Standard AS/NZS 1734:1997 Aluminium and aluminium alloys - Flat sheet, coiled sheet and plate (equivalent to BS EN 573-1). The material also meets other national standards

Description Aluminium 1100 is commercial purity aluminium with a controlled content of copper. It can be hardened by cold work: it is not heat treatable to higher strength. It has excellent ductility, up to 30% in annealed material of 1.3 to 6.0 mm thickness. The ductility is more limited in the H14 and H24 tempers

Corrosion Resistance
The '1xxx' series alloys have the best resistance to general corrosion of all the aluminium alloys. Resistance is excellent in aqueous solutions in the pH range 4 – 9.



The corrosion resistance of aluminium alloys relies on a protective surface oxide film, which when damaged is readily repaired by the rapid reaction between aluminium and oxygen. However, the high reactivity of the base metal can give rapid corrosion if the film cannot be repaired, so aluminium alloys are not suitable for use with reducing media. Alloy 1100 can be anodised to improve the corrosion resistance by thickening the protective surface film. Since aluminium is a reactive metal, it may corrode more quickly when in electrical contact with most other metals. The prediction of galvanic corrosion is complex; please consult APA for specific advice

Fabrication Aluminium 1100 is very readily cold formable in the annealed condition, as it is ductile. Forming loads and tool & press wear are generally less than with carbon steel. For piercingand blanking the punch to die clearance should be about 5% of the thickness per side for temper O,6% for H12&H14.

Welding Alloy 1100 is readily welded by the TIG and MIG processes. Commonly used filler alloys are 4043 and 1050. 4043 gives greater weld strength, but if the assembly is to be anodized, 1050 filler metal will give a closer colour match.

1100 may also be gas welded or resistance welded, but the resulting joints are not as strong or as corrosion resistant as the inert gas welded joints. Gas welding could result in excessive heat distortion and thinner gauges may burn through. Aluminium must be very dry & clean to avoid contamination &

porosity of the weld. It is essential that all traces of flux used in welding or brazing are removed by scrubbing with hot water.

Heat Treatment Alloy 1100 is annealed at 350_oC, time at temperature and cooling rate are Un-important. Stress relief is rarely required, but can be carried out at about 220_oC. If loss of strength is of concern, stress relief tests should be conducted.

C-3: PCM-PV STANDARDS

Testing Standard

There are no national and international standards for testing PCMs (Agyenima, Hewitta, Eamesb, & Smytha, 2009).

Welding Standard

ISO 10042:2005 specifies quality levels for imperfections in arc-welded joints in aluminium and its alloys. It applies to material thicknesses above 0,5 mm. It covers full-penetration butt welds and all fillet welds. The principles of the standard may also be applied to partial-penetration butt welds (ISO, 2018).

Three quality levels are given in order to permit application to a wide range of welded constructions. The quality levels refer to production quality and not to the fitness for purpose of the product manufactured.

The standard applies to:

- all types of weld, e.g. butt welds, fillet welds and branch connections;
- the following welding processes and their sub-processes as defined in ISO 4063:
  - 131....metal inert gas welding (MIG welding); gas metal arc welding /USA/,
  - 141....tungsten inert gas welding (TIG welding); gas tungsten arc welding /USA/,
  - 15......plasma arc welding;
- manual, mechanized and automatic welding;
- all welding positions.

C-4: PCM Safety Standards

safety data sheet **RT28HC**

according to: 1907/2006/EG

creation date: 22.12.2012 revised: 14.12.2018

SECTION 1: IDENTIFICATION OF THE SUBSTANCE/MIXTURE AND OF THE COMPANY

1.1 Product identifier:

Product name: RT28HC

1.2 Relevant identified uses of the substance or mixture

Application area: latent heat accumulators

1.3 Details of the supplier of the safety data sheet

Company: Rubitherm Technologies GmbH

Address: Imhoffweg 6,
DE - 12307 Berlin

Phone/Fax/E-Mail: +49 (30) 7109622-0 / msds@rubitherm.com

Internet: www.rubitherm.com

1.4 Emergency call number

+49 (30) 710962268; Mo-Fr; 8:00-16:00,

SECTION 2: HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Regulation (EC) No 1272/2008

Aspiration hazard, category 1

2.2 Label elements

Regulation (EC) Nr.1272/2008

Hazard statements

H304 May be fatal if swallowed and enters airways.

Precautionary statements:

P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician.

P331 Do NOT induce vomiting.

P405 Store locked up.

2.3 Other hazards

EUH066: Repeated exposure may cause skin dryness or cracking.

SECTION 3: COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

This product is a substance.

Substance	Paraffins, normal C>10
CAS.No.	64771-71-7
EG-No.	
Index-No.	
REACH reg.-No.	
EINEC-No.	265-233-4
hazard 1272/2008/EG	Asp.1; H304

For the wording of the listed risk phrases refer to section 16

SECTION4: FIRST AID MEASURES

4.1 Description of first aid measures

General advice: Due spilled liquids surfaces can become slippery. Take off contaminated clothing immediately. If you feel unwell, seek medical advice (show safety data sheet where possible).

If inhaled: In case of inhalation the liquid product, call a physician immediately (H304). In the case of inhalation of aerosol/mist move the person concerned to fresh air. If breathing is irregular or stopped, administer artificial respiration and call a physician. If breathing difficulty persists, consult a physician. If necessary supply them with oxygen. At normal ambient temperatures this product will be unlikely to present an inhalation hazard because of ist low volatility. At high temperature aerosol/mist can cause an irritation of the respiratory tract.

In case of skin contact: Take off all contaminated clothing. Wash off with soap and plenty of water. If skin irritation persists, call a physician.

In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. If eye irritation persists, consult a specialist.

If swallowed: Do NOT induce vomiting. Keep respiratory tract clear. Call a physician immediately(H304).

4.2 Most important symptoms and effects, both acute and delayed

No known symptoms to date.

4..3 Indication of any immediate medical attention and special treatment needed

Symptomatic treatment.

SECTION 5: FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media:
Water spray, carbon dioxide (CO_2), foam (qualified personnel only), dry (extinguishing) powder

Unsuitable extinguishing media:
Do not focus the water jet directly to the burning product; could induce spray and spread the fire.
Avoid simultaneous use of foam and water, water destroys the foam.

5.2 Special hazards arising from the substance or mixture specific hazards during firefighting

Exposition to high temperatures may produce hazardous decomposition products such as: carbon dioxide, carbon monoxide,smoke and hot particles. Adapt extinguishing measures to suit the environment.

5.3 Advice for firefighters special protective equipment for firefighters

Wear self-contained breathing apparatus and chemical protective suit. Adapt extinguishing measures to the environment.

SECTION 6: ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment.
Small spilled quantities: normal antistatic working clothes are appropriate.
Large spilled quantities: Use a bodysuit made of chemical resistant and heat resistant material.

6.2 Environmental precautions

If the product contaminates rivers and lakes or sewers inform respective authorities. Avoid water ingress underground. Do not flush into surface water or sanitary sewer system.

6.3 Methods and materials for containment and cleaning up

Contain escaping material with a non flammable, absorbent substance (e.g. sand), and disposal container in accordance with the legal requirements (see Section 13).

6.4 Reference to other sections

Information for safe handling see section 7.
Information about personal protection equipment see section 8.
Information about disposal see section 13.

SECTION 7: HANDLING AND STORAGE

7.1 Precautions for safe handling

Advice on safe handling:
Use personal protective equipment. Avoid dust formation and do not breathe in dust. Avoid contact with eyes and skin.
Do not smoke, drink or eat in the working area.

Advice on protection against fire and explosion

Usual measures of preventive fire protection. Keep away from flammable material. Take precautionary measures against static discharges. No smoking.

7.2 Conditions for safe storage, including any incompatibilities

Requirements for storage areas and containers:

Storage class (TRGS 510): VCI-storage category (LGK): 10-13 Miscellaneous combutible and non-combistible substances

Store in a cool, dry and well ventilated place, away from foodstuffs in closed containers.
Protect against frost, heat and solar irradiation. Storage of product only in original package. Do not store in passages.

SECTION 8: Exposure Control/Personal Protection

8.1 Control Paramters

National Occupational Exposure Limits No data available.

European Occupational Exposure Limits No data available.

DNEL-value:

Paraffins , normal C5-C20 No data available.

PNEC-value:

Paraffins , normal C5-C20 No data available.

8.2 Exposure Controls

Personal Protective Equipment:

Please follow the usual instructions when dealing with chemicals.
Avoid contact with eyes and skin.
Wear suitable protective clothing, gloves and safety glasses.
Do not smoke, drink or eat in the working area.

Technological protection:

Ensure good ventilation at the workplace especially while working with liquid product. Keep storage and handling temperature as low as possible.

Material of gloves:

Fluorinated rubber (FKM), nitrile rubber(NBR), Polychloroprene (CR), (observe the instructions of the manufacturer)

Hand protection:

Wear protective gloves. Consider the data of the manufacturers at the permeability and break-through times.Time of duration can be shortened by environmental and use conditions. Inspect for damages after and before use, replace them if necessary. Use skincare after work.

unsuitable gloves:

Eye protection:
Safety glasses with side guard. In case of high danger of splashing use additional face shield.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

Appearance:

Physical state:	solid; 20°C; 1013hPa
Form:	solid
Colour:	white
Odour:	almost odourless
Odour Threshold:	unapplicable

Safety related data:

Explosive properties:	not explosive
Steam pressure:	No data available.
Density:	No data available.
Water solubility:	insoluble
pH-value:	unapplicable
Melting point:	27-28°C
Boiling point:	>250°C
Flash point:	165°C
Ignition temperature:	>200°C

9.2 Other data

SECTION 10: STABILITY AND REACTIVITY

10.1 Reactivity	Stable at room temperature and atmospheric pressure.
10.2 Chemical stability	At appropriate storage and handling, the product is stable.
10.3 Possibility of hazardous reactions	In case of fire or heating above the recommended maximum temperature the formation of hazardous decomposition products and / or irritating gases may occur.
10.4 Conditions to avoid	Direct heating, contamination, direct sunlight, UV or ionizing radiation. Contact with strong oxidizing agents can lead tot he risk of fire.
10.5 Incompatible materials to avoid	Strong oxidizing agents.

10.6 Hazardous decomposition products No hazardous decomposition if used and stored according to specifications.

SECTION 11: TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

The mixture was not examined in its entirety on toxicological effects. The data refer to the respective component.

Paraffins, normal C5-20

Acute toxicity: Oral: LD50 Rat: > 2.000 mg/kg; OECD-Method 401 (literature value)
Dermal: LD50 Rabbit: > 2.000 mg/kg; OECD-Methode 402 (literature value)

Skin corrosion/irritation: Skin: Rabbit: slight irritating; OECD- Method 404 (literature value)
Eye: Rabbit: slight irritating; OECD- Method 405 (literature value)

Sensitisation: Maximization test: Guinea-Pig: not sensitizing; OECD-Method 406 (literatur value)

Carcinogenicity: No carcinogenic potential expected.

Mutagenicity: Ames-test: not mutagenic; OECD TG 471; (literature value)

Reproductive toxicity: No data available.

Additional information: May be fatal if swallowed and enters airways.

SECTION 12: ECOLOGICAL INFORMATION

12.1 Toxicity

substance	toxicity to fish	toxicity to daphnia	toxicity to algae
Paraffins, normal C5-20	No data available.	Alkanes, C12-26-branched and linear: In range of water solubility not toxic under test conditions.	Alkanes, C12-26-branched and linear: In range of water solubility not toxic under test conditions.

12.2 Persistence and degradability Alkane, C12-26-: easily biodegradable; > 60 %; 28 d; aerob; OECD TG 301 F (conclusion by analogy)

12.3 Bioaccumulation potential No data available.

12.4 Mobility in soil No data available.

12.5 Results of PBT and vPvB assessment No data available.

12.6 Other adverse effects No data available.

SECTION 13: DISPOSAL CONSIDERATIONS

13.1Waste treatment methods

Recommendation:	Disposal must be made according to official regulations The product can be incinerated in accordance with local regulations.
Waste code:	A waste code in accordance with the European Waste Catalogue (EWC) may not be assigned to this product since it admits of a classification only when the consumer uses it for some purpose. The waste code must be determined in agreement with the regional waste disposal authority or company. Disposal should be in accordance with applicable regional, national, and local laws and regulations. EU Waste Disposal Code (EWC): 13 08 99 oil waste not otherwise specified. Classification of waste is always the responsibility of the end user.
Contaminated packaging:	Contaminated packaging must be handled in the same way as the product.
Cleaned packaging:	Offer rinsed packaging material to local recycling facilities.

SECTION 14: TRANSPORT INFORMATION

14.1 UN number

International Carriage of Dangerous Goods by Road
ADR : No dangerous goods
International Carriage of Dangerous Goods by Rail
RID: No dangerous goods
International Carriage of Dangerous Goods by Inland Waterways
ADN: No dangerous goods
International Maritime Dangerous Goods
IMDG: No dangerous goods
Technical Instructions for the Safe Transport of Dangerous Goods by Air
ICAO/IATA: No dangerous goods

14.2 Proper shipping name

ADR: No dangerous goods
RID: No dangerous goods
ADN: No dangerous goods
IMDG: No dangerous goods
ICAO/IATA: No dangerous goods

14.3 Transport hazard class

ADR: No dangerous goods
RID: No dangerous goods
ADN: No dangerous goods
IMDG: No dangerous goods
ICAO/IATA: No dangerous goods

14.4 Packaging group

ADR: No dangerous goods
RID: No dangerous goods
ADN: No dangerous goods

IMDG: No dangerous goods

ICAO/IATA: No dangerous goods

14.5 Environmental hazards

ADR: Not Environmentally Hazardous.

RID: Not Environmentally Hazardous.

ADN: Not Environmentally Hazardous.

IMDG: Not marine pollutant.

ICAO/IATA: Not Environmentally Hazardous.

14.6 Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

The product is not covered by international regulation on the transport of dangerous goods.

14.7 Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

not relevant

SECTION 15: REGULATORY INFORMATION

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

Directive 96/82/EC	Directive 96/82/EC does not apply.
Occupational restrictions:	Employment restrictions for children and young workers in accordance with Directive 94/33/EC and the respective national provisions are to be observed.
water hazard class:	WGK 1: water hazard class 1; slightly hazardous to water; classification into Annex 3 of VwVwS;

15.2 Chemical Safety Assessment

A Chemical Safety Assessment has not been carried out.

SECTION 16: OTHER INFORMATION

Changes made since the last version:

This information is based on our present knowledge. However, this shall not constitute a guarantee for anyspecific product features and shall not establish a legally valid contractual relationship.

literature references and sources for data:

http://gestis.itrust.de/
http://echa.europa.eu/
http://www.reach-clp-helpdesk.de/

Rules:

Substance directive (67/548/EEC).
REACH Regulation 1907/2006/EC.
CLP Regulation (EC) No 1272/2008.

Full text of H-Statements referred to under sections 2 and 3.

H304 May be fatal if swallowed and enters airways.

Safety note:

P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician.
P331 Do NOT induce vomiting.
P405 Store locked up.

All information in this material safety data sheet (MSDS) is correct to the best of our knowledge, information and belief at the date of its publication. The data given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. Each customer shall make is own evaluation of appropriate use, shipping and storage for each specific material. Rubitherm makes no warranty either express or implied, including any warranties of fitness for a specific purpose. This safety datasheet does not replace any product information or specification.

APPENDIX D – LOGBOOK

Table 27 – Logbook

Meeting Date	Meeting/Event + Duration	Meeting/Event Summary
10/10/18	8:30 to 9:20 AM	A. Discussed with the Supervisor the general idea and objective of the Project and what equipment will be needed to execute the project such as Batteries, Solar Panels, Thermocouples and so on.
14/10/18	8:15 to 8:55 PM	A. Assigned a Group Leader and Editor B. Divided the work on **Chapter 1 & 2** among the group members. C. Group members were assigned topics to research and gather information on related to Heat Pipes and Phase Change Materials for PV Panel cooling.
21/10/18	8:14 to 8:46 PM	A. Discussed some changes that should be made on the **Chapter 1 & 2** draft and adding more information to the draft. B. Discussed at what at temperate should the Solar Panels be keep at and how will the cooling systems be attached to the Solar Panels. C. Group members were assigned to gather information about the cost of the needed equipment
26/10/18	7:40 to 8:04 PM	A. Divided the work on **Chapter 3** where o 2 members were assigned with the Phase Change Material Cooling System o 2 members with the Heat Pipe Cooling System o 1 member with the Solar Panel related work B. Decided to change the meeting hours to an earlier time during weekdays.
9/11/18	6:30 to 7:15 PM	A. Discussed what Values should be assumed for the Sun Insolation level and the Ambient temperature. B. Discussed if any changes were needed to be done on the proposed Heat Pipe Cooling System Design. C. Discussed about PCM type to be used and procurement. Discussed who should contact PCM Supplier
17/11/18	6:15 to 7:10 PM	A. Talked about looking for other PCM alternatives after realizing that the current PCM choice was too expensive. Discussed whether to glue the Heat Pipe Cooling System using thermal paste or Bolted it on the back of a frame then attach the frame to the PV Panel.

Meeting/Event Date	Meeting/Event Duration	Meeting/Event Summary
21/11/18 – 01/12/18	N/A (Midterms)	A. No work performed during this period due to Midterm examinations
3/12/18	6:14 to 6:35 PM	A. Divided the work on **Chapter 4 & 5** among the group members. B. Discussed All the information that is to be included in the Appendix. C. Divided the workload on outstanding in the report among the group members.
09/12/18	6:10 to 6:35 PM	A. Went through completed report to check if all parts are correct and completed before meeting with Supervisor.
14/12/18	N/A (Due Date)	A. Submitted report
21/01/19 – 18/02/19	Winter Break	A. Used this opportunity to look locally for sources of materials.
28/02/19	Ordered PCM	A. Ordered PCM from Rubitherm.
04/03/19	Ordered HP	A. Ordered Heat Pipes from Conrad.
06/03/19	Ordered PV Panels	A. Ordered PV Panels from a local source.
18/03/19	Bought Aluminium	A. Bought Aluminium Sheets from a local source.
08/04/19	Heat Pipes Arrival	A. Heat Pipes was delivered to Cyprus.
11/04/19 - 22/04/19	Midterm Exams	A. No worked Performed to focus on Midterm Examinations
15/04/19	PV Panels Arrival	A. PV Panels were delivered to Cyprus.
22/03/19	PCM Arrival	A. PCM was delivered to Cyprus.
24/04/19	PCM Container and Heat Pipe Saddle	A. Manufacturing of PCM Container and Heat Pipe Saddle commenced.
24/04/19 – 30/04/19	PCM Container	A. PCM Container Sent for Welding.
01/05/19 - 06/05/19	PV Panel Stand	A. Manufacturing of PV Panel Stand
13/05/19 – 23/05/19	Testing	A. Product Testing Commenced B. Results were captured and discussed.
23/05/19 – 24/05/19	Future Works and Conclusion. Report Deadline	A. Project was concluded and Future Works were evaluated B. Report Submission.

APPENDIX E - PROJECT TIMELINE

E – 1: Gantt Chart

Project Name: *PV Cooling*	**Group Name:** Easy Company	**Start Date:** 10/10/18 **Sub. Date:** 22/5/2019	Activity by months from the start of the project

October/2018			November/2018				December/2018		January/2019	February/2019	March/2019		April/2019	May/2019	
10-17	17-24	24-31	1-8	8-15	15-22	22-29	29-6	6-19	1-7	18-28	1-15	18-31	23-30	1-14	15-21

WBS	TASK	Task Led
1. – 5.	Report Writing	All Members
1.	Concept Gen; Introduction	All members
1.1. 1.2. 1.3. 1.4. 1.5.	Intro; Significance; Objective; Constraints; Organization	All members
2.	Literature Review	Othiman , Mpho, Sean. Waddah
2.1. 2.2. 2.3. 2.4.	Background; Solutions; Comparison; Standards	Othiman , Mpho, Sean. Waddah
3.	Design And Analysis	All members
3.1.	Proposed Designs	Mph,Wadda ,Qasi
3.2.	Engineering Standards	Sean, Othiman
3.3.	Design Calculations	Mpho, Waddah
3.4.	Cost Analysis	Mpho
4.	Manufacturing Plan	Mpho, Othiman, Qasi, Waddah
4.1.	Process Selection	Mpho, Qasi, Waddah
4.2.	Detailed Manufacturing	Othiman, Waddah
4.3.	Assembly	Mpho waddah
5.	Product Testing Plan	Sean, Mpho
5.1.	Objectives Verification	Sean
5.2.	Standards Verification	Sean
5.3.	FMEA	Mpho
	Material Procurement	Mpho, Sean, Othiman
	Manufacturing and Fabrication	Othiman , Mpho, Sean. Waddah
	Machining	Othiman , Mpho, Sean. Waddah
	Assembling	Othiman , Mpho, Sean. Waddah
	Testing	Othiman , Mpho, Sean. Waddah
6.	Results and discussions	Mpho, Waddah, Othiman,Sean
6.1	The results	Mpho, Waddah
6.2	The engineering standards	Sean
6.3	The constraints	Othiman
7.	Conclusion, Future work	Sean, waddah
7.1	Conclusion	Sean
7.2	Future work	Waddah
Appendix D	Logbook	Mpho
Appendix E	Project Timeline	Othiman
Appendix F	Engineering Drawings	Mpho, Sean, Waddah
1– 7. A - H	Report Compiling & Editing	Mpho

Figure 77 – Gantt Chart

E – 2: Work Breakdown Structure (WBS)

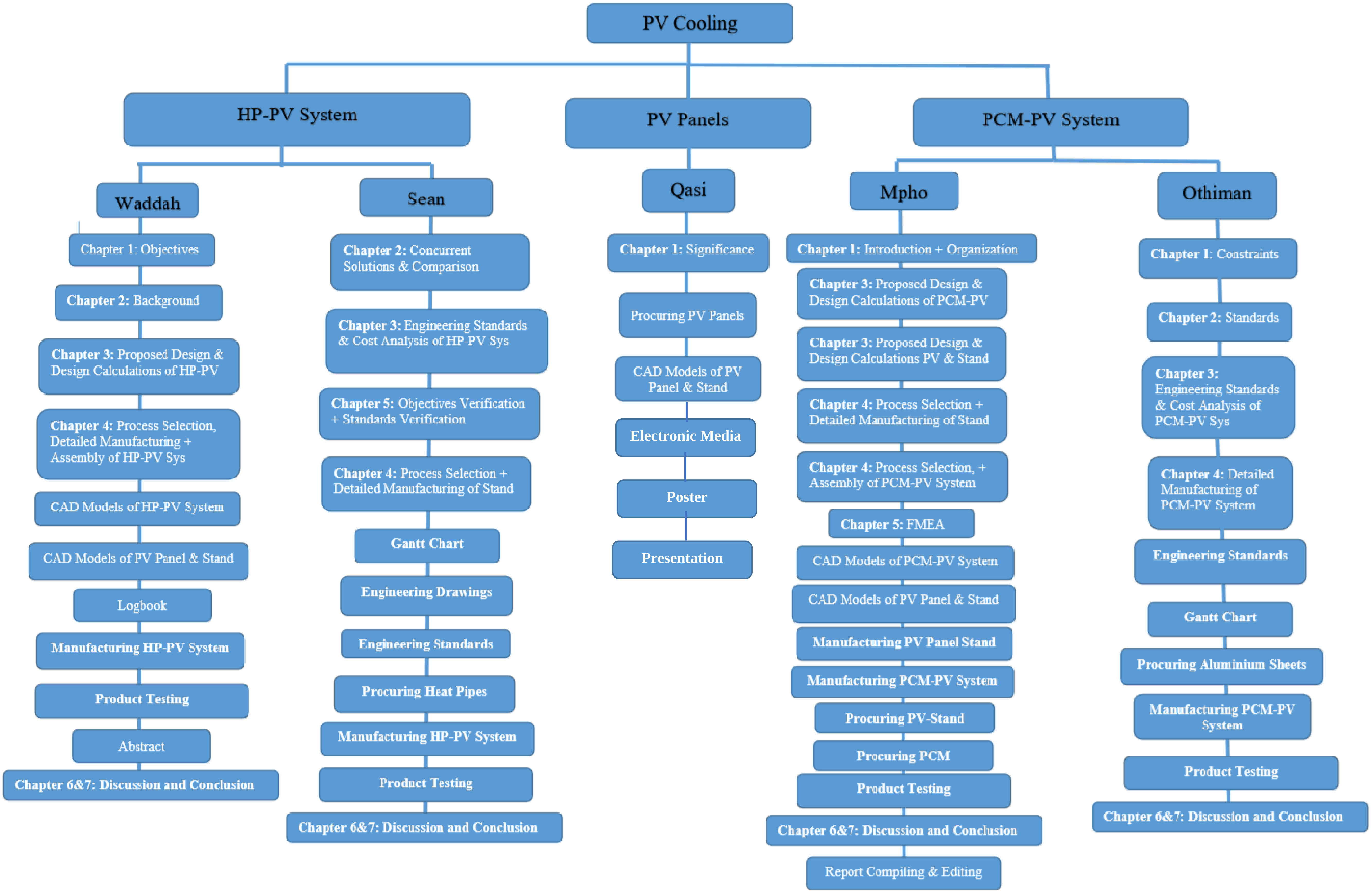
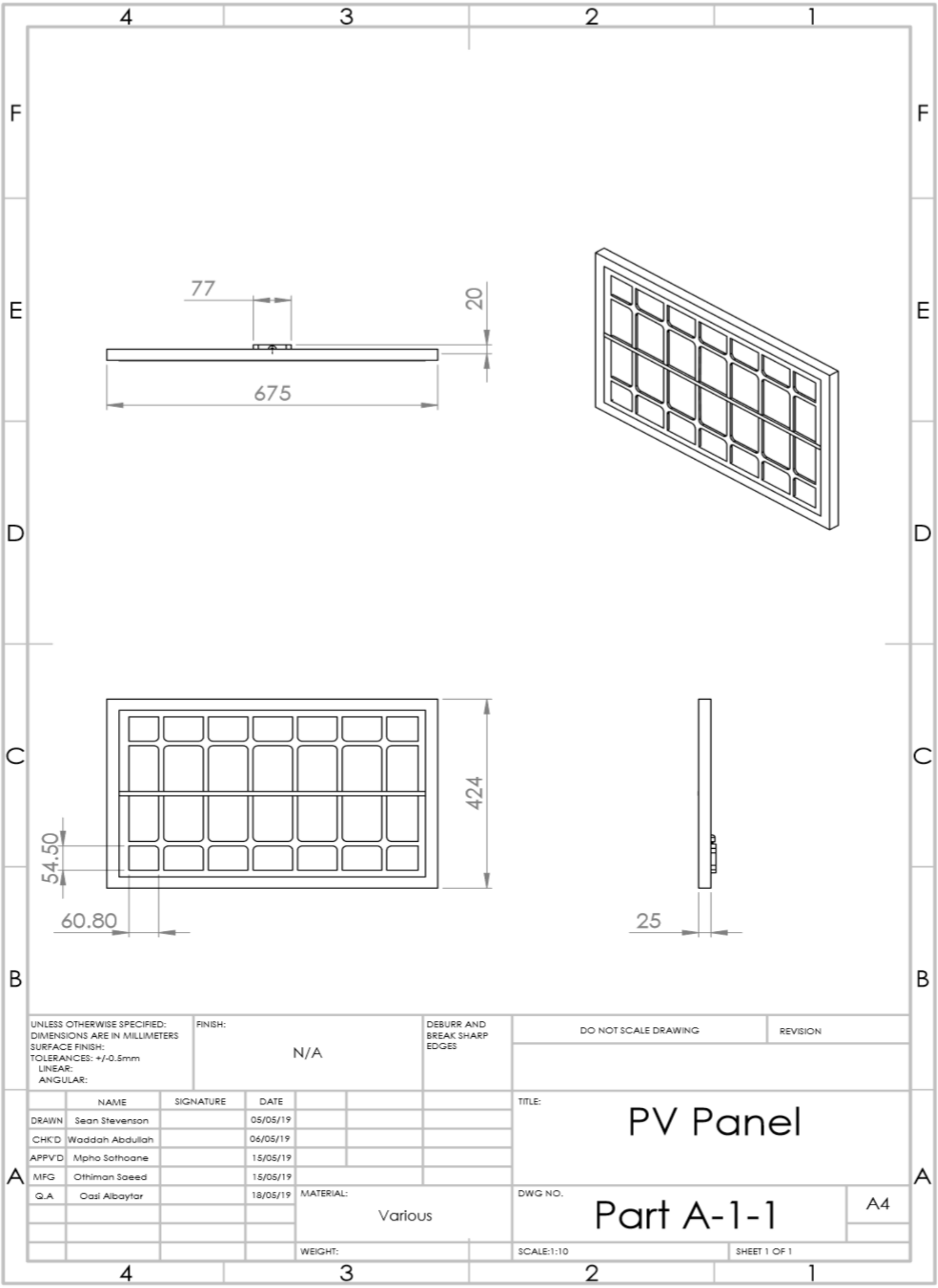
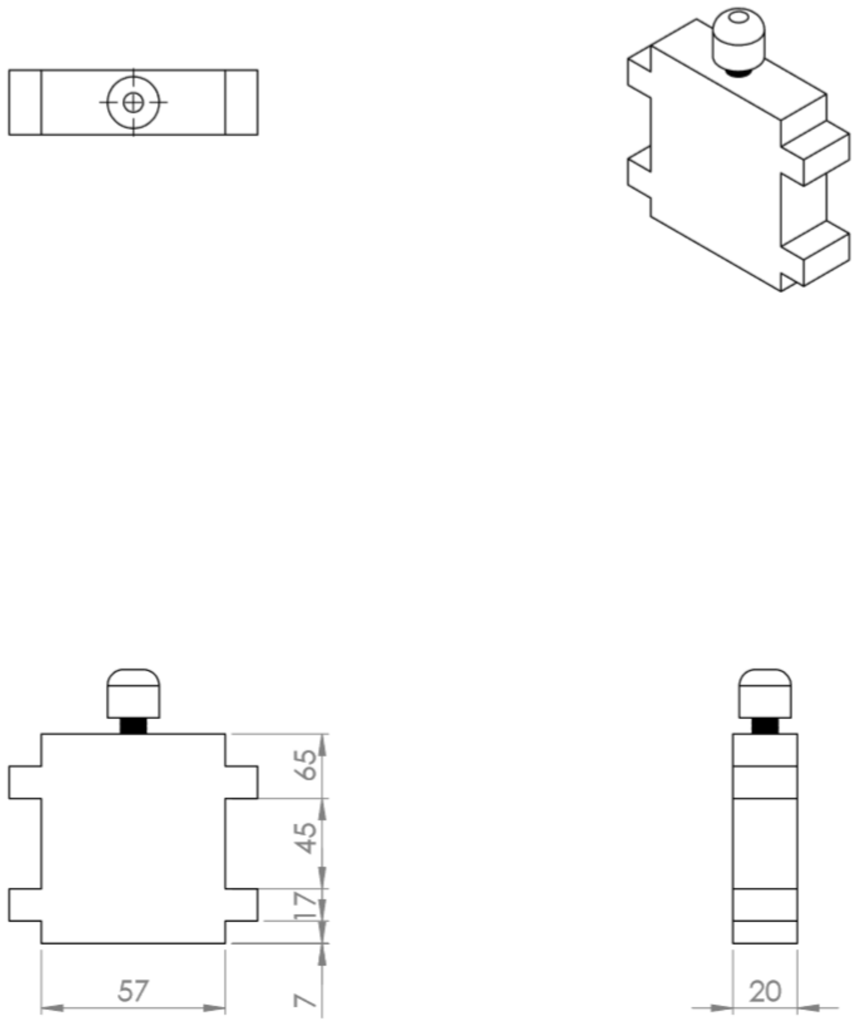


Figure 78 - WBS

APPENDIX F – ENGINEERING DRAWINGS

F – 1: DETAILED DRAWINGS





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: +/- 0.5mm
LINEAR:
ANGULAR:

FINISH: N/A

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

TITLE:

Electrical Block

MATERIAL: Plastic

DWG NO.

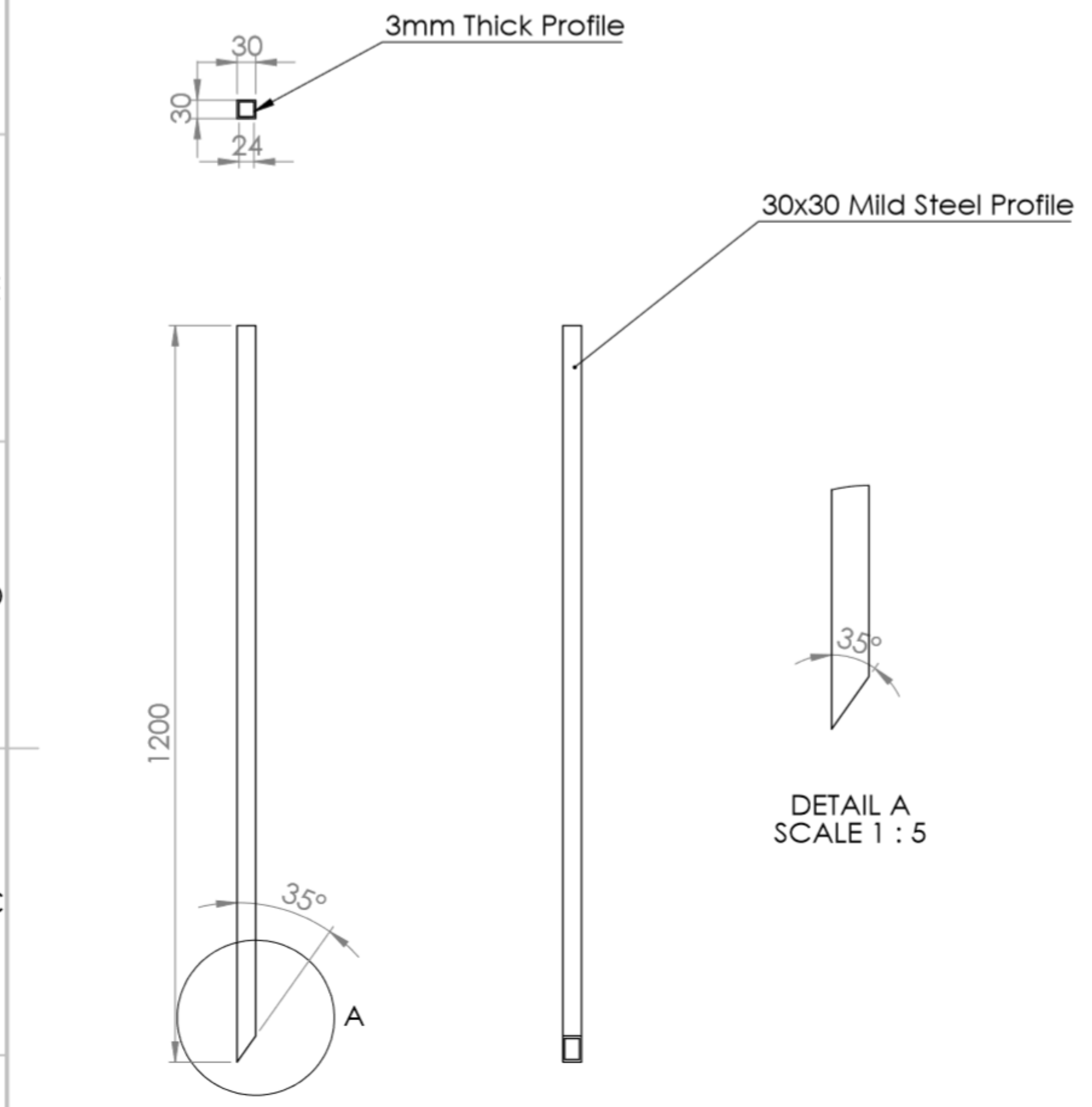
Part A-1-2

A4

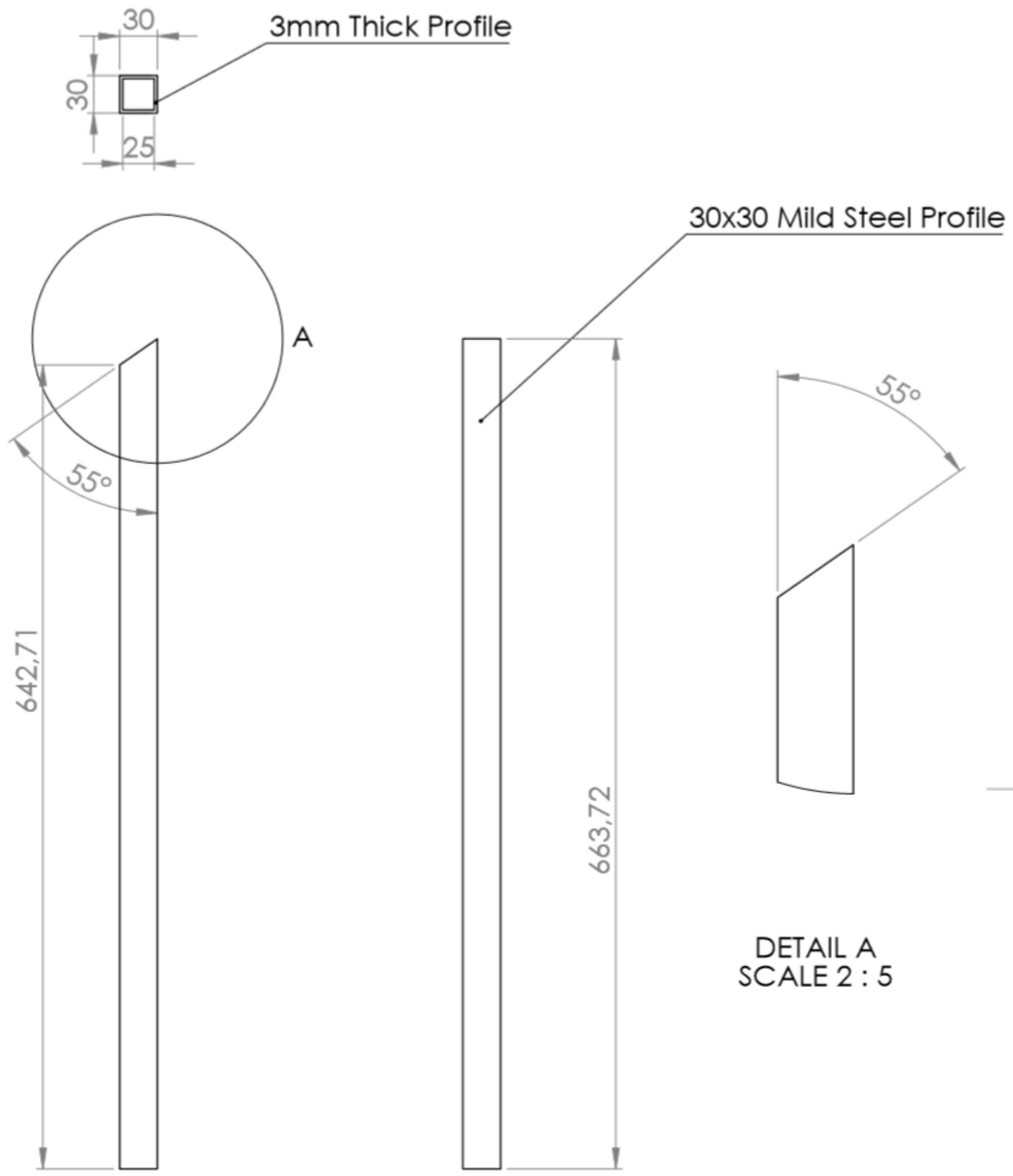
WEIGHT:

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: +/- 1mm LINEAR: +/- 1mm ANGULAR: +/- 1 Deg		FINISH: Smooth	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING 1:10	REVISION
	NAME	SIGNATURE	DATE	TITLE:	Hypotenuse Leg
DRAWN	Mpho Sothoane		05/05/19		
CHK'D	Waddah Essam		05/05/19		
APPV'D	Sean Stevenson		05/05/19		
MFG	Mpho Sothoane		12/05/19		
Q.A	Othiman Saeed		15/05/19	MATERIAL: Mild Steel	DWG NO. B-1-1 A4
				WEIGHT:	SCALE:1:10 SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES: +/- 1mm
LINEAR: +/- 1mm
ANGULAR: +/- 1 Deg

FINISH: Smooth

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

1:5

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Waddah Essam		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Othiman Saeed		15/05/19

TITLE:

Hind Leg

MATERIAL: Mild Steel

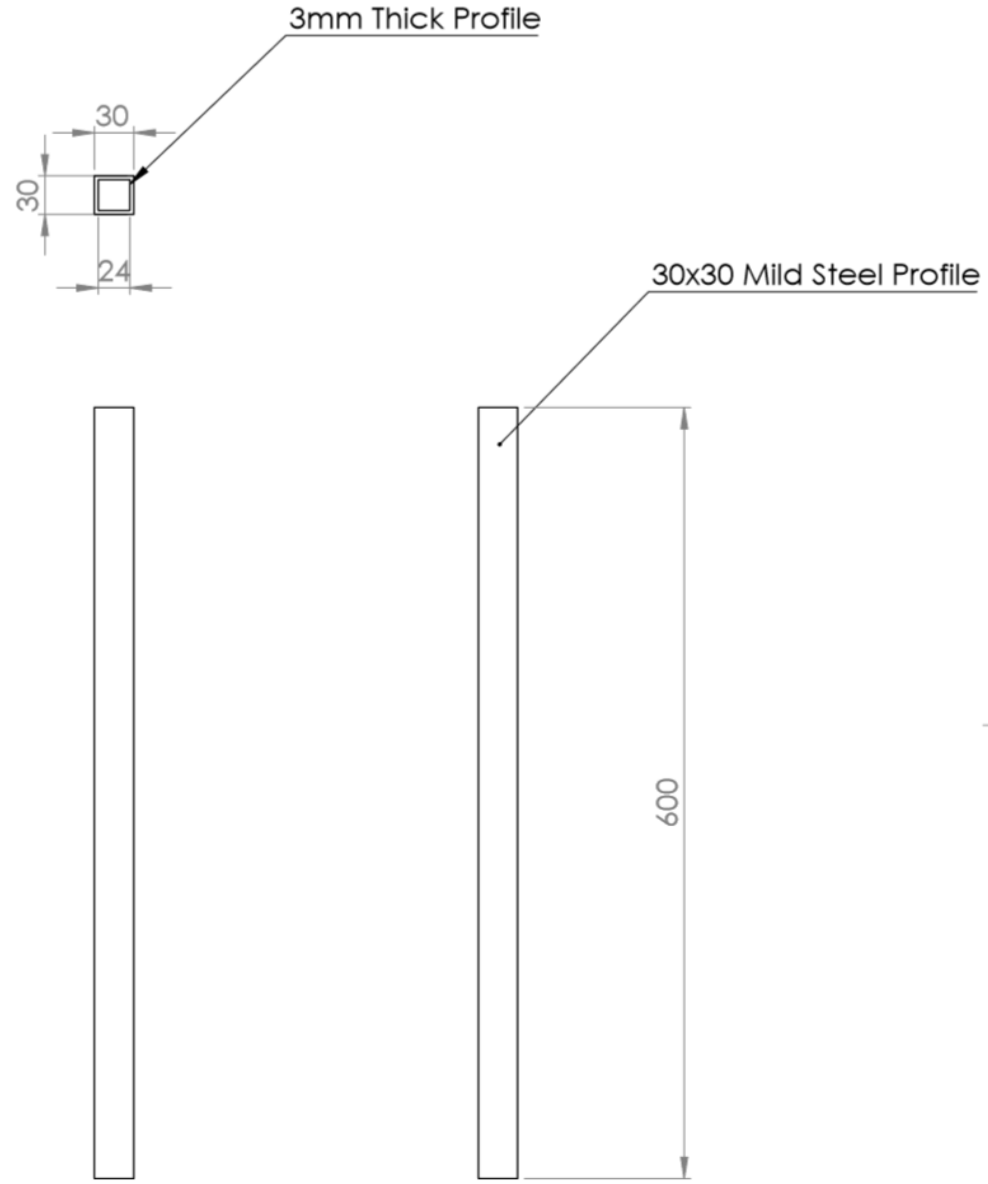
DWG NO. B-1-2

A4

WEIGHT:

SCALE:1:5

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES: +/- 1mm
LINEAR: +/- 1mm
ANGULAR: +/- 1 Deg

FINISH: Smooth

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

1:5

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Waddah Essam		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Othiman Saeed		15/05/19

TITLE: Cross Support Bar

MATERIAL: Mild Steel

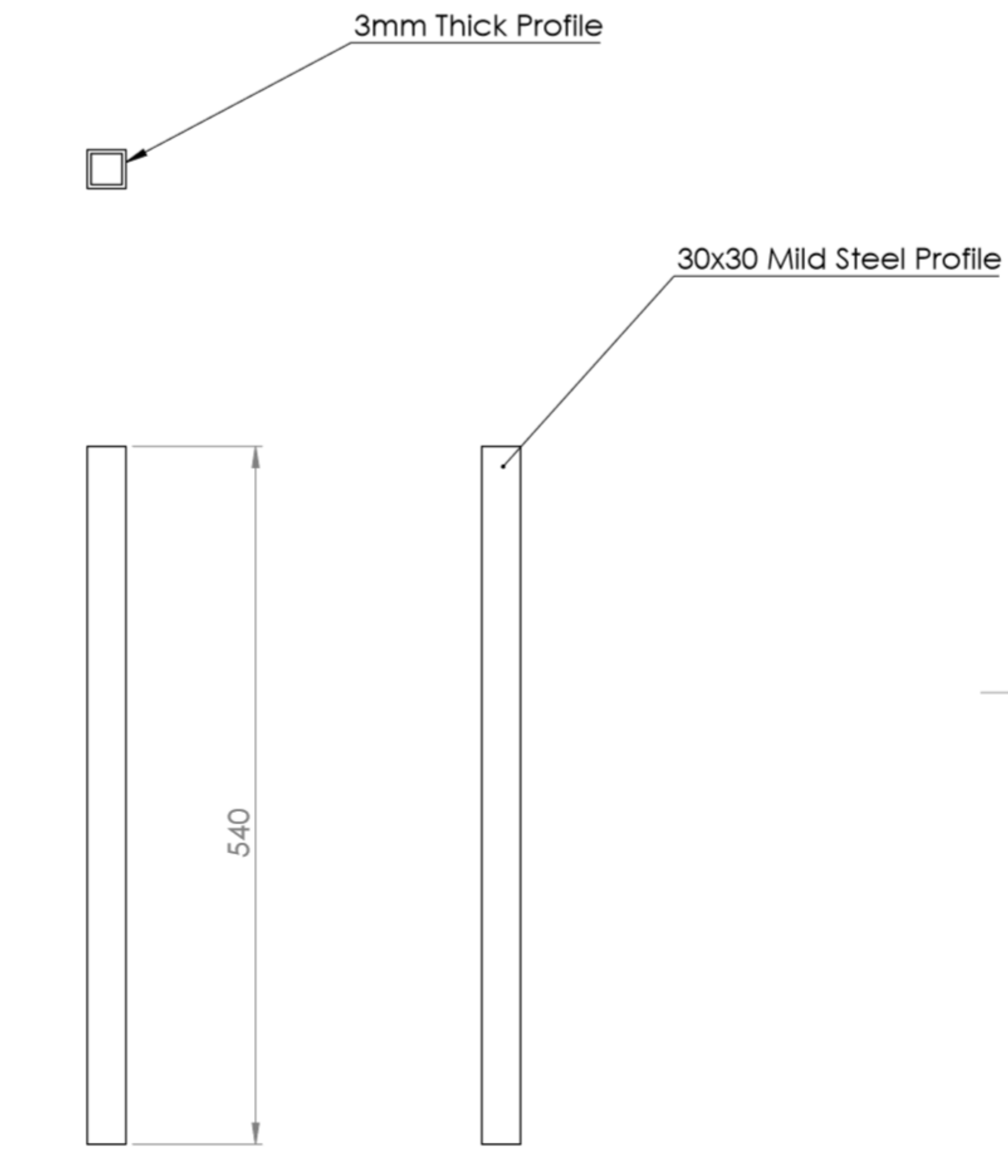
DWG NO. B-1-3

A4

WEIGHT:

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: +/- 1mm LINEAR: +/- 1mm ANGULAR: +/- 1 Deg	FINISH: Smooth	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING 1:5 / REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Waddah Essam		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Othiman Saeed		15/05/19

TITLE: Cross Bar

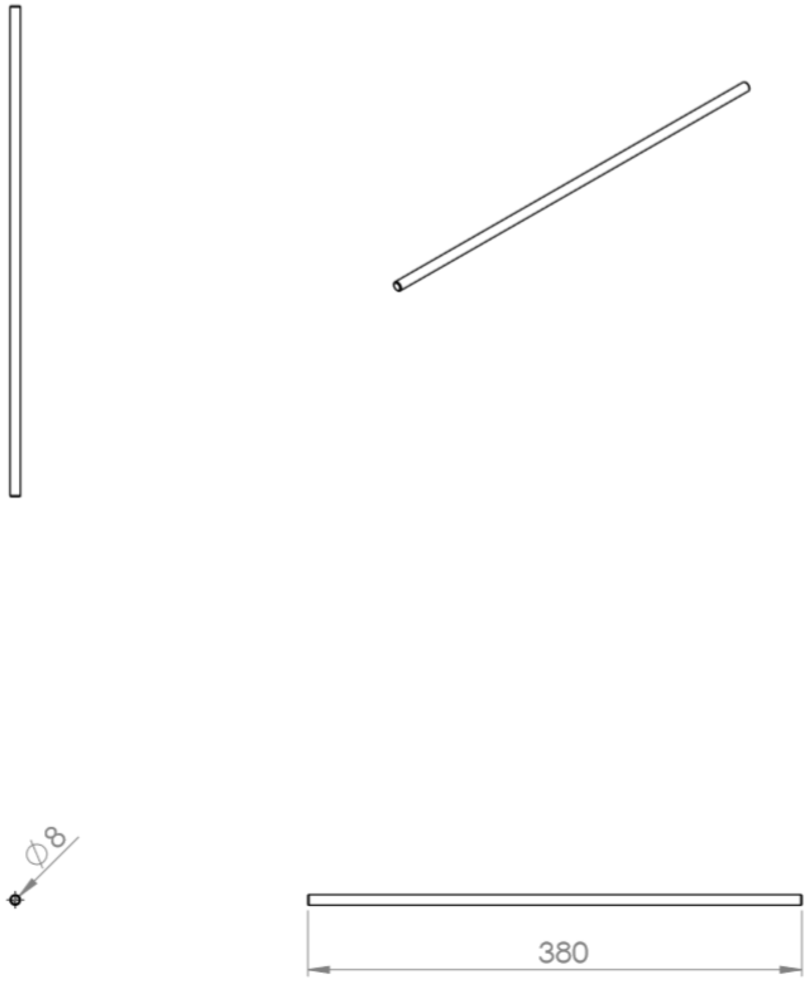
MATERIAL: Mild Steel

DWG NO. B-1-4 A4

WEIGHT:

SCALE:1:10

SHEET 2 OF 2



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: +/- 0.5mm
LINEAR:
ANGULAR:

FINISH: Smooth

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

TITLE: Heat Pipe

MATERIAL: Copper

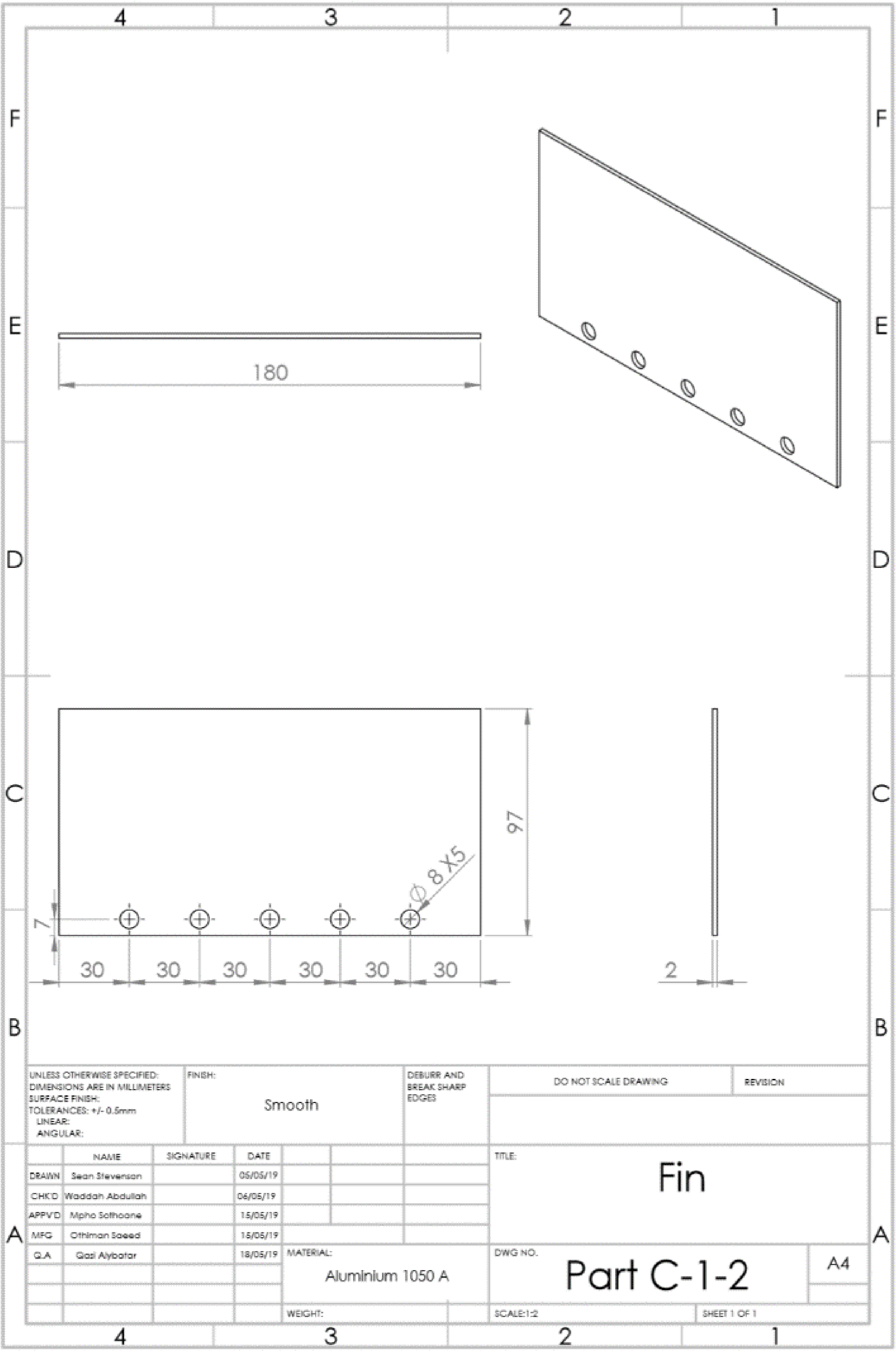
DWG NO. Part C-1-1

A4

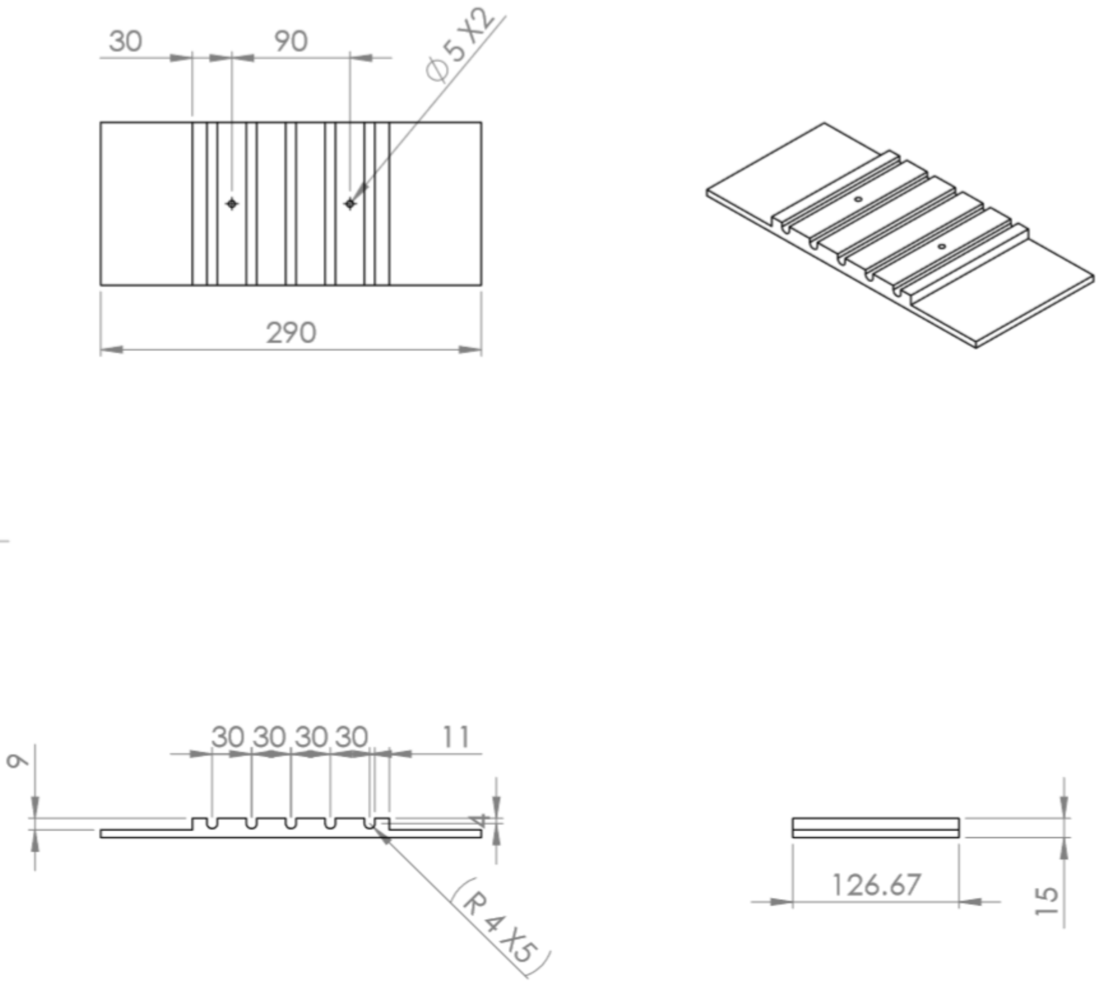
WEIGHT:

SCALE:1:5

SHEET 1 OF 1



180
97
Ø 8 X5
7
30
30
30
30
30
30
2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: +/- 0.5mm
LINEAR:
ANGULAR:
FINISH:
Smooth
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN Sean Stevenson 05/05/19
CHK'D Waddah Abdullah 06/05/19
APPV'D Mpho Sothoane 15/05/19
MFG Othman Saeed 15/05/19
Q.A Qazi Alybatar 18/05/19
MATERIAL:
Aluminium 1050 A
WEIGHT:
TITLE:
Fin
DWG NO.
Part C-1-2
A4
SCALE:1:2
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: +/- 0.5mm LINEAR: ANGULAR:	FINISH: Machined	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

TITLE: Saddle

MATERIAL: Aluminium 1050A

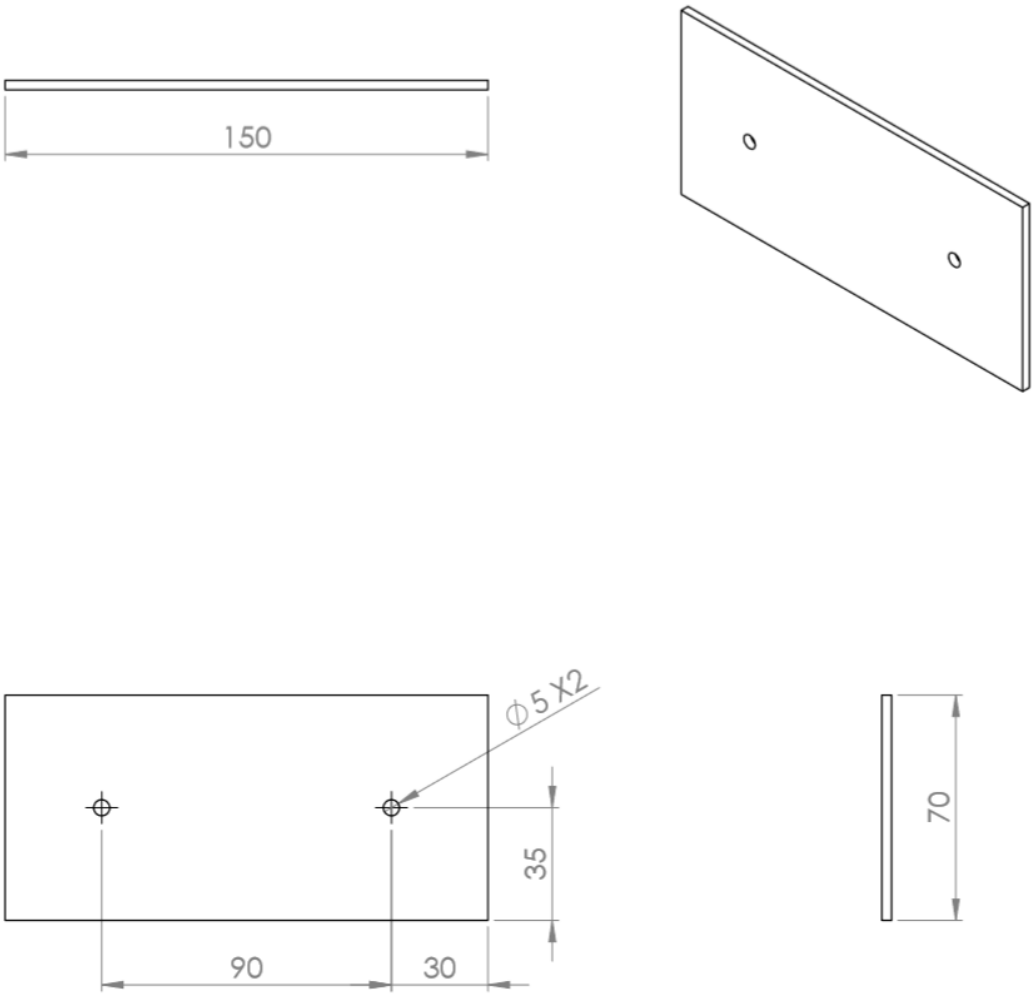
DWG NO. Part C-1-3

A4

WEIGHT:

SCALE:1:5

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: +/- 0.5mm LINEAR: ANGULAR:	FINISH: Smooth	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

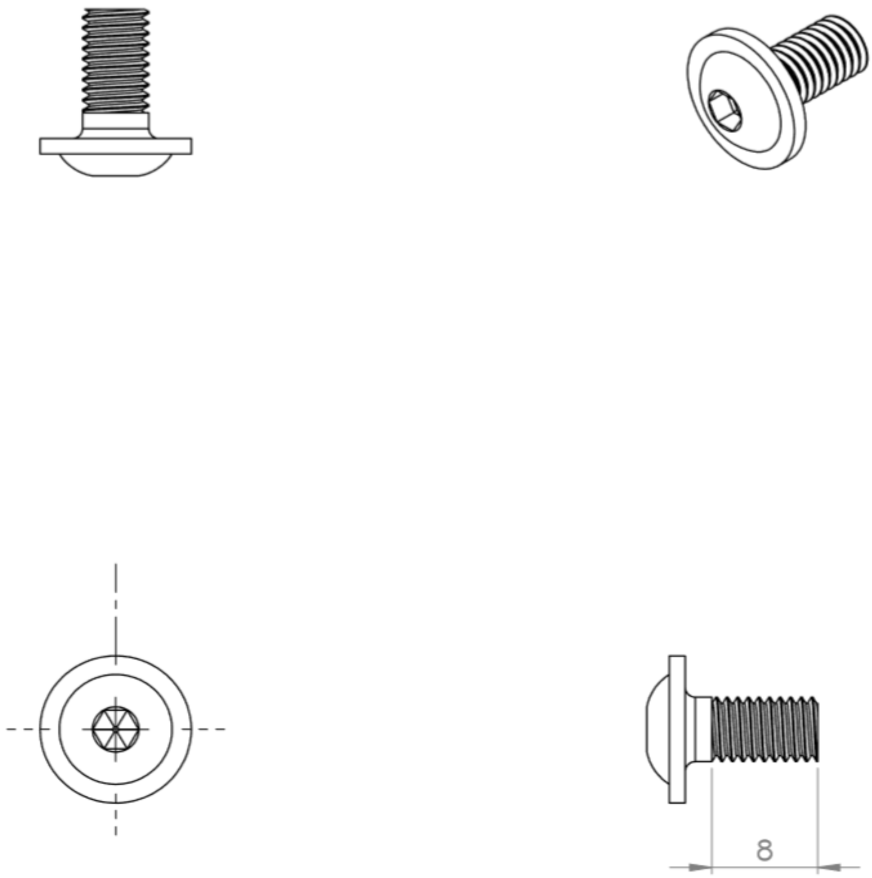
TITLE: **Fixing Plate**

MATERIAL: Aluminium 1050A

DWG NO. **Part C-1-4** A4

WEIGHT:

SCALE:1:2 SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: +/- 0.5mm
LINEAR:
ANGULAR:

FINISH: Machined

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

TITLE: M5 Hex Screw

MATERIAL: Steel

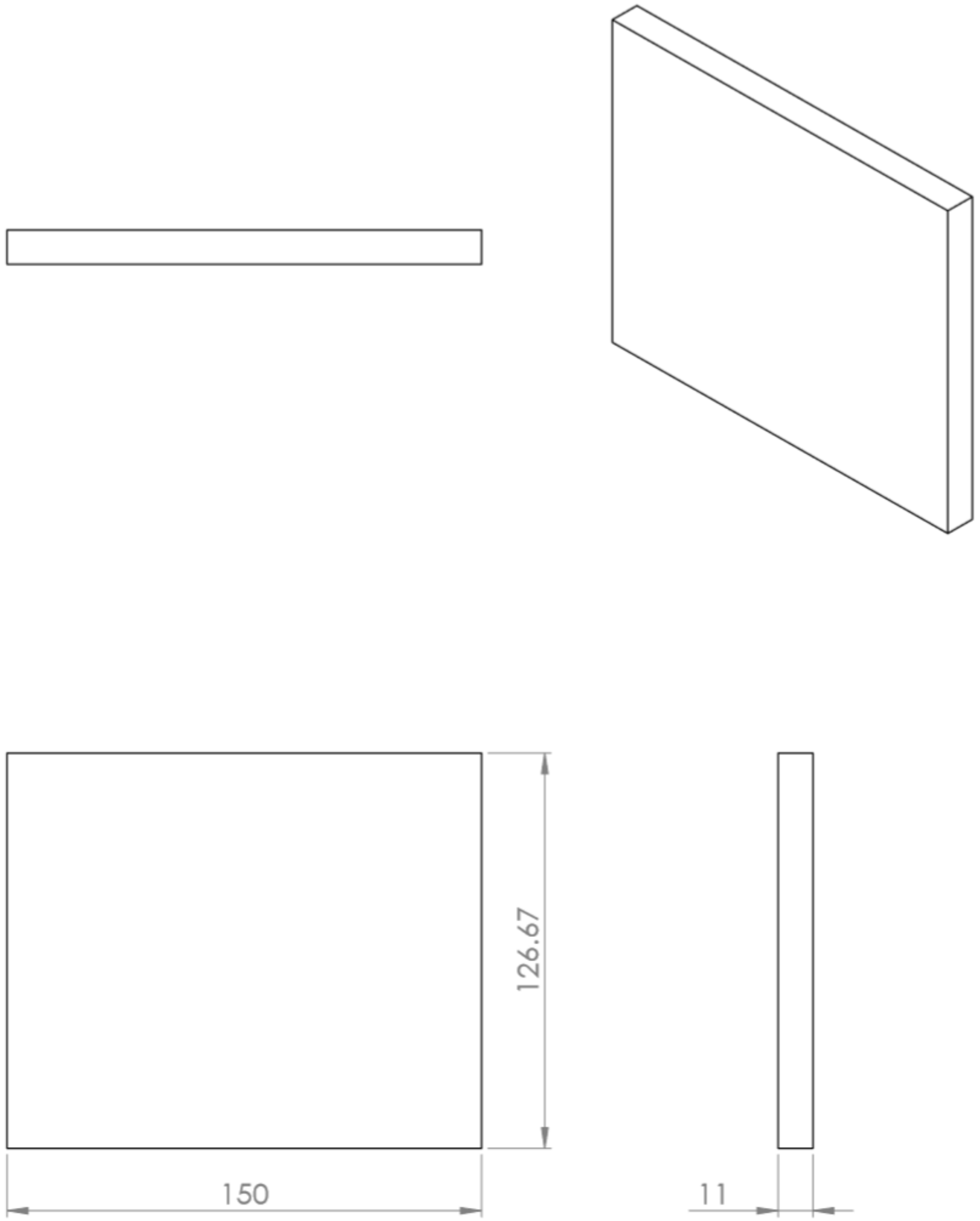
DWG NO. Part C-1-5

A4

WEIGHT:

SCALE:2:1

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: +/- 0.5mm LINEAR: ANGULAR:	FINISH: N/A	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothoane		15/05/19
MFG	Othiman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

TITLE: Insulation Foam

MATERIAL: Foam

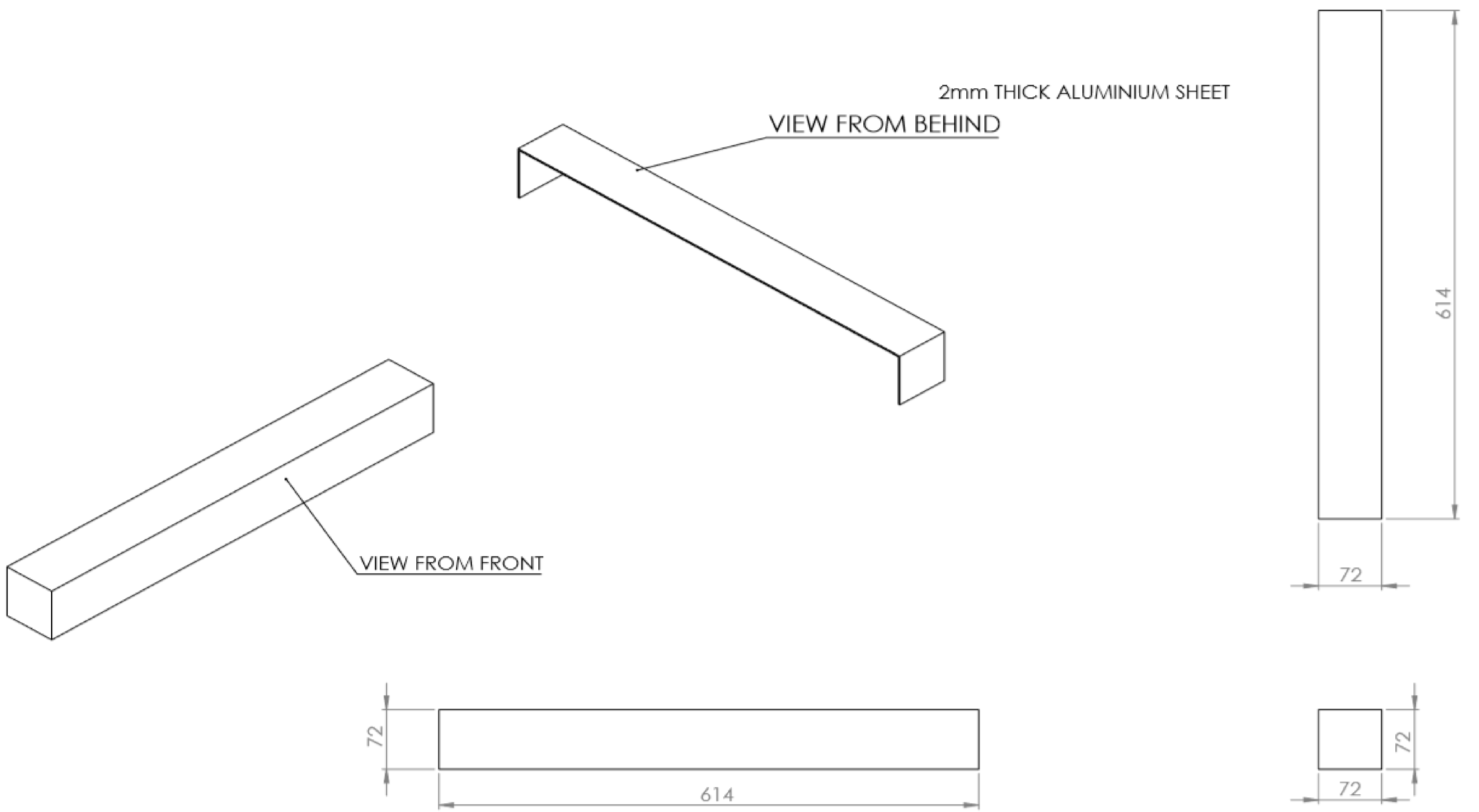
DWG NO. Part C-1-6

A4

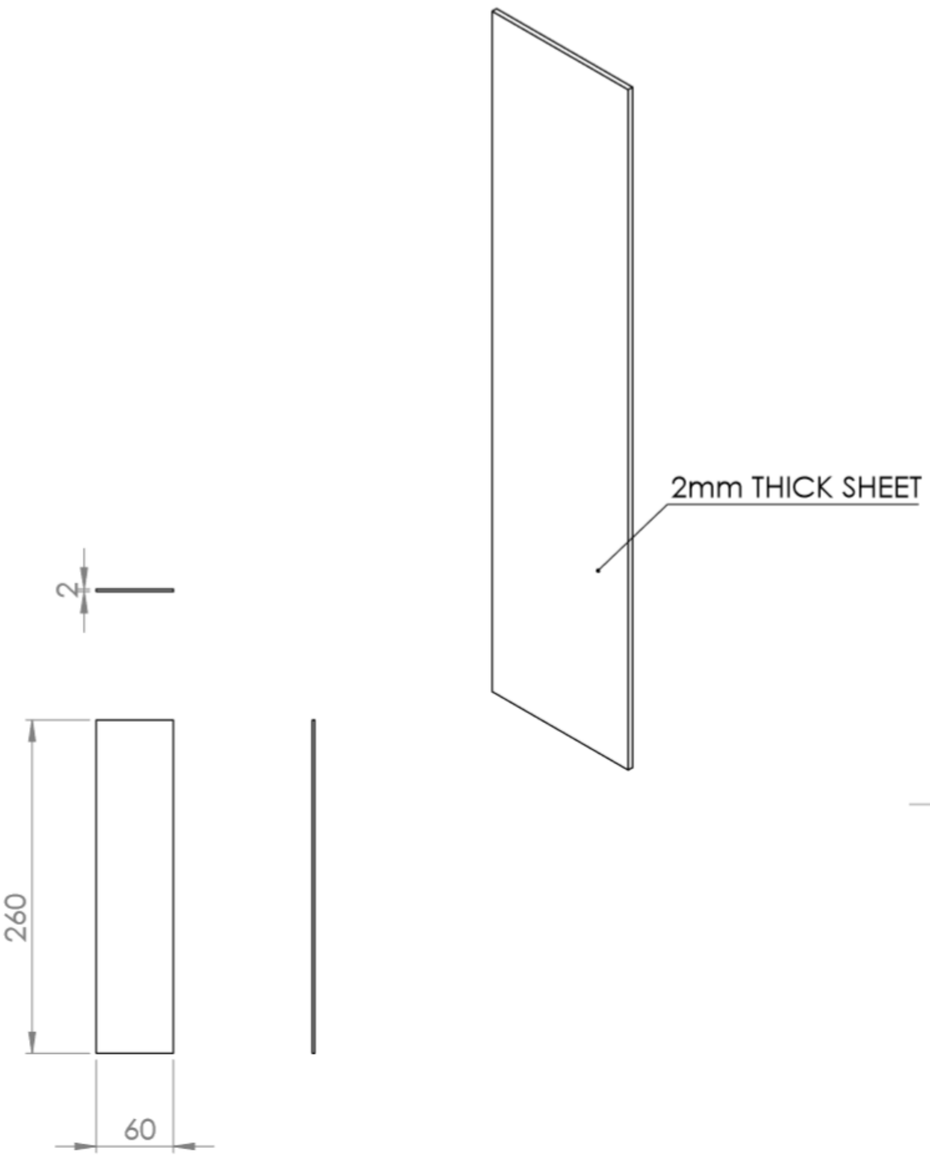
WEIGHT:

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: +/- 1mm LINEAR: ANGULAR:		FINISH: Smooth		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
					1:5	
	NAME	SIGNATURE	DATE		TITLE: Aluminium PCM Container Lid	
DRAWN	Mpho Sothoane		05/05/19			
CHK'D	Othman Saeed		05/05/19			
APPV'D	Sean Stevenson		05/05/19			
MFG	Mpho Sothoane		12/05/19			
Q.A	Qasi Albytar		15/05/19	MATERIAL: Aluminium 1050A	DWG NO. D-1-2	A3
				WEIGHT:	SCALE:1:5	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: +/- 1mm LINEAR: ANGULAR:	FINISH: Smooth	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
			1:5		

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Othiman Saeed		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Qasi Albytar		15/05/19

TITLE: PCM Fins

MATERIAL: Aluminium 1050A

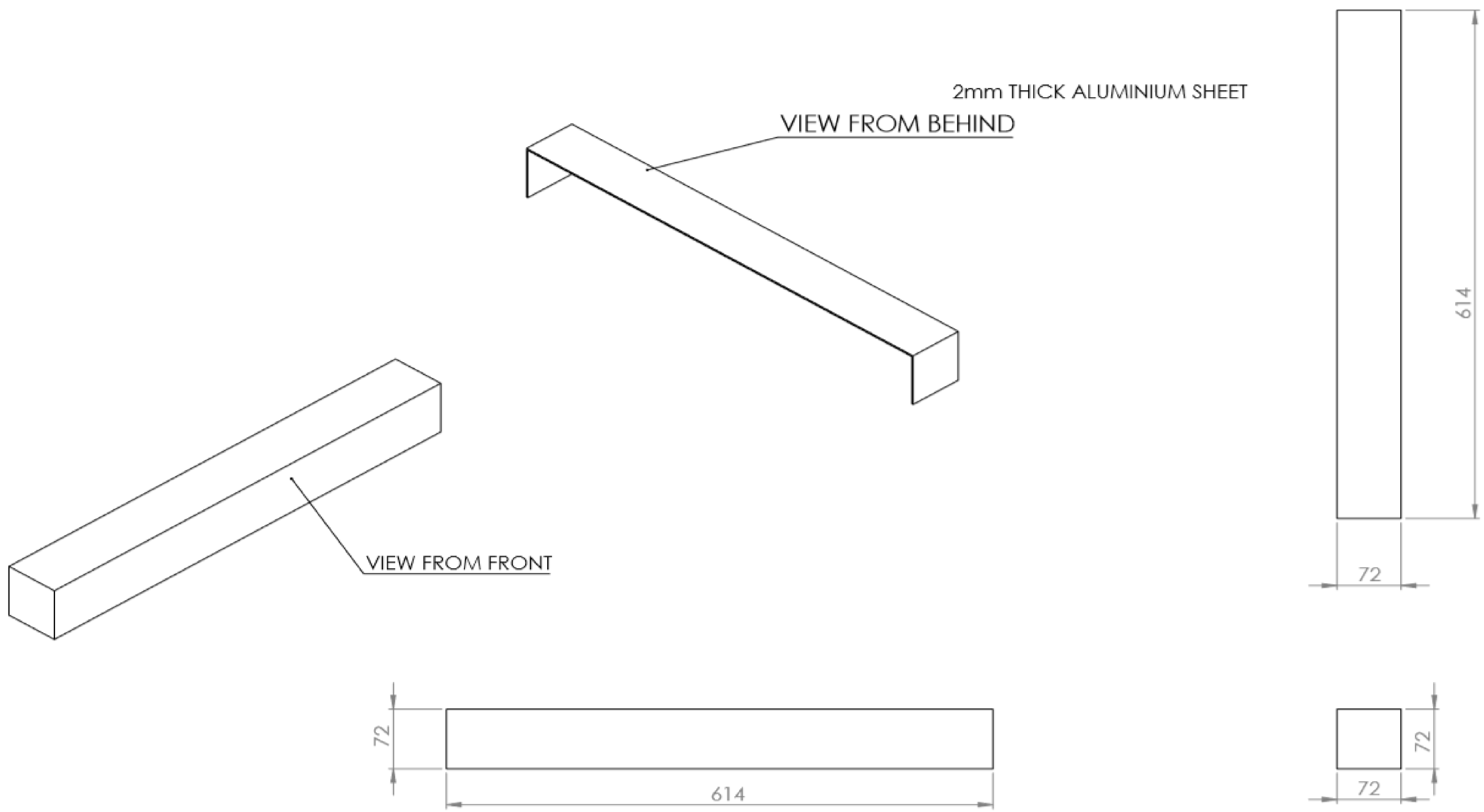
DWG NO. D-1-3

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: +/- 1mm LINEAR: ANGULAR:	FINISH: Smooth	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING 1:5	REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Othman Saeed		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Qasi Albytar		15/05/19

TITLE: Aluminium PCM Container Lid

MATERIAL: Aluminium 1050A

WEIGHT:

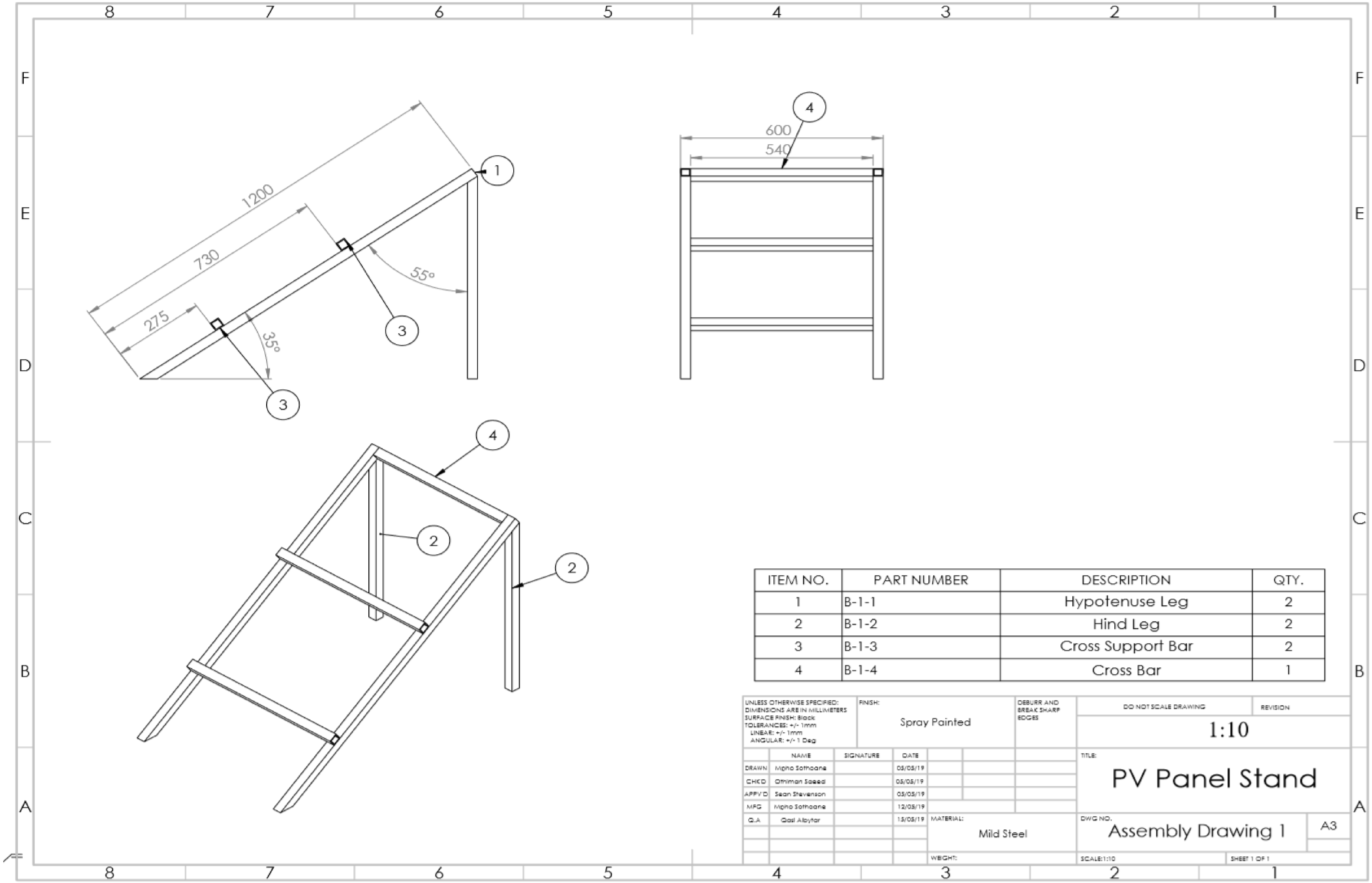
DWG NO. D-1-4

A3

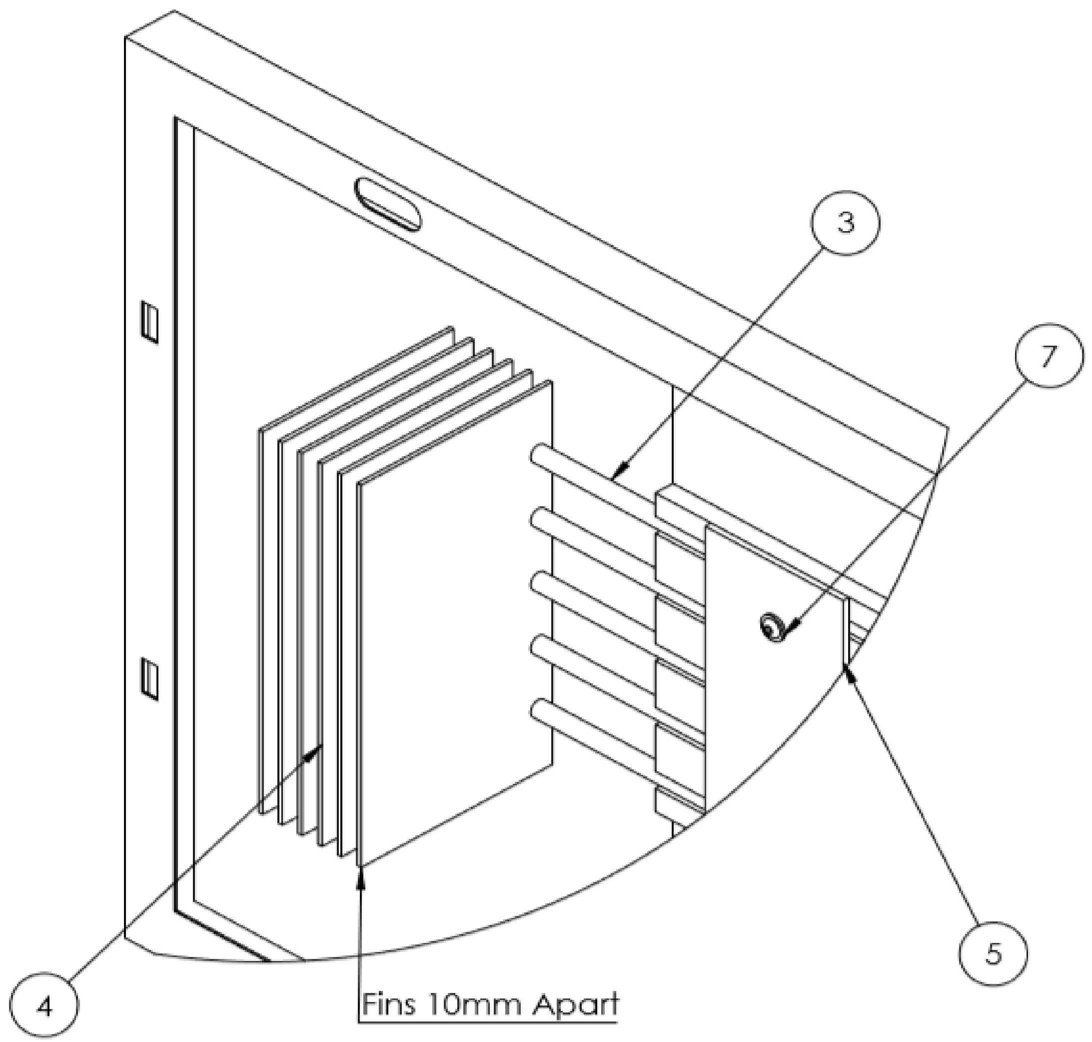
SCALE:1:5

SHEET 1 OF 1

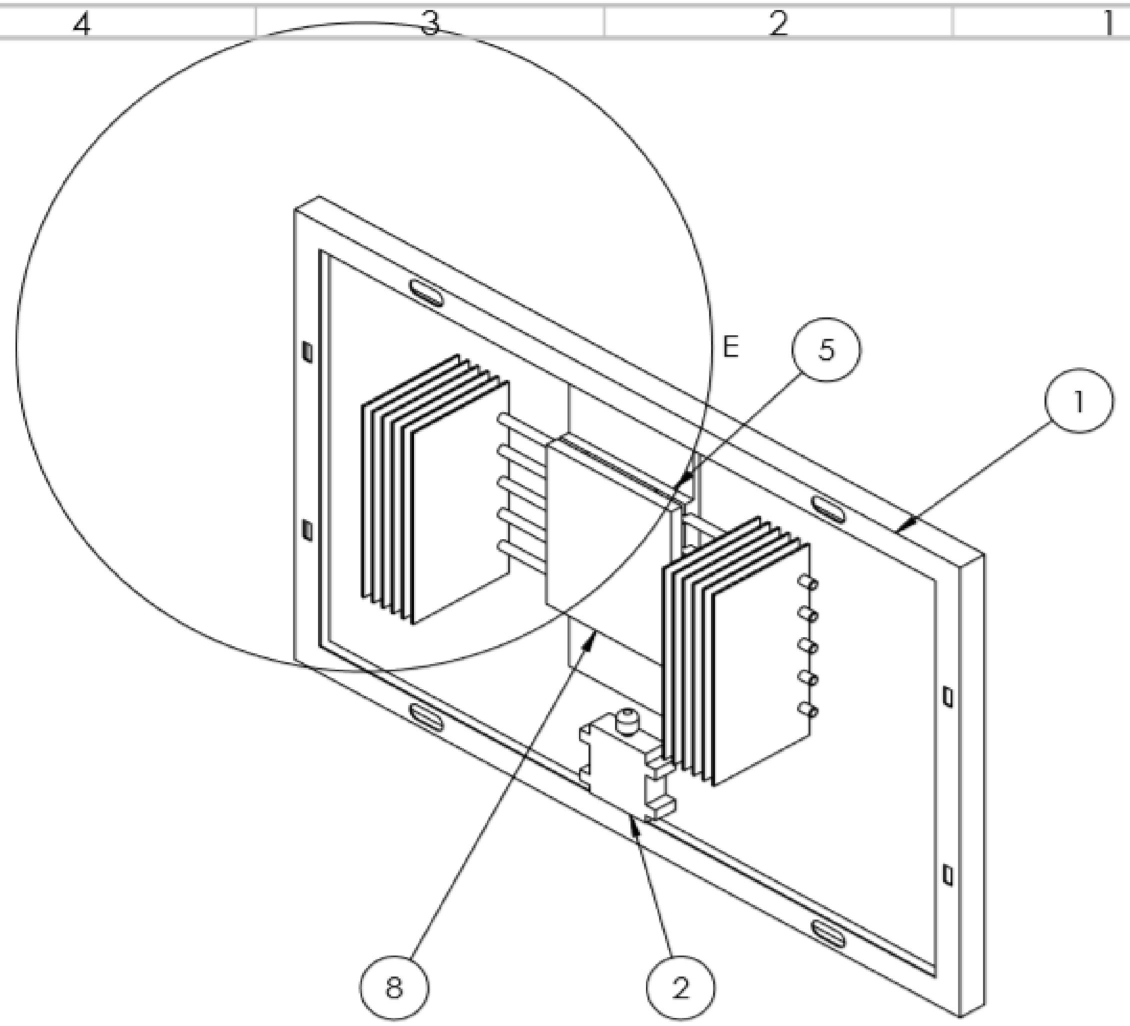
F – 2: ASSEMBLY DRAWINGS



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	B-1-1	Hypotenuse Leg	2
2	B-1-2	Hind Leg	2
3	B-1-3	Cross Support Bar	2
4	B-1-4	Cross Bar	1



DETAIL E
SCALE 2 : 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A-1-1	PV Panel	1
2	A-1-2	Electrical Block	1
3	C-1-1	Heat Pipe	5
4	C-1-2	Fin	12
5	C-1-3	Saddle	1
6	C-1-4	Fixing Plate	1
7	C-1-5	M5 Hex Screw	2
8	C-1-6	Insulation Foam	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: +/- 0.5mm
LINEAR:
ANGULAR:

FINISH: N/A

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Sean Stevenson		05/05/19
CHK'D	Waddah Abdullah		06/05/19
APPV'D	Mpho Sothane		15/05/19
MFG	Othman Saeed		15/05/19
Q.A	Qasi Albaytar		18/05/19

MATERIAL: Various

WEIGHT:

TITLE:

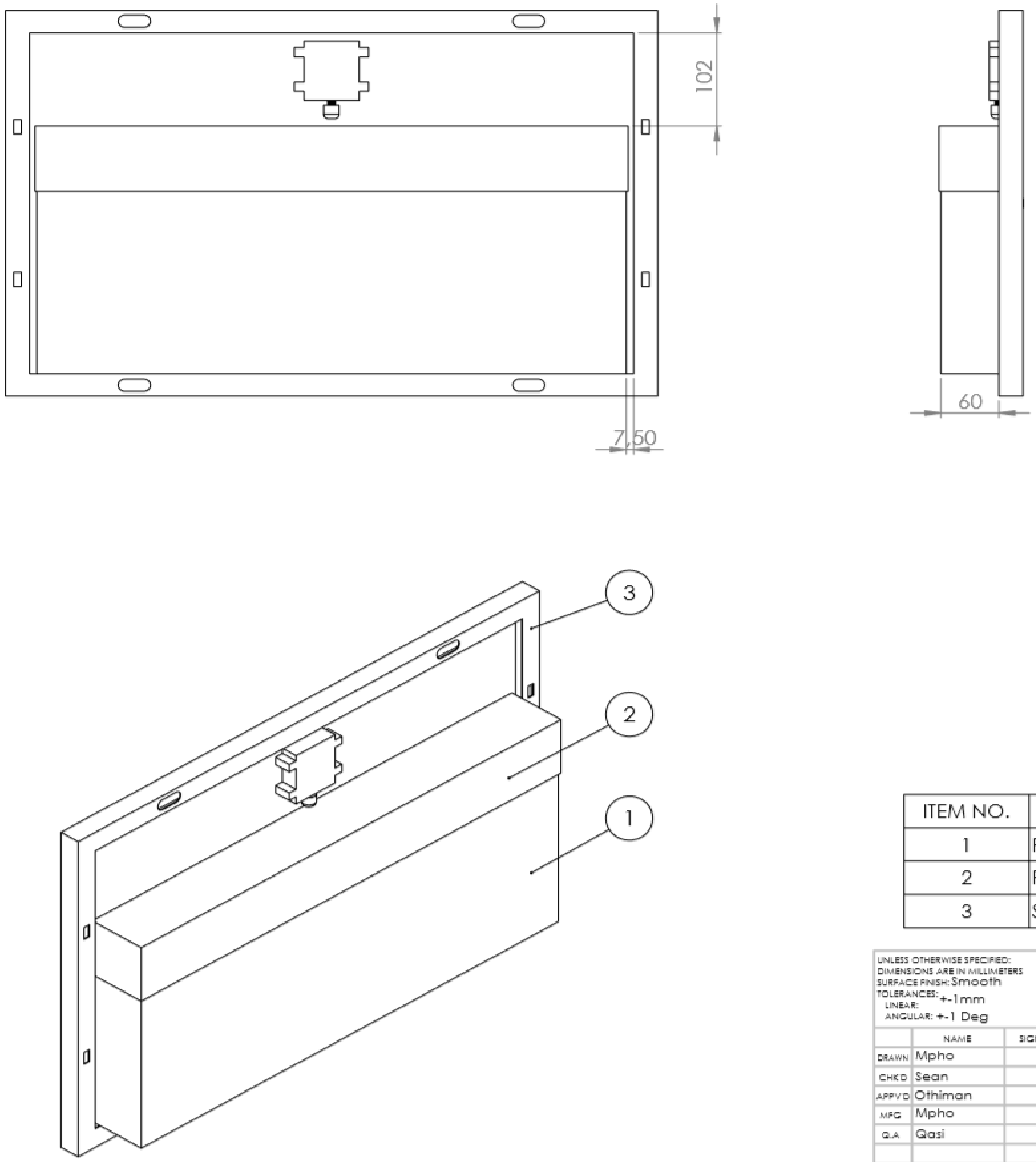
Heat Pipe Assembly

DWG NO. Assembly Drawing 2

A3

SCALE:1:5

SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PCM Container	Aluminium PCM COntainer	1
2	PCM Container Lid	Aluminium PCM Container Lid	1
3	Solar Panel 675x424	PV Panel	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES:
LINEAR: +-1mm
ANGULAR: +-1 Deg

FINISH: Smooth Surface

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

1:5

	NAME	SIGNATURE	DATE
DRAWN	Mpho		05/05/19
CHK'D	Sean		05/05/19
APPV'D	Othiman		05/05/19
MFG	Mpho		12/05/19
Q.A	Qasi		15/05/19

MATERIAL: Composed

WEIGHT:

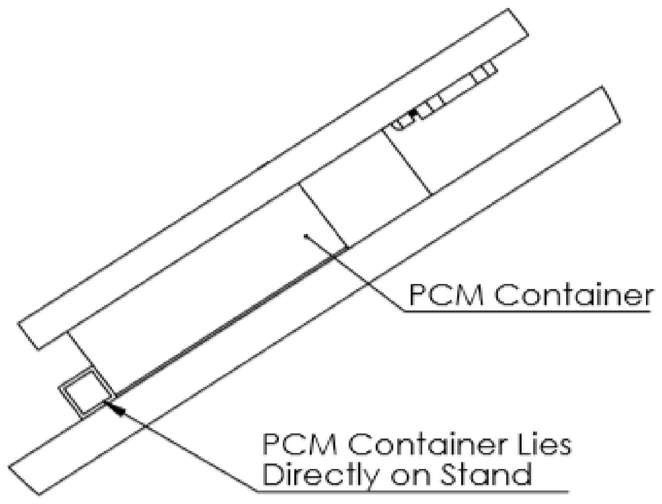
TITLE: PCM-PV

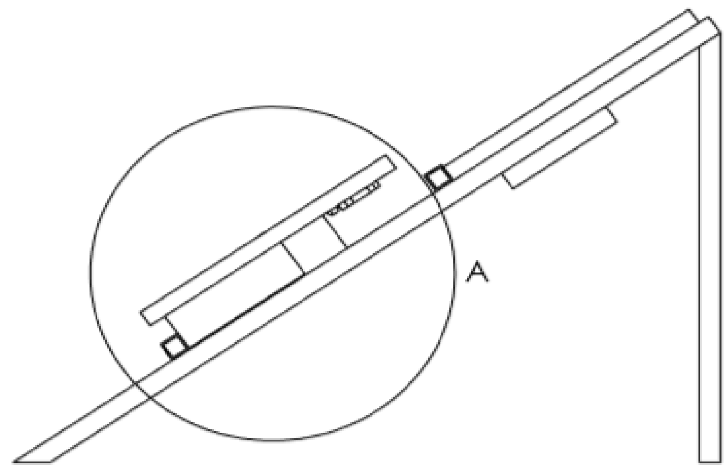
DWG NO. Assembly Drawing 3

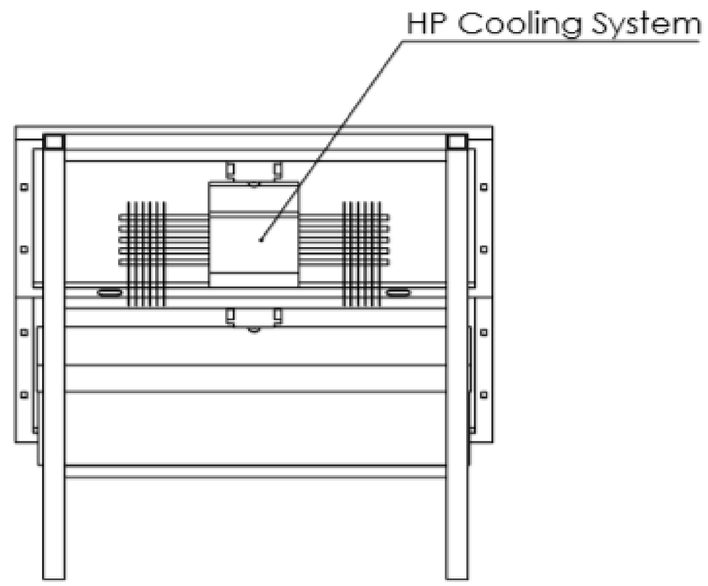
A3

SCALE:1:1

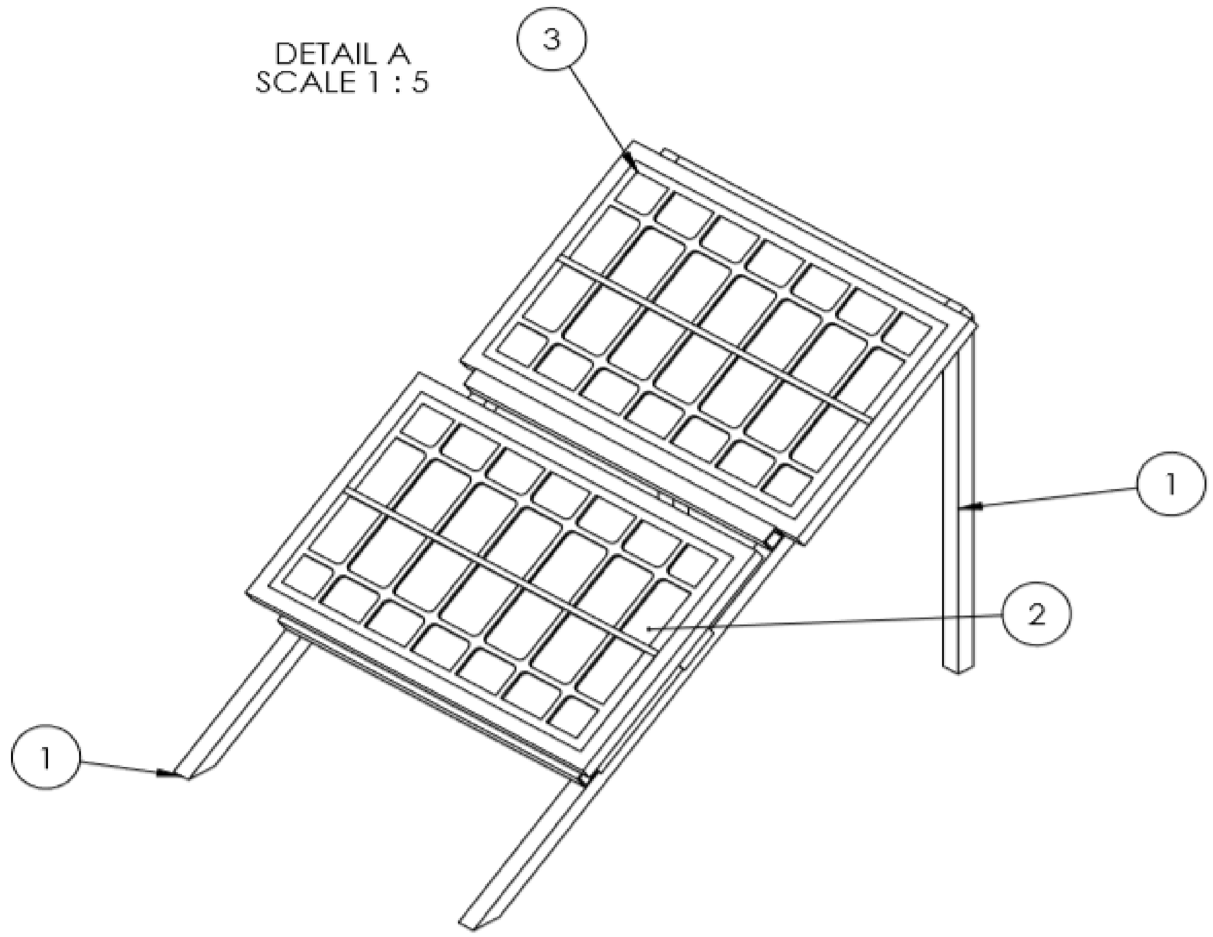
SHEET 1 OF 1







DETAIL A
SCALE 1 : 5



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PV Panel Stand	PV Panel Stand	1
2	PCM-PV System	PV Panel with Phase Change Material Cooling System Attached	1
3	HP-PV System	PV Panel with Heat Pipe Cooling System Attached	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Smooth
TOLERANCES: +/- 1mm
LINEAR: +/- 1mm
ANGULAR: +/- 1 Deg

FINISH: Smooth

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

1:10

	NAME	SIGNATURE	DATE
DRAWN	Mpho Sothoane		05/05/19
CHK'D	Othman Saeed		05/05/19
APPV'D	Sean Stevenson		05/05/19
MFG	Mpho Sothoane		12/05/19
Q.A	Qasi Albytar		15/05/19

MATERIAL: Composed

WEIGHT:

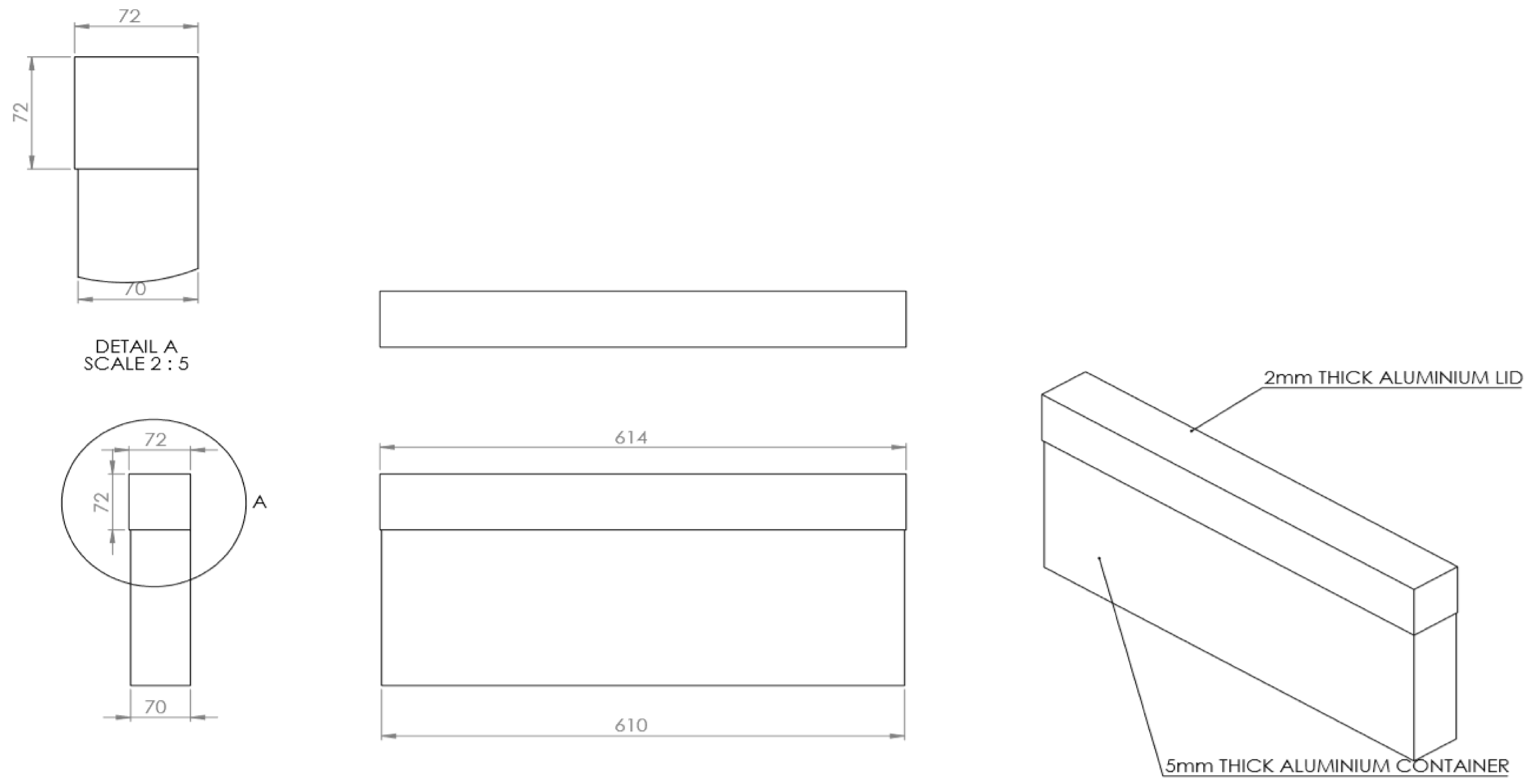
TITLE: Complete Assembly

DWG NO. Assembly Drawing 4

A3

SCALE:1:10

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Smooth TOLERANCES: LINEAR: +-1mm ANGULAR: +-1 Deg	FINISH: Smooth Surface	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING 1:5	REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mpho		05/05/19
CHK'D	Sean		05/05/19
APPV'D	Othiman		05/05/19
MFG	Mpho		12/05/19
Q.A	Qasi		15/05/19

MATERIAL: Aluminium 1050A

WEIGHT:

TITLE: Closed PCM Container

DWG NO. Assembly Drawing 5

A3

SCALE:1:5

SHEET 1 OF 1

APPENDIX G – SUPPORTING DOCUMENTS

G-1: PV PANEL SPECIFICATIONS

TommaTech solar panel characteristics

Table 28 - Electrical characteristics, STC: 1000W/m² Irradiance, 25°C module temperature, AM1.5g spectrum according to EN 60904-3

TOMMATECH

ELEKTRİKSEL ÖZELLİKLER

Model Tipi	TT5-18P	TT10-36P	TT20-36P	TT40-36P	TT80-36P	TT100-36P	TT160-36P	TT165-36P
Maksimum Güç (P_{max})	5 Wp	10 Wp	20 Wp	40 Wp	80 Wp	100 Wp	160 Wp	165 Wp
Açık Devre Gerilimi (V_{oc})	11,5	22,9	22,9	22,9	22,9	22,9	22,9	23,0
Kısa Devre Akımı (I_{sc})	0,53	0,53	1,11	2,23	4,45	5,52	8,89	8,93
Maksimum Güç Gerilimi (V_{mp})	9,70	19,4	19,4	19,4	19,4	19,4	19,3	19,5
Maksimum Güç Akımı (I_{mp})	0,52	0,52	1,04	2,07	4,14	5,16	8,30	8,50
Hücre Sayısı	18(2*9)	36(4*9)	36(4*9)	36(4*9)	36(4*9)	36(4*9)	36(4*9)	36(4*9)
Hücre Boyutu (mm)	20*78	20*78	39*78	39x156,75	78x156,75	97*156,75	156,75*156,75	156,75*156,75
Panel Boyutu (mm)	204x254x16	254x364x16	359x419x16	424*674*20	674*784*20	674*944*20	1488*675*35	1488*675*35
Ağırlık (kg)	1,4	1,4	1,75	3	5,8	7,4	10,8	10,8
Gerilim (V)	9V	12V	12V	12V	12V	12V	12V	12V
Maksimum Sistem Gerilimi	1000V DC							
Çalışma Sıcaklığı Aralığı	-40 ~ +85°C							

* Ölçüm toleransları STC±%3 NOCT±%5

MEKANİK ÖZELLİKLER

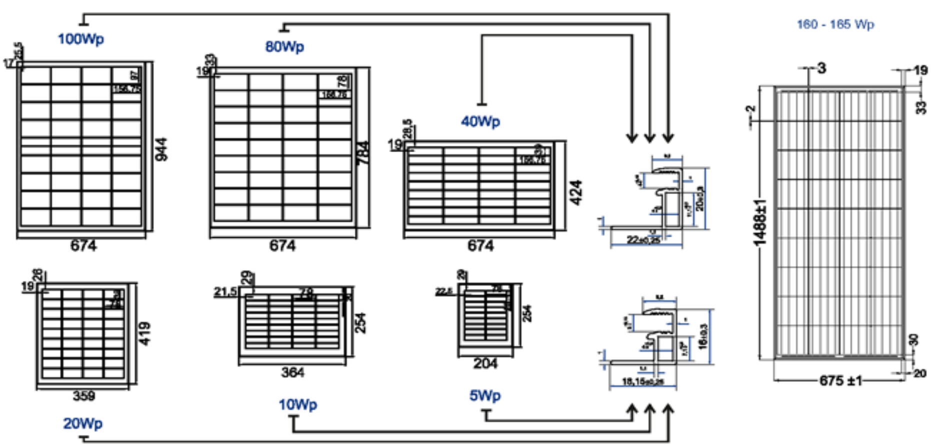
Solar Cam	3,2 mm Düşük Demirli, Temperli Cam
Çerçeve	Eloksal Kaplı Alüminyum
Bağlantı Kutusu	IP67
Kablo	4 mm², 1000 mm

SICAKLIK KATSAYISI

Nominal Çalışma Hücre Sıcaklığı (NOCT)	45°C±2°C
Sıcaklık Katsayısı (P_{max})	-0.41%/°C
Sıcaklık Katsayısı (V_{oc})	-0.33%/°C
Sıcaklık Katsayısı (I_{sc})	0.06%/°C

FİZİKSEL ÖZELLİKLER

Birim: mm



*Not: Elde edilen verilerin; Standart Test Koşulları: 1000 W/m² güneş ışınımı, 1,5 hava kütlesi ve hücre sıcaklığı 25°C. Nominal Test Koşulları: 800 W/m² güneş ışınımı, ortam sıcaklığı 20°C, rüzgar hızı 1m/s.Teknik destek için lütfen bize ulaşın kuhlmann@tommatech.de Gerçek veriler yapılan sözleşmelere tabi olacaktır. Bu parametreler sadece referans amaçlıdır ve bu sözleşmelerin bir parçası değildir. Teknik özellikler, önceden haber verilmeksizin değiştirilebilir.

www.tommatech.de

G-2: Phase Change Material

Data sheet

RT28HC

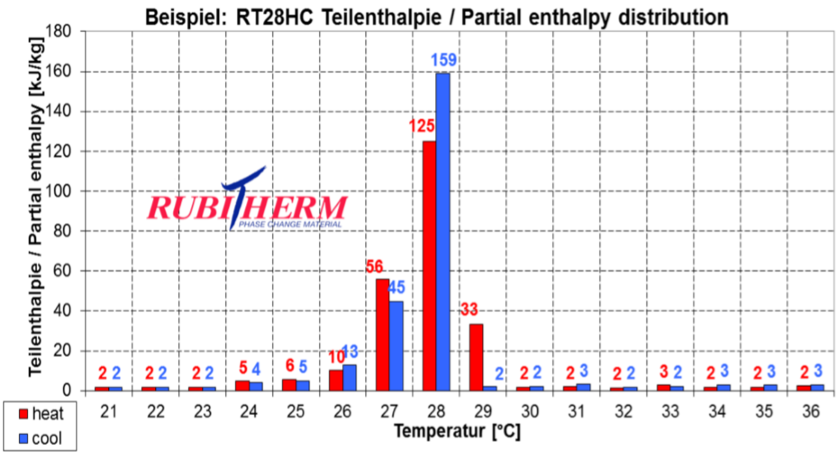
RUBITHERM® RT is a pure PCM, this heat storage material utilising the processes of phase change between solid and liquid (melting and congealing) to store and release large quantities of thermal energy at nearly constant temperature.
The RUBITHERM® phase change materials (PCM's) provide a very effective means for storing heat and cold, even when limited volumes and low differences in operating temperature are applicable.

We look forward to discussing your particular questions, needs and interests with you.

Properties:
- high thermal energy storage capacity
- heat storage and release take place at relatively constant temperatures
- no supercooling effect, chemically inert
- long life product, with stable performance through the phase change cycles
- melting temperature range between -4 °C and 100 °C

The most important data:

	Typical Values	
Melting area	**27-29** main peak: 28	**[°C]**
Congealing area	**29-27** main peak: 27	**[°C]**
Heat storage capacity ± 7,5%	**250**	**[kJ/kg]***
Combination of latent and sensible heat in a temperatur range of 21°C to 36°C.	**70**	**[Wh/kg]***
Specific heat capacity	**2**	**[kJ/kg·K]**
Density solid at 15 °C	**0,88**	**[kg/l]**
Density liquid at 40 °C	**0,77**	**[kg/l]**
Heat conductivity (both phases)	**0,2**	**[W/(m·K)]**
Volume expansion	**12,5**	**[%]**
Flash point	**165**	**[°C]**
Max. operation temperature	**50**	**[°C]**



Rubitherm Technologies GmbH
Sperenberger Str. 5a
D-12277 Berlin
Tel: +49 30 720004-62
Fax: +49 30 720004-99
E-Mail: info@rubitherm.com
Internet: www.rubitherm.com

The product information given is a non-binding planning aid, subject to technical changes without notice. Version: 31.05.2016

**Measured with 3-layer-calorimeter.*

Figure 79 – PCM Properties (Rubitherm, 2019)

G-3: ALUMINIUM 1050A

Aluminium Alloy 1050A H14 Sheet

aalco®

SPECIFICATIONS

Commercial	1050A
EN	1050A

Aluminium alloy 1050 is a popular grade of aluminium for general sheet metal work where moderate strength is required.
Alloy 1050 is known for its excellent corrosion resistance, high ductility and highly reflective finish.

Applications - Alloy 1050 is typically used for:
Chemical process plant equipment
Food industry containers
Pyrotechnic powder
Architectural flashings
Lamp reflectors
Cable sheathing

CHEMICAL COMPOSITION

BS EN 573-3:2009
Alloy 1050A

Element	% Present
Iron (Fe)	0.0 - 0.40
Silicon (Si)	0.0 - 0.25
Zinc (Zn)	0.0 - 0.07
Magnesium (Mg)	0.0 - 0.05
Titanium (Ti)	0.0 - 0.05
Manganese (Mn)	0.0 - 0.05
Copper (Cu)	0.0 - 0.05
Other (Each)	0.0 - 0.03
Aluminium (Al)	Balance

ALLOY DESIGNATIONS

Aluminium alloy 1050A also corresponds to the following standard designations and specifications but may not be a direct equivalent:
AA1050
S1B
A91050

TEMPER TYPES

The most common tempers for 1050 aluminium are:
- H14 - Work hardened by rolling to half hard, not annealed after rolling

SUPPLIED FORMS

Plain sheet
Plain sheet with a PVC coating on one side
Stucco sheet
Stucco sheet with a PVC coating on one side
Shate
- Sheet

GENERIC PHYSICAL PROPERTIES

Property	Value
Density	2.71 g/cm³
Melting Point	650 °C
Thermal Expansion	24 x10^{-6} /K
Modulus of Elasticity	71 GPa
Thermal Conductivity	222 W/m.K
Electrical Resistivity	0.0282 x10^{-6} Ω .m

MECHANICAL PROPERTIES

BS EN 485-2:2008
Sheet
0.2mm to 6.00mm

Property	Value
Proof Stress	85 Min MPa
Tensile Strength	105 - 145 MPa
Hardness Brinell	34 HB
Elongation A	12 Min %

Properties above are for material in the H14 condition

WELDABILITY

When welding 1050 to itself or an alloy from the same subgroup the recommended filler wire is 1100. For welding to alloys 5083 and 5086 or alloys from the 7XXX series, the recommend wire is 5356. For other alloys use 4043 filler wire.

FABRICATION

Workability – Cold: Excellent
Machinability: Poor
Weldability – Gas: Excellent
Weldability – Arc: Excellent
Weldability – Resistance: Excellent
Brazability: Excellent
Solderability: Excellent

[1 OF 2] CONTINUED

Figure 80 – Aluminum 1050A Properties (Aalco, 2015)

G–4: PCM Heat Transfer Enhancement

Table 29 – PCM Heat Transfer Enhancement Techniques (Ibrahima, Al-Sulaimana, Rahmana, Yilbasb, & Sahinb, 2017)

Fin materials	Fin geometry/orientation	System geometry	Phase change process	Nature of work	Effect of fin number/ dimension	Main outcome	Reference
Aluminium	Rectangular/inside inner tube containing PCM	Cylindrical tube	Solidification	Numerical/ experimental	Not included/not included	Solidification time is faster approximately by the reciprocal of number of fins.	[38]
Stainless steel	Circular/around HTF tube	Cylindrical tube	Melting and solidification	experimental	Not included/ included	Thick-finned-tube system gives about 2 times higher heat transfer coefficient than the unfinned tube.	[43]
–	Rectangular/around HTF tube	Cylindrical tube	solidification	Numerical/ experimental	Included/included	Increase in fin number reduced the solidification rate by about 14%.	[39]
Steel	Rectangular/vertical	Rectangular	Melting and solidification	Experimental	Not included/not included	About 40% reduction in solidification time due to the presence of fins.	[44]
Bronze	Circular/around a horizontal HTF tube	Shell and tube	Solidification	Numerical/ experimental	Not included/ included	The energy storage increases with increasing fin radius and decreasing fin space.	[45]
Copper	Spiral/around heating rod	Cylindrical tube	Melting	Experimental	Not included/ included	The equivalent thermal conductivity of the PCM increased by 3 times due to the presence of the fins. Furthermore, reducing the fin pitch leads to better melting process.	[46]
Copper	Longitudinal, circular/around HTF tube	Cylindrical tube	Melting and solidification	Experimental	Not included/ included	System with longitudinal fins gave the best thermal response during melting than the one with circular fins.	[47]
Copper	Rectangular/around HTF tube	Shell and tube	Melting and solidification	Numerical/ experimental	Not included/ included	Increase in HTF inlet temperature, mass flow rate and fin height gives higher PCM charging rate.	[41]
Copper	Rectangular/around HTF tube	Triplex concentric tubes	Melting	Numerical/ experimental	Included/included	The total melting time for TTHX geometry with the highest number of fins was decreased by 34.7%.	[57]
Copper	Rectangular/around HTF tube	Triplex concentric tubes	Solidification	Numerical/ experimental	Included/included	The total solidification time for TTHX geometry with the highest number of fins was decreased by 35%.	[58]
Copper	Rectangular/around HTF tube	Triplex concentric tubes	Melting	Numerical/ experimental	Not included/ included	The use of internal–external fin reduced the melting time of the PCM by 43.3%.	[59]
Brass	Rectangular/longitudinal vertical around HTF tube	Shell and tube	Melting and solidification	Experimental	Not included/not included	About 12.5% and 24.52% reduction in melting time for HTF inlet temperature 80 °C and 85 °C respectively due to fins.	[51]
–	Y-shaped/around HTF tube	Shell and tube	Solidification	Numerical	Not included/ included	The optimized unit can achieve an increase of 24% of the system efficiency.	[52]
Aluminium	Rectangular/ around HTF tube	Rectangular shell and tube	Melting and solidification	Experimental	Not included/ included	Mainly investigated the effects of HTF flow parameters.	[53]
Aluminium	Rectangular/fixed vertically on a horizontal base	Rectangular	Melting	Numerical	Not included/ included	Transient melting process of the PCM depends on the thermal and geometrical parameters of the system.	[62]
Aluminium	Rectangular/fixed between two base plates	Rectangular	Melting and solidification	Numerical	Not included/ included	The minimum enhancement rate achieved with widely spaced fins was 3 times higher.	[64]
Aluminium alloy	Rectangular/fixed vertically on a horizontal base	Rectangular	Melting	Numerical/ experimental	Included/included	Increasing the number of fins and height increases the overall thermal performance of the heat sink.	[65]
Copper	Rectangular/fixed horizontally on a vertical wall	Rectangular	Melting	Numerical	Included/included	The use of fins promotes rapid melting, followed by a low melting after the PCM in the inter-fin regions has been liquefied.	[66]
Aluminium	Rectangular/around HTF tube	Shell and tube	Solidification	Numerical	Included/not included	The results showed faster energy extraction from the PCM to the HTF as well as increase in the outlet HTF temperature.	[49]

G-5: Aluminium 1100 Thermal Properties:

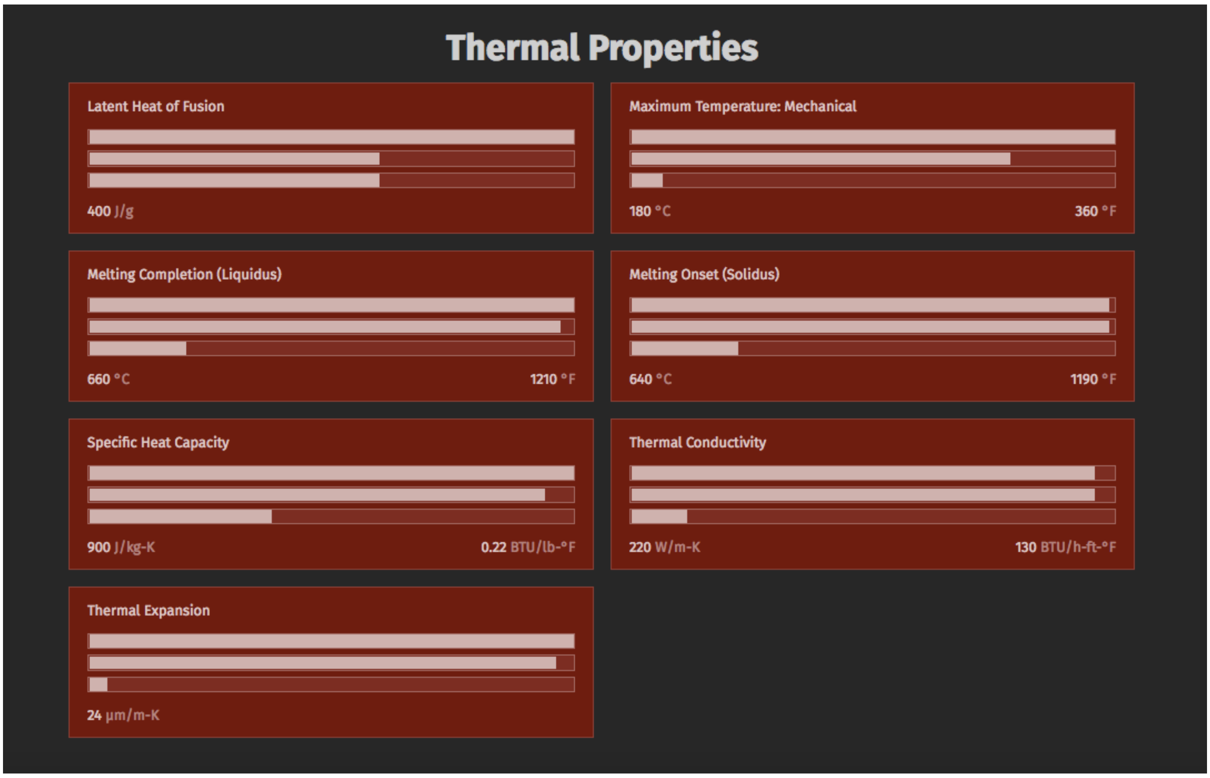


Figure 81 – Aluminium 1100 Thermal Properties (ASTM, 2014)

G-6: Aluminium 6061 Thermal Properties

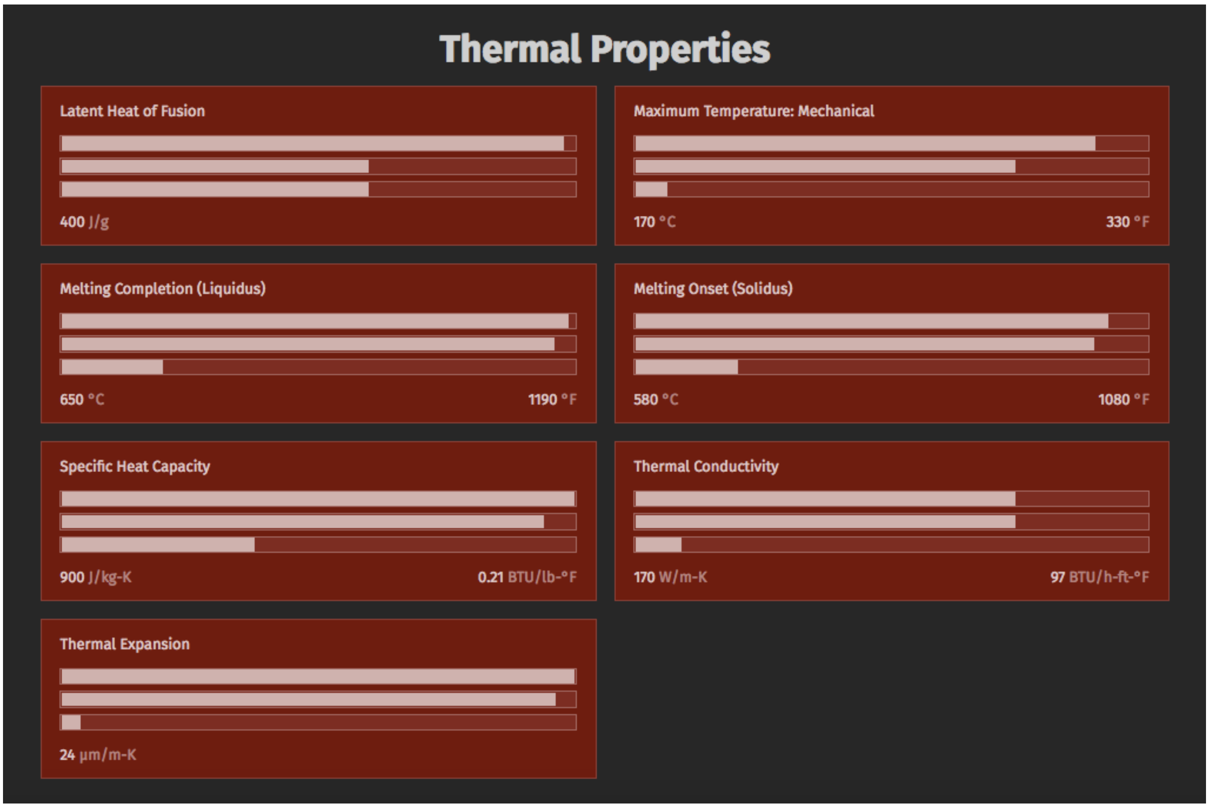


Figure 82 – Aluminium 6061 Thermal Properties (ASTM, 2014)

G-7: ALUMINIUM 6063 THERMAL PROPERTIES

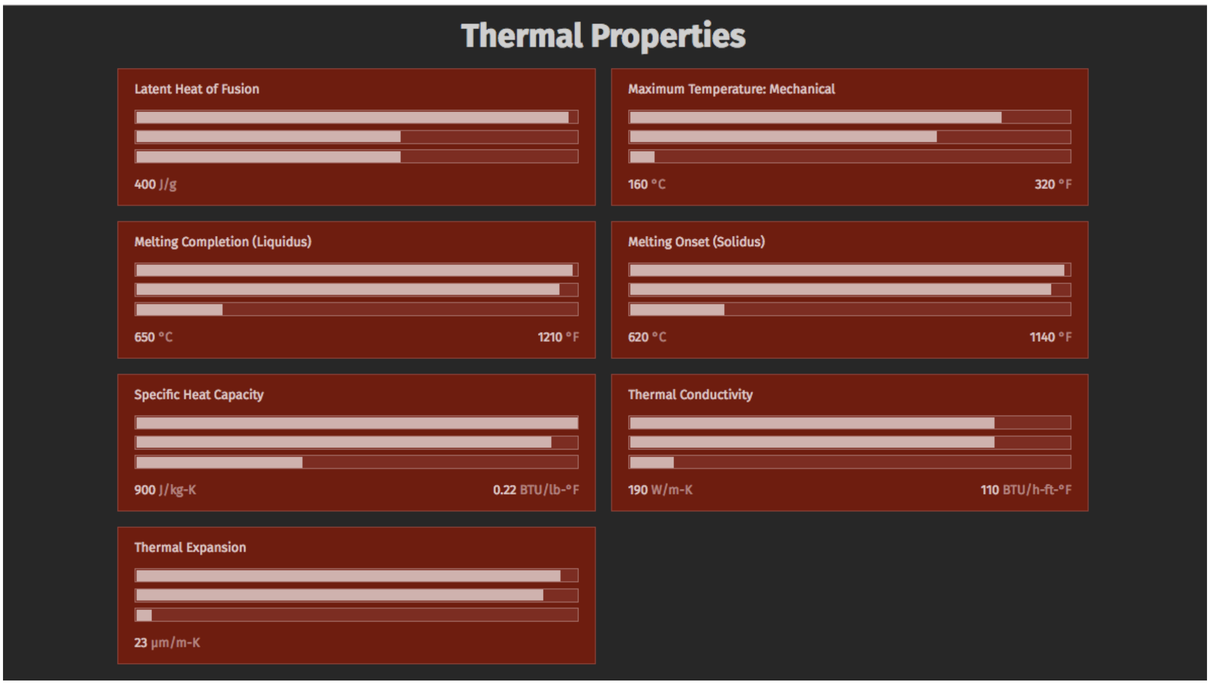


Figure 83 – Aluminium 6063 Thermal Properties (ASTM, 2014)

G-8: COPPER & WATER PROPERTIES

Table 30 – Copper and Water Properties (CCI, 2018)

	Density ρ (kg/m^3)	Specific heat at constant pressure c_p (J/kg·K)	Thermal conductivity k (W/m·K)	Electrical conductivity σ (S·m^{-1})
Pure water	991.1	4179	0.613	0.05
Copper (Cu)	8933	385	401	5.96×10^7
Alumina (Al_2O_3)	3970	765	40	3.69×10^7
Silver (Ag)	10500	235	429	6.3×10^7
Titanium Oxide (TiO_2)	4250	686.2	8.9538	0.24×10^7